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Effects of water deficit on urban forest growth in a dryland South America region

Incidencia del déficit hídrico en el crecimiento del bosque urbano de una zona árida de Sudamérica

Martinez CF[1], FA Roig[2], JB Cavagnaro[3], MA Cantón[1], AM Di Blasi[4]

Abstract. Urban forests located in dryland regions of Argentina are sustained mostly by groundwater and water coming from thawing in the Andes. This is because the most commonly planted tree species have high water requirements and are most often exposed to water shortage. This study assessed the effect of water deficit on diverse growth variables in saplings of *Acacia visco* (native tree species) and *Morus alba* (exotic tree species), two common tree species in the urban forests of Mendoza's Metropolitan Area. Saplings were exposed to different levels of water deficit under controlled nursery conditions during three growing seasons. There were three watering treatments: replacement of (1) 100% transpired water (control treatment or T1), (2) 66% transpired water (moderate water deficit treatment or T2), and (3) 33% transpired water (severe water deficit treatment or T3). The impact of water stress was greater in the exotic tree-species, *M. alb*a. The growth variables height, stem diameter, leaf area, and annual tree-ring width showed no significant differences between T1 and T2 in *A. visco*. In T3, tree growth was reduced in both species compared to T1. However, *M. alba* trees were more sensitive to any water deficit than *A. visco*. This latter species showed more resistance than *M. alba* to moderate water stress conditions, which even promoted growth of *A. visco*. These results highlight the importance of selecting tree species with low water consumption in sustainable urban forests of cities located in dryland environments.

Keywords: Urban forestry; Drylands; Mendoza, Argentina; *Acacia visco; Morus alba*.

Resumen. Los bosques urbanos situados en ciudades de zonas áridas de Argentina se sustentan principalmente con el riego artificial proveniente de aguas subterráneas y deshielos cordilleranos. Esto se debe a que las especies forestales más cultivadas son de alta demanda hídrica y están expuestas a condiciones de escasez de agua para su crecimiento. Este trabajo evaluó el efecto del déficit hídrico en el crecimiento de ejemplares jóvenes de *Acacia visco* (especie forestal nativa) y *Morus alba* (especie exótica), ambas de uso frecuente en el bosque urbano del Área Metropolitana de Mendoza. Las especies mencionadas fueron expuestas a distintos niveles de déficit hídrico durante tres estaciones de crecimiento en condiciones controladas de vivero. Se aplicaron tres tratamientos de riego: T1 llamado Control (con reposición del 100% del agua transpirada), T2 llamado Déficit Hídrico Moderado (reposición del 66%) y T3 llamado Déficit Hídrico Severo (reposición del 33%). Simultáneamente se midieron distintas variables de crecimiento: altura de planta, diámetro de tronco, área foliar y ancho de anillos de crecimiento. Los ejemplares de *M. alba* mostraron baja resistencia a cualquier nivel de déficit hídrico, mientras que en *A. visco* se observó una mayor resistencia a dicho estrés. Por ejemplo, las variables de crecimiento no mostraron diferencias significativas entre los tratamientos Control y Déficit Hídrico Moderado para *A. visco*. En esta especie, se observó incluso un efecto promotor del crecimiento bajo Déficit Hídrico Moderado. El Déficit Hídrico Severo redujo el crecimiento en ambas especies. Estos resultados reflejan la importancia de seleccionar especies forestales de bajo consumo hídrico. De esta forma, estas especies contribuirán al mantenimiento de la sustentabilidad de los bosques urbanos situados en ambientes de zonas áridas.

Palabras clave: Bosque urbano; Zonas áridas; Mendoza-Argentina; *Acacia visco*; *Morus alba*.

[1] Instituto de Ciencias Humanas Sociales y Ambientales INCIHUSA – Centro Científico Tecnológico CCT CONICET Mendoza, Argentina. Av. Ruiz Leal s/n. Parque General San Martín, Mendoza, Argentina. C.P. 5500. Tel. 0054 261-5244310. Fax 0054 261-5244001.
[2] Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales IANIGLA – Centro Científico Tecnológico CCT CONICET Mendoza, Argentina. Av. Ruiz Leal s/n. Parque General San Martín. Ciudad de Mendoza. C.C.131 C.P. 5500. Tel. 0054 261-5244204.
[3] Instituto de Biología Agrícola de Mendoza IBAM. Facultad de Ciencias Agrarias – Universidad Nacional de Cuyo. Alte. Brown 500. Chacras de Coria, Luján de Cuyo, Mendoza. C.P. M5528AHB. Tel.: 0054 261-4135010 (int. 1307). Fax 0054 261 4960460.
[4] Centro Científico Tecnológico CCT CONICET Mendoza, Argentina. Av. Ruiz Leal s/n. Parque General San Martín. Ciudad de Mendoza.C.C.131 C.P. 5500. Tel.: 0054 261-5244029.
Address Correspondence to: Claudia Fernanda Martinez, *e-mail*: cmartinez@mendoza-conicet.gov.ar
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INTRODUCTION

Urban forests are a key factor in regulating air temperature and moisture in cities located in arid and semiarid regions (Cantón et al., 2001; Konijnendijk et al., 2006). However, scarce rainfall affects the growth of exotic trees with high water demands (Le Houérou et al., 1988). In this sense, tree species with the capacity to withstand limited water resources (Clark & Kjelgren, 1990) directly reduce vulnerability to water stress. This ensures urban forest sustainability and conservation, by promoting a proper balance between forest growth, urban structure, environmental facilities, and services (Bernatzky, 1978; Miller, 1997; Ode & Fry, 2006). In cities located in arid climates, urban forest sustainability is determined by the quality and quantity of the most limiting growth resource (Thompson et al., 1994). In particular, successful tree growth depends on additional water from an efficient irrigation system. In the Mendoza Metropolitan Area (MMA), Argentina, an urban region where 62% of the provincial population is concentrated, 79% of the urban trees are exotic species, which require more water than that naturally provided by local rains. Due to the arid conditions imposed (~200 mm of rainfall per year), the urban forest is fed by water melting from the glaciers in the Andes (Álvarez, 2000). This water, distributed through an irrigation system with channels of pre-Hispanic origin, has shown fluctuations over the last century, with a declining trend during the most recent decades. Hence, urban tree growth has been affected by varying degrees of water deficit. Decreasing precipitation implies the need to quantify trees' drought tolerance. This is essential to develop strategies that optimize urban forest development, and contribute to the reasonable use of water resources in the face of increasing aridity.

This study assessed, through controlled watering, the effect of water stress on various growth variables in *Acacia visco* Lorentz ex Griseb and *Morus alba* L. saplings, two common tree species in the urban forest of the MMA. Our objective was to know which species was more tolerant and better adapted to water stress while maintaining acceptable growth rates. This would lead to a more efficient use of water in cities located in arid and semi-arid environments.

MATERIALS AND METHODS

Study area. The Province of Mendoza is located in central-western Argentina (32°-38° S, 67°-70° W; 720 masl: Norte, 2000). The climate is dry and temperate with cold winters (July mean = 7.3 °C) and warm summers (January mean = 24.9 °C), and a wide daily and seasonal variation in temperature. Winds are moderate (average speed: 11 km/h), except for episodic, strong wind events [i.e., Zonda (Föhn): Norte, 2000]. Solar radiation is high in both amount and intensity throughout the year (2762 sun hours/year), and potential evapotranspiration is 1558.72 mm/year (Berra & Ciancaglini, 1979). The Aridity Index (AI) for the city of Mendoza (1951-2000) is 0.174, typical of a low arid bioclimate. In this city, 76% of the 198 mm annual rainfall occurs between October and March (González Loyarte et al., 2009). If 800 mm are added to the calculation of the annual AI, it reaches a value greater than 0.75. This corresponds to the humid or sub-humid climate conditions which are necessary to sustain the current urban forest in the MMA. This area is located in the agriculture oasis irrigated by the Mendoza River (Capitanelli, 1967).

Experimental design. The effect of water deficit on tree growth was determined through controlled watering experiments using saplings in nursery conditions, following López Lauenstein et al. (2004). The selected species, *A. visco* and *M. alba*, have water requirements of 300 mm/year and 700 mm/year, respectively. Thirty trees of each species between 2 and 3 years old, and initial heights of 0.75 m and 1.15 m, respectively, were randomly separated in groups of ten plants each, which were subjected to the following watering treatments:

T1: watering volume equivalent to 100% of transpired water, referred to as the control group; **T2**: watering volume equivalent to 66% of transpired water, referred to as a moderate water deficit, and **T3**: watering volume equivalent to 33% of transpired water, referred to as a severe water deficit. For each watering, the volume of water (*Wv*) was determined as the difference in pot weights between two successive waterings, according to the following equation:

$$Wv = (W_1 - W_2)$$

Where: Wv = water volume,
W_1 = pot weight at field capacity,
W_2 = pot weight at the actual moment of the watering.

To protect plants against hail, the experiment was conducted under a wire mesh where plants received a mean radiation of 91% of the free incident radiation. This level of radiation, albeit higher than the light saturation level of C_3 plants (approximately 1200 μeinstein/m^2/sec), is similar to the radiation received by trees growing under urban conditions (Taiz & Zaiger, 2003).

The experiment was performed during three complete consecutive growing cycles, between January 2007 and March 2010. There were two waterings per week from the beginning of active vegetative cycle (August 15) until total leaf fall (May 15). Watering during the vegetative recess was reduced to once every two weeks. There were a total of 210 waterings during the experiment. The length of the assay was similar to that conducted on saplings in cities of the Northern Hemisphere (Whitlow et al., 1992). Black polyethylene, 1.5 L containers were filled with soil similar to that used for reforestation by the MMA municipalities (see Table 1). Pots were protected with a plastic cover, preventing the addition of any supplementary water from rain or dew, to evaluate only transpired water. Each pot was placed on a tray to recover and add back the drained water.

Table 1. Physical and chemical properties of the substrate used under nursery conditions (Martinez et al., 2009).
Tabla 1. Propiedades fisico-químicas del sustrato utilizado para las plantas del ensayo de vivero (Martinez et al., 2009).

Texture	Sandy-loam
Electric conductivity	1835 dS/m at 25 °C
Fertility	Nitrogen: 2688 ppm
	Phosphorus: 8.82 ppm
	Potassium: 1178 ppm
	Organic matter: 4.51%

Growth variables. Plant height, stem diameter, leaf area and ring width were measured during the experiment. Plant height was measured from the collar to the tip of each plant on a monthly basis. Stem diameter at the collar height was measured with a caliper. Leaf area was determined using a non-destructive method: an acetate template with a squared grid (1 cm x 1 cm) was utilized with this purpose. The acetate grid was placed on each leaf to count the number of grid points intercepted by the leaf surface. The total sum of points estimated the area of each leaf, and the total leaf area was estimated by multiplying the mean leaf area by the number of leaves (Normand & Campbell, 1989). This variable was measured on four randomly selected plants per treatment group during the months of active growth (October to February). Ring width was measured using a Velmex caliper with 0.001 mm precision (Stokes & Smiley, 1968). These measurements were made at the stem cross-section close to the collar of the plants, mounted on wooden supports and polished to highlight the anatomical ring structure. These cross-sections were obtained at the end of the experiment (March 2010). From a set of samples we obtained 10-16 μm thick cross-sections using a sliding microtome (Jung BioCut 130) to analyze the distribution of the vessel elements (hydrosystem) per growth ring.

Pre-dawn and midday leaf water potentials were recorded using a Pressure Chamber Assi (Scholander et al., 1965). Stomatal conductance was measured with a Leaf Porometer Decagon Devices model SC-1 (Taiz & Zeiger, 2003). Measurements of both variables were performed before and after each watering during the active growth months. Daily minimum and maximum temperatures, precipitation, wind speed and relative humidity were used to characterize the climatic conditions. This information was obtained from the nearby weather station located at the CCT-CONICET, Mendoza (Norte, 2000).

Statistical analysis. We conducted ANOVA using the software R (http://www.r-project.org/). The Bartlett test was used to analyze the homogeneity of variance (homocedasticity). Mean comparisons were made using the Tukey test at significance level of $p \leq 0.05$. ANOVA comparisons were made for measurements taken in January and September for all three treatment groups together over the entire experimental period. The selection of these two months is based on their relevance to the vegetative cycle, as September signals the beginning of seasonal growth, and January is the month with the highest water demand. The difference between the final and initial values was also assessed for the different variables.

RESULTS

Plant height. *Acacia visco* experienced similar growth in all three groups until October-November 2007 (Fig. 1). From this date on, at the beginning of the summer season, there were clear differences in the T3 group, with a severe water deficit. T1 and T2 showed similar height increases, whereas plants in T3 showed a slower growth than T1 and T2. This growth pattern was similar during the following two growing cycles, resulting in a typical sigmoid growth curve (Fig. 1A). By the end of the experiment, *A. visco* increased its height by 151% in T1, 165% in T2 and 93% in T3. Group T2 showed no significant differences from group T1 (Table 2). The statistical model (ANOVA) explained 63% of the variability, with both curve slopes and straight-line equations confirming this result. The variation between final and initial mean values showed significant differences between T1 and T2 *versus* T3.

The differential water availability clearly affected height of *M. alba* from the beginning of the experiment (Table 2). During the second growing cycle, the three treatments were stabilized, showing a plateau in the curves (Fig. 1B). This situation was not repeated in the third growing cycle. Analysis of the percentage difference between initial and final heights allowed to compare growth under T2 and T3 *versus* T1. By the end of the experiment, *M. alba* increased significantly its height by 76% in T1, 68% in T2 and 53% in T3 (Table 2). It means that height growth decreased when water availability was limited in the substrate, and it was affected under any water deficit. Growth was reduced more in *M. alba* than in *A. visco* in all treatment groups (Table 2). The statistical model (ANOVA) explained 68% of the variability.

Stem diameter. At the start of the first annual growth cycle, there was a delay in diameter growth in *A. visco* (Fig. 2). This was probably due to the initial responses to the experimental conditions. After a brief increase in growth, plants experienced a reduction in stem diameter, which increased again the rest of the season. This was particularly true for plants in T1 and T2. During the second year, growth increased in T1 and T2, but not in T3. During the third year, T3 showed a clearly

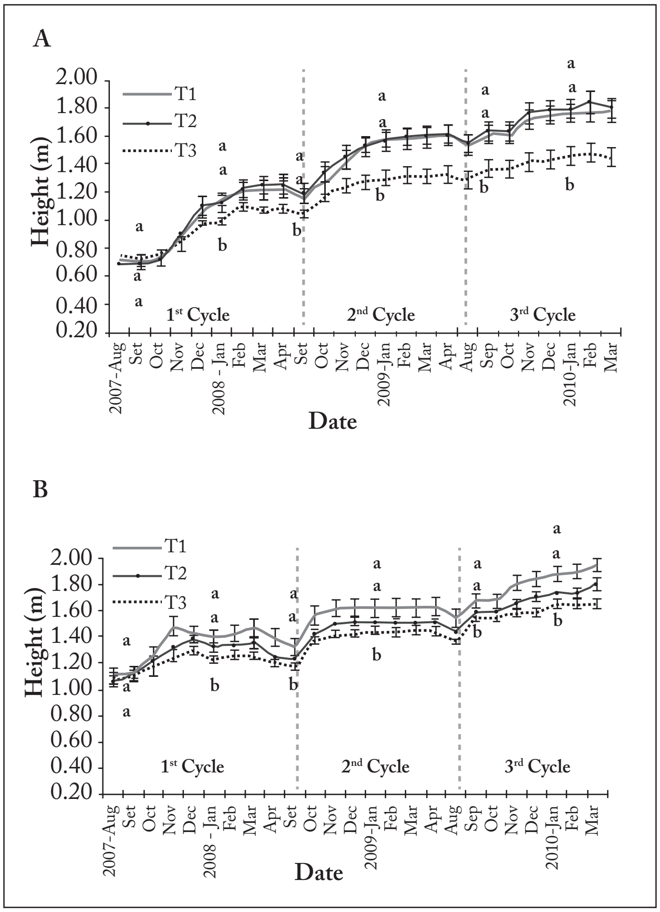

Fig. 1. Monthly height variation in (A) *Acacia visco* and (B) *Morus alba* over the three studied growth cycles. The broken, vertical line indicates the start of each growing cycle. Different letters indicate significant differences at p≤0.05. Means for all three water treatments (n=10 per treatment), and those of September and January were compared using the Tukey test. T1 = Untreated control (field capacity); T2 = Moderate water deficit; T3 = Severe water deficit.
Fig. 1. Variación de los valores medios mensuales de altura en (A) *Acacia visco* y (B) *Morus alba* durante los tres ciclos de aplicación de los tratamientos de riego. Líneas punteadas indican el inicio de cada ciclo de crecimiento. Letras distintas indican diferencias significativas (p≤0,05) resultantes de la comparación estadística mediante Test de Tukey para los tres tratamientos hídricos (n=10 por tratamiento), y los meses de Septiembre y Enero. T1 = Control (no tratado, a capacidad de campo); T2 = Estrés hídrico moderado; T3 = Estrés hídrico severo.

different growth rate compared to T1 and T2. The curves for each group confirmed this tendency (Fig. 2A).

A greater growth reduction was observed in *M. alba* than in *A. visco* at the start of the first cycle (Fig. 2B). It was followed by a sudden increase during early summer in the first year. After that, growth curves exhibited a decreasing tendency until mid-fall in all three treatment groups. Significant differences were found between T1 and T2 compared to T3 during the three growth cycles of the experiment (Fig. 2B).

Table 2. Height variation (%) between the beginning and end of the experiment (August 2007-March 2010) in *Acacia visco* and *Morus alba* for the three water treatments. Different letters within the same column indicate significant differences at p≤0.05.
Tabla 2. Variación porcentual de altura en *Acacia visco* y *Morus alba* para los tres tratamientos hídricos entre el comienzo y el fin del ensayo (Agosto 2007-Marzo 2010). Letras distintas en una misma columna indican diferencias significativas para p≤0,05.

Treatment	*Acacia visco*		*Morus alba*	
	Variation (%)	Tukey test	Variation (%)	Tukey test
T1	151	a	76	a
T2	165	a	68	b
T3	93	b	53	c

Stem diameter growth in *A. visco* increased with increasing volumes of water (see Table 3), explaining 85% of the total variability, according to the ANOVA. As with stem height, the percentage variation in stem diameter was greater in T1 and T2 than in T3 (Table 3). With a moderate water restriction (T2), stem diameter growth was comparable to that under the control group (T1) (Table 3).

Mean stem growth diameter for *M. alba* plants was greater in T1 than in T2, although differences were not statistically significant. Water volume explained 40% of the variability, according to the ANOVA, and variability within each treatment group decreased with reduced water volume. A moderate water restriction did not significantly affect stem diameter growth in this species.

Leaf area. *Acacia visco* steadily increased its leaf area, but with no significant differences between treatment groups over the first year of the experiment. The only exception was in November, where T1 and T2 showed a greater leaf area than T3 (Fig. 3A). During the second year, plants showed significant differences between T1 and T2 *versus* T3 (Fig. 3A). Toward the end of the experiment, leaf area showed an abrupt decline in all three treatment groups, and T1 and T2 showed a greater leaf area than T3 (Fig. 3A). *Morus alba* exhibited a slight increase in leaf area at the beginning of the first cycle, while during the second cycle it experienced a marked initial increase, and finally became stable by the end of the active growth period. The third cycle began with a mean value that dropped abruptly in all treatment groups. Next, leaf area increased gradually, and the differences tracked changes in watering volume. Under T3, the leaf area was significantly lower than in T1 and T2 by the end of the experiment (Fig. 3B).

In T2, *Acacia visco* showed a stronger tendency for larger leaves than T1. In T3, leaf areas were much smaller than those in T1 and T2 (Table 4). Due to the small sample size, a Kruskal-Wallis test was applied to fulfill the normality assumption required by the ANOVA. The comparison between final and initial values yielded significant differences between T1 and T2 *versus* T3 (Table 4). *Morus alba* showed a similar leaf area in T1 and T2, and values in these treatments were greater than those in T3. The percentage variation of leaf area was greater in *A. visco* than in *M. alba* (Table 4). The increase in leaf area in *Acacia visco* under T3 was higher than that in *Morus alba* under T1.

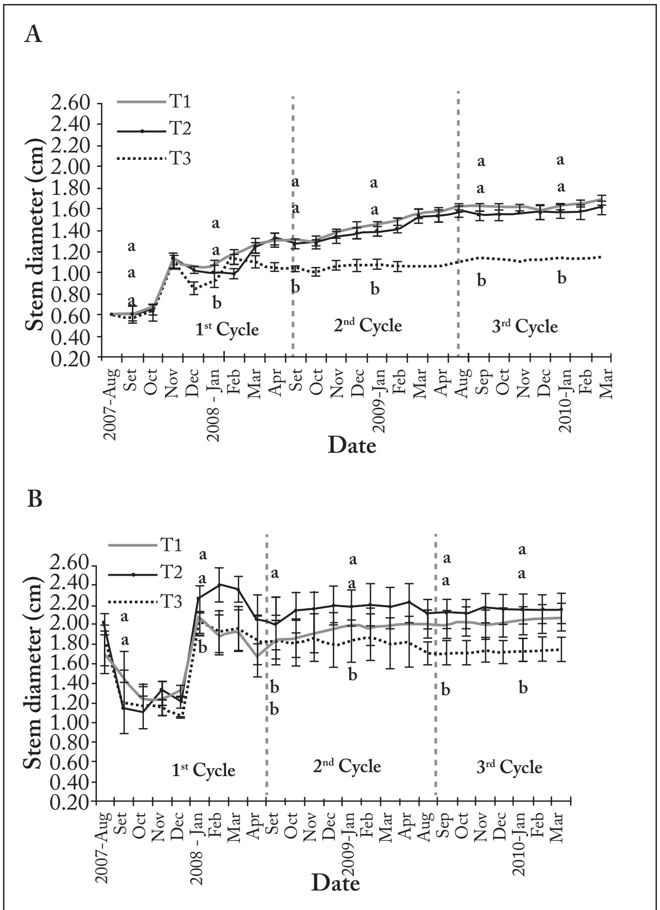

Fig. 2. Monthly stem diameter variation in (A) *Acacia visco* and (B) *Morus alba* over the three studied growth cycles. The broken, vertical line indicates the start of each growing cycle. Different letters indicate significant differences at p≤0.05. Means for all three water treatment (n=10 per treatment) and those of September and January were compared using the Tukey test. T1 = Untreated control (field capacity); T2 = Moderate water deficit; T3 = Severe water deficit.

Fig. 2. Variación de los valores medios mensuales de diámetro de tallos en (A) *Acacia visco* y (B) *Morus alba* durante los tres ciclos de aplicación de los tratamientos de riego. Líneas punteadas indican el inicio de cada ciclo de crecimiento. Letras distintas indican diferencias significativas (p≤0,05) resultantes de la comparación estadística mediante Test de Tukey para los tres tratamientos hídricos (n=10 por tratamiento) y los meses de Septiembre y Enero. T1 = Control (no tratado, a capacidad de campo); T2 = Estrés hídrico moderado; T3 = Estrés hídrico severo.

Table 3. Variation of stem diameter (%) from the beginning to the end of the experiment (August 2007-March 2010) on *Acacia visco* and *Morus alba* in all three water treatments. Different letters within the same column indicate significant differences at p≤0.05.

Tabla 3. Variación porcentual del diámetro de troncos en *Acacia visco* y *Morus alba* para los tres tratamientos hídricos, desde el comienzo hasta el final del ensayo (Agosto 2007-Marzo 2010). Letras distintas en una misma columna indican diferencias significativas para p≤0,05.

Treatment	*Acacia visco*		*Morus alba*	
	Variation (%)	Tukey test	Variation (%)	Tukey test
T1	175	a	22	a
T2	170	a	7	a
T3	87	b	-2	b

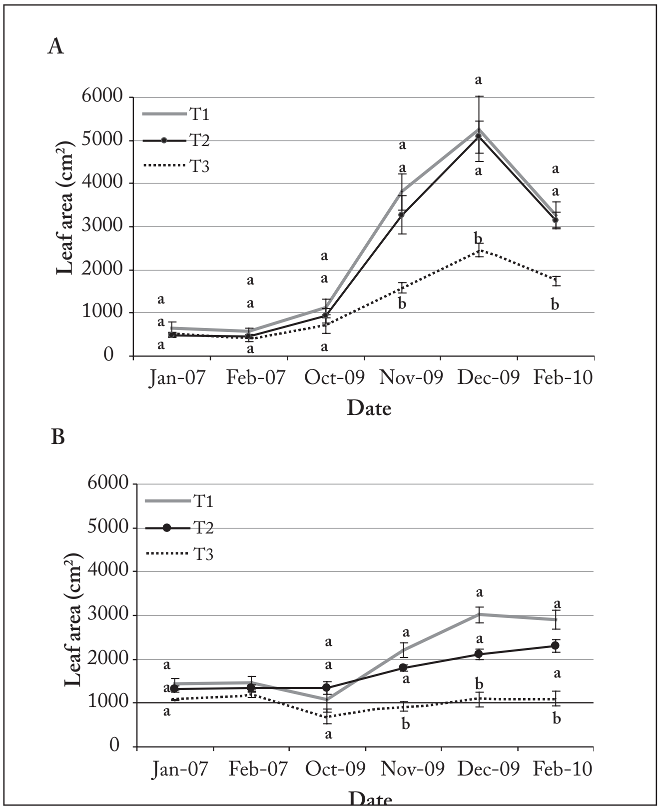

Fig. 3. Mean monthly leaf area variation in (A) *Acacia visco* and (B) *Morus alba* over the entire experimental period. Different letters indicate significant differences at p≤0.05. Means for all three water treatments (n=10 per treatment) and those of September and January were compared using the Tukey test. T1 = Untreated control (field capacity); T2 = Moderate water deficit; T3 = Severe water deficit.

Fig. 3. Variación de los valores medios mensuales de área foliar en (A) *Acacia visco* y (B) *Morus alba* durante todo el ensayo experimental. Letras distintas indican diferencias significativas (p≤0,05) resultantes de la comparación estadística mediante Test de Tukey para los tres tratamientos hídricos (n=10 por tratamiento) y los meses de Septiembre y Enero. T1 = Control (no tratado, a capacidad de campo); T2 = Estrés hídrico moderado; T3 = Estrés hídrico severo.

Table 4. Variation of leaf area (%) during the entire experiment (August 2007-March 2010) for *Acacia visco* and *Morus alba* for all three water treatments. Different letters within the same column indicate significant differences at p≤0.05.

Tabla 4. Variación porcentual del área foliar en *Acacia visco* y *Morus alba* para los tres tratamientos hídricos durante todo el ensayo experimental (Agosto 2007-Marzo 2010). Letras distintas en una misma columna indican diferencias significativas para p≤0,05.

Treatment	*Acacia visco*		*Morus alba*	
	Variation (%)	Tukey test	Variation (%)	Tukey test
T1	402	a	103	a
T2	670	a	75	a
T3	251	b	5	b

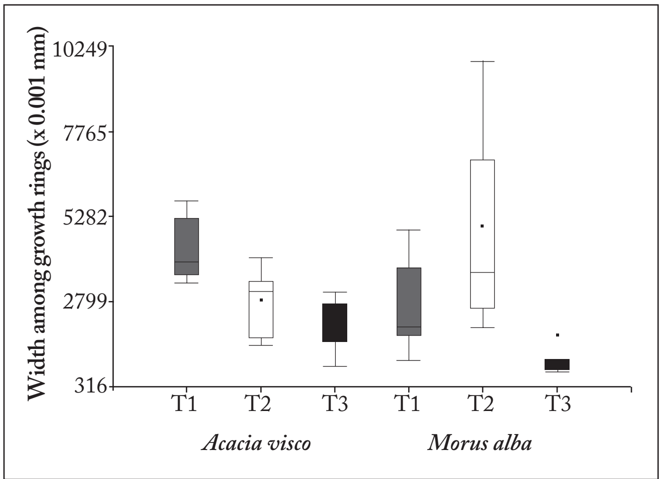

Fig. 4. Box-plot for mean growth ring widths during the experiment period (2007-2010) by species and water treatment. Interquartile Rank (Q3-Q1), mean, median and data dispersal are indicated. Different letters indicate significant differences at p≤0.05. T1 = Untreated control (field capacity); T2 = Moderate water deficit; T3 = Severe water deficit.

Fig. 4. Gráficos de cajas para los valores medios de ancho de anillos de crecimiento para el período de ensayo (2007-2010) por especie y tratamiento hídrico. Se indican: Rango Intercuartílico (Q3-Q1), media, mediana y la dispersión de los datos. Letras distintas indican diferencias significativas para p≤0,05. T1 = Control (no tratado, a capacidad de campo); T2 = Estrés hídrico moderado; T3 = Estrés hídrico severo.

Tree-ring growth. Annual growth ring width in *Acacia visco* was reduced when the water volume was also reduced. Under T1, this variable was higher in this species than in *Morus alba*. A significant difference was noted between T1 and T3. In T2, *M. alba* presented the widest growth rings, compared to T1, but with the highest variability in measurements (Fig. 4). Plants under T3 displayed the lowest growth, with little data variability between growth cycles.

Leaf water potential. Measurements, taken after each watering, showed higher water potentials at pre-dawn than at midday (e.g., see Fig. 5). This is evidence of higher pre-dawn soil moisture conditions, and of plants with closed stomata in equilibrium with soil moisture, for both *Acacia visco* and *Morus alba* (Fig. 5). Nevertheless, differences were significant, according to the Tukey test, only for *A. visco*. Plants under T1 produced very low midday values (-2.4 MPa) compared to T2 and T3, with ranges of -1.0 to -1.2 MPa at pre-dawn, and -2.0 to -2.3 MPa at midday.

Morus alba always had the highest values for leaf water potential, with ranges of -0.4 to -0.5 MPa at pre-dawn, and -0.7 to -0.8 MPa at midday (Fig. 5). Differences were not statistically significant between treatment groups within the same species.

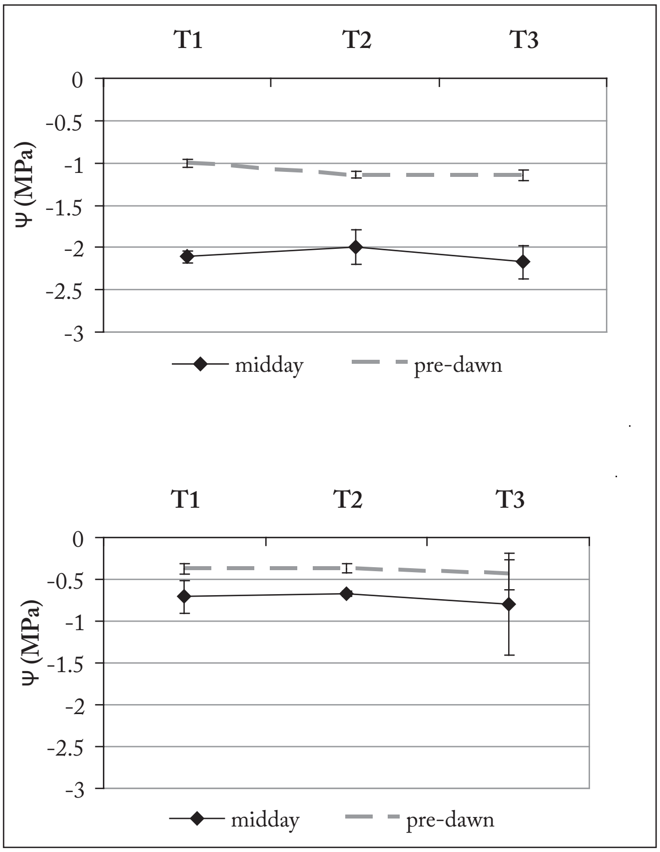

Fig. 5. Measurements of pre-dawn and midday leaf water potential following waterings during the first treatment year (2007). Values are the mean ± 1SE of n=4 (A) *Acacia visco;* (B) *Morus alba*. T1 = Untreated control (field capacity); T2 = Moderate water deficit; T3 = Severe water deficit.

Fig. 5. Mediciones de potencial hídrico foliar antes del amanecer y al mediodía luego de riegos durante el primer año de tratamientos (2007). Los símbolos son el promedio ± 1EE de n=4. (A) *Acacia visco*; (B) *Morus alba*. T1 = Control (no tratado, a capacidad de campo); T2 = Estrés hídrico moderado; T3 = Estrés hídrico severo.

Values measured previous to watering (Fig. 6) reflected the effects of severe water deficit (T3), particularly under pre-dawn conditions in *A. visco*. Before watering, *M. alba* showed significant differences only for midday values, and in T1 and T2 *versus* T3 (Fig. 6). This suggests that *M. alba* was more strongly affected by a severe water restriction. Midday values following watering were significantly different between T1 and T2 with respect to T3 for both species. The range of leaf water potential in these cases was from -0.8 to -1.9 MPa at pre-dawn and from -1.0 to -1.9 MPa at midday. The highest values of leaf water potential at midday compared to those at pre-dawn was probably due to the fact that all measurements were taken the same day as watering, when the water had probably not yet reached the roots.

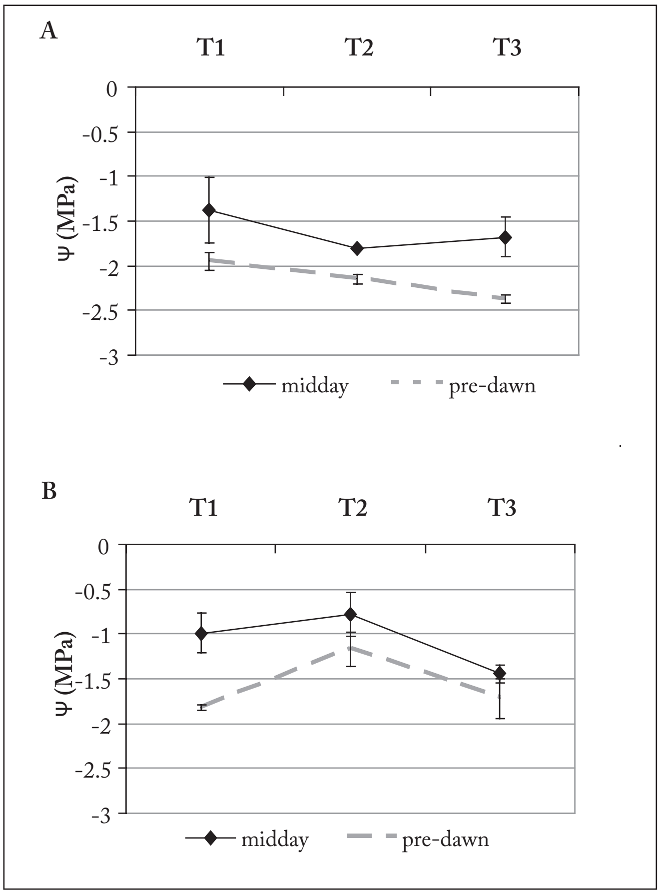

Fig. 6. Measurement of pre-dawn and midday leaf water potential on a date previous to waterings during the last treatment year (2010). Values are the mean ± 1SE of n=4. (A) *Acacia visco*; (B) *Morus alba*. T1 = Untreated control (field capacity); T2 = Moderate water deficit; T3 = Severe water deficit.

Fig. 6. Mediciones de potencial hídrico foliar antes del amanecer y al mediodía en una fecha previa a los riegos durante el último año de tratamiento (2010). Los símbolos son el promedio ± 1EE de n=4. (A) *Acacia visco*; (B) *Morus alba*. T1 = Control (no tratado, a capacidad de campo); T2 = Estrés hídrico moderado; T3 = Estrés hídrico severo.

Stomatal conductance. Stomatal conductance values previous to watering during the first year reached significant differences for both species, comparing groups T1 and T3 (Fig. 7). Highest values in both species were observed in the control group (Fig. 7A). During the second year, the range of variation was smaller, which led us to assume that the effect was likely due to a variable water volume. A comparison of means showed significant differences only for *Acacia visco,* where stomatal conductance was higher in T3 than in T1 Fig. 7B).

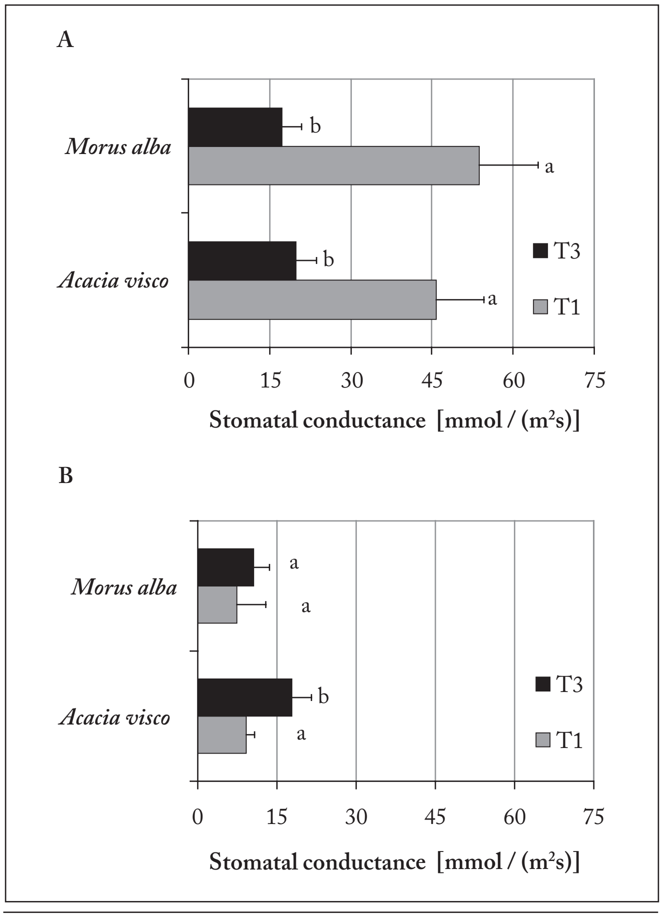

Fig. 7. Stomatal conductance before an irrigation event in saplings of *Acacia visco* and *Morus alba* maintained at field capacity (Control, T1) or under a severe water deficit (T3) during the experimental period. (A) First year of observations (2008); (B) second year of observations (2009). Different letters indicate significant differences at p≤0.05 using the Tukey test. Each histogram is the mean ± 1SE of n=4.

Fig. 7. Conductancia estomática antes de un riego en plantas jóvenes de *Acacia visco* y *Morus alba* mantenidas a capacidad de campo (Control, T1) o expuestas a un déficit hídrico severo (T3) durante el período experimental. (A) Primer año de mediciones (2008); (B) Segundo año de mediciones (2009). Letras distintas indican diferencias significativas con p≤0,05 usando el Test de Tukey para la comparación múltiple de medias. Cada histograma es el promedio ± 1EE de n=4.

Watering volume. The volume for each watering (***Wv***) varied with the species, treatment group and watering frequency (Table 5). During the experiment, *M. alba* showed a higher mean watering volume than *A. visco*. Pearson's correlation coefficient between the two species was r = 0.80. Comparing watering volumes for different seasons and treatment groups, volumes were similar in autumn and winter, seasons of reduced growth, when the need for water naturally diminishes.

Tabla 5. Mean transpiration (cm^{3}day/dm^2) and standard error for each species and water treatment, during the months of greater water demand (October to February).
Table 5. Transpiración promedio (cm^{3}día/dm^2) y error estándar de cada especie y tratamiento para los meses de mayor demanda de riego (octubre a febrero).

Treatment	*Acacia visco*		*Morus Alba*	
	Transpiration (cm^{3}day/dm^2)	Standard Error	Transpiration (cm^{3}day/dm^2)	Standard Error
T1	0.57	0.20	0.78	0.17
T2	0.54	0.12	0.56	0.11
T3	0.35	0.05	0.52	0.05

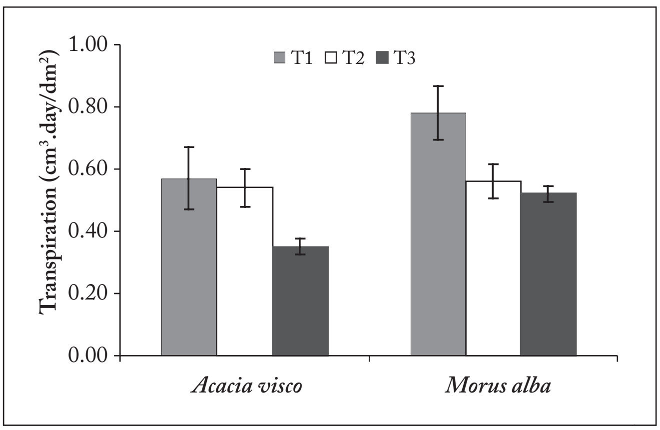

Fig. 8. Transpiration of *Acacia visco* and *Morus alba* during the months of higher water demand (October to February). Each histogram is the mean ± 1SE of n=4. T1 = Untreated control (field capacity); T2 = Moderate water deficit; T3 = Severe water deficit.
Fig 8. Transpiración de *Acacia visco* y *Morus alba* durante los meses de mayor demanda de riego (Octubre a Febrero). Cada histrograma es el promedio ± 1EE de n=4. T1 = Control (no tratado, a capacidad de campo); T2 = Estrés hídrico moderado; T3 = Estrés hídrico severo.

When calculating the average watering volume for the months of higher irrigation demand (October to February), which partially depends on the leaf area of each species, it was observed that *M. alba* needed a greater volume of water than *A. visco* to replace losses by transpiration. The water requirements were similar in T2 and T3. On the other hand, *A. visco* showed a lower transpiration than *M. Alba* (see Table 5), with significant differences between T1 and T2 *versus* T3. This species also showed reduced water consumption as a function of leaf area for all treatments in comparison to *M. alba* (Fig. 8).

DISCUSSION AND CONCLUSIONS

Trees that make up urban forests in drylands were exposed to water stress, whose effects on growth can be estimated from saplings, as suggested by Kjelgren & Clark (1992) and Pita Andreu & Pardos Carrión (2007). There is growing interest in improving knowledge about the ecophysiology of urban forests, particularly those exposed to water limitations (Clark & Kjelgren, 1990; Gleick et al., 2003). However, there is little information in the literature on these topics, specifically regarding urban forests in cities located in arid zones (Bernatzky, 1978; McCarthy & Pataky, 2010).

We evaluated the effects of water restriction on the growth of *A. visco* and *M. alba* saplings, two species commonly used in the city of Mendoza; experiments were conducted under controlled watering conditions. Study duration is supported by experiments undertaken by Whitlow et al. (1992) and Rodríguez Negrete et al. (2005) in cities of the Northern Hemisphere. Our results contribute to ecophysiological issues that have been mostly unexplored in urban forests (Whitlow & Bassuk, 1998). During the initial stages of the experiment, variations were observed in growth parameters, which might be attributed to the acclimatization of the plants to the new environmental conditions. At the beginning the second and third year of the experiment, general growth tendencies were observed; these can be related to the distinct levels of water deficit, with significant differences between species and watering treatment groups.

Morphological (plant height, stem diameter, leaf area, treering growth) and physiological (leaf water potential, transpiration) growth responses depended on the degree of water deficit and the species. Under severe water stress, both species were significantly affected, showing reductions in all morphophysiological variables. In the case of *A. visco*, growth was similar under moderate water restriction and control plants. This suggests that an intermediate water limitation does not restrict growth in this species. A severe water restriction resulted in reduced growth of tree-rings, in particular after the second year of the experiment. The accumulated growth in these annual rings indicated that under severe water restriction, radial growth was reduced by approximately 45% compared to the control plants. In terms of leaf water potential, there were significant differences between pre-dawn and midday values from the beginning of the experiment. The minimum leaf water potential at midday was observed on plants exposed to a moderate water deficit. Higher values were observed in the control compared to plants exposed to a moderate or severe water deficit. Measurements of leaf water potential at the end of the experiment more clearly reflected the effects of a severe water stress, especially at midday. The measurement range, from -1.5 to -2.0 MPa, is comparable to that presented by Clark & Kjieldan (1990) in *Acer* sp. saplings.

Responses in *M. alba* depended on the applied water deficit. Plant height was the most affected variable, with significant reductions of 8% and 15% for the moderate and severe water restriction treatments, respectively, compared to the control group. Stem diameter and leaf area were only affected under a severe water restriction, with reductions relative to the control plants of 15% and 62%, respectively. Similar results have been reported on *Prosopis chilensis* and *Prosopis flexuosa* saplings (López Laustein et al., 2005). These authors reported that a decreased water availability reduced stem diameter by 35% compared to control plants. Under severe water restriction, radial growth (i.e., of annual rings) was reduced by around 31% in comparison to control plants. Initial measurements of leaf water potential did not significantly differ between pre-dawn and midday. Values prior to watering were, as expected, lower at midday than at pre-dawn as a result, at least in part, of stomatal closure. There were significant differences between the control and moderate deficit groups *versus* severe deficit group. Values for leaf water potential in our study are similar to those reported by other authors (Bunce et al., 1977; Whitlow & Bassuk, 1992). Stomatal conductance did not significantly differ between the two species. Under a severe water deficit, 20% of the plants died two months before the end of the experiment. This demonstrates a low tolerance to a severe and prolonged water stress, which maintained over time, resulted in reductions in growth during the species cycle, affecting its resilience and causing death.

Monitoring growth in this experiment generated new information on biological characteristics of young plants of two forest species frequently used in urban forests in the arid West of Argentina. Results similar to ours have been reported for cities in other countries (Nowak, 1994; Dwyer et al., 2003; Dineva, 2004). Even though working with saplings, the results can be extrapolated to adult plants (Esper et al., 2008). Our results indicate that with moderate levels of water restriction it is possible to ensure growth of saplings, particularly in *Acacia visco*. However, a severe water deficit (33% of transpired water) affected the majority of the growth variables in both species. The exception to these responses was seen in the growth rings and stomatal conductance of *Morus alba*.

Information on the water requirements of the studied species is relevant and pertinent to develop guidelines that optimize the volume and frequency of waterings appropriate for urban tree establishment in drylands (Whitlow et al., 1992). *Morus|alba* required more water to replace losses by transpiration, while *A. visco* showed lower water consumption as a function of leaf area. This response of *A. visco* contributes to its tolerance to conditions of moderate water deficits, and indicates a better adaptation to these conditions. Similar results have been obtained in trees located in the extensive subtropics, and in the north and south of the Province of Mendoza (Dalmasso, 2010). The correlation between the growth variables and the water requirements of the studied species indicated that *A. visco*, as a native species from the northwestern Argentina, showed acceptable growth with low volumes of water. *Morus alba* was more sensitive to soil water reductions, in particular to the effects on plant height. Our findings as well as those of prior experiments (Martinez et al., 2009), reflect a greater tolerance in *A. visco* than in *M. Alba* for growing under conditions of moderate water stress.

Findings of this study are useful to suggest management strategies for urban irrigation, and the selection of appropriate species in terms of reforestation programs. The selection of *A. visco* is suggested, with acceptable growth patterns, making it appropriate for forest renovation in cities located in arid zones. The selection criterion of using native species with low water consumption, supported by McPherson (2002) and Chen et al. (2011), contributes to the sustainability of urban forests in drylands.

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