Transpiration, photosynthetic responses, tissue water relations and dry mass partitioning in C*allistemon* plants during drought conditions

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ABSTRACT

Callistemon is an Australian species used as ornamental plant in Mediterranean regions. The objective of this research was to analyse the ability of *Callistemon* to overcome water deficit in terms of adjusting its physiology and morphology. Potted *Callistemon laevis* Anon plants were grown in controlled environment and subjected to drought stress by reducing irrigation water by 40% compared to the control (irrigated to container capacity). The drought stress produced the smallest plants throughout the experiment. After three months of drought, the leaf area, number of leaves and root volume decreased, while root/shoot ratio and root density increased. The higher root hydraulic resistance in stressed plants caused decreases in leaf and stem water potentials resulting in lower stomatal conductance and indicating that water flow through the roots is a factor that strongly influences shoot water relations. The water stress affected transpiration (63% reduction compared with the control). The consistent decrease in g_s suggested an adaptative efficient stomatal control of transpiration by this species, resulting in a higher intrinsic water use efficiency (P_n/g_s) in drought conditions, increasing as the experimental time progressed. This was accompanied by an improvement in water use efficiency of production to maintain the leaf water status. In addition, water stress induced an active osmotic adjustment and led to decreases in leaf tissue elasticity in order to maintain turgor. Therefore, the water deficit produced changes in plant water relations, gas exchange and growth in an adaptation process which could promote the faster establishment of this species in gardens or landscaping projects in Mediterranean conditions.

Key words: Water stress; Potted *Callistemon citrinus*; Gas exchange; Pressure-volume curves

Abbreviattions: ET, evapotranspiration; F_v/F_m, efficiency photosystem II; g_s, stomatal conductance; L; root length; P_n, net photosynthesis; RWC_{tlp}, relative water content at turgor loss point; T, transpiration; ε, bulk modulus of elasticity; Ψ_l, leaf water potential; Ψ_{os}, leaf osmotic potential at full turgor; Ψ_s, stem water potential; Ψ_{tlp}, leaf water potential at turgor loss point; $1/Lp$, root hydraulic resistance.

1. Introduction

Callistemon belongs to the Myrtaceae family and is the most important Australian ornamental species, which shown interesting characteristics (rapid growth**,** abundant flowering with unusual shapes and brilliant colours and great variety of forms and volumes) (Mitchem, 1993; Lao and Jiménez, 2002). Most *Callistemon* species have adapted and been used in Mediterranean conditions, where they show some degree of tolerance to environmental stresses such as drought (Lippi et al., 2005). They are also known for their high salt tolerance (Lippi et al., 2003). It is for these reasons that *Callistemon* has enjoyed considerable success as a flowering shrub for use in gardens and urban landscaping in the Mediterranean area. However, the prolonged water stress resulting from low rainfall and high temperatures in summer in this area may alter the plant's physiological and morphological behaviour, especially in imported species. Such changes may involve complex functional and structural adaptations to increase the drought tolerance of the plant: These include plant growth regulation, osmotic adjustment, decreased stomatal conductance, and changes in the elastic properties (Zollinger et al., 2006), all of which may improve the plant water status and the resistance of plants to water stress by limiting water loss in the face of high evaporative demand (Sánchez-Blanco et al., 2004). However, drought-stress can also decrease photosynthetic rates and shoot and leaf growth or delay and reduce flower numbers, size and/or quality (Cameron et al., 1999) which would affect the plant's visual appeal, a particularly important factor in ornamental plants destined for use in gardens and landscaping.

In these conditions, irrigation management is an important factor and there is considerable pressure on the ornamental plant industry to produce crops more efficiently, reducing the quantity of water regimes (Sweatt and Davies, 1984) without losing ornamental characteristics (Cameron et al., 2006). In this sense, monitoring nursery moisture regimes and understanding morphological and physiological shoot and root responses of seedlings to water management are critical for optimising the production of high-quality seedlings (Franco et al., 2006). However, little is known about these responses in “foreign” Mediterranean ornamental shrubs such as *Callistemon*.

The objective of this study was to evaluate the physiological and whole plant response of *Callistemon laevis* in control and drought plants under controlled conditions to contrasting irrigation treatments. The results are evaluated in terms of biomass partitioning, water use efficiency and water relations to understand the adaptative role of this species to drought stress.

2. Materials and methods

2.1. Plant material and experimental conditions

Six month old rooted cuttings of Australian *Callistemon laevis* Anon (*Callistemon citrinus splendens* Stapf) were transplanted into 14 cm × 12 cm pots (1.2 L) filled with a mixture of coconut fibre, black peat and perlite (2:1:1) and amended with osmocote plus (2 g L^{-1} substrate) (14:13:13 N,P,K + microelements). The experiment was carried out in a growth chamber. The environmental conditions of the chamber for plant growth were selected to simulate natural changes in temperature and photosynthetic photon flux density. Both parameters gradually increased from 6:00 h to 13:00 h, reaching values of 28 ºC and 350 µmol m^{-2} s^{-1} and then progressively decreased until 20 ºC and darkness (22:00 h). The relative humidity ranged between 40 and 60%. Although the radiation levels present in the growth chamber were lower than those experienced by the studied plants in the field, we assumed that the specific photosynthetic active radiation levels used were of secondary importance compared to the contrast of irrigation treatments. Thus, the results of light response curves to quantify the degree of limitation in the photosynthesis response of this species showed high levels of photosynthesis for the light intensity used in this assay, close to half of the maximum photosynthesis at saturating light.

2.2. Treatments

The plants were watered daily to container capacity during the two weeks prior to starting the treatments.

Plants were grouped into four repetitions (n=4) of eight plants per treatment (64 plants in total, 32 per treatment) and were submitted to two irrigation treatments: container capacity (control) and drought treatment.

To determine the substrate maximum water holding capacity, three samples were uniformly mixed and packed to a bulk density of 0.165 g cm^{-3}. The pots' surfaces were covered with aluminium foil to prevent water evaporation and the lower parts were submerged, to half the pot's height, in a water bath and then were left to equilibrate overnight. The next day, the pots were removed and left to freely drain until drainage became negligible. Afterward, the fresh weight was recorded and then the substrate was introduced inside an oven at 105 ºC until constant weight. Later, the difference between the fresh weight and oven-dry weight was measured and consequently a volumetric water content of 54% was calculated and considered as the substrate's field capacity.

In the control treatment, substrate moisture was maintained above and close to container capacity by daily irrigation. Thus, no significant drainage was obtained in all days of the experiment. Drought treatment was maintained close to 50% to container capacity, also by daily irrigation. During the experimental period, drought plants received around 40% of the amount of water compared with the control treatment. The water added to each pot during the experimental period was 12.71 L and 5.03 L for control and drought plants, respectively. The electrical conductivity of water applied was 0.5 dS m^{-1}.

2.3. Biomass accumulation and electrolyte leakage

At the end of both irrigation treatments, five plants per treatment were harvested. The substrate was gently washed from roots, and the plants were divided into shoots (stems and leaves) and roots. Leaf numbers and leaf areas were determinated using a leaf area meter (Delta-T Devices Ltd., Cambridge, UK), in the same five plants per treatment. These were oven dried at 70 ºC until they reached a constant mass to measure the respective dry weights. The roots were cleaned by low pressure water applied through a flat nozzle. The cleaned root systems were then placed in a metacrylate tray coupled to a double scanner connected to a computer with a Root System Analyser (Winrhizo LA 1600 Regent Inc., USA). The root systems were put in an oven to dry immediately after the root length measurements. Root density was determined by dividing the dry weight by root volume.

Plant height was measured weekly during the experimental period and the relative growth rate was calculated as the rate of increase of height per unit of initial plant height.

The rates of passive ion leakage from stress-sensitive plant tissue can be used as a measure of alterations of membrane permeability. In our case, ion leakage was estimated at the end of the experiment, according to the method described by Lafuente et al., (1991). Thirty leaf discs, each 2 mm in diameter, from each plant, with eight replicates per treatment, were pooled and incubated in 10 mL 0.3 M mannitol in a 50 mL centrifuge tube. The tubes were shaken at 120 cycles min^{-1} and the conductivity of the solution was measured after 24 h using a Crison Model 524 digital conductivity meter (Crison Instruments S.A., Barcelona, Spain). Tubes containing the solution were weighed and heated to boiling for 10 min. After cooling to room temperature, while still shaking, deionised water was added to restore their initial weight and the total conductivity was measured after an additional 0.5 h of shaking. Ion leakage rates were expressed as a percentage of the total conductivity.

2.4. Transpiration, stomatal conductance and photosynthesis responses

Transpiration (T) and evapotranspiration (ET) were measured gravimetrically throughout the experimental period, being determined from the difference in weights (weight after irrigation and weight before irrigating again) using a balance (capacity 5.2 kg and accuracy of 0.01 g, Sartorius, model 5201). Transpiration was measured in three plants per treatment, in which the surface substrate was covered to avoid loss through evaporation. Three pots of the same treatment were placed on a balance with a MITRA programmer that recorded the weight every half an hour. Transpiration and evapotranspiration were similar due to evaporation from the soil was very low. The pots had small surface substrate in relation with total leaf area and consequently soil evaporation was lower than 2% ET.

Water use efficiency of production (WUE) was calculated at the end of the experiment by dividing the increment in the aerial dry weight by the water used (g aerial dry weight per liter water).

Stomatal conductance (g_s) and the net photosynthetic rate (P_n) were determined in five plants during the hours of maximum illumination using a gas exchange system (LI-6400, LI-COR Inc., Lincoln, NE, USA).

The values of chlorophyll fluorescence on the adaxial leaf surface were taken after exposing the leaves to dark for 20 min (Camejo et al., 2005). The values of F_v/F_{vm} were read directly in the fluorometer (OS-30 OptiScience Inc., Tyngsboro, MA, USA).

2.5. Plant water relations

During the experiment, leaf water potential (Ψ_l) and stem water potential (Ψ_s) were measured in five plants per treatment. Ψ_l was measured in mature leaves, which were exposed to direct light for at least 1 h before measurement. Ψ_l was estimated according to the method described by Scholander et al., (1965), using a pressure chamber (Soil Moisture Equipment Co, Santa Barbara, CA, USA), for which leaves were placed in the chamber within 20 s of collection and pressurised at a rate of 0.02 MPa s^{-1} (Turner, 1988).

Ψ_s was measured on non-transpiring leaves that had been bagged with both a plastic sheet and aluminium foil for at least 1 h before measurement in order to prevent leaf transpiration, in this way leaf water potential equalled stem water potential (Begg and Turner, 1970). Measurements were made in five plants per treatment.

Estimates of the bulk modulus of elasticity (ε), leaf osmotic potential at full turgor (Ψ_{os}), leaf water potential at turgor loss point (Ψ_{tlp}) and relative water content at turgor loss point (RWC_{tlp}) were obtained at the end of the different irrigation treatments in three leaves per plant and five plants per treatment, via pressure-volume analysis of leaves, as outlined by Wilson et al., (1979). The bulk modulus of elasticity (ε) at 100% relative water content was calculated using the formula:

$$\varepsilon = (RWC_{tlp} \times \Psi_{os}) / (100 - RWC_{tlp})$$

where ε is expressed in MPa, Ψ_{os} is the osmotic potential at full turgor (MPa) and RWC_{tlp} is the relative water content at turgor loss point.

Leaves were excised in the dark, placed in plastic bags and allowed to reach full turgor by dipping the petioles in distilled water overnight. Pressure-volume curves were obtained from periodic measurements of leaf weight and balance pressure as leaves dried on the bench at constant temperature of 20 ºC. The leaf drying period for each curve was about 3-5 h.

Hydraulic resistance (1/*Lp*) was determined at the end of the experimental period in five plants per treatment as the inverse of the root hydraulic conductivity (*Lp*), measured according to Ramos and Kaufmann (1979). Plants were de-topped and the substrate was carefully washed from the roots, which were submerged in a container of water and placed in the pressure chamber with the cut stump exposed. The air pressure in the chamber was increased at an approx. rate of 0.4 MPa min^{-1}, up to a final pressure of 0.8 MPa. A small piece of plastic tubing was fitted to the stump and the exudate was collected every 5 min and its volume measured. After the exudation measurements, the root systems were placed in an oven at 80 °C until they reached a constant dry weight. Root hydraulic conductivity was calculated using the formula:

$$Lp = J / (P \times W)$$

where Lp is expressed in mg g^{-1} s^{-1} MPa^{-1}, P is the applied hydrostatic pressure (MPa), W is the dry weight of the root system (in g), and J is the water flow rate through the entire root system (in mg s^{-1}).

2.6. Statistical analyses

The data were analysed by one-way ANOVA using Statgraphics Plus for Windows 5.1 Software (Manugistics Ltd., Rockville, MD, USA). Ratio and percentage data were subjected to an arcsine square-root transformation before statistical analysis to ensure homogeneity of variance Treatment means were separated with Duncan's Multiple Range Test ($P \leq 0.05$).

3. Results

3.1. Biomass accumulation and electrolyte leakage

Water deficit was seen to have significantly altered *Callistemon* plant growth by the end of the experiment; although the changes differed depending on the plant organ studied (Fig. 1). The greatest accumulation of dry matter in relation to total plant dry matter was seen in the leaves of the control plants and in the roots of stressed plants. The total dry matter of drought-treated plants was 47% of the control values (Table 1); both total leaf area and the number of leaves decreased to 41 and 50%, respectively, compared with control plants. However, the root/shoot ratio increased in the plants grown under drought conditions. Water deficit had a significant effect on root morphology (Table 2). Total root length decreased with water stress (27%), a reduction observed in all sizes of root. In relation to the root distribution, water deficit increased the percentage of fine roots and decreased those with a diameter higher than 0.5 mm. In general, stressed plants showed a reduced root volume, although root dry weight was not modified, with the result that root density increased.

Plant height was significantly inhibited from the beginning of the deficit treatment (Fig. 2A), which produced the smallest plants throughout the experiment. At the end of the experiment the reductions were around 30% compared with the control. A similar pattern in the relative growth rate for both treatments was observed (Fig. 2B) and two growth periods being evident during the experiment (8 and 14 weeks), although the stressed plants showed a certain delay compared with the control.

Membrane damage, assessed by ion leakage of the control and drought-exposed plants was significantly higher in the latter (Table 1).

3.2. Transpiration, stomatal conductance and photosynthesis responses

The evolution of transpiration (T) along the study period is showed in Fig. 3. In the control, daily T values fluctuated throughout the experiment between 43 mL d^{-1} and 150 mL d^{-1} (Fig. 3A). Daily T values increase coinciding with the two growth periods (Figure 2A). As regards cumulative data, the transpiration at the beginning of the experiment (1-7 weeks) was close to 60% that the level reached throughout the rest of the experimental period. In contrast, in the drought treatment, the daily T level was more maintained in the experiment reaching mean values of around 47 ml/d (about 40% of the control). The behaviour of the transpiration rate on a representative day of the period can be seen in Fig. 3B. T was higher during the morning and decreased during the afternoon. The highest value was reached between 13 and 17 h especially in control plants (7.2 mL per 30 min), coinciding with the highest temperature (28 ºC) after which, transpiration decreased. In drought plants, the transpiration curve was more stable throughout the day, independently of temperature changes. Daily accumulated T showed a maximum of 150 mL pot^{-1} and 47 mL pot^{-1} in the control and drought treatments, respectively.

Water stress affected stomatal functionality (Fig. 4): stomatal conductance (g_s) and the net photosynthetic rate (P_n) decreased in drought-exposed plants in relation to the control treatment, although intrinsic water use efficiency was different in each treatment. The values of P_n/g_s in the water deficit plants were higher than those of the control plants throughout the experimental period. As the experimental time progressed greater intrinsic water use efficiency (higher P_n/g_s) was observed in the stressed plants. Also, exposing plants to water stress increased water use efficiency of production (WUE), expressed as dry weight per unit of water consumption (3.61 g L^{-1} and 4.68 g L^{-1} for control and stressed plants, respectively). The F_v/F_m values were not affected by the drought treatment (Table 1).

3.3. Plant water relations

Leaf water potential (Ψ_l), and stem water potential (Ψ_s) values were recorded during the hours of maximum illumination (Fig. 5A, B). In the control treatment Ψ_l and Ψ_s values were always higher than in water deficit treatment (Fig. 5A). For each treatment, Ψ_s showed less negative values that those found for Ψ_l. The differences between Ψ_s and Ψ_l measured simultaneously of the same plant were higher for the control treatment (Fig. 5A, B). The water deficit applied produced increases in root hydraulic resistance, with values of 1.02 and 3.20 g MPa s mg^{-1} recorded for the control and drought treatments, respectively (Table 3).

The parameters derived from the pressure-volume curve for control and stressed plants are shown in Table 3. Both leaf osmotic potential values at full turgor (Ψ_{os}) and leaf water potential at turgor loss point (Ψ_{tlp}) decreased markedly two fold in the water deficit plants. The difference between the Ψ_{os} values obtained for the control and deficit irrigated plants were taken as an estimate of the osmotic adjustment (1.58 MPa for water stress). The point of zero turgor occurred at much lower water potential values (-4.09 MPa). In contract, the bulk modulus of elasticity (ε) increased (75%) in the water deficit treatment.

4. Discussion

Leaf growth is often more reduced than root growth as a result of water stress (Hsiao and Xu, 2000; Franco et al., 2006), indicating that shoots and roots respond differently to drought (Bacelar et al., 2007; Álvarez et al., 2009). This was confirmed in our conditions because the application of a water deficit to the plant substrate led a decrease in aerial dry matter accumulation, leaf area and height while the contrary effect on root mass was seen, provoking a redistribution of dry matter in favour of the roots at the expense of shoots (higher root/shoot ratio) (Montero et al., 2001; Sánchez-Blanco et al., 2009). These changes, which have been described in other ornamental species (Shao et al., 2008; Mugnai et al., 2005) can be considered as a morphological adaptation of the plant to water stress to reduce the evaporative surface area (de Herralde et al., 1998) and to induce a lower consumption of water (Bañón et al., 2004). On the other hand, the plants growth in pots under water deficit had appreciable and rapid response in the relative growth rate, with plant height decreasing even under climatic conditions of moderate evaporative demand. Some authors have suggested that to detect water stress in plants can be different when the plants grown in pots, with restricted root volume than in soil-cultivated plants (Gallardo et al., 2006; Miralles et al., 2009). These results are useful because the application of drought treatment during nursery production can be used as a technique to reduce the excessive growth in ornamental plants without applying plant growth retardants (Morvant et al., 1998).

Transpiration and, consequently water consumption in the water stressed plants decreasing substantially. In plants subjected to no water restriction, transpiration was greater at the time of higher water demand (higher temperature and illumination conditions), which is agrees with the observation of numerous authors (Alarcón et al., 2000; Montero et al., 2001; Nicolás et al., 2005).

Water stress appeared to affect transpiration (reduction of 63% of the control) as seen from the substantial decrease in stomatal conductance in these plants during the experimental period (values below 60 mmol m^{-2} s^{-1} *vs* 130 in control). This response could affect to net CO_2 assimilation rate, leading to lower plant biomass production (Brugnoli and Bjorkman, 1992; Mugnai et al., 2009). Thus, the fact that F_v/F_m values were maintained at 0.80 in both treatments throughout the experimental period demonstrates the lack of drought-induced damage to PSII photochemistry, suggesting that *Callistemon laevis* is a drought-tolerant species (Genty et al., 1987; Mugnai et al., 2009). The intrinsic water use efficiency (P_n/g_s) progressively increased in the water stressed plants throughout the period, indicating a predominant stomatal control over photosynthesis (Gulías et al., 2009). The consistent decrease in g_s suggested an adaptative efficient stomatal control of transpiration by this species (Hessini et al., 2008). In this sense, most woody species increase their intrinsic water use efficiency,

CO_2 assimilation remaining proportionally higher than water vapor loss from the stomata as an additional drought acclimatation. The advantage in the case of these plants is that controlled drought may lead to an accumulation of carbohydrate reserves in the plants and together with the increased root: shoot ratio and root density could promote a more rapid establishment of ornamental plants in the garden or landscape (Cameron et al., 2006; Franco et al., 2006). Also, water use efficiency of production (WUE) measured as dry weight per unit of water used, improved in the stressed plants, an observation that has been associated with the application of deficit irrigation regimes (Cameron et al., 2006; Álvarez et al., 2009) to maintain leaf water status of these species (Hessini et al., 2008).

In this study, the reduction in plant growth and g_s caused by the drought could be related to changes in the plant water status. The higher root hydraulic resistance in stressed plants may have caused the leaf and stem water potentials decrease, which caused a substantial fall in stomatal conductance (Pereira and Chaves, 1993; Munné-Bosch et al., 1999). It has been reported that the threshold level for the decline of water potential to cause a decrease in stomatal opening ranges from -0.7 to -1.2 MPa for different ornamental species (Ackerson, 1985; Sánchez-Blanco et al., 2009). The fact that the Ψ_l values were always lower than Ψ_s is because Ψ_l reflected a combination of many factors such as environmental conditions, soil water availability, hydraulic conductivity and stomatal regulation, while Ψ_s is more directly related to whole plant transpiration and root hydraulic conductivity (Choné et al., 2001). The stem water potential has been successfully used as a water deficit indicator in fruit crops (Garnier and Berger, 1985; McCutchan and Shackel, 1992). In our conditions, the difference between Ψ_s and Ψ_l could be a good indicator of shoot transpiration in these plants, since the pattern of these differences throughout the experimental was similar to those observed for transpiration.

The significantly lower values of Ψ_{os} in stressed callistemon plants suggest an active osmotic adjustment in leaves and, besides, water stress also induced a decrease in leaf tissue elasticity. Many species show these responses as tolerance mechanisms to drought in order to maintain turgor (Meinzer et al., 1990; Hessini et al., 2008).

In conclusion, the tolerance of *C. laevis* to the drought was related to morphological and physiological adaptations: That is the ability to adjust osmotic potential to enhance rigidity and to modify leaf gas exchange, is accompanied by a capacity for photosynthesis and to reduce water losses though transpiration. The reductions in aerial dry weight (leaf area, leaf number and height), together with increases in the root: shoot ratio and root density, could promote the more rapid establishment of these species in Mediterranean conditions.

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FIGURE CAPTIONS

Fig. 1. Partitioning mass in *Callistemon* plants subjected to control and water stress at the end of the experiment. Each histogram represents the mean of five values and the vertical bars indicate standard errors.

Fig. 2. Plant height (A), and relative growth rate (B) in *Callistemon* plants subjected to control and water stress during the experimental period. Values are means (n = 32) and the vertical bars indicate standard errors.

Fig. 3. Transpiration during the experimental period (T, A) and daily transpiration during a representative day of the period (B) in *Callistemon* plants subjected to control and water stress.

Fig. 4. Evolution of the intrinsic water use efficiency (P_n/g_s) in *Callistemon* plants subjected to control and water stress during the experimental period.

Fig. 5. Evolution of the leaf water potential (Ψ_l, A) and stem water potential (Ψ_s, B) in *Callistemon* plants subjected to control and water stress during the experimental period. Each histogram represents the mean of five values and the vertical bars indicate standard errors.

Fig. 1

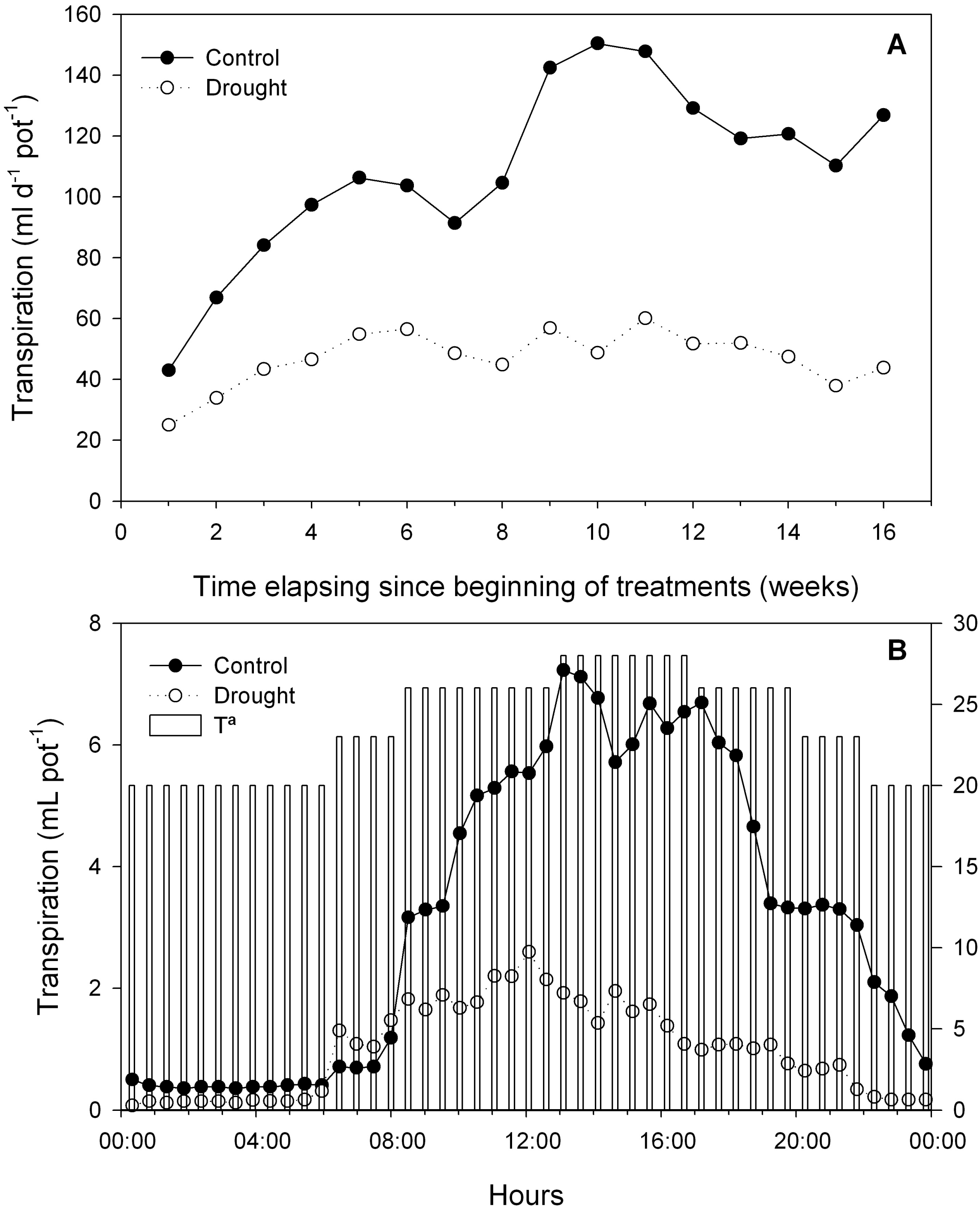
A
Control
Drought
Transpiration (ml d-1 pot-1)
Time elapsing since beginning of treatments (weeks)
B
Control
Drought
Ta
Transpiration (mL pot-1)
Temperature (ºC)
Hours

Fig. 2

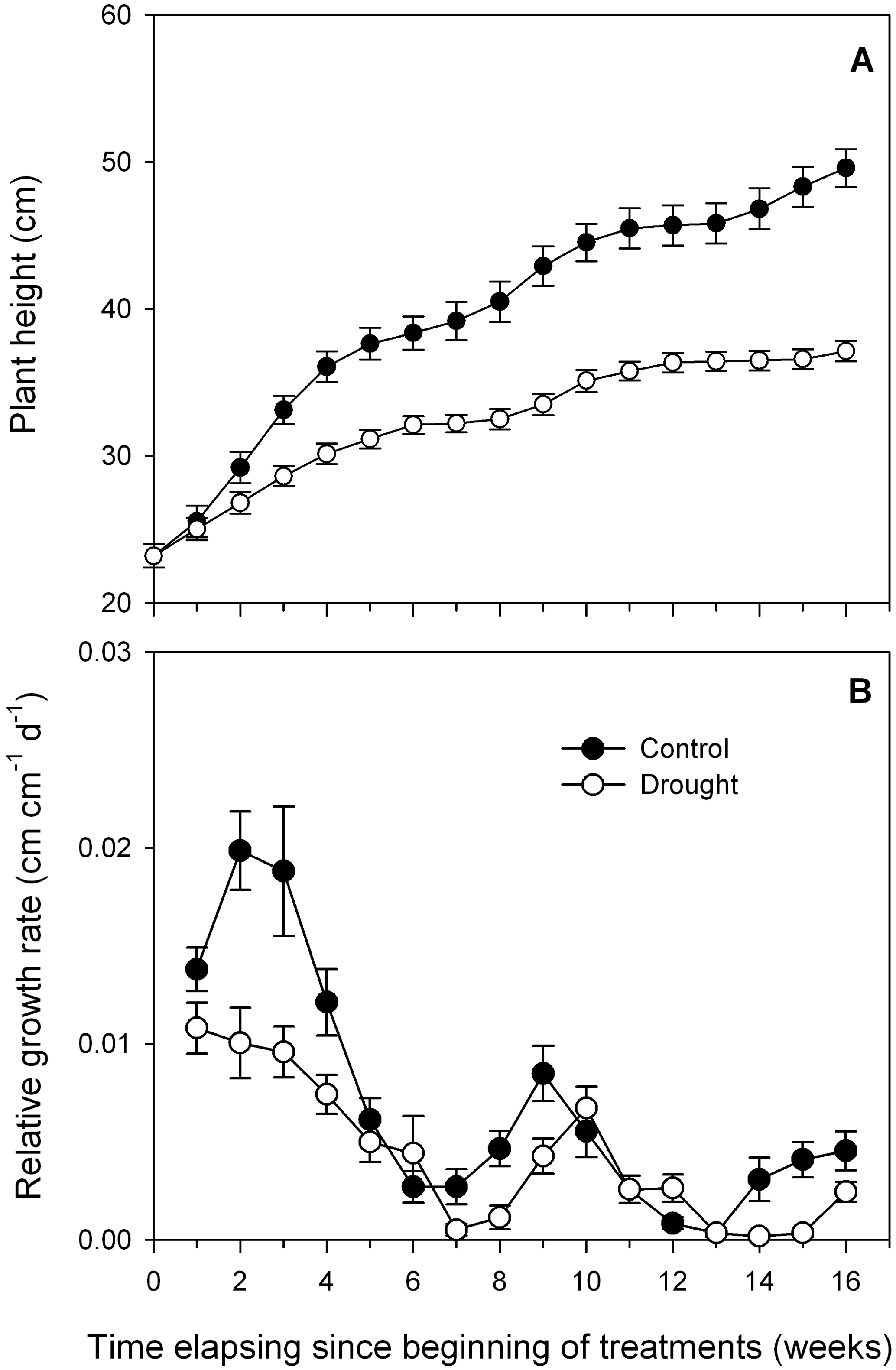
A
B
Plant height (cm)
60
50
40
30
20
Relative growth rate (cm cm-1 d-1)
0.03
0.02
0.01
0.00
Control
Drought
0
2
4
6
8
10
12
14
16
Time elapsing since beginning of treatments (weeks)

Fig. 3

Control
Drought
Dry weight/Total dry weight (%)
70
60
50
40
30
20
10
0
Leaves
Stem
Root
Part of the plant

Fig. 4

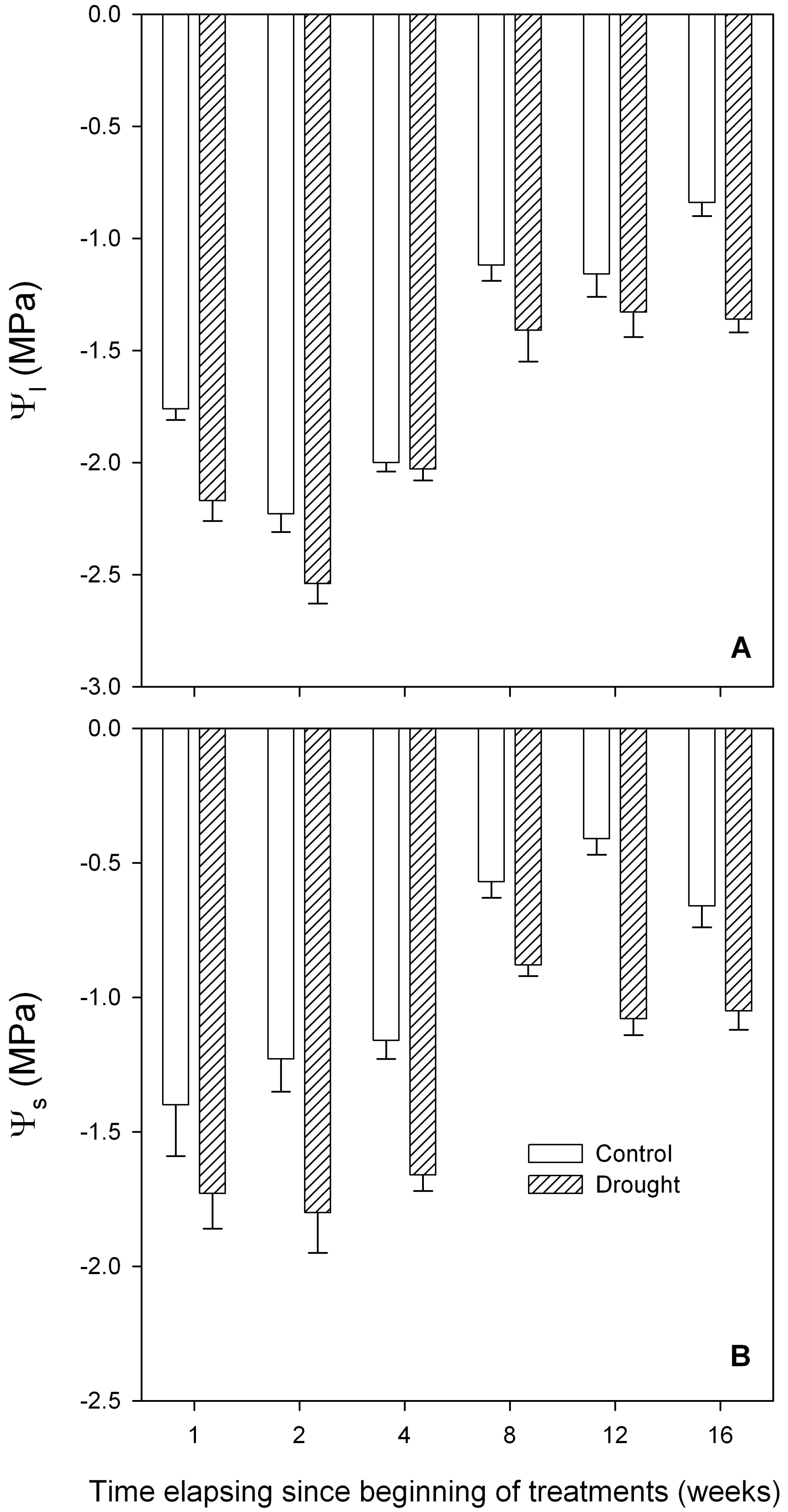
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
Ψ_l (MPa)
A
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
Ψ_s (MPa)
Control
Drought
B
1
2
4
8
12
16
Time elapsing since beginning of treatments (weeks)

Fig. 5

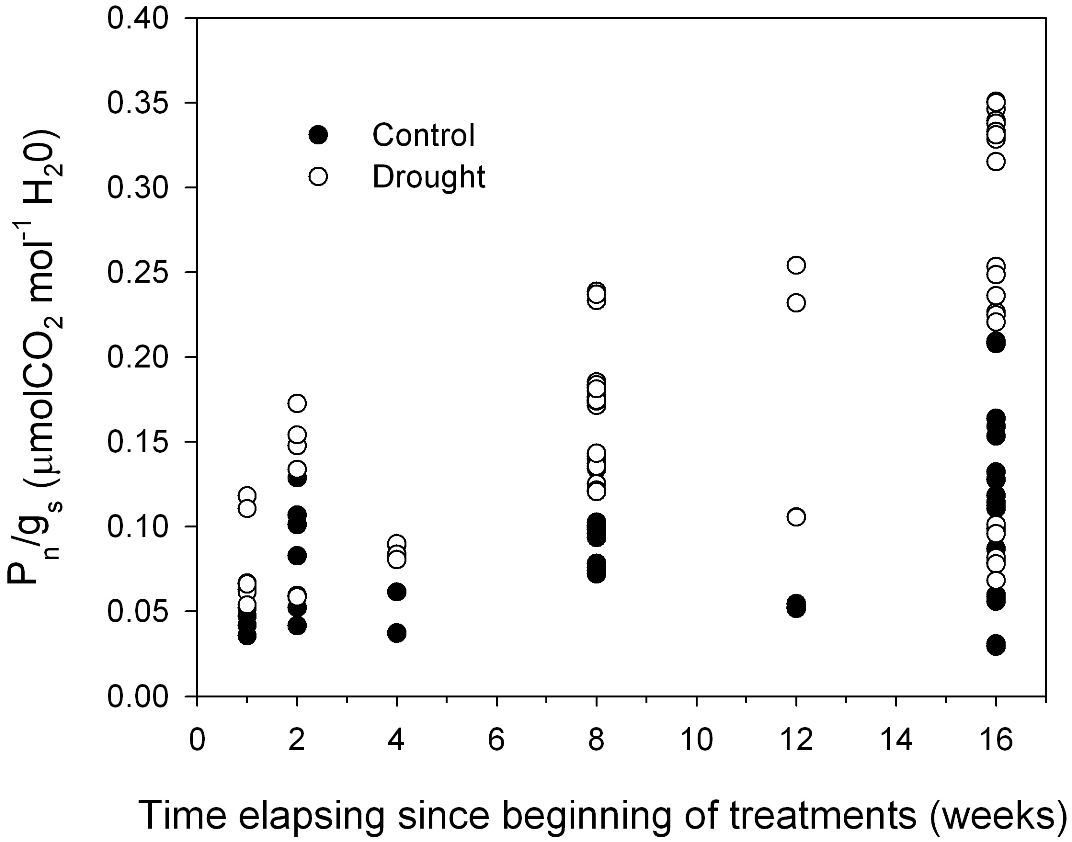
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Control
Drought
P_n/g_s (µmolCO_2 mol^{-1} H_20)
0
2
4
6
8
10
12
14
16
Time elapsing since beginning of treatments (weeks)

Table 1

Growth parameters, ion leakage and chlorophyll fluorescence (F_v/F_m) in potted *Callistemon* plants subjected to control and water stress at the end of the experiment. Each value is the mean of five plants per treatment.

Parameters	Treatments		Significance
	Control	Drought	
Total dry weight (g plant^{-1})	51.01±2.03	24.36±0.30	***
Root/shoot ratio	0.20±0.01	0.42±0.02	***
Number of leaves	444±51.7	224±15.5	**
Total leaf area (cm^2)	2913.7±125.0	1183.0±55.9	***
Total ion leakage (%)	23.96±0.04	34.19±0.07	*
F_v/F_m	0.79±0.06	0.81±0.03	ns

*P <0.05, **P <0.01 and ***P <0.001.

Table 2

Root morphology in potted *Callistemon* plants subjected to control and water stress at the end of the experiment. Each value is the mean of five plants per treatment.

Parameters	Treatments		Significance
	Control	Drought	
Total root length (cm)	3556±151	2595±154	**
$L_{\phi<0.5\ mm}$ (%)	49.28±0.02	55.33±0.01	*
$L_{0.5<\phi<2.0\ mm}$ (%)	38.09±0.01	33.86±0.01	*
$L_{\phi>2.0\ mm}$ (%)	12.15±0.01	10.24±0.01	*
Root volume (cm^3)	4.74±0.46	2.96±0.13	**
Root dry weight (g)	8.59±0.50	7.42±0.37	ns

*P <0.05, **P <0.01 and ***P <0.001.

Table 3

Leaf water relations parameters derived from pressure-volume curves and root hydraulic resistance ($1/L_p$) in *Callistemon* plants subjected to control and water stress at the end of the experiment. Each value is the mean of five plants per treatment.

Parameters	Treatments		Significance
	Control	Drought	
Ψ_{os} (MPa)	-1.77±0.07	-3.35±0.07	***
Ψ_{tlp} (Mpa)	-2.27±0.11	-4.09±0.10	***
ε (Mpa)	8.27±0.87	14.40±1.57	*
$1/L_p$ (g s MPa mg^{-1})	1.02±0.10	3.20±0.44	**

*P <0.05, **P <0.01 and ***P <0.001.