

Original article

Afforestation with *Pinus halepensis* reduces native shrub performance in a Mediterranean semiarid area

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Abstract

It has been often suggested that the introduction of *Pinus halepensis* with afforestation could facilitate long-term colonisation and development of late-successional species in Mediterranean dry and semiarid areas, but this affirmation has rarely been experimentally tested in the field. In this study, we analyse the effects of planted *P. halepensis* density (0, 1500 and 3470 trees·ha⁻¹) on soil moisture at two depths (0–10 and 10–30 cm), and on the physiological status of three shrub species (*Quercus coccifera*, *Erica multiflora* and *Rhamnus lycioides*) in a semiarid area of SE Spain. Afforestation with *P. halepensis* had a negative effect on soil moisture, an effect that increased with tree density. This effect was more pronounced at 0–10 cm depth than at 10–30 cm depth, and was especially evident after the spring and late summer rainfalls. During spring and summer, mean predawn water potentials in the area without *P. halepensis* were –1.5, –2.4 and –2.2 MPa for *Q. coccifera*, *E. multiflora*, and *R. lycioides*, respectively. Mean net photosynthesis values in the same area and period were 1.2, 1.0 and 1.5 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ for *Q. coccifera*, *E. multiflora*, and *R. lycioides*, respectively. Similarly, mean stomatal conductance was 15.1, 16.4 and 21.7 $\text{mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$ for *Q. coccifera*, *E. multiflora*, and *R. lycioides*, respectively. Values were substantially reduced (up to 56%) with increasing *P. halepensis* density, suggesting the presence of a strong competition for water. Our results provide evidence that the introduction of *P. halepensis* with afforestation has a negative effect on existing late-successional shrubs, and suggest that this introduction does not stimulate successional processes in Mediterranean semiarid areas.

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Keywords: Afforestation; Ecophysiology; Mediterranean; *Pinus halepensis*; Semiarid; Shrubs; Soil moisture

1. Introduction

Trees modify resource flow and microclimate conditions beneath and around their canopies through processes such as rainfall interception, shading, litter accumulation, dry deposition, and root dynamics (Belsky et al., 1989; Rhoades, 1997; Breshears et al., 1998). Through these changes, trees can have important effects on shrubs, both positive and negative. Negative effects would be driven by precipitation interception by tree canopies and by belowground competition for available soil moisture (Belsky et al., 1989; Barnes and Archer, 1999). Positive effects would be mainly driven by the reduction of high light intensities by tree canopies, which may decrease soil and leaf temperature, reduce transpiration losses, increase soil water availability, and prevent photoinhibition during drought (Breshears et al., 1998; Valladares

and Percy, 1997), and by an increase of soil fertility underneath tree canopies (Callaway, 1995). Current theoretical models predict that, in stressful environments, facilitation would prevail over competition as a major plant–plant interaction (Bertness and Callaway, 1994). This view has often been adopted during afforestation programs (establishment of new forests by seeding or planting of nonforested land) in semiarid areas. It has been often argued that the introduction of trees with afforestation would have a positive effect on late-successional understory shrubs as planted trees ameliorate harsh climatic conditions and improve soil conditions underneath their canopies (Ruiz de la Torre, 1973; Montero and Alcanda, 1993).

Aleppo pine (*Pinus halepensis* Miller) is the most important tree in the Western Mediterranean Basin, where it covers more than 2 800 000 ha, and is the prevailing tree species in dry and semiarid areas (Quézel, 2000). From the beginning of last century, *P. halepensis* has been extensively used in afforestation, one of the reasons argued for its widespread

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Table 1

Texture of the surface soil (0–30 cm depth) in the three studied zones. *Pinus halepensis* density was 0, 1500, and 3470 trees·ha⁻¹ for the None, Low and High zones, respectively. Data represent means \pm 1 S.E. ($n = 5$)

Depth (cm)	Textural class	None	Low	High
0–10	Sand (%)	38.53 \pm 0.96	31.26 \pm 2.11	31.42 \pm 3.83
	Silt (%)	42.74 \pm 1.06	40.22 \pm 2.63	42.97 \pm 3.94
	Clay (%)	18.73 \pm 0.70	28.52 \pm 3.37	25.61 \pm 5.98
10–30	Sand (%)	37.1 \pm 4.15	28.24 \pm 3.26	32.47 \pm 3.51
	Silt (%)	44.26 \pm 4.69	40.93 \pm 3.93	40.95 \pm 4.25
	Clay (%)	18.62 \pm 3.54	30.72 \pm 4.62	26.61 \pm 6.07

use being its role in succession (Gil and Aránzazu, 1993; Barbéro et al., 2000). As *P. halepensis* is a pioneer species, it has been suggested that the introduction of *P. halepensis* into degraded areas could facilitate the long-term colonisation and development of late-successional species (Montero and Alcanda, 1993; Gil and Aránzazu, 1993). However, this affirmation has rarely been experimentally tested, and woody plant interactions in *P. halepensis* stands remain largely unknown. The few studies performed so far on woody plant interactions in *P. halepensis* stands do not support the prevalence of facilitation over competition as abiotic stress does, as expected by theoretical models (Bertness and Callaway, 1994). Under dry conditions in NE Spain, Lookingbill and Zavala (2000) reported the presence of a positive relationship between oak (*Quercus ilex* L.) seedlings and *P. halepensis* trees, suggesting that the latter could facilitate oak seedlings establishment. Using experimental plantations in semiarid afforestations in SE Spain, Maestre et al. (2003) showed the presence of interference between *P. halepensis* and introduced shrub seedlings, despite improved microclimatic and soil conditions under pine canopies.

Understanding the effects of the introduction of *P. halepensis* on existing vegetation is a question of great importance to improve our knowledge about vegetation dynamics in Mediterranean afforestations and natural forests. It also can be useful to evaluate past and current forest policies based on the extensive use of this species in the Mediterranean Basin and in other parts of the world such as South Africa, where this species became a successful invader (Richardson, 1998). We evaluated soil moisture and ecophysiological responses (predawn water potentials, stomatal conductance and net photosynthesis) of native shrubs with contrasting root systems (*Quercus coccifera* L., *Erica multiflora* L., and *Rhamnus lycioides* L.) in a semiarid shrubland forested with *P. halepensis*. *Pinus halepensis* has a shallow root system, with maximum density of fine roots occurring at less than 50 cm depth (Ares and Peinemann, 1992; Hernández, 1998; Canadell et al., 1999). Thus, we expect an increase of the negative effect of *P. halepensis* on *R. lycioides* and *E. multiflora* as compared to *Q. coccifera*, since the former two shrubs have shallower root systems than the latter one (Rambal, 1984; Specht, 1988). Our main objectives were: (i) to evaluate the effect of *P. halepensis* tree density on soil moisture at different depths, and (ii) to assess the effect of the presence and density of *P. halepensis* on the ecophysiology

of shrubs during the course of the summer drought period. We tested the following hypotheses: (i) *P. halepensis* has a negative effect on soil moisture, (ii) *P. halepensis* has a negative effect on physiological features of shrubs (water potentials and photosynthesis), and (iii) the effect of *P. halepensis* is more negative in shallow-rooted species than in deep-rooted ones.

2. Materials and methods

2.1. Study area

We conducted our study on the North Slope of the Ventós Mountain, located in the province of Alicante, in SE Spain (latitude 38°29' N, and longitude 0°37' W). The altitude ranges between 600 and 900 m a.s.l., and the climate is semiarid, with a 30-year mean annual precipitation of 302 mm, and a mean annual temperature of 18.2 °C (Pérez Cueva, 1994). Soils are *Entisols*, developed from sandstone. They have a silty texture (Table 1), a bulk density of 0.98 g cm⁻³ and 58.3% porosity (Bellot et al., 1999). The natural vegetation is a shrubland dominated by species such as *Q. coccifera*, *Pistacia lentiscus* L., *R. lycioides*, and *E. multiflora*. In addition, there are stands of *P. halepensis* that derive from afforestation performed during 1965. These plantations, which were established with a different tree density in different areas, did not remove adult individuals of existing shrubs, making the site suitable for the purposes of this study.

2.2. Sampling design and measurements

Within the study site, we selected three areas with a different adult *P. halepensis* density: 0, 1500, and 3470 trees·ha⁻¹ (thereafter referred to as None, Low, and High zones, respectively). *Pinus halepensis* trees had a similar average size in the Low and High zones (height = 5.8 m, DBH = 6.3 cm, and crown projection = 1.9 m²). Photosynthetically active radiation (PAR) at 1.5 m height differed substantially between zones, with mean midday values of 1782 and 1671 $\mu\text{E m}^{-2} \text{s}^{-1}$ at the None zone during late May and July 1996, respectively. These values were reduced, on average, 12% and 28% at the Low and High zones, respectively.

We also measured soil moisture in each of the three selected zones between April and September 1996. Soil volu-

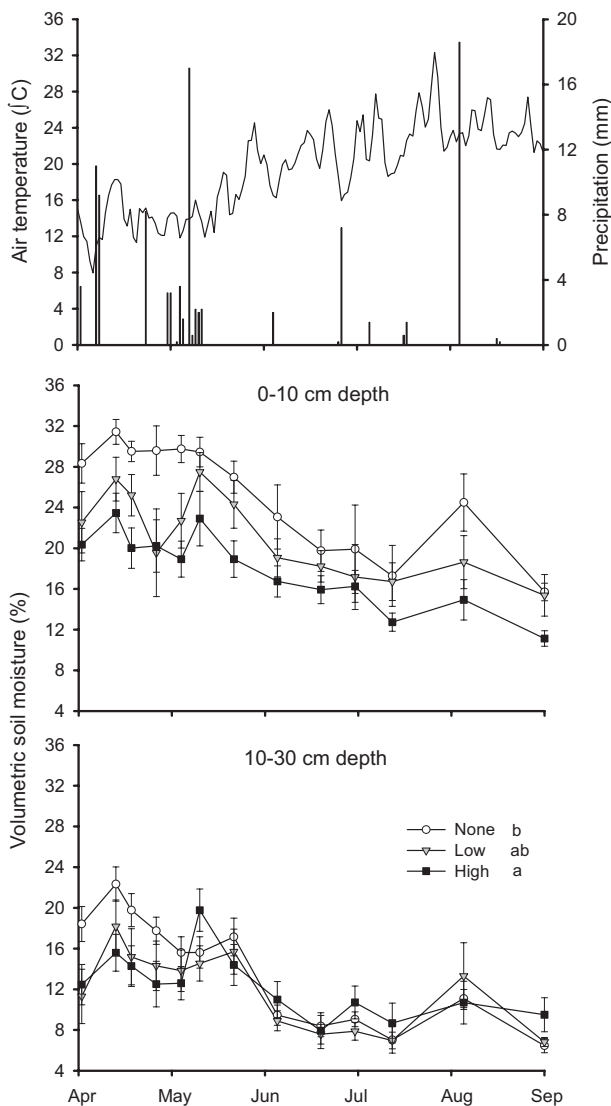


Fig. 1. Evolution of climatic characteristics (upper graph) and soil moisture (central and lower graphs) between April and September 1996. In the upper graph, vertical bars and a continuous line indicate rainfall and daily average temperature, respectively. For soil moisture, data represent means \pm 1 S.E. ($n = 5$). *Pinus halepensis* density was 0, 1500, and 3470 trees·ha⁻¹ for the None, Low and High zones, respectively. Different lowercase letters close to the legend indicate the presence of significant differences between zones after repeated-measures ANOVA (SNK test, $P < 0.05$).

metric water contents were measured by using Time Domain Reflectometry (TDR; Topp and Davis, 1985). Measurements were performed weekly with a Tektronix 1502C metallic TDR tester (Tektronix, Beaverton, CO, USA). TDR probes were inserted vertically at three depths: 0–10, 10–30 and 30–50 cm. Five TDR probes per depth and zone were installed under the canopy of randomly selected shrubs during March 1996. Since the soil moisture at 30–50 cm did not show significant differences with the soil moisture recorded at 10–30 cm (Repeated-measures ANOVA, $P > 0.05$), in this paper we show only results from the 0–10 and the 10–30 cm depths. Climatic variables between April and September 1996 were continuously recorded by a solar powered meteorological station (CDR10, Campbell Scientific, Logan, USA)

located in the None zone. Air temperature and precipitation were measured at 15-min intervals and were automatically stored as daily means.

To evaluate the effects of introduced *P. halepensis* on the ecophysiology of shrubs, we measured gas-exchange parameters and predawn xylem water potentials (Ψ_{pd}) during the late spring and summer of 1996. Measurements of Ψ_{pd} were performed on 3 May, 29 May, and 25 July 1996, while those of gas-exchange parameters were taken on the two latter dates. On each sampling date, we randomly selected three adult individuals per species and zone, except for *E. multiflora* at the Low zone, where no individuals were available. Ψ_{pd} measurements were performed in situ during the 2 h before sunrise on terminal shoots with a pressure chamber system (Soilmoisture 2005, Santa Barbara, CA, USA). Diurnal courses of net assimilation (A), and stomatal conductance (g_s) were measured using an IRGA porometer portable photosynthesis system (ADC model LC-4, Analytical Development Corporation, Hoddesdon, UK). For each sampling hour, measurements for all species and replicates were taken within a 1-h interval, starting at 09:00, 12:00, and 17:00 h solar time, following the procedure described by Long et al. (1996), and using the equations of Von Caemmerer and Farquhar (1981). At the start of each measurement day, we randomly selected two branches per shrub (three individuals per species and zone) located at the outer edge of the canopy, for easier access. In each branch, three healthy fully developed leaves were selected and tagged for repeated gas-exchange measurements throughout the day.

2.3. Statistical analyses

Ψ_{pd} data were analysed to test for differences between zones separately for each species and sampling date by using one-way analysis of variance (ANOVA). Differences between species within each zone and sampling date were analysed in the same way. Gas-exchange parameters (A , and g_s) were analysed to test the differences between zones separately for each sampling date, moment of the day, and species by one-way ANOVA. For these analyses, the two values obtained for each individual were averaged. Soil moisture measurements were analysed with a three-way ANOVA (zone, depth and time), with repeated measures of one of the factors (time). In all ANOVA analyses, the Student–Newman–Keuls (SNK) test was used to evaluate differences between zones. Prior to ANOVA analyses, data were checked for normality and homogeneity of variances, and were log-transformed when necessary to correct deviations from these assumptions. In addition to these analyses, we calculated the size of the effect of *P. halepensis* density on soil moisture and Ψ_{pd} . We defined the effect of *P. halepensis* on soil moisture and Ψ_{pd} as negative when these variables were lower at the Low and High zones as compared to the None zone. We obtained the effect of low *P. halepensis* density comparing the None and Low zones, and the effect of high *P. halepensis* density comparing the None and High zones. We obtained

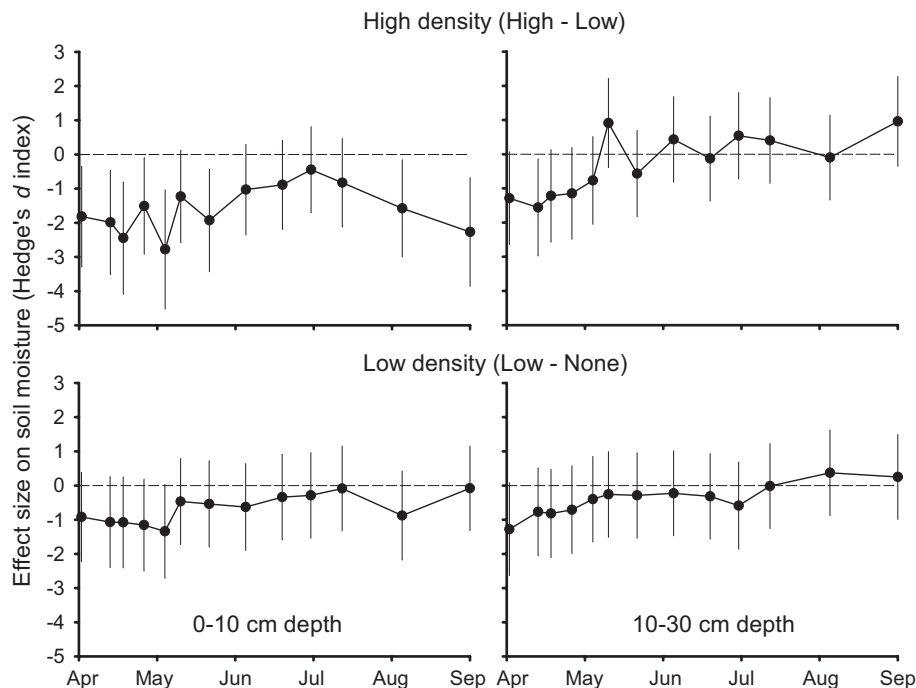


Fig. 2. Effect of *P. halepensis* tree density on soil moisture at two depths between April and September 1996. Data represent values of Hedge's *d* index \pm 95% confidence intervals. Negative and positive values of this index indicate a negative and a positive effect of *P. halepensis*, respectively. To calculate each effect we used data from the zones shown in brackets. *P. halepensis* density was 0, 1500, and 3470 trees·ha⁻¹ for the None, Low and High zones, respectively.

the size of these effects and their confidence intervals using the "Hedges' *d* index" as described in Gurevitch and Hedges (2001). In all cases, negative and positive values of this index indicate a negative and a positive effect of *P. halepensis*, respectively. All the statistical analyses were performed using the SPSS 9.0 package (SPSS Inc., Chicago, USA).

3. Results

3.1. Soil moisture dynamics

Precipitation during the studied period (April–August 1996) was 99.8 mm per year, close to the 30-year average annual rainfall (104 mm). Main rainfall events were concentrated in early April and May, with sporadic rainfall events during the rest of the study period (Fig. 1). The accumulated rainfall during the 15 days before the field measurements was 6.6, 4.2 and 1.4 mm for the sampling dates of 3 May, 29 May and 25 July, respectively. Peak air temperatures, higher than 32 °C, were registered during late July.

Soil moisture clearly reflected the evolution of rainfall, and reached maximum values with early spring rainfalls (Fig. 1). We found significant differences between zones throughout the studied period (Repeated-measures ANOVA, $F_{\text{zone}} = 4.48$, $df = 2.24$, $P = 0.022$; $F_{\text{zone} \times \text{depth}} = 1.99$, $df = 2.24$, $P = 0.158$), with higher soil moisture at the None zone as compared to the High zone. We also found significant differences between depths (Repeated-measures ANOVA, $F_{\text{depth}} = 53.63$, $df = 1.24$, $P < 0.001$), with higher soil moisture at the 0–10 cm depth. The lack of a significant zone

\times depth interaction suggests that the effect of pine density was the same at both depths. The negative effect of *P. halepensis* on soil moisture increased with density at both depths, but it was significant only at the high pine density (Fig. 2). This effect was more pronounced at the 0–10 cm than at the 10–30 cm depth, and was especially evident after spring and late summer rainfalls.

3.2. Predawn water potential dynamics

The dynamics of Ψ_{pd} were closely related to those of soil moisture (Fig. 1), and reflected usual seasonal decreases in soil moisture from spring to summer (Fig. 3). We found a strong effect of *P. halepensis* density on the water status of shrubs. For all evaluated species, we found a clear significant trend to decreasing predawn water potential with the increase of *P. halepensis* density in early May. This trend became less evident by the late-May sampling period, but there were still significant differences between zones for all species. In summer, these differences disappeared for all species. It is interesting to note the differences between species found in July. At this time, *Q. coccifera* had significantly higher Ψ_{pd} than *R. lycioides* in the three zones, and than *E. multiflora* in the High zone (one-way ANOVA; $F_{\text{None zone}} = 5.45$, $df = 2.6$, $P = 0.045$; $F_{\text{Low zone}} = 15.47$, $df = 1.4$, $P = 0.01$; $F_{\text{High zone}} = 121.29$, $df = 2.6$, $P < 0.001$). Significant differences between *E. multiflora* and *R. lycioides* were also found in the High zone, with lower Ψ_{pd} values in the former species.

The negative effect of *P. halepensis* on Ψ_{pd} increased with tree density (Fig. 4). This effect decreased in magnitude during the course of the summer except in *E. multiflora*,

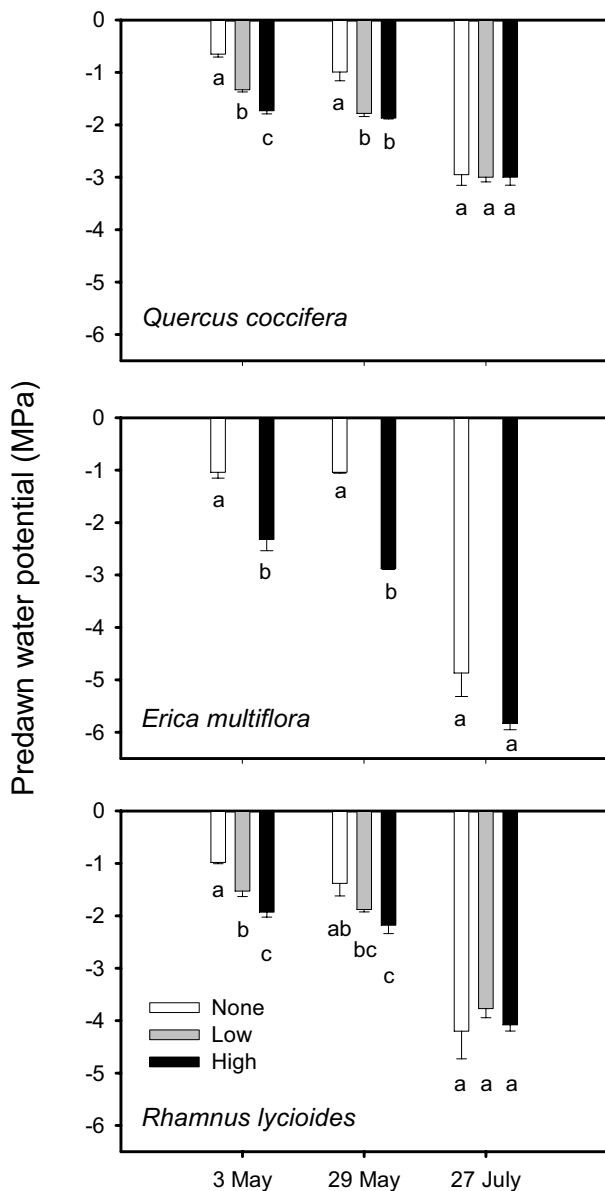


Fig. 3. Evolution of predawn water potentials of the three shrub species evaluated. Data represent means \pm 1 S.E. ($n = 3$). *P. halepensis* density was 0, 1500, and 3470 trees·ha⁻¹ for the None, Low and High zones, respectively. Different lowercase letters indicate the presence of significant differences between zones after one-way ANOVA (SNK test, $P < 0.05$).

which showed an increase between May and July measurements. In early May, the effect of *P. halepensis* was more pronounced on *Q. coccifera* than the other two species. In late May, the effect of *P. halepensis* was more pronounced on *E. multiflora*. In July, this effect was close to zero.

3.3. Gas-exchange dynamics

For most species and sampling dates, peak values of A near $2.8 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ and g_s above $32 \text{ mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$ were found in the mornings (Figs. 5 and 6). The presence of *P. halepensis* reduced A and g_s for most species and sampling dates. In May, significant differences in A and g_s between zones with and without *P. halepensis* were found in

most sampling times. Differences between species at this date were scarce in the three zones. In July, the values of A and g_s were considerably lower than those registered in May, but the differences between zones were minimised. However, significant differences between the None and the Low and High zones in A were found in *Q. coccifera* and *R. lycioides* during the afternoon measurements. *E. multiflora* showed significant differences in the same variable at midday. It is interesting to note the decrease in the values of A and g_s found in *E. multiflora* between May and July as compared with that observed in the other two species.

4. Discussion

4.1. Effects of *Pinus halepensis* on soil moisture

In accordance with our first hypothesis, we found a clear negative effect of *P. halepensis* on soil moisture. Soil moisture was reduced as *P. halepensis* density increased, especially after the main rainfall events of early spring and late summer. Several mechanisms may explain the results obtained. The reduction observed might be caused by the interception of rainfall by the canopy of trees, which reduced the total amount of water reaching the soil. At the High zone, the interception by *P. halepensis* canopies may represent up to 35% of total annual rainfall, while at the None zone this interception drops up to 23% of total annual rainfall (Chirino et al., 2001). Probably, the fact that more than the 90% of rainfall events were below 10 mm could justify this high interception value (Bellot et al., 1999). But it is also likely that water uptake by *P. halepensis* contributes to these differences. Significant water uptake from the first 15 cm of soil has been detected in other species of the same genus, such as *Pinus edulis* Engelm. (Breshears et al., 1997). However, this effect is not universal. Maestre et al. (2003) measured no differences in soil moisture at the 0–20 cm depth between microsites located under the canopy of *P. halepensis* and in open areas without vegetation during most of the year in afforestation close to the study area. Also, Koehler et al. (1986) reported that adult *P. halepensis* individuals had only a negligible impact on the water balance at the 0–15 cm depth in the south of France. Further studies are needed to elucidate the relative importance of the mechanisms involved in the reduction of soil moisture induced by the introduction of *P. halepensis* observed in this study.

Interestingly, we found higher soil moisture at the 0–10 cm depth throughout the studied period compared to the lower soil levels. We believe that this result may be due to the presence of a higher root density at the 10–20 cm depth. López et al. (2001) showed that the 10–20 cm depth interval had the highest biomass of fine roots in a *Q. ilex* forest of NE Spain. In that study, root biomass at the 10–20 cm depth was nearly double that found at the 0–10 cm depth. Cañellas and San Miguel (2000) have also found high vertical variability in the fine root distribution of *Q. coccifera* shrublands in E

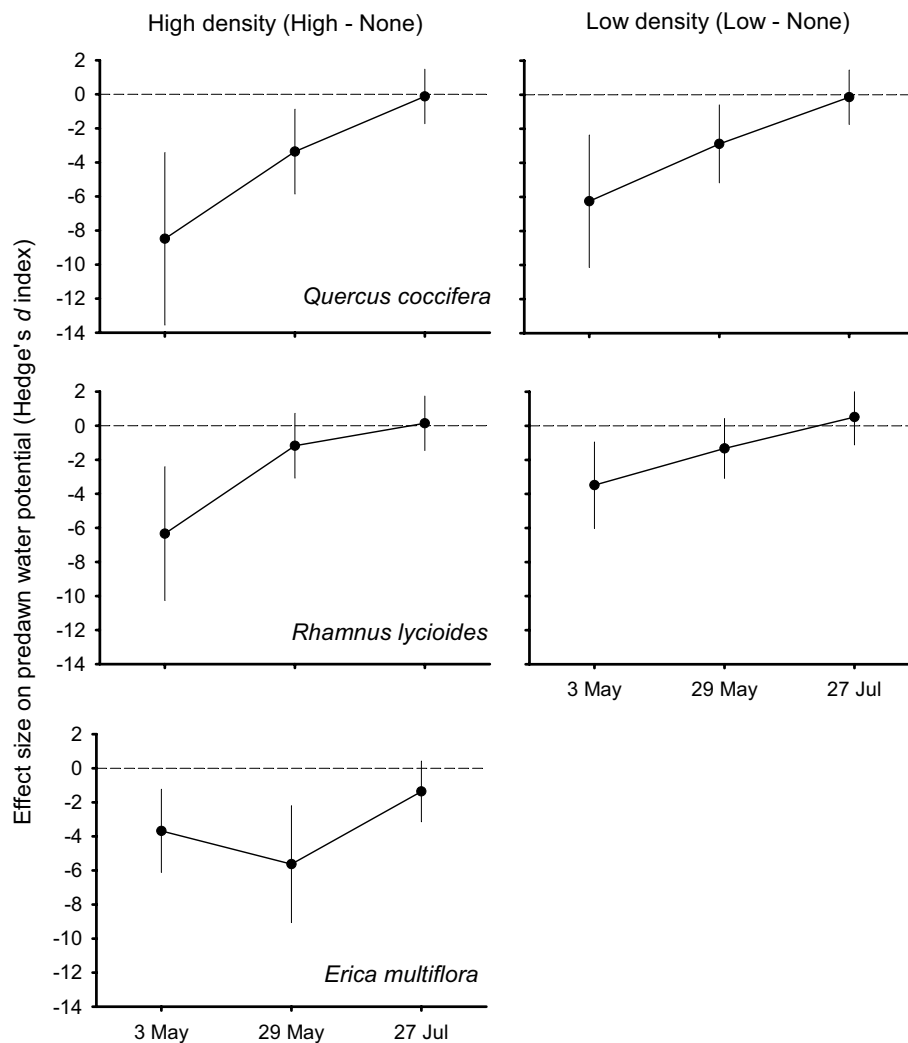


Fig. 4. Effect of *P. halepensis* density on the response of shrub predawn water potentials in spring and early summer. Rest of legend as for Fig. 2.

Spain. These authors report values of fine root biomass at 0–15 cm depth that were 5.9 ± 2.8 (mean \pm S.D., $n = 5$) times higher than those existing at 15–30 cm depth. Since fine roots are the main components of root systems involved in water uptake (Kozłowski et al., 1991), and have a high turnover rate (Fitter, 1999), higher concentration of these roots at 10–20 cm depth would explain the depletion of soil moisture observed at this depth. Some qualitative measurements performed in the study area suggest that over 80% of roots are located at the 0–30 cm depth (Hérendez, 1998). However, as the soil moisture dynamics are the same from 10 to 50 cm depth, it may be worth noting that remaining roots (over 20%) are likely to have access to water available at this depth.

4.2. Effects of *P. halepensis* on shrub ecophysiology

Our second hypothesis (*P. halepensis* has a negative effect on the physiological features of shrubs) was also confirmed by our results. During the spring, Ψ_{pd} , A and g_s of all shrub species were significantly reduced with increasing *P. halepensis* density, suggesting the presence of strong competition for soil moisture. A similar conclusion is pro-

vided by Valladares and Pearcy (2002) comparing the performance of sun and shade leaf physiology in a Californian shrub. The negative effect of *P. halepensis* was reduced during summer, when soil moisture differences between zones were minimal.

A constant pattern of differences in Ψ_{pd} was found between species throughout the study period. The Ψ_{pd} of *Q. coccifera* was considerably higher than that of *E. multiflora* and *R. lycioides*, irrespective of the density of *P. halepensis*. These differences, which were especially evident during the summer, suggest that *Q. coccifera* is able to gain access to deep-water sources not available for the rest of species (Rambal, 1984). This partition in the use of water, if consistent in time, could help to explain the coexistence of these species in semiarid Mediterranean shrublands (Castro-Díez and Montserrat, 1998).

Peak values of A and g_s were observed for most species and zones during the morning, and decreased during the course of the day. This pattern is similar to that observed for other Mediterranean species during the summer (Pugnaire et al., 1996; Haase et al., 1999). Beneficial effects of PAR

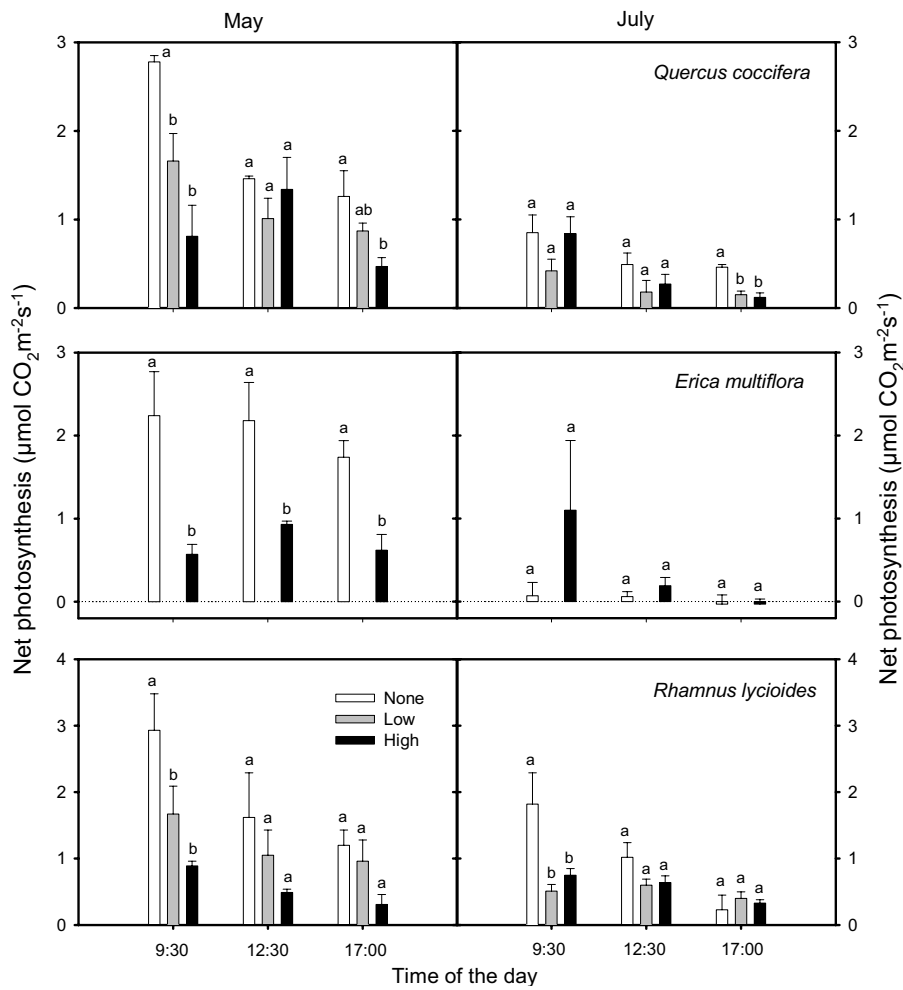


Fig. 5. Daily evolution of net photosynthesis evaluated in late May (left graph) and July (right graph). Data represent means \pm 1 S.E. ($n = 3$). *P. halepensis* density was 0, 1500, and 3470 trees·ha⁻¹ for the None, Low and High zones, respectively. Different lower case letters indicate the presence of significant differences between zones after one-way ANOVA (SNK test, $P < 0.05$). The time of the day is labelled with the hour in middle of each measurement course.

reduction provided by *P. halepensis* canopies did not improve A and g_s of evaluated species. This may be due to the higher drought conditions experienced by the shrubs located underneath tree canopies. Environmental conditions were especially stressful during the July period due to low soil moisture and high air temperature, which reached 40 °C at midday (data not shown). These conditions promoted the presence of drought-inhibition of photosynthesis (Flexas and Medrano, 2002), as suggested by the strong reductions observed in A and g_s as compared to the values obtained in May. This reduction was especially important in the None zone, where the rates of the A and g_s values were the highest in May, and may be favoured by the strong depletion in soil moisture, together with the increase in PAR, registered in this zone.

Our third hypothesis (the effect of *P. halepensis* is more negative in shallow-rooted species than in deep-rooted ones), was partially supported by our results. Contrary to expectations, the effect of *P. halepensis* was more pronounced in *Q. coccifera* than in the other two species in early May. This pattern changed in late May, where the effect of *P. halepensis*

was more pronounced in *E. multiflora*. These results suggest that shallower roots may be important for the water status of *Q. coccifera* during the spring, and agree with the observations of Rambal (1984), who showed how the water uptake from this shrub species gradually shifted downwards as the soil dried during the summer. We suggest that, during the spring, water acquisition from the upper parts of the soil is important, and competition with *P. halepensis* is more intense. As the soil dries during the summer, this shrub species takes water from deeper sources, escaping from competition with *P. halepensis*. Further experiments are needed to confirm the relative importance that shallow versus deep roots have in the water status of *Q. coccifera*.

4.3. Implications of *Pinus halepensis* introduction for shrubland dynamics and management

The importance of positive and negative interactions between plant species under field conditions has been largely demonstrated in recent decades, but few studies so far have evaluated these issues in afforestation programs. Our results

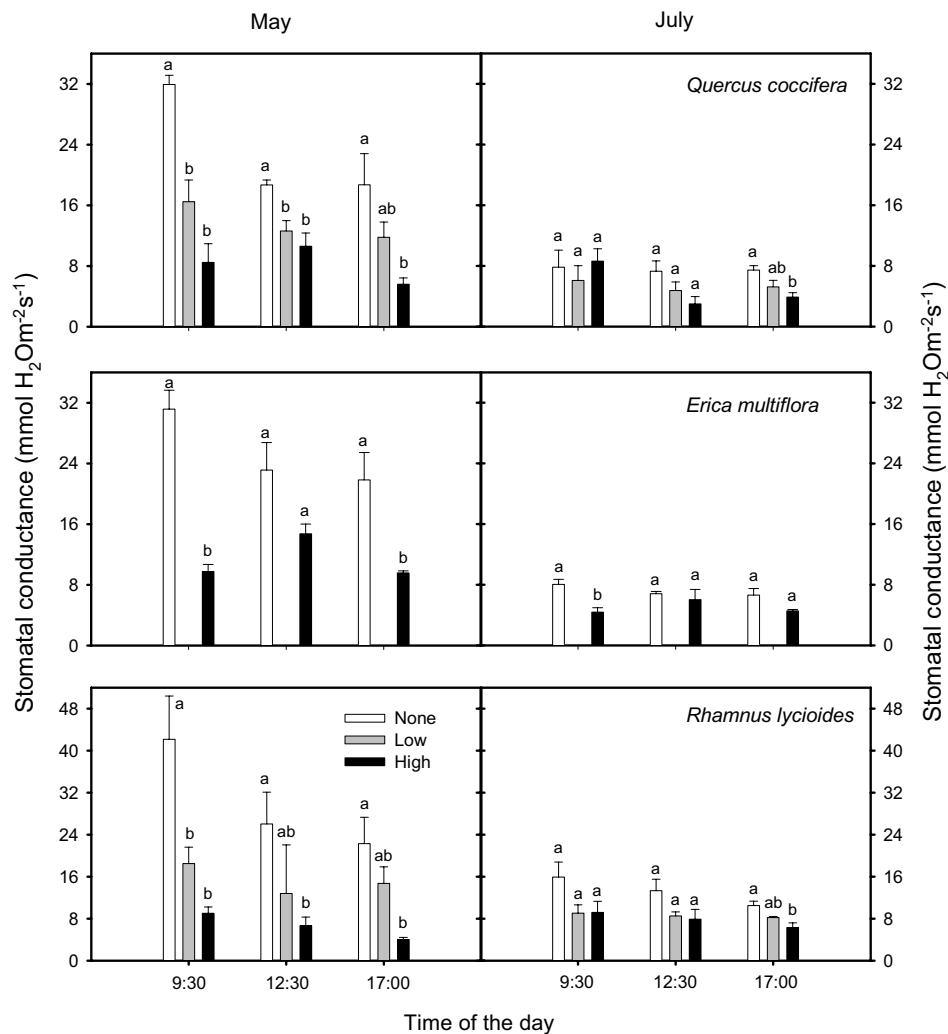


Fig. 6. Daily evolution of stomatal conductance evaluated in late May (left graph) and July (right graph). Rest of legend as for Fig. 5.

agree with those of Maestre et al. (2003), and suggest that improved microclimatic conditions by the development of *P. halepensis* canopy can not balance the reduction in soil water availability promoted by the introduction of this species, resulting in a negative effect on the performance of native shrubs. This negative effect may have long-term consequences for the structure and dynamics of large arid and semiarid areas throughout the world, where this species has been introduced in recent decades. Our results suggest that the introduction of *P. halepensis* may not stimulate successional processes in semiarid shrublands, and contribute to the debate about the appropriateness of the extensive use of this species in Mediterranean areas (Ortuño, 1990; Bellot et al., 2001), as well as in other places where water is the main limiting resource. The use of native shrubs adapted to local environmental conditions, combined with techniques such as nursery hardening (Vilagrosa et al., 2003), and the use of microsites provided by existing vegetation (Maestre et al., 2001), could be a valid alternative to the extensive *P. halepensis* plantations traditionally carried out in Mediterranean dry and semiarid areas of the world.

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