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TAMARIX ARBOREA VAR. *ARBOREA* AND *TAMARIX PARVIFLORA:* TWO SPECIES VALUED FOR THEIR ADAPTABILITY TO STRESS CONDITIONS

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The choice of stress resistant and highly adaptable species is a fundamental step for landscaping and ornamental purposes in arid and coastal environments such as those in the Mediterranean basin. The genus *Tamarix* L. includes about 90 species with a high endurance of adversity. We investigated the water relations and photosynthetic response of *Tamarix arborea* (Sieb. ex Ehrenb.) Bge. var. *arborea* and *T. parviflora* DC. growing in an urban environment. Both species showed no evidence of drought or salt stress in summer, and appeared to follow two strategies with *T. arborea* var. *arborea* investing in high carbon gain at the beginning of the summer, and then reducing photosynthetic activity at the end of the season, and *T. parviflora* showing lower but constant levels of photosynthetic activity throughout the vegetative season. For landscaping and ornamental purposes, we suggest *T. arborea* var. *arborea* when a fast-growing, high-cover species is necessary, and *T. parviflora* when less-invasive species are required.

Keywords: Tamarisks – drought stress – photosynthesis – water potential

INTRODUCTION

The genus *Tamarix* L. includes about 90 salt-secreting species that show a high adaptability to different environments and a high endurance of adversity [1, 8, 25].

For the Italian vascular flora, *Tamarix* is a yet not well-investigated genus [22]. Surveys on the diversity, ecology, distribution and leaf anatomy of *Tamarix* species in Italy were recently carried out [2, 7, 23, 24]. Among the species investigated *Tamarix arborea* (Sieb. ex Ehrenb.) Bge. var. *arborea* and *T. parviflora* DC. are those that show a wider distribution in Italy, although they have been confused in the past with other taxa, especially with *T. gallica* L. and *T. africana* Poir.

In the Mediterranean Basin, where coastal areas are largely affected by human overexploitation, the use of species able to tolerate heavy-metals and other abiotic stresses may represent a low-cost solution for phytoremediation in these harsh environments [10, 14]. For example, *T. gallica* is a widespread species in coastal Mediterranean areas, showing a high adaptability to different environments and a high tolerance to heavy-metal polluted soils [1]. Since *Tamarix* species can endure

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*Corresponding author; e-mail address: francesca.grisafi@unipa.it extreme climatic conditions [5], they are often used as bio-ameliorative species in soils subjected to strong erosion [6, 13, 19]. While *Tamarix* species are reported as invasive for riparian ecosystems in the USA [17], in Mediterranean areas they are appreciated in urban landscaping as ornamental species because of their resistance to stress, as they are resistant to high salinity, drought and pollution and because they are often able to reach deeper into the water table than other species commonly used in landscaping. *T. arborea* var. *arborea* is usually cultivated in public and private gardens while *T. parviflora* is also gradually naturalizing in various regions of the Italian territory [22, 23]. The choice of the species for ornamental use in an urban environment should be related not only to growth form and appearance, but also to physiological traits. *Tamarix* species may show differences in their eco-physiology that lead to different levels of fitness in a certain environment, and the knowledge of their resistance or potential invasiveness can help in the choice of the species to be introduced.

In this study we compared physiological traits of *T. arborea* var. *arborea* and *T. parviflora*, growing as roadside vegetation in the city of Palermo (Sicily, southern Italy) in early summer and autumn. The aim was to evaluate which of the species is the most suitable for landscaping purposes, on the basis of water-relation and productivity parameters. The effect of salinity on growth of *T. arborea* var. *arborea*, was also determined by comparing shrubs set at 40 m from the water front and shrubs growing at 180 m from the shore.

MATERIAL AND METHODS

Study site and plant material

The study was carried out in two nearby sites of the city of Palermo (38°06’51.45”N, 13°22’36.52”E). The first site (RS, road-side) was located along a main traffic route at ca. 180 m from the sea, while the other (WF, water-front) was located on the other side of the road at 40 m from the sea-front.

Three plants of *Tamarix arborea* and three of *Tamarix parviflora* were used for measurements at the RS site, and three plants of *T. arborea* were sampled at the WF site. The trees grew in flower-beds and were approximately 3 m high. Trees were subject to heavy pollution due to the intense traffic of cars and trucks along the road. Plants received no irrigation apart rainfall.

Table 1

Air pollution data (SO_2, NO_2, CO and PM10) in June and October

	SO_2 (µg/m^3) 24-h monthly average	NO_2 (µg/m^3) 1-h monthly maximum	CO (mg/m^3) 8-h monthly maximum	PM10 (µg/m^3) 24-h monthly average
June	1	99	0.8	30
October	2	126	3.3	42

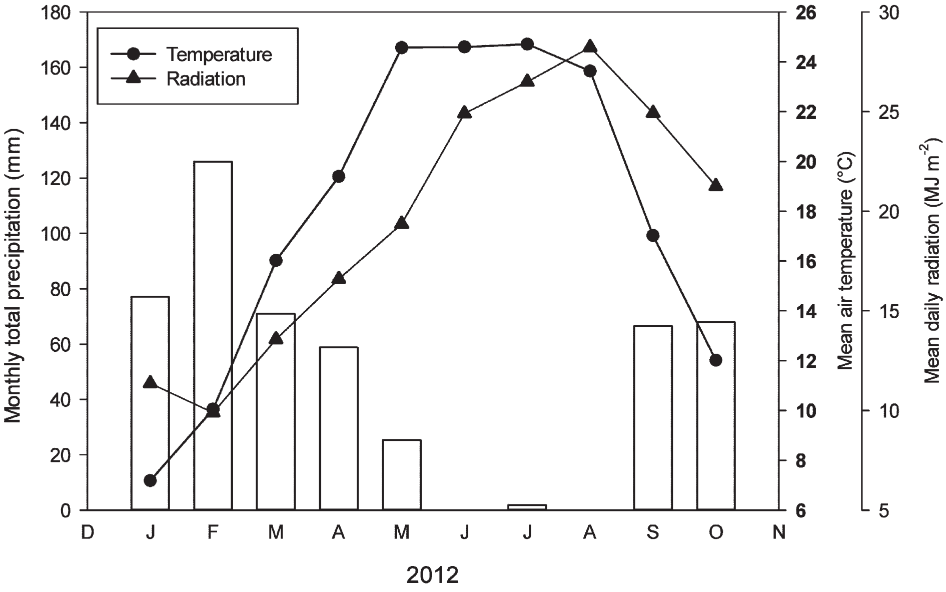

Fig. 1. Precipitation, air temperature and solar radiation in a typical climatic annual conditions

All measurements were done on leafy twigs growing at breast height on the south-facing part of the canopy, in June and October of a typical climatic annual conditions (Fig. 1). Total monthly rainfall, mean air temperature and solar radiation data for the city of Palermo in such period were obtained from the Servizio Informativo Agrometerologico Siciliano (SIAS) and are reported in Fig. 1. Data on air pollution were obtained from RAP S.p.A. Risorse Palermo Ambiente and are reported in Table 1.

Leaf gas exchange measurements

In the genus *Tamarix*, leaves are actually short shoots bearing scale-like leaves, however the term 'leaf' has been used for simplicity [8]. Net photosynthesis (A), stomatal conductance to water vapour (g_s) and leaf transpiration (E) were measured on 3–5 leaves per individual using an infra-red gas analyzer (HCM 1000, Walz) under ambient light and CO_2 conditions. Measurements were taken on clear, sunny days in June and October on mature leaves growing in full sunlight between 10:00 and 12:00 h. After recording gas exchange measurements, the leaf sample enclosed in the cuvette was excised and the projected leaf area within the gas exchange cuvette was measured with a portable leaf area meter (AM100, Analytical Development Company, Hoddesdon, UK). Gas exchange data were expressed on a leaf area basis. After drying the leaf samples at 60 °C to constant weight, leaf dry weight (DW) was measured and leaf mass per area (LMA) was calculated by dividing sample DW by leaf area.

Pigment content

Chlorophyll and carotenoid content were determined by spectrophotometric analysis. From each tree, three leaf samples (0.1 g FW) were ground in a mortar and extracted in an 80% (v/v) aqueous solution of acetone; after a first centrifugation the pellet was re-suspended in 80% acetone and total pigment content of the pooled supernatant was assayed spectrophotometrically at 652 nm (Beckman Coulter DU 800) and quantified [9].

Water relations

Leaf water potential was measured with a pressure bomb (SKPM 1400, Skye Instruments Ltd., Powys, UK) on two leafy twigs per tree collected every two hours from 07:00 to 17:00 h.

Leaf water potential at turgor loss point (Ψ_{TLP}), osmotic potential at full turgor (π_0) and maximum bulk elastic modulus (ε_{max}) were obtained by pressure-volume (PV) curves according to Tyree and Hammel [21] on 5 leafy twigs per species.

Statistical analysis

All data are presented as mean values ± standard deviation. Data were analysed with one-way analysis of variance (ANOVA), using the software package SigmaPlot 12 (Systat Software, Inc., San Jose, USA). Tukey's test was used to compare means when ANOVA was significant ($P < 0.05$).

RESULTS

Growth and climatic conditions

In *Tamarix* species leaves usually appear in March–April. In *T. arborea* var. *arborea*, leaves appeared about two weeks earlier than in *T. parviflora.* When measurements were carried out, in June, leaves had reached full development. Initial signs of senescence were observed in November and leaf fall was completed at the beginning of December.

In 2012, maximum mean air temperature was reached in May, and remained around 24 °C until August. Mean air temperature dropped to 17 °C in September and to 12 °C in October, when autumn determination of physiological parameters was made. Rainfall occurred regularly from January to May, decreasing gradually during the spring, and the summer season was dry, except for very scarce precipitation in July. In September and October there was about 14 mm of total rainfall each month (Fig. 1).

Photosynthesis, stomatal conductance and transpiration

In early summer, net photosynthetic rate in *T. parviflora* was 3.2 µmol CO_2 m^{-2} s^{-1}, about one third of that measured in *T. arborea* var. *arborea* (Fig. 2A). When comparing growth sites, in *T. arborea* var. *arborea* *A* was slightly but not significantly higher at the WF site (12.3 µmol CO_2 m^{-2} s^{-1}) than in trees growing along the roadside (10.4 µmol CO_2 m^{-2} s^{-1}). *T. parviflora* maintained similar photosynthetic rates in October, while there was a marked seasonal effect on *T. arborea* var. *arborea,* where *A* dropped to 0.78 and 2.3 µmol CO_2 m^{-2} s^{-1} at RS and WF, respectively.

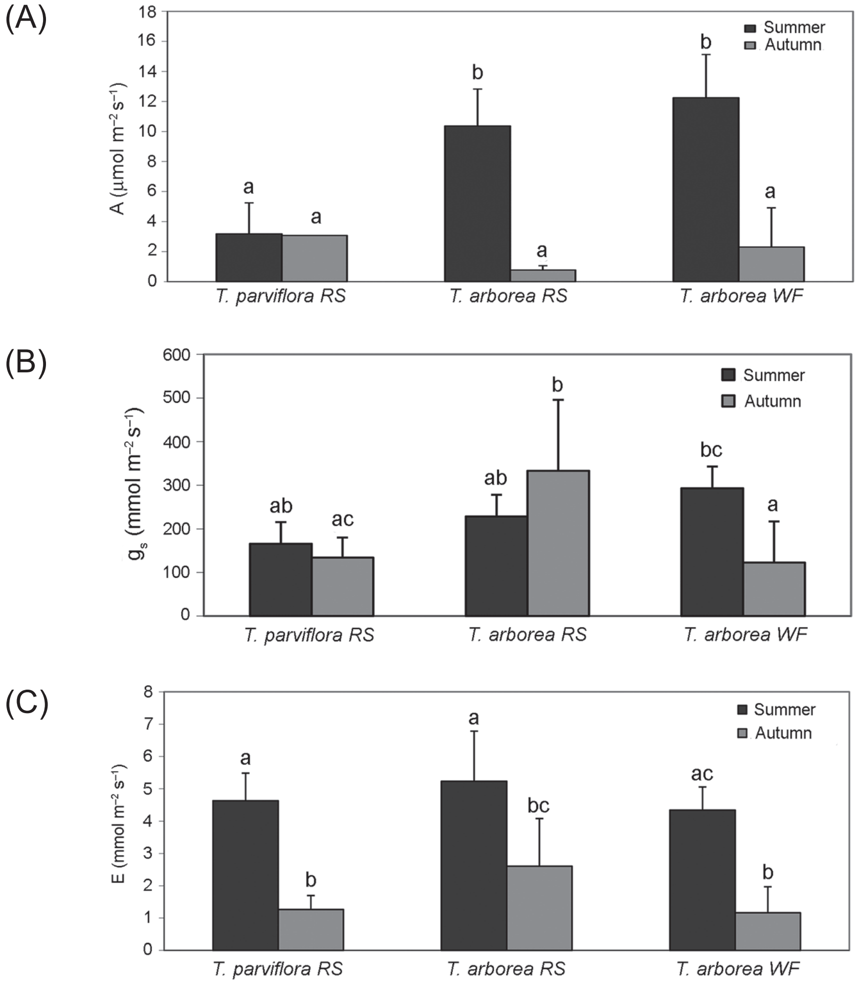

Fig. 2. Net photosynthesis (A), stomatal conductance (B) and transpiration (C) in *T. arborea* var. *arborea* and *T. parviflora* at RS and WF locations in summer and autumn 2012. Data are reported as mean values ± standard deviation (n = 9–15). Different letters indicate significant differences ($P < 0.05$)

Stomatal conductance (g_s) ranged from 123 to 333 mmol H_2O m^{-2} s^{-1} (Fig. 2B). In June g_s did not vary significantly between species or sites. *T. arborea* var. *arborea* at WF showed a significant reduction in g_s between summer and autumn, from 293 to 123 mmol H_2O m^{-2} s^{-1}, while g_s of *T. arborea* var. *arborea* at RS was 333 mmol H_2O m^{-2} s^{-1}, significantly higher than that of the same species at WF and of *T. parviflora* at the same site.

In June, transpiration rate (E) was 4.7 mmol H_2O m^{-2} s^{-1} on average, with no significant differences between species or sites. In October, E was significantly reduced in all species and sites, and ranged from 1.2 mmol H_2O m^{-2} s^{-1} in *T. arborea* var. *arborea* at WF to 2.6 mmol H_2O m^{-2} s^{-1} in *T. arborea* var. *arborea* at RS (Fig. 2C).

Leaf mass per area (LMA) measured on samples collected in June ranged between 150 and 200 g m^{-2}, with the lowest value measured for *T. arborea* var. *arborea* at RS (Fig. 3). In October, LMA increased for all samples, ranging from 210 to 240 g m^{-2}, though this increase was significant only for *T. arborea* var. *arborea* at RS.

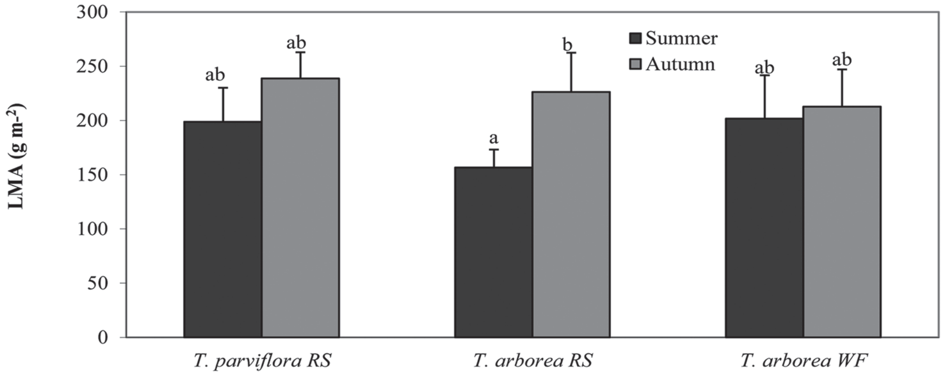

Fig. 3. Leaf mass per area in *T. arborea* var. *arborea* and *T. parviflora* at RS and WF locations in summer and autumn 2012. Data are reported as mean values ± standard deviation (n = 9–15). Different letters indicate significant differences ($P < 0.05$)

Pigment content

The leaf total chlorophyll content of the two species (Fig. 4A) did not show any significant differences between species or sites in summer, and ranged between 980 and 1140 µg g^{-1} FW. In autumn, only *T. parviflora* showed a significant reduction in chlorophyll content. Mean carotenoid content (Fig. 4B) was the same for *T. parviflora* and *T. arborea* var. *arborea* at WF (164 µg g^{-1} FW) in summer, while it was significantly lower in *T. arborea* var. *arborea* at RS (129 µg g^{-1} FW). In autumn, the carotenoid content decreased in *T. arborea* var. *arborea* at both sites, with a more pronounced decrease at RS, while in *T. parviflora* there was a slight but not significant increase. The chlorophyll a/b ratio ranged from 3.19 to 3.95 with the highest value in *T. parviflora* at RS and the lowest one in *T. arborea* var. *arborea* at WF.

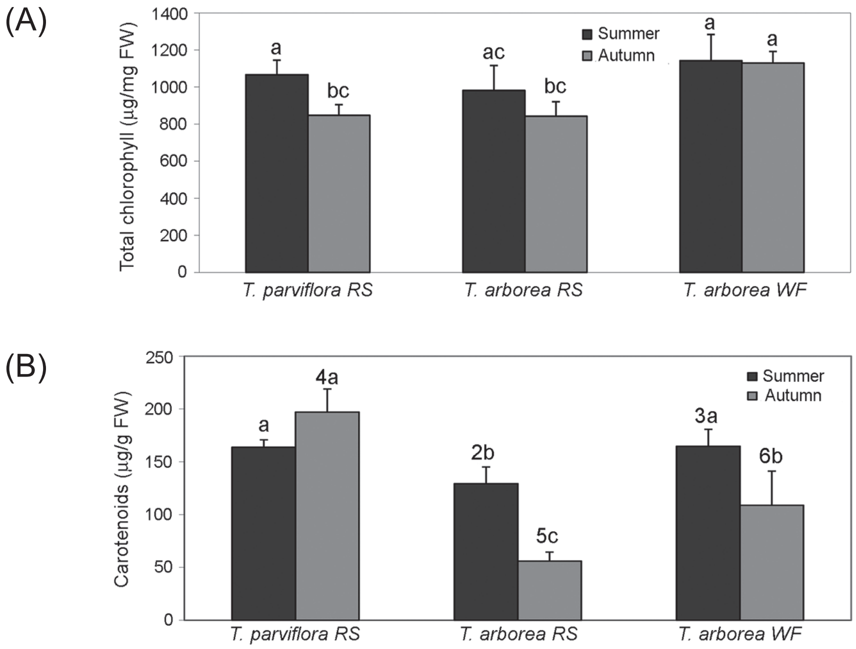

Fig. 4. Leaf chlorophyll (A) and carotenoid (B) content in *T. arborea* var. *arborea* and *T. parviflora* at RS and WF locations in summer and autumn 2012. Data are shown as mean values ± standard deviation (n = 9). Different letters indicate significant differences ($P < 0.05$)

Leaf water relations

The water potential at turgor loss point (Ψ_{TLP}) in June was –2.4 ± 0.4 and –2.5 ± 0.1 MPa for *T. parviflora* and *T. arborea* var. *arborea,* respectively. In *T. arborea* var. *arborea* in October there was a slight change in Ψ_{TLP} that decreased, though not significantly, to –2.6 ± 0.1 MPa. Leaf elasticity modules (ε), more variable in *T. arborea* var. *arborea* than in *T. parviflora*, did not show significant differences between species and seasons, though the lowest value was found in the latter species during the summer.

Since leaves started to detach from the twigs after a few water potential measurements, probably due to the beginning of senescence, only a few points for the autumn PV curves of *T. parviflora* could be obtained.

The highest values of leaf water potential (Ψ_L) were measured at 07:00. In June they were not significantly different between species or sites: the least negative values were –1.35 MPa for *T. parviflora* at RS and –2.02 MPa for *T. arborea* var. *arborea* at WF. Ψ_L remained rather stable throughout the day (Fig. 5A), with a minimum value of about –2.0 MPa at midday. Their mean values were always slightly above those of Ψ_{TLP}. In October, the daily course of Ψ_L showed more marked fluctuations than in June (Fig. 5B). The Ψ_L in the early morning was significantly lower in *T. arborea* var.

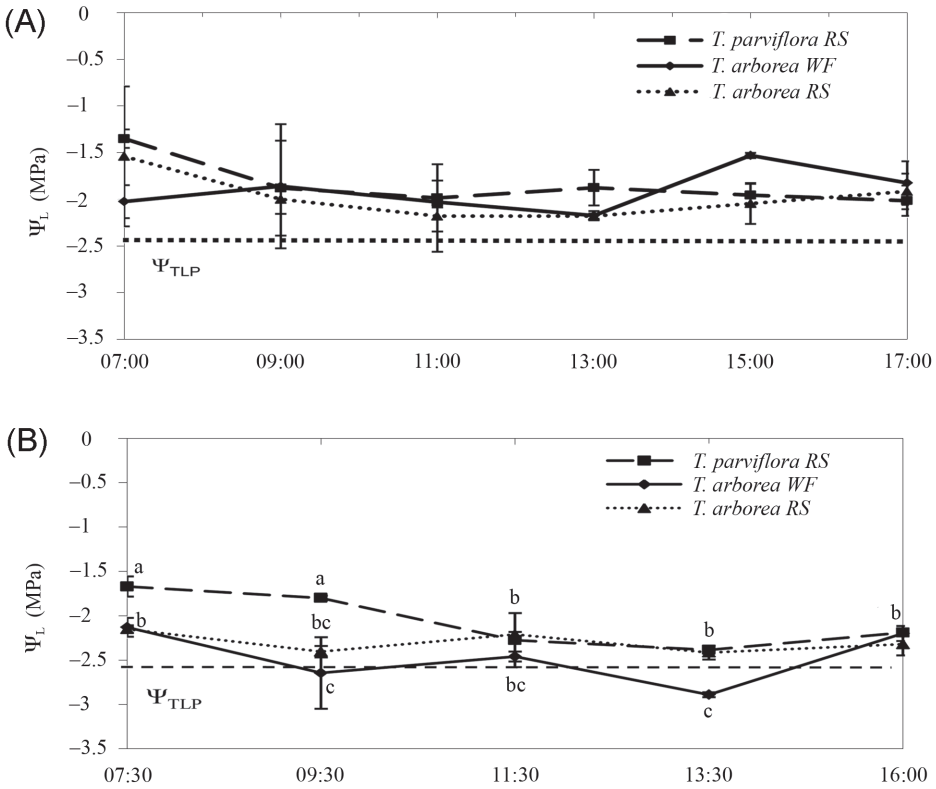

Fig. 5. Daily pattern of leaf water potential (Ψ_L) in *T. arborea* var. *arborea* and *T. parviflora* at RS and WF locations in summer (A) and autumn (B) 2012. Data are reported as mean values ± standard deviation (n = 6). The dashed line indicates leaf water potential at turgor loss point. Different letters indicate significant differences ($P < 0.05$)

arborea than in *T. parviflora* in both sites. At the RS site, the minimum values (around –2.4 MPa) were measured between 11:30 and 13:30, and were not significantly different between the two species. In *T. arborea* var. *arborea* at WF Ψ_L dropped to –2.9 MPa at 13:30, significantly below Ψ_{TLP}.

DISCUSSION

Drought stress and salinity affect leaf physiological traits such as water potential, transpiration, stomatal conductance and photosynthesis in most species [18, 20]. On the other hand, seasonal effects on plant growth and development may be difficult to detect in field studies where many other sources of variation cannot be controlled [4]. In this comparative study on *Tamarix* species, photosynthesis showed the most remarkable seasonal differences: *T. arborea* var. *arborea* showed quite higher levels of assimilation (*A*) in early summer, that largely decreased in autumn at both sites. Photosynthesis in *T. parviflora*, instead, showed lower but constant levels of *A* in both sampling seasons. In summer, stomatal conductance (g_s) was similar between the two species, so the higher levels of *A* in *T. arborea* var. *arborea* could be due to higher carbon assimilation rates. The drop of *A* in *T. arborea* in autumn might be due to a decrease in carbon assimilation rates, as the *A* rates were the same at both locations, but at RS *T. arborea* var. *arborea* showed significantly higher g_s. It has been suggested that photosynthesis was limited by the non-stomatal component for *T. gallica*, particularly during drought [15]. Diversity in photosynthesis and stomatal conductance has recently been reported also for *T. gallica* and *T. africana* in different environmental conditions [11], related both to morphological and physiological differences between the species. In addition, in *T. arborea* var. *arborea* at RS, the significantly lower levels of carotenoids suggested that photosynthetic activity could be decreased by higher levels of photoinhibition [16].

Both species showed isohydric behaviour, with relatively constant levels of leaf water potential, consistently with the results reported for *T. gallica* [15]. No drought stress was evidenced at the beginning of summer, as both species at both locations did not show turgor loss in leaf tissues, in agreement with the findings that *Tamarix* species are able to tolerate drought, typically by deriving water from the water table [3, 12]. At the WF site, *T. arborea* var. *arborea* showed significantly lower levels of midday leaf water potential in autumn, resulting in stomatal closure and a certain degree of drought stress that could be due to leaf exposure to higher levels of salinity due to sea spray.

CONCLUSIONS

The studied *Tamarix* species showed the typical behaviour of other representatives of the genus, showing no evident drought stress in summer, even when growing in non-irrigated conditions. Exposure to salt spray slightly affected the water relation parameters of *T. arborea* var. *arborea*, but there was no detrimental result of this factor on photosynthesis or growth. *T. arborea* var. *arborea* appears to follow a strategy of investing in high carbon gain in the early summer, reducing photosynthetic activity at the end of the season. *T. parviflora*, instead, shows lower levels of photosynthetic activity, that does not change throughout the seasons. This behaviour is evident also in the different habitus of the two shrubs, with a larger and thicker canopy of *T. arborea* var. *arborea* that expands faster and earlier than *T. parviflora*, that, on the whole, is a slow-growing and less invasive species. Both species appear to be indicated for landscaping, re-vegetation and as well as ornamental purposes, with *T. arborea* var. *arborea* when a fast-growing, higher-cover species is necessary, and *T. parviflora* when less-invasive species are required.

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