New Forests

Should we use meshes or solid tube shelters when planting in Mediterranean semiarid environments?

--Manuscript Draft--

Manuscript Number:	NEFO-D-17-00259R1
Full Title:	Should we use meshes or solid tube shelters when planting in Mediterranean semiarid environments?
Article Type:	S.I. : 3rd Restoring Forests
Keywords:	afforestation; restoration; Water potential; Chlorophyll Fluorescence; Quercus coccifera; Rhamnus lycioides
Corresponding Author:	Juan A. Oliet, Ph.D. Universidad Politécnica de Madrid Madrid, SPAIN
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Universidad Politécnica de Madrid
Corresponding Author's Secondary Institution:	
First Author:	Juan A. Oliet, Ph.D.
First Author Secondary Information:	
Order of Authors:	Juan A. Oliet, Ph.D.
	Raúl Blasco
	Patricio Valenzuela
	María Melero de Blas
	Jaime Puértolas
Order of Authors Secondary Information:	
Funding Information:	Spanish Ministry of Science and Innovation (TRACE-Project PET2008_0325) — Dr. Juan A. Oliet
Abstract:	Tree shelters in Mediterranean environments have a two-sided effect. They not only protect seedlings from browsing but also ameliorate microclimatic conditions, improving post-planting survival and growth. However, the ecophysiological basis of these effects are poorly understood. A factorial experiment combining light transmissivity and shelter type (solid tube vs mesh wall) was carried out to assess the impact of contrasting microclimatic characteristics on seedling performance and physiological stress levels of shelters in two Mediterranean shrubland species (Quercus coccifera and Rhamnus lycioides) planted in a semiarid site. Even though seedlings in solid tube shelters experienced higher temperature and were slightly more photoinhibited, they had higher predawn water potential and, in general, better survival and growth than in mesh wall shelters. However, these effects were species-specific, with Rh. lycioides more favoured by solid wall shelters than Q. coccifera. However, root growth cannot explain these interactions between species and shelter type on seedling survival. Since light transmission had a marginal effect compared with wall type, we proposed that the observed effects and interaction with species are not dependent on light intensity or temperature but on other microclimatic differences like air velocity or light quality and distribution. Further studies should assess the importance of these factors on post-planting growth and physiological stress levels, which can be critical for matching the correct tree shelters type for each species in plantations in semiarid environments.
Suggested Reviewers:	Dugald C. Close

	dugald.close@utas.edu.au Similar studies in Australia with same ecophysiological basis
	María Noelia Jiménez noelia.jimenez.ext@juntadeandalucia.es

Response to Reviewers:

MANUSCRIPT NEFO S 17 00259
Madrid, May 19 2018
COVER LETTER TO Revision #1

Dear Dr. Jacobs

Thank you very much for your email from April 19 concerning the review of the manuscript NEFO 17 00336 Should we use meshes or solid tube shelters when planting in Mediterranean semiarid environments?. We would like to thank the reviewers for their helpful comments, which we believe have improved the clarity and impact of the work. Virtually all the changes proposed by the reviewers have been incorporated in the new version. These changes are highlighted in red font in our revised manuscript, and references to previous or current manuscript position of the changes are presented to facilitate location and checking. Main changes consisted in presenting a different Figure 4 and correspondent post-hoc test in agreement with Reviewer#1 suggestion. Also minor changes in the text have been conducted accordingly. Please note that specific reviewer inquiries are in italics, and our responses are in bold.

\---

COMMENTS FOR THE AUTHOR:

Editor-in-Chief: Thank you for submitting your manuscript, which has now been appraised by an Associate Editor and two expert reviewers. Your manuscript will be acceptable after minor revision based on Associate Editor and reviewer comments below. Please provide a covering letter detailing your specific changes in response to each point raised by the Associate Editor and reviewers. Your revision is due within 6 weeks.

AE: The paper by Oliet et al. (NEFO-D-17-00259) describe a solid study with interesting results. Although much used in practice, not much have been published concerning physiological responses of seedlings to various plant tube materials and designs. Therefore this manuscript is interesting for readers of New Forests and is worth publishing. Both reviewers are positive with some comments that should be adressed before publication.

Thanks a lot for the positive appraisal of the manuscript

Reviewer #1: The paper studies the influence of two types of shelters (mesh/tube) differing in their light transmissivity on the responses of hardwood shrubby species (Rhamnus and kermes oak) planted in a semiarid environment (Central Spain). This topic is indeed of interest for forest and restoration operations in which the early development of seedlings in harsh conditions is a major issue. The authors have carried out a convincing field experiment; the methods used are well detailed and sound; the results are also clearly exposed. Besides, the paper is very well written and the authors have shown a deep knowledge of the literature on this topic. I also found that combining analysis of above- and belowground morphological traits with ecophysiological (predawn potential, fluorescence) and microclimatic measurements is original and shed light on the processes explaining the results obtained. In summary, I really enjoyed reading this paper.

Thanks a lot for your positive inputs!

Despite the undoubted quality of the manuscript, I have relatively minor concerns about some points I would like the authors to consider First, I was not convinced that the authors have always used statistical post-hoc tests in appropriate manner. For instance in Figure 4, post-hoc tests have been made to compare the combined treatments species*shelter*light transmissivity but it is unclear if the interaction is significant or not. If not, please consider to show results in a different way (analyzing for instance the main effects only as in Fig 1 or interaction of the second order). Same remark for Table 4: the interaction Species*Shelter is only significant for root length (Table 3), so post-hoc tests are not appropriate when analyzing the influence of the treatments on the other variables. Please check this point in your different analyses and correct if necessary.

We agree with the reviewer about the appropriateness of using post-hoc test for species*shelter*light transmissivity combinations if this tird order interaction is not significant. We have followed the Reviewer's suggestions in Figure 4 by analyzing the second order interaction for height and diameter, including in this figure the degree of signification of the ANOVA test for each of them. We have reworded the result section accordingly (Lines 320 to 322 of revised version).
With regard to Table 4, we have removed post-hocs letters for all variables except root length. New explanations are given at Table foot.

Second, the duration of the study is somewhat low: 16 months only from February 2014 to June 2015. I acknowledge that the first summer is often of a primary importance for plant survival but it also corresponds to a transplanting shock. To what extent this latter consideration could have influenced your results? Can you add some additional comments on this?

We have added some comments in the Introduction to clarify this question (Lines 100 to 102 of revised version).

Lastly, I have not well understood the method about roots measurements: what do you mean exactly when you indicate that "protruding roots from the plug" were analysed (P5)? I suppose it corresponds to the term "new root" introduced later in the paper. Can you clarify this point?
Some pictures (if available), showing for instance the types of shelter would be helpful for the reader I think.

We refer to the roots that emerge out of the plug. As they do not include new roots formed within the plug, we agree with the reviewer that "new root" can be confusing. Therefore, we have changed "new roots" for "protruding roots" along the text, and explained more the "protruding" issue by adding "out of the plug" (see line 210-211 of revised version).
We do not believe that pictures showing the types of shelter can be too helpful, providing the description given in Mat and Methods are clear enough, as they include transmissivity levels, colors, dimensions of the shelters and net holes dimensions.

Specific remarks

P1L50 benifited = favoured ?
Done
P2L0 leporidae= rabbits and hare? It is easier to understand for the reader
Changed to rabbits and hares
P2L39-51 I particularly appreciated the good analysis of the literature!
Thanks!
P5 Were the protector stabilized by any particular system during the planation? Were there buried in the soil to assure stabilization?
Yes, the protector was stabilized with a stake and buried in the soil. We have added this detail in Mat and Meth.
P5 L41-42 See above remark about the roots
It has been already clarified. See above answer to your remarks.
P7L5 You should call up Fig1 here
Done
P7L17 Table 3 to be replaced by Table 1
You are right. Done
P7L29 Can you indicate how was VPD determined (several formulas are possible)?
VPD was determined using Rosenberg formula:
Rosenberg ND, Blad BL, Berma SB (1983) Microclimate: the biological environment. 2nd Edition. John Willey and Sons. USA. 495 pp.
We have included this reference.
P7L38 Indicate (Table 2)

Done

P7L49-50 was higher for Rh lycoides (89) than for Q coccifera (80%?)

We have added corresponding value for Q. coccifera survival (75 ± 5.8%).

P7L57 after 'light transmissivity level" you can refer to Fig 4a. I think it's better to split Fig 4 in 4a and 4b

We mention Figure 4A in the following line. We have split Figure 4 in A and B

P8L12 See remark above about root, this parameter "new root length" should be more clearly explained in the M&M section

Done. See response to this comment above.

P8L33 Microclimatic conditions more favourable (T, VPD) inside mesh shelters during…

Added T and VPD in the sentence

P8L43-44 Yes, it's difficult to interpret small differences with fluorescence

P9L4-5 "restricted air movment…reduces foliar water loss and improved hydric water status" Yes, one could have expected a higher RH value inside tubes than inside mesh but this was not observed

P18L54 "among levels of factor" is not very clear. Indicate that letters show significant differences between the type of proctor x and among the transmissivity levels

Done as suggeted

P15 0.081 not in bold

Done, thanks for the thoroughly review.

P20 remove "aa" for solid tube 80%

Done

P21 Fig 4a) heigh and 4b) diameter

Done

Reviewer #2: The work by Oliet et al. was aimed at improving the knowledge of the ecophysiological mechanisms occurring in plants growing in tree-shelter after transplanting in arid environments. They compared the effect of two types of shelter - plastic tube and mesh- in combination with three different gradients of light transmissivity on seedlings of two species usually planted in arid environments for restoration purposes (Quercus coccifera and Rhamnus lycoides). Despite in international literature the studies on the effect of tree-shelter on early seedling development are pretty spread, most of them are focused on describing the shelter effect against browsing and/or on survival and seedling early morphology. Few experiments are designed to understand the ecophysiological basis to explain such findings. This is the strength point of this study, which was planned and carried out accurately. I enjoyed reading the manuscript by Oliet et al; all sections of the manuscript are well written, materials and methods are correct, and results are interesting and properly presented and discussed. Thus, my recommendation is to accept the manuscript.

Just check citations in the text vs reference list (e.g. in page 2 Dupraz and Bergez 1999 and Mariotti et al. 2015 are cited but not present in reference list).

Thanks a lot for your comments. We have incorporated mentioned references in the list.

Should we use meshes or solid tube shelters when planting in Mediterranean semiarid environments?

Juan A. Oliet[1], Raul Blasco[1], PatricioValenzuela[2], María Melero de Blas[3], Jaime Puértolas[4]

1 Departamento de Sistemas y Recursos Naturales, Universidad Politécnica de Madrid, 28040 Madrid, Spain. E-mail address: juan.oliet@upm.es. Phone: +34 913366412. ORCID 0000-0001-7719-9327

2 Center of Applied Ecology & Sustainability (CAPES), Pontificia Universidad Católica de Chile, 4860 Macul, Santiago, Chile.

3 World Wildlife Foundation-España. 28005 Madrid, Spain

4 Lancaster Environment Centre, Lancaster University, Lancaster LA1 4YQ, UK.

ORCID 0000-0002-6132-0679

Abstract

Tree shelters in Mediterranean environments have a two-sided effect. They not only protect seedlings from browsing but also ameliorate microclimatic conditions, improving post-planting survival and growth. However, the ecophysiological basis of these effects are poorly understood. A factorial experiment combining light transmissivity and shelter type (solid tube vs mesh wall) was carried out to assess the impact of contrasting microclimatic characteristics on seedling performance and physiological stress levels of shelters in two Mediterranean shrubland species (*Quercus coccifera* and *Rhamnus lycioides*) planted in a semiarid site. Even though seedlings in solid tube shelters experienced higher temperature and were slightly more photoinhibited, they had higher predawn water potential and, in general, better survival and growth than in mesh wall shelters. However, these effects were species-specific, with *Rh. lycioides* more favoured by solid wall shelters than *Q. coccifera*. However, root growth cannot explain these interactions between species and shelter type on seedling survival. Since light transmission had a marginal effect compared with wall type, we proposed that the observed effects and interaction with species are not dependent on light intensity or temperature but on other microclimatic differences like air velocity or light quality and distribution. Further studies should assess the importance of these factors on post-planting growth and physiological stress levels, which can be critical for matching the correct tree shelters type for each species in plantations in semiarid environments.

Keywords Afforestation; Restoration; Water potential; Chlorophyll fluorescence; *Quercus coccifera; Rhamnus lycioides*

Introduction

Animal browsing is an important threat to the successful establishment of planted seedlings (Burney and Jacobs 2018). The incidence of browsing is highly dependent on the ecological characteristics of the reforested area that affects the animal specific composition and their abundance. Landscapes such as cropland matrixes tend to support high amounts of rabbits, hares and other generalist species (Calvete et al. 2004) that can be very detrimental for young plantations and result in major economic losses and delays in the restoration process. Among the most common system to protect seedlings is the use of individual tree shelters (Devine and Harrington 2008). Tree shelters are usually plastic tubes enclosing seedlings shoots to preclude browsing. Broadly speaking, two types of tree shelters are commercially available: solid tubes and meshes. Solid tubes are made in a continuous plastic wall, while meshes are open nets that allows free air circulation throughout the seedling. Solid tubes can also be ventilated by several holes. These characteristics have a strong influence on the environmental conditions around the protected plant (Bergez and Dupraz 2009). Therefore, tree shelters not only play a mere physical barrier role, but also can affect plant establishment and growth in additional ways by the changes in temperature, light, vapor pressure deficit or others (Dupraz and Bergez 1999; Oliet and Jacobs 2007; Pemán et al. 2010; Puértolas et al. 2010; Mariotti et al. 2015). There are numerous studies from different geographical areas analyzing the response of planted seedlings to the use of solid tube shelters in relation to the micro-environmental conditions inside (Del Campo et al. 2006; Jacobs 2011; Close et al. 2009; Bellot et al. 2002; Bergez and Dupraz, 2000). As expected, plant response is species- and environment-specific (Oliet et al. 2003; Padilla et al. 2011 Devine and Harrington 2008; Defaa et al. 2015). In semiarid areas, the use of solid tubes has proven to be on average beneficial for survival and growth (Piñeiro et al. 2013). On the contrary, the number of studies analyzing the effect of meshes is much lower (but see Ward et al. 2000; Devine and Harrington 2008), despite this type of protector is broadly used in operational plantations (Taylor et al. 2006; Van Lerbherghe 2014). Unlike solid tubes, meshes allows air circulation, which precludes greenhouse effect, while reducing radiation incidence on the leaves. Although these effects could be beneficial for plant establishment in harsh areas, we are only aware of two studies addressing plant response to both types of tree shelters under semiarid Mediterranean conditions (Close et al. 2009; Padilla et al. 2011). Results from these studies are opposite, probably due to different site conditions and species, which reinforces the necessity of improving the knowledge of physiological basis for that responses.

Constructive characteristics of tree shelters are variable. Apart from different heights to adapt to herbivory size (Van Lerbherghe 2014), other characteristics such as ventilation, color or light transmissivity affect micro-environmental conditions inside. Ventilation reduces air overheating during midday (Bergez and Dupraz 2009). Light transmissivity affects the amount of incident radiation, with effects on the intensity of stress and on plant growth response that could be crucial for plant survival under harsh conditions (Oliet et al. 2003). For example, photoinhibition can occur in shade tolerant species when protected by highly transmissive solid wall shelters (Puértolas et al. 2010), and some studies reveal a species-specific response of resources allocation to shoot or root as a function of shade tolerance (Jiménez et al. 2005; Puértolas et al. 2010; Vázquez de Castro et al. 2014). This could explain differences in survival between species with contrasted functional traits planted in Mediterranean environments under a gradient of light transmissivity (Oliet et al; 2003 and 2015). However, these studies have only compared gradients of light transmissivity within solid wall tube shelters, but the characteristics of mesh shelters (higher ventilation, different quality of the transmitted light) might interact with light transmission to determine the effects on survival and performance.

The objective of our experiment is to compare the effect of both types of tube shelters (solid and mesh) on two species (*Quercus coccifera* L. and *Rhamnus lycioides* L.) under semiarid Mediterranean conditions. We assessed first year after planting survival, growth and physiological stress levels (water potential and photochemical efficiency) and under a gradient of light transmissivity (40, 60 and 80 %) for both types of shelters. Testing a gradient of light transmissivity for both types of guards will help to characterize the tree shelter ecophysiological system by assessing the relative contribution of different environmental variables on seedling response during establishment. Despite the duration of the study is relatively short, it includes post planting summer, which under harsh Mediterranean conditions is the most critical period in terms of survival (Villar-Salvador et al. 2012). The selected species are sprouting shrubs widespread in the western Mediterranean Basin. In semi-arid environments, they are considered keystone species affecting community composition and ecosystem function (Maestre and Cortina, 2003). *Q. coccifera* is widely used in afforestations in the semiarid areas of the Mediterranean basin (Maestre and Cortina, 2004; Sackali and Ozturk 2004), although frequently accounts for low planting success (Baquedano and Castillo 2006). So far, the use of *Rh. lycioides* has been constrained to small scale or experimental plantations (Trubat et al. 2011; Chirino et al. 2013). Semiarid areas of the Mediterranean Basin are among the most challenging zones for the establishment of woody vegetation. Numerous biotic and abiotic factors negatively affect survival of planted young trees in these zones. Summer drought combined with excess of radiation and high temperatures (Martínez-Ferri et al. 2000; Niinemets and Keenan 2014) can reduce post summer survival to very low levels (Villar-Salvador et al. 2012). Besides, predation by small mammals, birds or ungulates constitutes another major source of failure (Leverkus et al. 2013). All these factors dramatically reduce the efficiency of restoration efforts. In addition, the current scenario of climate change, with higher probabilities of extreme, harsh summers in these areas (Giorgi and Lionello 2008), suggests that the success of restoration programs in dry Mediterranean environments will require improvements in planting techniques (Cortina et al. 2011; Vallejo et al. 2012). Our study could contribute to improve establishment success of key woody species in these challenging areas by a better management of tree shelters.

Materials and methods

Study site and plant material

The study site is located in an old cropland of central Spain in Toledo province (39°39′8’’N, 3°28′5’’W, elevation 660 m a.s.l.). The slope of the planting area is North aspect with a moderate 14% steep. Soils are mostly Inceptisols (Gómez-Miguel and Badía-Villas, 2016). In accordance with a sample from study site, soils are deep (0 to 110 cm) of mostly loamy texture (22.4-35.2% sand, 44.0-48.7 % silt and 19.7-29.1 % clay) . Horizons are light-colored highly basic (pH from 7.9 to 8.3) and calcic, with organic matter ranging from 2.14% (upper) to 0.86% (deepest horizon). Maximum electric conductivity of deepest horizon is low (170 $\mu S \cdot cm^{-1}$). Permeability is high for the first two horizons (0-30 cm) and moderate below this depth, according to Gandullo (1985). The climate is Mediterranean semiarid, with mean annual precipitation of 418 mm and mean annual temperature of 14.2ºC. Summers are very hot and dry, with drought periods lasting four months, mean maximum temperature of 33ºC in July and absolute maximum temperature reaching 43ºC. Winters are cold with frequent frosts. Temperature can drop to -11ºC and the mean minimum temperature is 0.9ºC in January (Ninyerola et al. 2005). During the planting year (2014) annual rainfall was much lower than average (252 mm), with a prolonged dry period from May to September of accumulated rainfall as low as 32 mm (data from National Agency of Meteorology, Agriculture and Environment Department, Spanish Government).

Seedlings of *Q. coccifera* and *Rh. lycioides* were raised from seeds of provenance region ES29 Montes de Toledo (Alía-Miranda et al. 2009) and cultivated in 200 cm^3 cells (plant density 370 m^{-2} Plasnor, Spain). After one year in the nursery and prior to planting, seedling height, root collar diameter, total biomass and root biomass were 22.1±1.5 cm, 5.5± 0.4 mm, 8.1±0.4 g and 5.0±0.4 g, respectively, for *Q. coccifera*, and 22.9±1.5 cm, 3.8± 0.3 mm, 4.7±0.6 g and 1.4±0.2 g, respectively, for *Rh. lycioides* (n=10). These values fall within the recommended ranges for both species according to Pemán et al. 2013.

Field experiment

The site was cross subsoiled prior to planting at a 60 cm depth with two rippers 1 m apart to reduce soil compaction. Subsoiling was conducted following contour lines separated by two meters and perpendicular directions. Seedlings were planted on January 11, 2014 every 1 m along contour lines (spacing was 2 x 1 m), after manually opening holes (0.3 m × 0.3 m × 0.3 m) in the junction of the subsoiling furrows. No weed control were conducted during the experiment, as the seed bank of weeds was weak in this area, specially under the arid conditions of the planting year. Both species were alternated within each planting row, and shelter treatments were randomly assigned to each seedling. The experimental design was a 2×2×3 factorial design, with the following factors and levels: (1) species (*Q. coccifera* vs. *Rh. lycioides*), (2) tree shelter type (solid wall vs. mesh) and (3) light transmissivity of the solid plastic or mesh (values around 40, 60 or 80%). The solid wall tube shelters were made from plastic material supplied by Repsol Química (Spain). Additives were added to the copolymer base to reach the light transmissivities tested in this experiment, maintaining the red/far red ratio around 1 (neutral shade) (Vázquez de Castro et al. 2014). Hand-made tubes using the plastic sheets were circular, single-walled tubes, 50 cm tall × 10 cm wide, with four ventilation holes facing each other of 2.5 cm width and situated at 18 and 36 cm in height. Mínimum value of 40% light transmissivity was considered as a target when designing shelters that promote biomass allocation to roots and improve water balance of Mediterranean seedlings (Vázquez de Castro et al. 2014). Solid plastic tubes were stabilized by fixing a plastic stake with clamps and burying the shelter in the soil. Plastic meshes were chosen among available polyethylene products in the market. Mesh of 80% was a 60 cm tall × 15 cm wide cylindrical blue net with holes 8 × 8 mm (Protec Blaunet model, Projar SA, Spain). 60 % light transmissivity mesh was also a 60 cm tall × 15 cm wide cylindrical black net with holes 2.4 × 2.4 mm (P40 model, Projar S.A., Spain). And 40 % light transmissivity mesh was a was a 60 cm tall × 12 cm wide cylindrical black net with holes 4 × 3 mm (V8 model, Improfort Limited, Spain). Meshes were stabilized by using two plastic stakes. Actual light transmissivity of solid tubes and meshes under field conditions was determined in several daily cycles of photosynthetically active radiation (PAR) measurements with two or three sensor replicates (QSO-SUN, Onset, USA) per shelter type connected to a U12 data-logger (Onset, USA). Values were registered every 10-15 minutes. Light transmissivity was averaged along the mean daily cycle. Mean transmissivity percentages were 77 (named solid tube 80 %), 58 (named solid tube 60 %) and 36 (named solid tube 40 %) % for solid tubes and 83 (plastic mesh 80 %), 56 (plastic mesh 60 %) and 46 (plastic mesh 40 %) % for meshes. A total of 300 seedlings per species were planted, of which 50 seedlings were randomly assigned to each combination of type of shelter × transmissivity. As experimental plot was small and homogeneous, arrangement of treatments was fully randomized, and no blocking or grouping as a mean to control experimental error was necessary.

Monitoring plant response and microclimatic conditions for shelter types

Seedlings survival was measured four times along the study, from June 2014 to February 2015. Some apparently dead seedlings resprouted after measurements and were accounted as live in the following assessment. Height and basal stem diameter were measured on every plant at the end of October 2014. Seedlings biomass and root development were evaluated from five randomly chosen seedlings per treatment and species (60 plants in total) that were destructively harvested on February 28, 2015. Using small hand tools, root systems were carefully excavated from soil up to a depth of 70 cm and taking care to retain roots > 1 mm diameter. Shoots were separated from the roots at the root collar and all parts were frozen until processing. Roots protruding out of the plug were excised and washed free from soil with tap water. Leaves and protruding roots were scanned and leaf area and root length measured with an image analyzer (ImageJ V1.48®, National Institutes of Health, USA). After these measurements, dry mass of each component (leaves, stem, plug roots and protruding roots) was determined by oven drying them at 65 ºC for 48 h and weighing.

Physiological measurements took place in two consecutive sunny days of June (14 and 15) and July (15 and 16) 2014 in five seedlings per shelter type, transmissivity and species (60 seedlings in total, 30 per day). A small window was opened in the solid or mesh wall of the shelters to facilitate sampling for water potential and chlorophyll fluorescence measurements; the window was otherwise closed. Shoot xylem water potential was measured at predawn (Ψ_{pd}). A 3-7 cm healthy twig of the upper third of the plant was excised between 05.00 and 07.00 AM, wrapped in aluminum foil, kept in sealed polyethylene bags and stored refrigerated in an ice box. Water potential was measured within 3 h using a pressure chamber (Model 1000®, PMS Instruments Company, USA). To check potential confounding effect of time since twig excising and measurement on water potential, both variables were plotted and no significant correlation was found (data not shown). Chlorophyll fluorescence was evaluated on the same plants. The ratio of variable to maximum fluorescence (F_v/F_m) as a surrogate of maximum photochemical efficiency of photosystem II was measured through the opened window with a fluorometer (FMS, Hansathech Instruments, UK). A fully expanded leaf of the upper third of the seedling was chosen. Prior to F_v/F_m measurements, that were done at predawn (07.00 AM) and midday (13.30 PM) leaves were dark acclimated for 30 min (Kalaji et al. 2014).

To assess the effect of light transmissivity of tube shelters on internal microclimate conditions, air temperature and relative humidity (RH) data logger sensors (U23-001 Onset, USA) were installed in the shelters from 14 to 25 June 2014. All this period was cloudless. Sensors were randomly installed inside two shelters of each shelter type × light transmissivity combination (12 sensors in total), attached to a stake at a height between both pairs of ventilation holes for solid tubes and the same height for meshes. Temperature and RH were recorded every 15 min. Vapor pressure deficit (VPD) was calculated from temperature and RH data following Rosenberg et al. (1983) method.

Data processing and statistical analysis

Post summer (October 2014) and 13 months (February 2015) after planting survival data were analyzed using a generalized lineal model based upon a binomial errors distribution with a logit link function. Full model included shelter type, light transmissvity, species, and all interactions among factors as predictors. Post hoc comparisons among treatments for last measurement (February 2015) were done using Bonferroni correction for paired comparisons.

In case of plant development (height, diameter, biomass and root length), a general lineal model with three main fixed factors as per survival were applied by running a three ways analysis of variance (ANOVA). Physiological data were analyzed similarly, although a fourth fixed factor (summer month, June and July) was included in the model. Non-normal data (basal stem diameter in October 2014 and all data from February 2015 plant excavation) were previously converted to logarithmic forms to fulfill normality and variance homogeneity requirements. When ANOVA showed significance, differences among means were identified using a Tukey post-hoc test. Differences were considered statistically significant if $P < 0.05$. Results are given as mean ± SE throughout the paper.

Data from temperature and relative humidity inside tube shelters were averaged per sensor and time to represent a mean daily cycle.

All the statistical analyses were performed using software R version 3.1.1 (R Core Team 2014 Vienna, Austria). Figures were produced using Sigmaplot, Version 12.0 (Sigma Plot 2012, Inc., San Jose, CA, USA).

Results

Physiological response to shelters (maximum photochemical efficiency and water potential) and microclimate in summer.

Maximum photochemical efficiency (F_v/F_m) at both pre-dawn and midday was significantly affected by all factors of the study during June and July. Besides, significant interactions were found between month of measurement and shelter type (mesh or solid tube) and those two factors and species for predawn F_v/F_m (Table 1). Seedlings growing in solid tubes showed lower values of both predawn and midday F_v/F_m than those in meshes, although differences were lower for predawn (0.02) than for midday (0.06) (Figure 1). A drop in F_v/F_m was found with increasing light transmissivity, with plants growing in lightest tubes (80 %) having lowest values of both pre-dawn and midday maximum photochemical efficiency. In addition fluorescence plants response to light transmissivity was higher for midday F_v/F_m, as seedlings in 60 % light transmissivity shelters had also minimum values as per lightest shelters (Figure 1). On average, F_v/F_m dropped from June to July (data not shown) and, by species, predawn and midday F_v/F_m for *Rh. lycioides* was higher (0.83±0.00 and 0.72±0.01) than that of *Q. coccifera* (0.77±0.00) and 0.69±0.01, respectively).

Predawn water potential during summer months was only affected by shelter type (Table 1). Seedlings in meshes were significantly more water stressed, with values of -3.11±0.12 MPa, while plants growing in solid tubes were more hydrated (-2.32±0.11 MPa).

Averaged temperature in solid wall shelters during the daylight period in late June was higher than that in meshes, with maximum differences (pooling the three light transmissivity levels) reaching 7.3ºC at 13:15 h solar time (Figure 2). Temperature differences among light transmissions were minor, with the 80 % shelter tending to have higher temperatures than the rest (1.1ºC, data not shown). Differences in RH among type of shelters and light transmissivities were minimum (Figure 2). As a consequence, VPD inside shelters follow the same pattern as temperature, with solid tubes having maximum VPD differences (after averaging by light transmissivity) of 1.86 kPa at 13:15 h solar time (Figure 2).

Survival and growth

Post summer survival (October 2014) was significantly affected by type of shelter and light transmissivity, although shelter type interacted with species (Table 2). One year after planting (February 2015), the interaction between shelter type and transmissivity became also significant (Table 2). Survival was almost double in solid wall shelters (84 ± 3 %) than in meshes (45 ± 4 %) for *Rh. lycioides* (Figure 3). In contrast, for *Q. coccifera* only the mesh of 80% light transmissivity had significantly lower survival (Figure 3). In February 2015, this combination of shelter type and transmissivity had the lower survival in both species (Figures 3). Overall survival of *Rh. lycioides* in February 2015 was slightly superior to *Q. coccifera* (68 ± 3 versus 60 ± 4 %, respectively), but survival in the most favorable shelter (solid wall tube 60%) was higher for *Rh. lycioides* (89 ± 4.6%) than for *Q. coccifera* (75 ± 5.8%).

Post summer height was significantly affected by all factors and by almost every second order interactions among them ($P<0.001$), with the exception of species × shelter type ($P = 0.07$). Seedlings growing under 40 and 60% light transmissivity grew similarly in height, while a detrimental effect of height growth appears when plants grew under maximum light transmissivity level. Besides, this pattern is much more intense for seedlings growing in meshes and for *Rh. lycioides* (Figure 4A). Thus, differences ranged between almost same height across transmissivities for *Q. coccifera* and plants growing in solid tubes, to a significant depletion in height under 80 %

transmissivity for *Rh. lycioides* and those gowing in meshes (Figure 4A). Post-summer basal stem diameter (BSD) was significantly affected by shelter type (*P*<0.001) and by a light transmissivity × shelter type interaction (*P*=0.03). BSD of plants within solid tubes were on average 18 % larger than that in meshes with no differences between light transmissivity within shelter types except for the 80 % mesh, which were significantly smaller for *Rh.lycioides* and almost significant for *Q. coccifera* (Figure 4B). No significant third order interaction appeared among three factors for height or diameter. Cross values for this three factors combination are presented in Supplementary material.

For all biomass and growth traits measured after plant excavation in February 2015 (13 months after planting), no significant effect was found for light transmissivity (Table 3). However, leaf area and shoot biomass was significantly bigger in solid wall tubes than in meshes (64 and 33 % respectively) (Tables 3 and 4). Protruding roots length was also greater in solid tubes and affected by the interaction of this factor with species: it was 78% longer in *Q. coccifera* and not significantly different from meshes in *Rh. lycioides* (Tables 3 and 4). Shoot:root ratio ($g \cdot g^{-1}$), specific leaf area and specific root length of seedlings were unaffected by shelter type or light transmissivity. Most of the evaluated traits from excavation were species-specific: *Q. coccifera* leaf area was 65 % higher, while protruding roots length, shoot:root ratio and specific root length were 36, 60 and 40 % lower than those of *Rh. lycioides*. Nevertheless, data from plant excavation 13 months after planting show high variability levels (Table 4), precluding the declaration of additional significant responses to tested factors.

Discussion

Unexpectedly, seedlings in solid wall tubes showed a higher survival and growth for almost every combination of light transmissivity and species. Microclimatic conditions inside mesh shelters (T, VPD) during the hot Mediterranean summer were expected to decrease heat and water stress compared to solid wall shelters. In fact, chlorophyll fluorescence data suggests a higher degree of photoinhibition in solid tubes with differences deepening from the beginning (June) to midsummer (July). Maximum photochemical efficiency is more sensitive to thermal than to hydric stress, as shown in a wide variety of woody species that presented significant reduction in F_v/F_m under higher temperatures (Matías et al. 2017; Methy et al. 1997). However, values were always close to 0.8, which is considered the optimum value (Bjorkman and Demmig, 1987) and the differences between both shelter types were small. Deactivation of reaction centers of photosystem II is part of the acclimation process to avoid photodamage when photosynthesis is impaired (Demmig-Adams and Adams, 1992). The small changes observed here might only reflect slight differences in this deactivation but with no impact on plant capacity to survive and grow.

In contrast, differences in predawn water potential were in agreement with seedling performance. Average predawn water potential registered in summer for both species in plastic mesh (-3.1 MPa) indicates a moderate level of water stress. *Q. coccifera* shows drastic reduction of assimilation rate with ψ_{pd} values below -2 MPa (Baquedano and Castillo 2006) which implies reduction of root growth. Even though these values are higher than the critical water potential values (-6 MPa) inducing fatal embolism (Vilagrosa et al. 2003), they could impair plant functioning and internal carbon budget, putting plants in higher risk of reaching those critical values.

Several hypotheses can be formulated to explain the lower ψ_{pd} in meshes. Air velocity inside solid wall shelters is negligible, even for ventilated tubes (Bergez and Dupraz 2000). Restricted air movement creates a thicker and less conductive boundary layer that reduces foliar water loss and improves hydric status. This effect has been demonstrated in previous works with solid wall shelters under controlled conditions (Kjelgren and Rupp, 1997; Bergez and Dupraz, 1997), where water losses of seedlings in tube shelters was much lower than in unprotected ones. Even though mesh shelters might restrict air movement, they allow some air circulation through leaves. This would decrease leaf-air boundary layer conductance (Lambers 2008), accelerating soil water depletion in the root-zone. Within this hypothesis the increase in transpiration demand due to air movement in meshes would be more intense than the higher VPD inside solid wall shelters provoked by temperature.

Alternatively, increased air velocity also induces stomatal closure and hence decreased carbon gain, which along with lower air temperature during spring in mesh shelters could explain the observed reduction in growth in this type of shelters. Besides the effects related to differences in air movement between mesh and tube shelters, growth reduction could be linked to light quality and distribution. Even though the experimental factorial design allowed the comparison of both types of shelters with similar total radiation levels, light inside tubes was exclusively diffuse while in meshes there was a mixture of direct and indirect radiation. Moreover, leaves in meshes were exposed not only to those patches of different light quality and intensity, but also to relatively rapid changes as the sun moved during the day or the leaves were shaken by wind. These rapid changes similar to sunflecks within or beneath canopies can decrease photosynthetic efficiency and water use efficiency, as the capacity of photoacclimation to contrasting light conditions cannot cope with such rapid changes (Townsend et al. 2017). Potentially, these two negative effects on carbon gain described above could impair root growth, which is essential for summer survival in dry environments (Padilla and Pugnaire, 2007), and has been linked to survival rates in *Q. coccifera* across a range of different tree shelters (Bellot et al. 2003). However, unlike the latter study, no relationship between root growth and survival was observed here. For *Rh. lycioides*, even though survival was much higher in tubes, root length was similar to mesh shelters, while *Q. coccifera* roots grew less in mesh shelters but only survival was impaired for the 80% transmissivity.

This species-specific effect of the type of shelter on seedling performance confirms that the effect of tube shelters on seedling performance depend on the ecophysiological features of the species (Puértolas et al. 2010; Vazquez de Castro et al. 2014). These previous studies pointed towards shade tolerance as the main trait explaining plant responses to tree shelters. Shade tolerant species were more benefited from protection, as root growth was less negatively affected by the reduction in light compared to intolerant species. Moreover, light reduction during summer could explain increased survival in *Q. ilex* (Puértolas et al. 2010). Also, *Rh. lyciodes* benefits from shade in semiarid plantations (Soliveres et al. 2008). However, our results suggest that other characteristics might also contribute to explain differential effects across species. Lack of knowledge on the physiological characteristics of *Rh. lycioides* makes difficult to understand the basis of these differences. It seems that the higher overall survival rates of this species compared to *Q. coccifera*, which are coincident with previous studies (Trubat et al. 2008, 2011), could be linked to faster root growth. Adults from *Rh. lycioides* show higher assimilation rates than *Q. coccifera* during spring, which could explain larger growth and root development (Bellot et al. 2004). The reason for the clear differences in survival between mesh and tube shelters within *Rh.* lycioides, which are less evident than in *Q. coccifera,* are not easy to explain with the current information available. Further studies should investigate which functional attributes other than shade tolerance determine seedling response to tube shelters.

Acknowledgments

This study was funded by TRACE-Project PET2008_0325 (Spanish Ministry of Science and Innovation) and co-financed by Respol Química S.A and by WWF program to restore Spanish forests. The comments of two anonymous reviewers substantially improved the manuscript.

References

Bellot J, Maestre FT, Chirino E, Hernández N, de Urbina JO (2004) Afforestation with *Pinus halepensis* reduces native shrub performance in a Mediterranean semiarid area. Acta Oecologica 25:7–15

Burney OT, Jacobs DF (2018) Species selection–A fundamental silvicultural tool to promote forest regeneration under high animal browsing pressure. Forest Ecol Manag 408:67-74

Alía Miranda R, García Del Barrio JM, Iglesias Sauce S, Mancha Núñez JA, de Miguel y Del Ángel J, Nicolás Peragón JL, Pérez Martín F, Sánchez de Ron D (2009) Regiones de procedencia de especies forestales españolas. Organismo Autónomo Parques Nacionales. Madrid

Baquedano FJ, Castillo FJ (2006) Comparative ecophysiological effects of drought on seedlings of the Mediterranean water-saver Pinus halepensis and water-spenders Quercus coccifera and *Quercis ilex.* Trees 20:689-700

Bellot J, Ortiz de Urbina JM, Bonet A, Sánchez JR (2002) The effects of treeshelters on the growth of *Quercus coccifera* L. seedlings in a semiarid environment. Forestry 75(1):89-106

Bergez JE, Dupraz ZC (1997) Transpiration rate of *Prunus avium* L. Seedlings inside an unventilated treeshelter. Forest Ecol Manag 97:255-264

Bergez JE, Dupraz ZC (2000) Effect of ventilation on growth of *Prunus avium* seedlings grown in treeshelters. Agr Forest Meteorol 104:199-214

Bergez JE, Dupraz ZC (2009) Radiation and thermal microclimate in tree shelter. Agr Forest Meteorol 149:179-186

Bjorkman O, Demmig B (1987) Photon yield of O2 evolution and chlorophyll fluorescence characteristics at 77 K among vascular plants of diverse origins. Planta 170:489–504

Calvete C, Estrada R, Angulo E, Cabezas-Ruiz S (2004) Habitat factors related to wild rabbit conservation in an agricultural landscape. Landscape Ecology 19:531–542

Chirino Miranda E, Puertolas Simon E, Garcia Vinas JI, Gaston Gonzalez A, Prada Saez MA (2013) *Rhamnus alaternus* L. y *Rhamnus lycioides* L. In:Pemán García J, Navarro Cerrillo RM, Nicolás Peragón JL, Prada Sáez,MA, Serrada Hierro R (coords). Producción y Manejo de semillas y plantas forestales. Naturaleza y Parques Nacionales. Serie Forestal. Ministerio de Agricultura, Alimentación y Medio Ambiente. Madrid Vol II. pp 226-249

Close DC, Ruthrof K X, Turner S, Rokich DP, Dixon K W (2009) Ecophysiology of species with distinct leaf morphologies:effects of plastic and shadecloth tree guards. Rest Ecol 17 (1):33-41

Cortina J, Amat B, Castillo V, Fuentes D, Maestre FT, Padilla FM, Rojo L (2011) The restoration of vegetation cover in the semi-arid Iberian southeast. Journal of Arid Environments 75:1377-1384

Defaa C, Elantry S, El Alam SL, Achour A, El Mousadik A, Msanda F (2015) Effects of tree shelters on the survival and growth of argania spinosa seedlings in mediterranean arid environment. International Journal of Ecology. http://dx.doi.org/10.1155/2015/124075

Del Campo A, Navarro RM, Aguililla A, Gonzalez E (2006) Effect of tree shelter design on water condensation and run-off and its potential benefit for reforestation establishment in semiarid climate.s Forest Ecol Manag 235:107–115

Demmig-Adams B, Adams WW (1992) Photoprotection and other responses of plants to high light stress. Annual Review of Plant Physiology and Plant Molecular Biology 43:599-626

Devine W, Harrington CA((2008) Influence of four tree shelter types on microclimate and seedling performance of Oregon white oak and western redcedar. Research Paper PNW-RP-576, USDA Forest Service, Pacific NorthWest Research Station, 54 pp

Dupraz C, Bergez JE (1999) Carbon dioxide limitation of the photosynthesis of *Prunus avium* L. seedlings inside an unventilated treeshelter. Forest Ecol Manag 119:89-97

Gandullo JM (1985) Ecología Vegetal. Fundación Conde del Valle de Salazar, Madrid, 208 pp

Giorgi F, Lione(llo P (2008) Climate change projections for the Mediterranean region. Global and Planetary Change 63:90-104

Gómez-Miguel (VD, Badía-Villas D (2016) Soil Distribution and Classification. In: JF Gallardo (ed) The Soils of Spain, World Soils Book Series, Springer, pp 11-48

Jacobs DF (2011) Reforestation of a salvage-logged high-elevation clearcut:Engelman spruce seedling response to tree shelters after 11 growing seasons. West J Appl For 26(2):53-56

Jiménez MN, Navarro FB, Ripoll MA, Bocio I, De Simón E (2005) Effect of shelter tubes on establishment and growth of *Juniperus thurifera* L. (*Cupressaceae*) seedlings in Mediterranean semi-arid environment. Ann For Sci 62:717–725

Kalaji HM, Schansker G, Ladle RJ et al (2014) Frequently asked questions about in vivo chlorophyll fluorescence: practical issues. Photosynth Res 122:121–158

Kjelgren R, Rupp LA (1997) Establishment in treeshelters I:shelters reduce growth, water use, and hardiness, but not drought avoidance. Hortscience 32:1281-1283

Lambers H, Chapin FS, Pons TJ (2008) Plant physiological ecology Springer, Second Edition, New York, 604 pp

Leverkus A, Castro J, Puerta-Piñero C, Rey Benayas JM (2013) Suitability of the management of habitat complexity, acorn burial depth, and a chemical repellent for post-fire reforestation of oaks. Ecol Eng 53:15–22

Maestre F, Cortina J (2003) Small-scale spatial variation in soil CO2 efflux in a Mediterranean semiarid steppe. Appl Soil Ecol 23:199–209

Maestre FT, Cortina J (2004) Are *Pinus halepensis* plantations useful as a restoration tool in semiarid Mediterranean areas? Forest Ecol Manag 198:303–317

Mariotti B, Maltoni A; Jacobs, DF, Tani A (2015) Tree shelters affect shoot and root system growth and structure in *Quercus robur* during regeneration establishment. European Journal of Forest Research 134(4):641-652

Martínez-Ferri E, Balaguer L, Valladares F, Chico JM, Manrique E (2000) Energy dissipation in drought-avoiding and drought-tolerant tree species at midday during the Mediterranean summer. Tree Physiol 20:131-138

Matías L, Castro J, Villar-Salvador P, Quero, JL, Jump AS (2017) Differential impact of hotter drought on seedling performance of five ecologically distinct pine species. Plant Ecology 218:201-212

Methy M, Gillon D, Houssard C (1997) Temperature-induced changes of photosystem II activity in *Quercus ilex* and *Pinus halepensis*. Can J Forest Res 27:31-38

Niinemets U, Keenan T (2014) Photosynthetic responses to stress in Mediterranean evergreens: mechanisms and models. Environ Exp Bot 103:24–41

Ninyerola M, Pons X, Roure JM (2005) Atlas Climático Digital de la Península Ibérica. Metodología y aplicaciones en bioclimatología y geobotánica. Universidad Autónoma de Barcelona, Bellaterra

Oliet JA, Jacobs DF (2007) Microclimatic conditions and plant morpho-physiological development within a tree shelter environment during establishment of *Quercus ilex* seedlings. Agr Forest Meteorol 144:58–72

Oliet JA, Navarro R, Contreras O (2003) Evaluación de la aplicación de mejoradores y tubos en repoblaciones forestales. Consejería de Medio Ambiente de la Junta de Andalucía, 234 pp

Oliet JA, Vázquez de Castro A, Puértolas J (2015) Establishing *Quercus ilex* under Mediterranean dry conditions: sowing recalcitrant acorns versus planting seedlings at different depths and tube shelter light transmissions. New Forests 46:869-883

Padilla FM, Miranda JD, Ortega R, Hervás M, Sánchez J, Pugnaire FI (2011) Does shelter enhance early seedling survival in dry environments? A test with eight Mediterranean species. Applied Vegetation Science 14:31–39

Padilla FM, Miranda J, Pugnaire FI (2007) Early root growth plasticity in seedlings of three Mediterranean woody species. Plant and Soil 296:103-113

Pemán García J, Navarro Cerrillo RM, Nicolás Peragón JL, Prada Sáez MA, Serrada Hierro, R (Coords.) (2013) Producción y Manejo de semillas y plantas forestales. Naturaleza y Parques Nacionales. Serie Forestal. Ministerio de Agricultura, Alimentación y Medio Ambiente. Madrid.

Pemán J, Peguero-Pina JJ, Valladares F, Gil-Pelegrín E (2010) Evaluation of unventilated treeshelters in the context of Mediterranean climate: Insights from a study on *Quercus faginea* seedlings assessed with a 3D architectural plant model Ecol Eng 36:517–526

Piñeiro J, Maestre FT, Bartolomé L, Valdecantos A (2013) Ecotechnology as a tool for restoring degraded drylands:a meta-analysis of field experiments Ecol Eng 61 (2013) 133– 144

Puértolas J, Oliet JA, Jacobs DF, Benito LF, Peñuelas JL (2010) Is light the key factor for success of tube shelters in forest restoration plantings under Mediterranean climates? Forest Ecol Manag 260:610-617

Rosenberg ND, Blad BL, Berma SB (1983) Microclimate: the biological environment. 2nd Edition. John Willey and Sons. USA. 495 pp.

Sakcali MS, Ozturk M (2004) Eco-physiological behaviour of some mediterranean plants as suitable candidates for reclamation of degraded areas. Journal of Arid Environments 57:1–13

Soliveres S, Monerris J, Cortina J (2008) El uso de parches artificiales mejora el rendimiento de una repoblación de *Rhamnus lycioides* en medio semiárid.o Cuad Soc Esp Cienc For 28:125-130

Taylor TS, Loewenstein EF, Chappelka AH (2006) Effect of animal browse protection and fertilizer application on the establishment of planted Nuttall oak seedlings. New Forest 32:133–143

Townsend AJ, Retkute R, Chinnathambi K, Randall JW, Foulkes J, Carmo-Silva E, Murchie EH (2017) Suboptimal photosynthetic acclimation in wheat. Plant Physiology. https://doi.org/10.1104/pp.17.01213

Trubat R, Cortina J, Vilagrosa A (2008) Short-term nitrogen deprivation increases field performance in nursery seedlings of Mediterranean woody species. Journal of Arid Environments 72:879–890

Trubat R, Cortina J, Vilagrosa A (2011) Nutrient deprivation improves field performance of woody seedlinngs in a degraded semi-arid shrubland. Ecol Eng 37:1164-1173

Vallejo VR, Smanis A, Chirino E, Fuentes D, Valdecantos A, Vilagrosa A (2012) Perspectives in dryland restoration:approaches for climate change adaptation. New Forest 43:561-579

Van Lerbherghe P (2014) Proteger los árboles contra los daños de la fauna cinegética. Los protectores de malla Proyecto Pirinoble. Unión Europea. Institut pour le Développement Forestier, Paris, France, 35 pp

Vázquez de Castro A, Oliet JA, Puértolas J, Jacobs DF (2014) Light transmissivity of tube shelters affects root growth and biomass allocation of *Quercus ilex* L. and *Pinus halepensis* Mill. Ann For Sci 71:91-99

Vilagrosa A, Bellot J, Vallejo VR, Gil-Pelegrin E (2003) Cavitation, stomatal conductance, and leaf dieback in seedlings of two co-occurring Mediterranean shrubs during an intense drought. Journal of Experimental Botany 54:2015-2024

Villar-Salvador P, Puértolas J, Cuesta B, Peñuelas JL, Uscola M, Heredia-Guerrero N, Rey Benayas JM (2012) Increase in size and nitrogen concentration enhances seedling survival in Mediterranean plantations. Insights from an ecophysiological conceptual model of plant survival. New Forests 43(5-6):755-770

Ward JS, Gent Martin PN, Stephens GR (2000) Effects of planting stock quality and browse protection-type on height growth of northern red oak and eastern white pine. Forest Ecol Manag 127:205-216

Tables

Table 1

Table 1. Results from ANOVA (Snedecor F and associated probability *P*) test for the effects of Month of measurement (June and July), Species (*Q. coccifera* and *Rh. lycioides*), Shelter type (solid tube and plastic mesh) and Transmissivity (80-60-40 %) during 2014 summer on predawn water potential (Ψ_{pd}) and leaf fluorescence at predawn ($F_v/F_{m_{pd}}$), midday ($F_v/F_{m_{md}}$).

		Ψ_{pd}		$F_v/F_{m_{pd}}$		$F_v/F_{m_{md}}$	
	df	F	*P>F*	F	*P>F*	F	*P>F*
Month (M)	**1**	0.02	0.89	6.10	**0.01**	5.40	**0.02**
Species (S)	**1**	1.80	0.18	60.94	**<0.001**	5.08	**0.02**
Shelter Type (ST)	**1**	22.49	**<0.001**	6.11	**0.01**	19.80	**<0.001**
Transmissivity (T)	**2**	0.15	0.85	6.30	**0.002**	3.64	**0.02**
Month × Species	**1**	0.11	0.73	0.01	0.93	2.30	0.13
Month × Shelter Type	**1**	0.001	0.97	10.83	**0.001**	0.58	0.44
Species × Shelter Type	**1**	0.47	0.49	0.01	0.92	0.40	0.52
Month × Transmissivity	**2**	0.17	0.83	0.12	0.88	0.14	0.86
Species × Transmissivity	**2**	1.17	0.31	2.64	0.07	0.72	0.48
Shelter Type × Transmissivity	**2**	0.01	0.99	0.37	0.68	0.98	0.37
M × S × ST	**1**	0.01	0.93	4.75	**0.03**	3.49	0.06
M × S × T	**2**	0.250	0.77	0.08	0.91	0.53	0.58
M × ST × T	**2**	0.12	0.88	0.41	0.66	0.11	0.89
S × ST × T	**2**	1.05	0.35	0.71	0.49	0.24	0.78
M × S × ST × T	**2**	0.16	0.85	1.24	0.29	0.65	0.52

Significant values ($P<0.05$) are highlighted in bold

Table 2

Table 2. Contrasts of the generalized linear model effects for survival in October 2104 and February 2015 of *Q. coccifera* and *Rh. lycioides* species planted with solid tubes or meshes (Shelter type) under three levels of light transmissivity (40- 60- 80%).

		October 2014		February 2015	
	df	Wald χ^2	$P > \chi^2$	Wald χ^2	$P > \chi^2$
Species (S)	1	6.07	**0.014**	3.04	0.081
Shelter type (ST)	1	31.67	**0.000**	38.86	**0.000**
Transmissivity (T)	2	7.25	**0.027**	12.18	**0.002**
Species × Shelter Type	1	11.00	**0.001**	14.12	**0.000**
Species × Transmissivity	2	1.17	0.556	0.90	0.637
Shelter type × Transmissivity	2	3.76	0.153	7.37	**0.025**
S×ST×T	2	0.60	0.742	0.21	0.898

Significant values (P<0.05) are highlighted in bold

Table 3

Table 3. Results from ANOVA (Snedecor F and associated probability *P*) test for the effects of Species (*Q. coccifera* and *Rh. lycioides*), Shelter type (solid tube and plastic mesh) and Transmissivity (80-60-40 %) on morphological traits of seedlings excavated in February 2015

		Leaf Area		Protruding Roots length		Shoot weight		Shoot/Root		Specific Leaf Area		Specific Root Length	
	df	F	*P*	F	*P*	F	*P*	F	*P*	F	*P*	F	*P*
Species (S)	1	12.59	**0.001**	6.68	**0.01**	2.48	0.12	83.30	**0.001**	0.007	0.97	16.43	**0.001**
Shelter type (ST)	1	23.86	< **0.001**	3.88	**0.05**	8.14	**0.006**	0.81	0.37	1.13	0.29	1.02	0.31
Transmissivity (T)	2	0.57	0.56	0.13	0.87	1.34	0.26	1.83	0.16	0.13	0.87	0.62	0.54
Species × Shelter type	2	0.03	0.86	4.15	**0.04**	0.03	0.86	0.57	0.45	0.16	0.68	1.29	0.26
Species × Transmissivity	1	0.31	0.73	0.30	0.74	0.06	0.93	0.09	0.91	1.05	0.35	0.46	0.63
Shelter type × Transmissivity	2	1.66	0.19	0.95	0.39	0.45	0.63	2.7	0.07	1.54	0.22	0.27	0.78
S × ST × T	2	2.07	0.13	2.35	0.08	1.43	0.24	1.20	0.30	2.66	0.08	1.5	0.21

Significant values ($P<0.05$) are highlighted in bold

Table 4. Morphological traits by species (*Q. coccifera* and *Rh. lycioides*) as affected by shelter type (plastic mesh or solid tube) of seedlings excavated in February 2015.

	Q. coccifera		*Rh. lycioides*	
	Plastic mesh	Solid tube	Plastic mesh	Solid tube
Leaf Area (cm^2)	60.60 ± 10.9	127.03 ± 20.43	36.15 ± 10.93	77.25 ± 19.0
Protrud. roots length (mm)[1]	82.93 ± 14.60^b	147.50 ± 20.77^a	171.47 ± 49.33^a	189.30 ± 56.83^a
Shoot weight (g)	3.44 ± 0.47	5.11 ± 0.80	2.98 ± 0.93	4.39 ± 1.20
Shoot/Root ratio ($g \cdot g^{-1}$)	0.58 ± 0.0	0.59 ± 0.0	1.40 ± 0.23	1.55 ± 0.27
Specific leaf area ($cm^2 \cdot g^{-1}$)	74.07 ± 15.37	58.48 ± 5.23	72.84 ± 15.27	63.09 ± 6.5
Specific root length ($cm \cdot g^{-1}$)	159.59 ± 25.97	180.80 ± 55.63	323.94 ± 63.80	246.09 ± 46.83

[1] As Species × Shelter type was significant for this variable (see Table 3), different letters following mean values ± SE denote differences among combination treatments after Tukey's post hoc test.

Figures

Figure 1

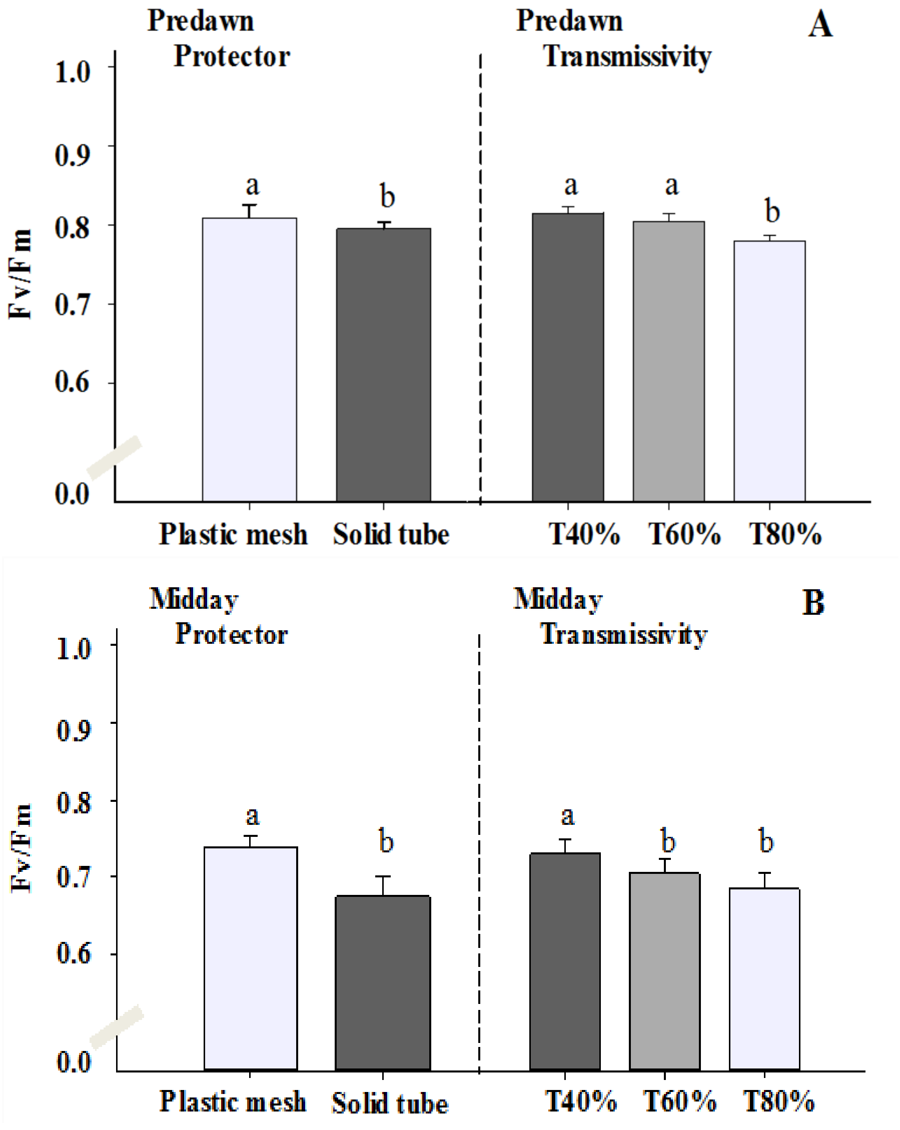


Figure 1. Summer predawn (A) and midday (B) photochemical efficiency (F_v/F_m) as affected by shelter type (plastic mesh or solid tube) and light transmissivity (T40-T60-T80 %). Data are averaged by species and month of measurement (June and July 2014). Different letters between Shelter type and among Transmissivity levels denote differences among levels of factors after Tukey's post hoc test. Error bars represent ± SE.

Figure 2

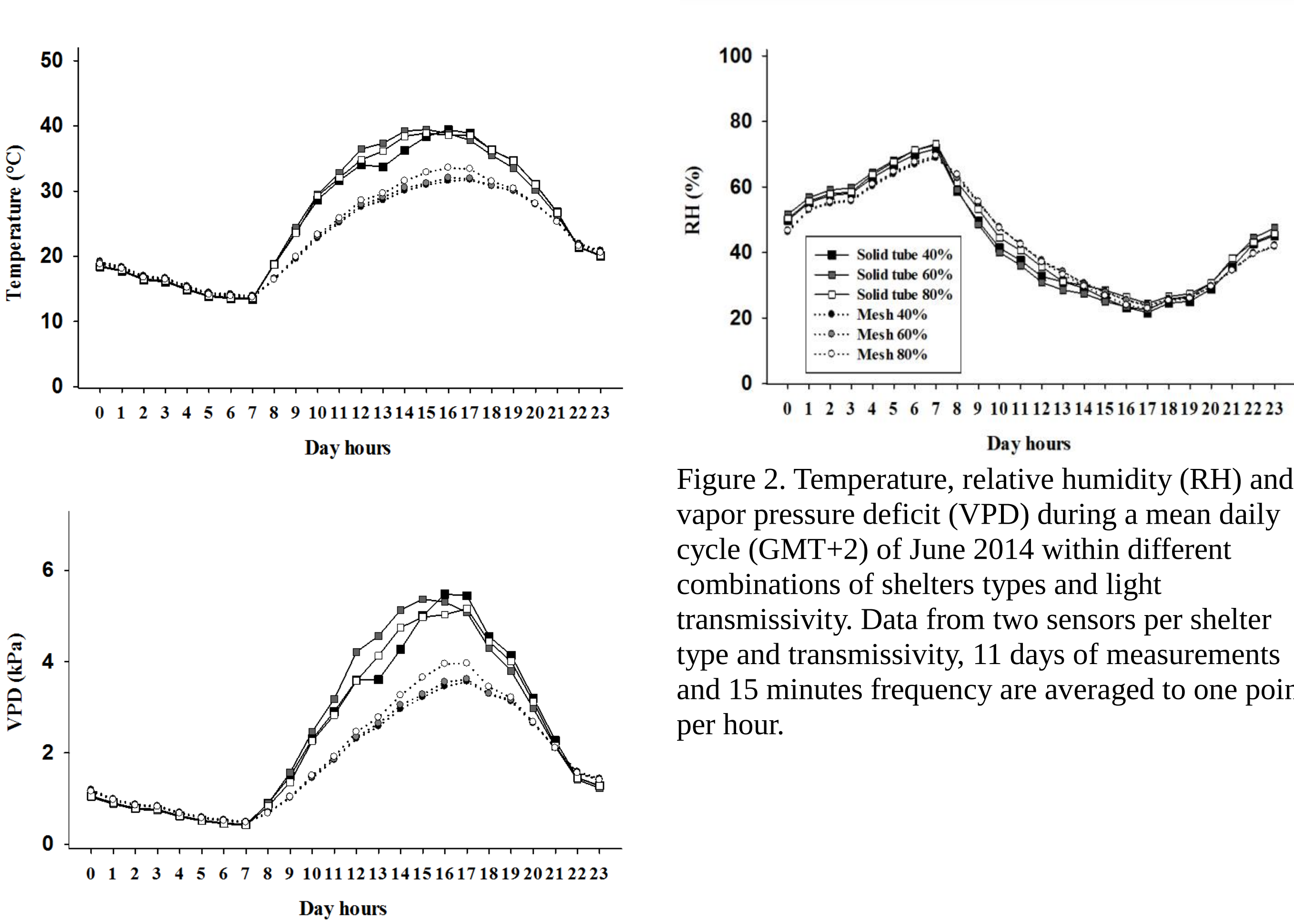


Figure 2. Temperature, relative humidity (RH) and vapor pressure deficit (VPD) during a mean daily cycle (GMT+2) of June 2014 within different combinations of shelters types and light transmissivity. Data from two sensors per shelter type and transmissivity, 11 days of measurements and 15 minutes frequency are averaged to one poin per hour.

Figure 3

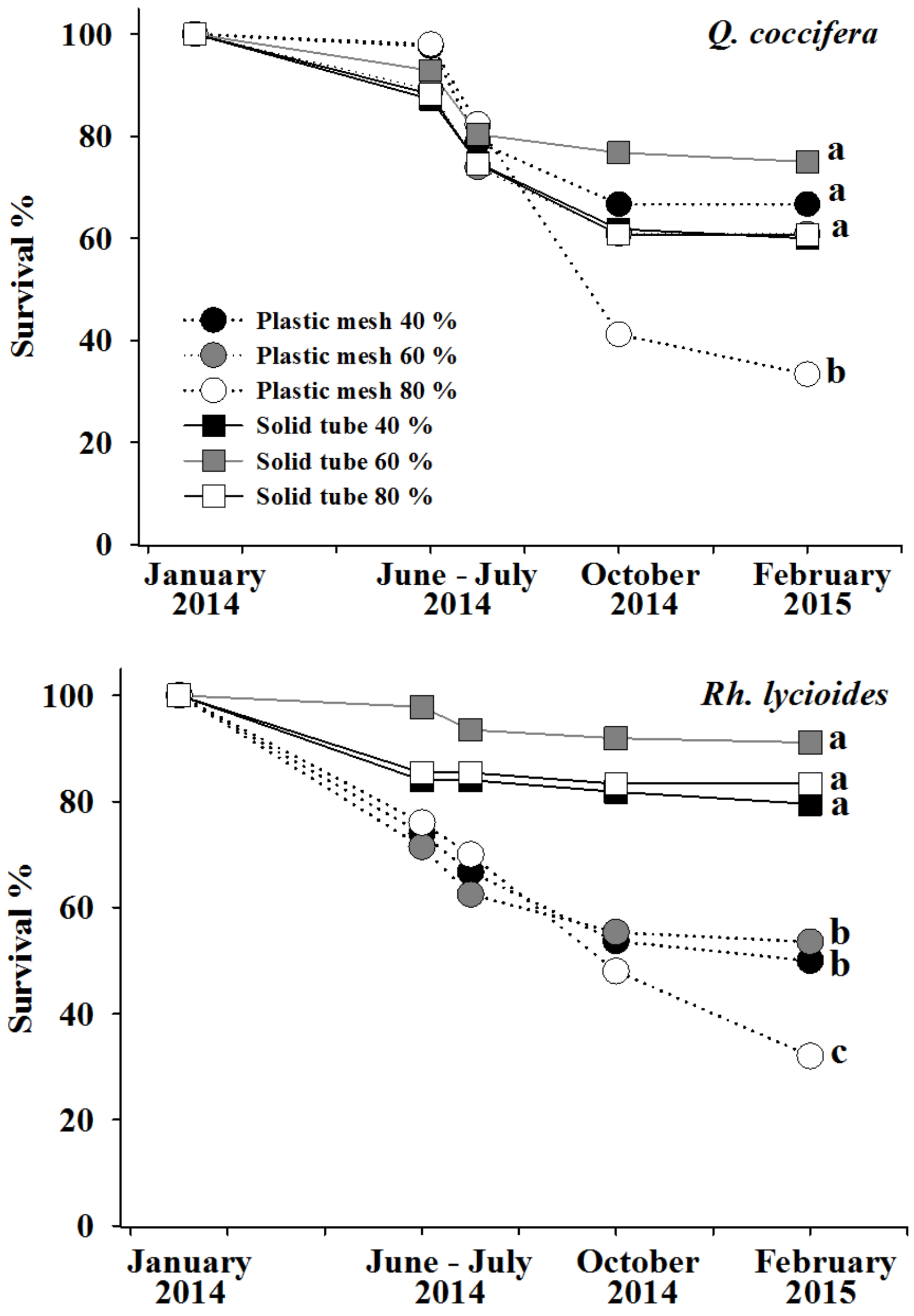


Figure 3. Survival of *Q. coccifera* (top) and *Rh. lycioides* (bottom) along the study period as affected by type of shelter (plastic mesh and solid tube) and transmissivity (40%, 60% and 80%). Letters at the end of each treatment denote significant differences during last measurement (February 2015).

Figure 4

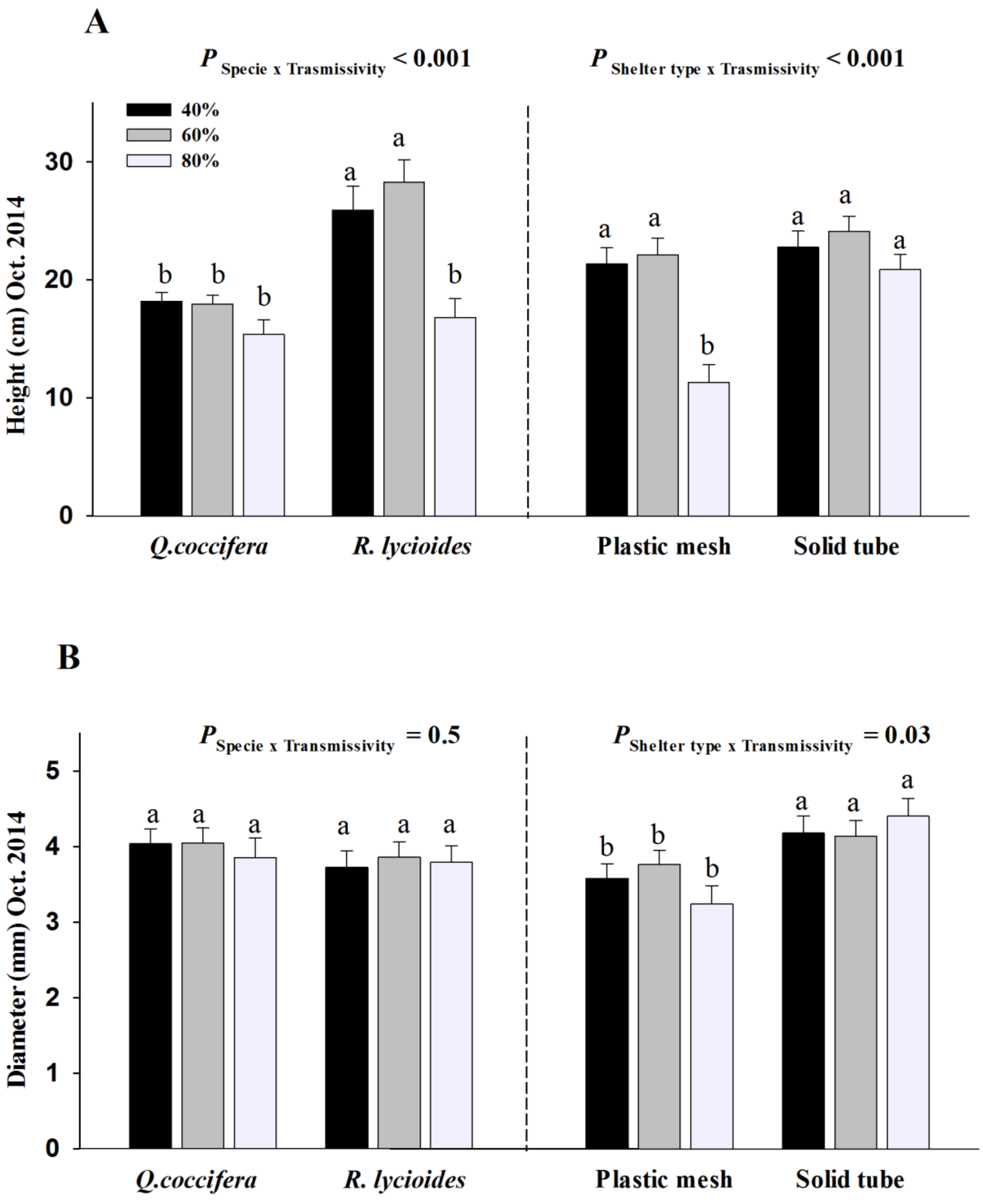
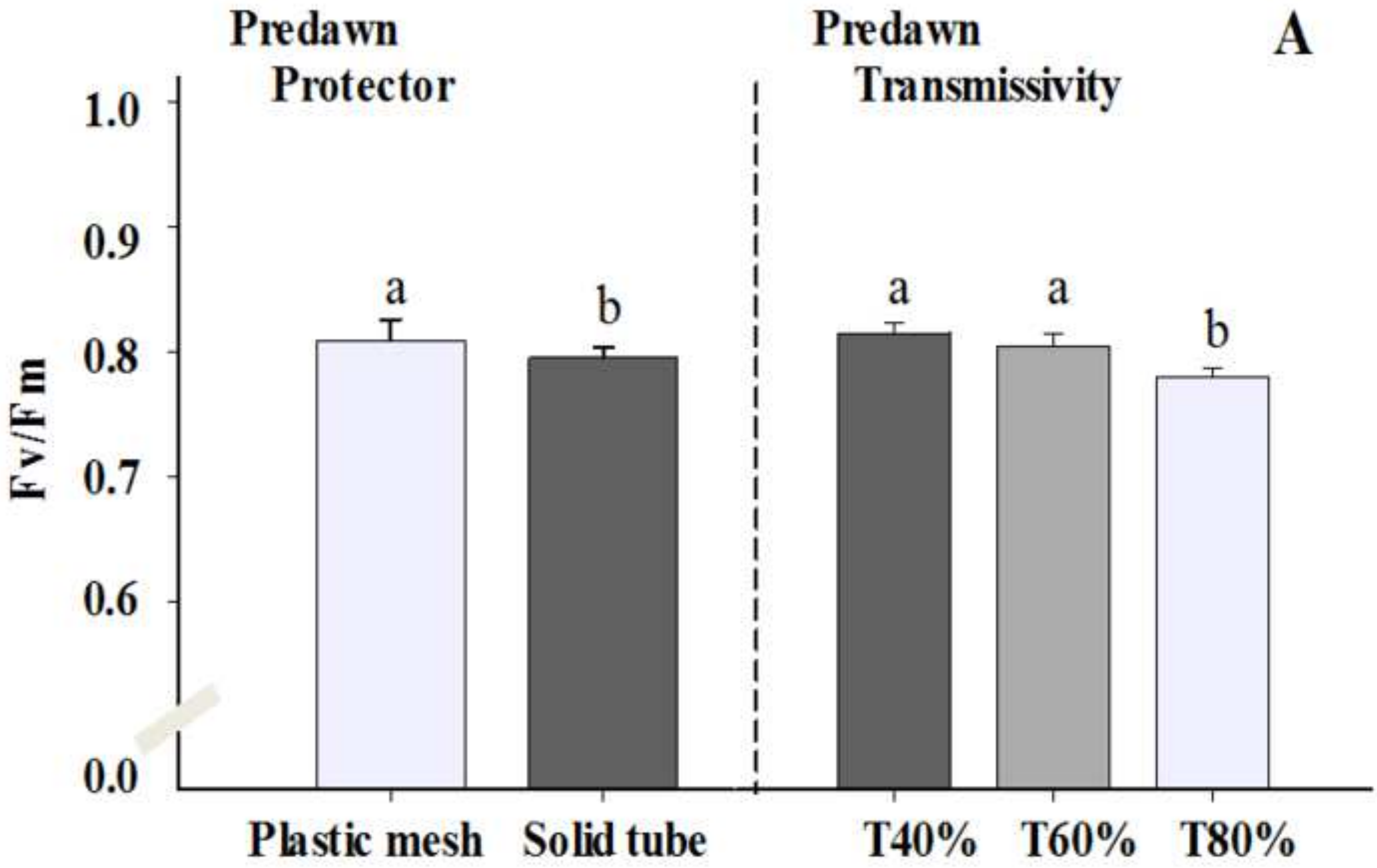
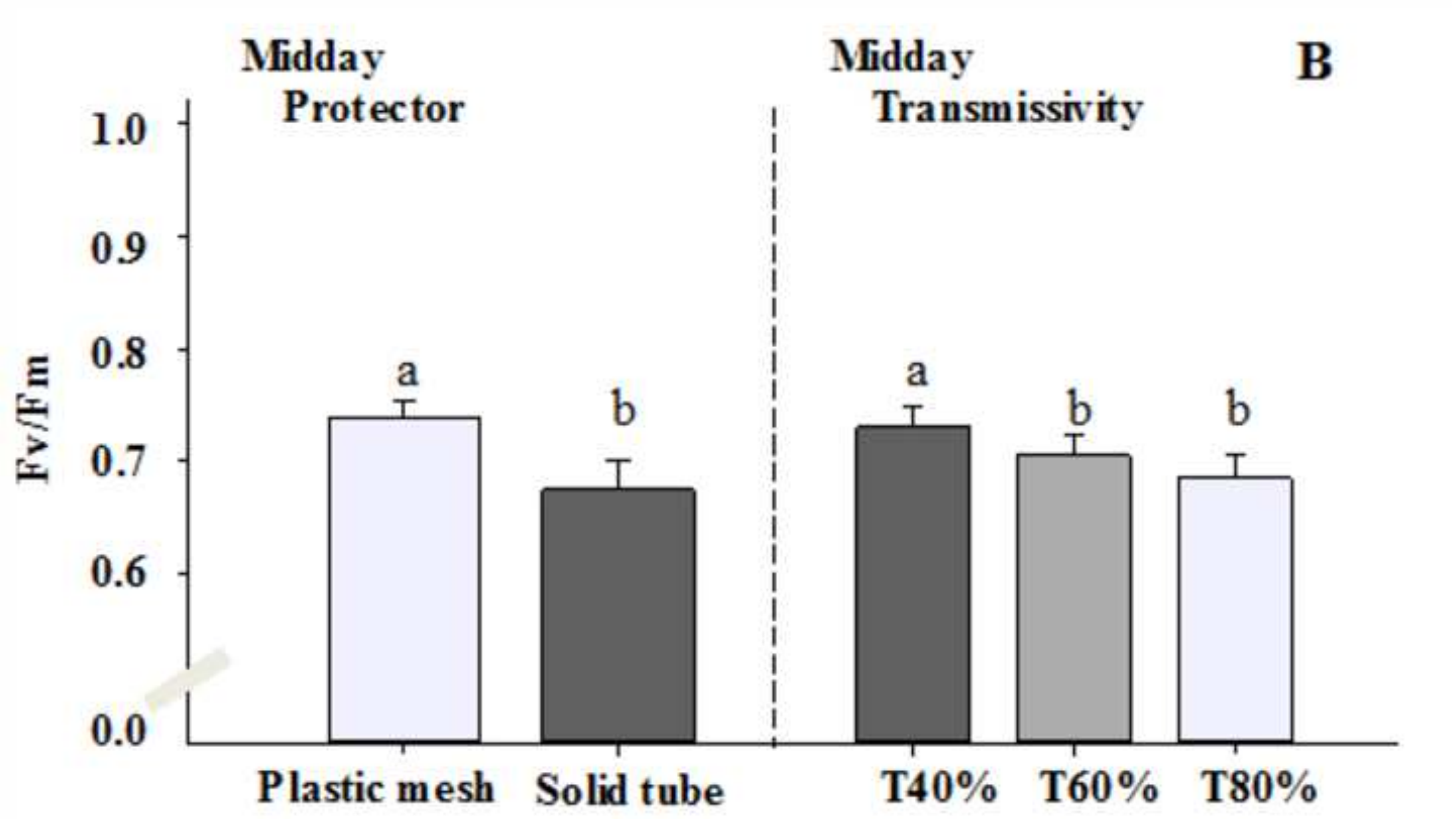
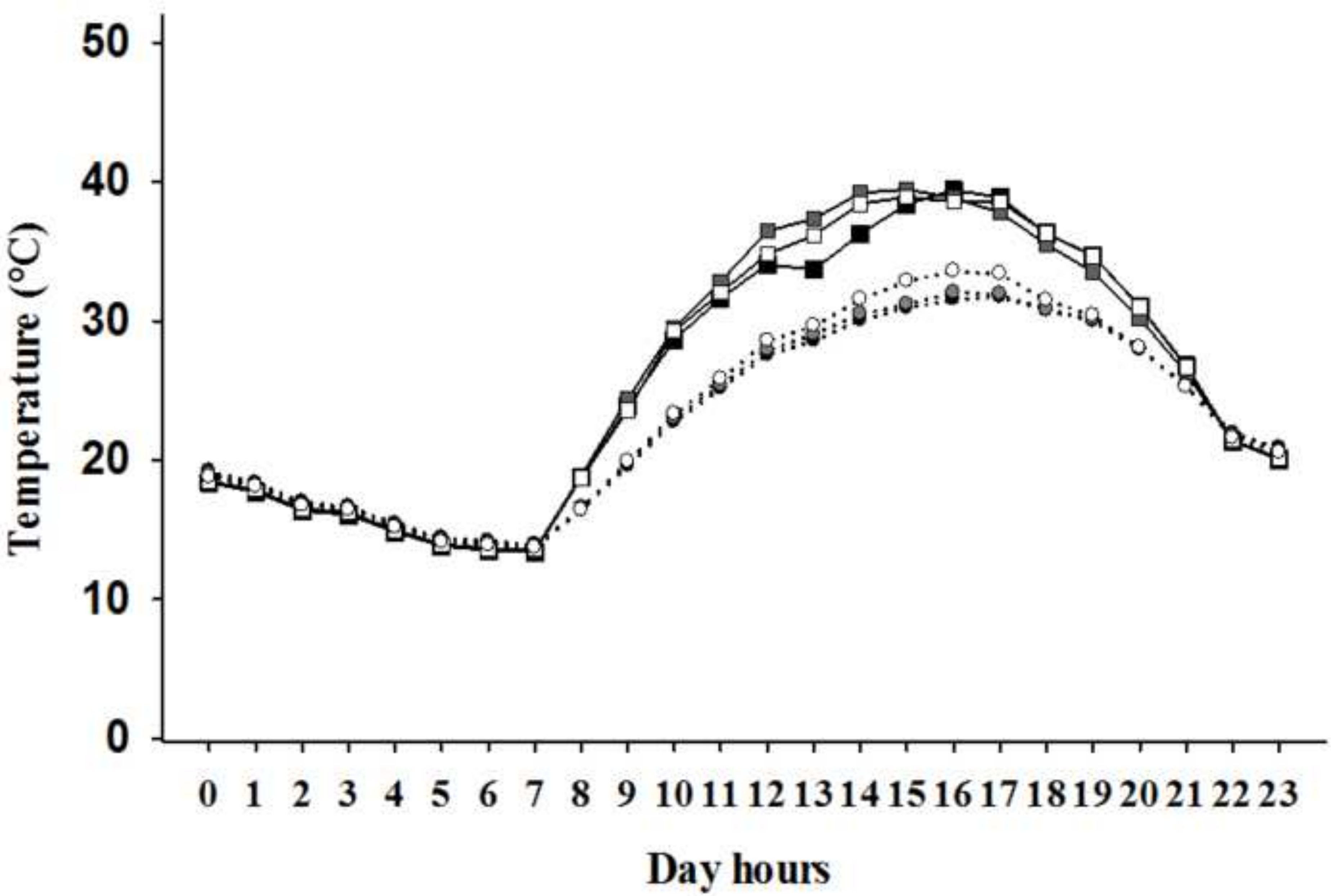
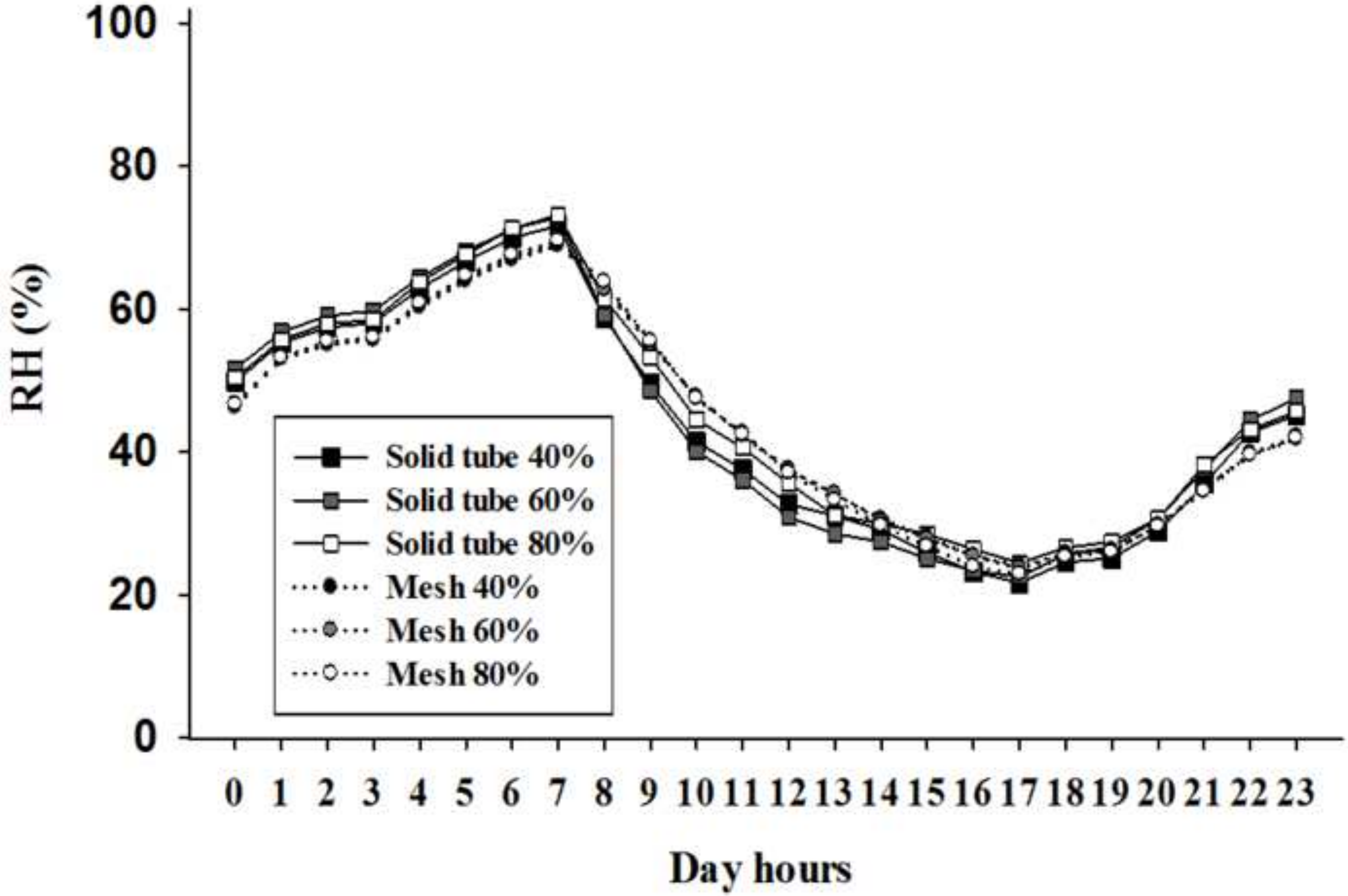


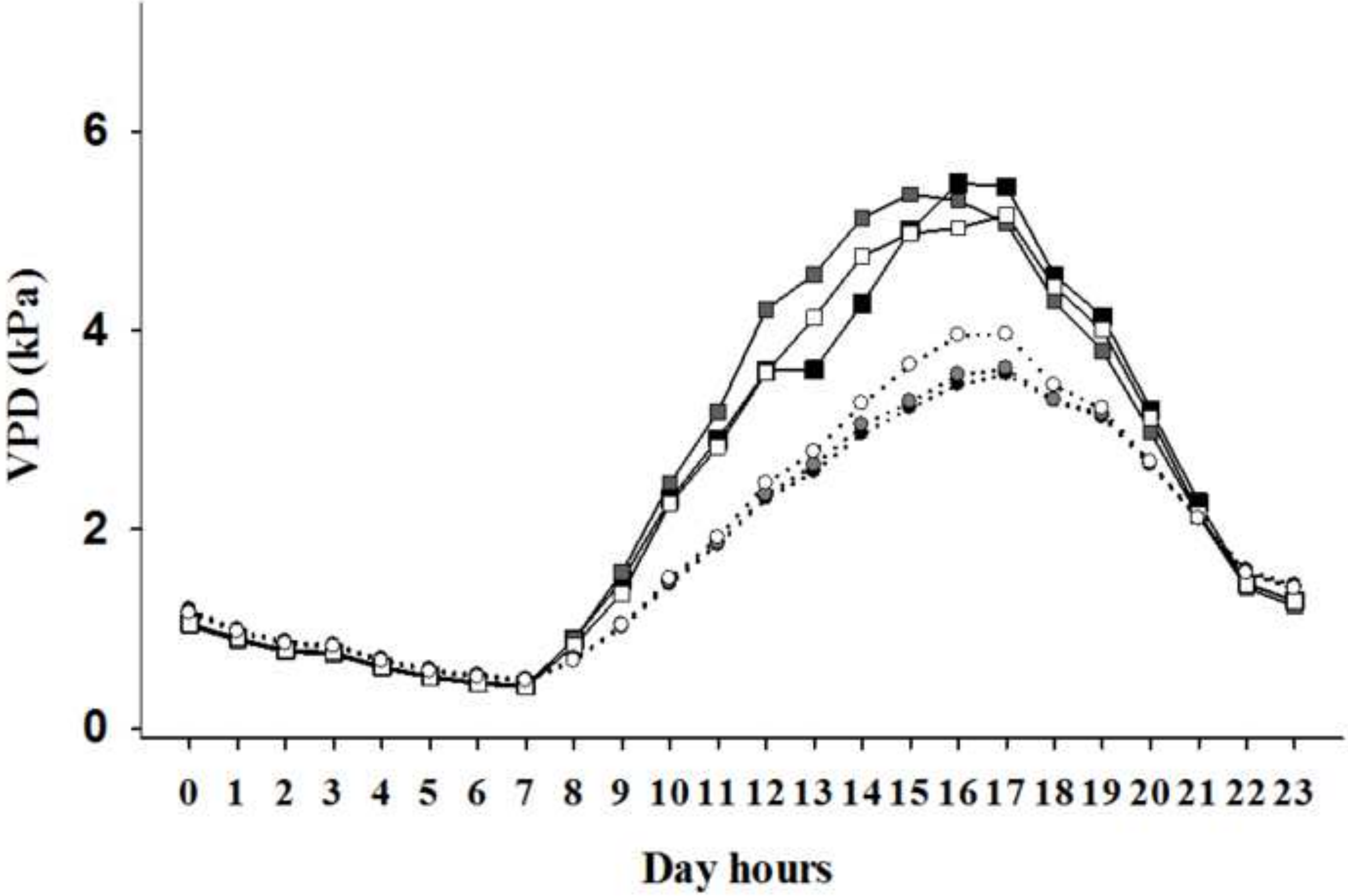
Figure 4. Post summer height (A) and basal diameter (B) of tested species (*Rh. lycioides* and *Q. coccifera*) in October 2014 as affected by shelter type (plastic mesh or solid tube) and light transmissivity (40-60-80 %). Different letters denote differences among levels of treatments after Tukey's post hoc test. Error bars represent ± SE. *P* values for second order interaction are shown on top of each subfigure

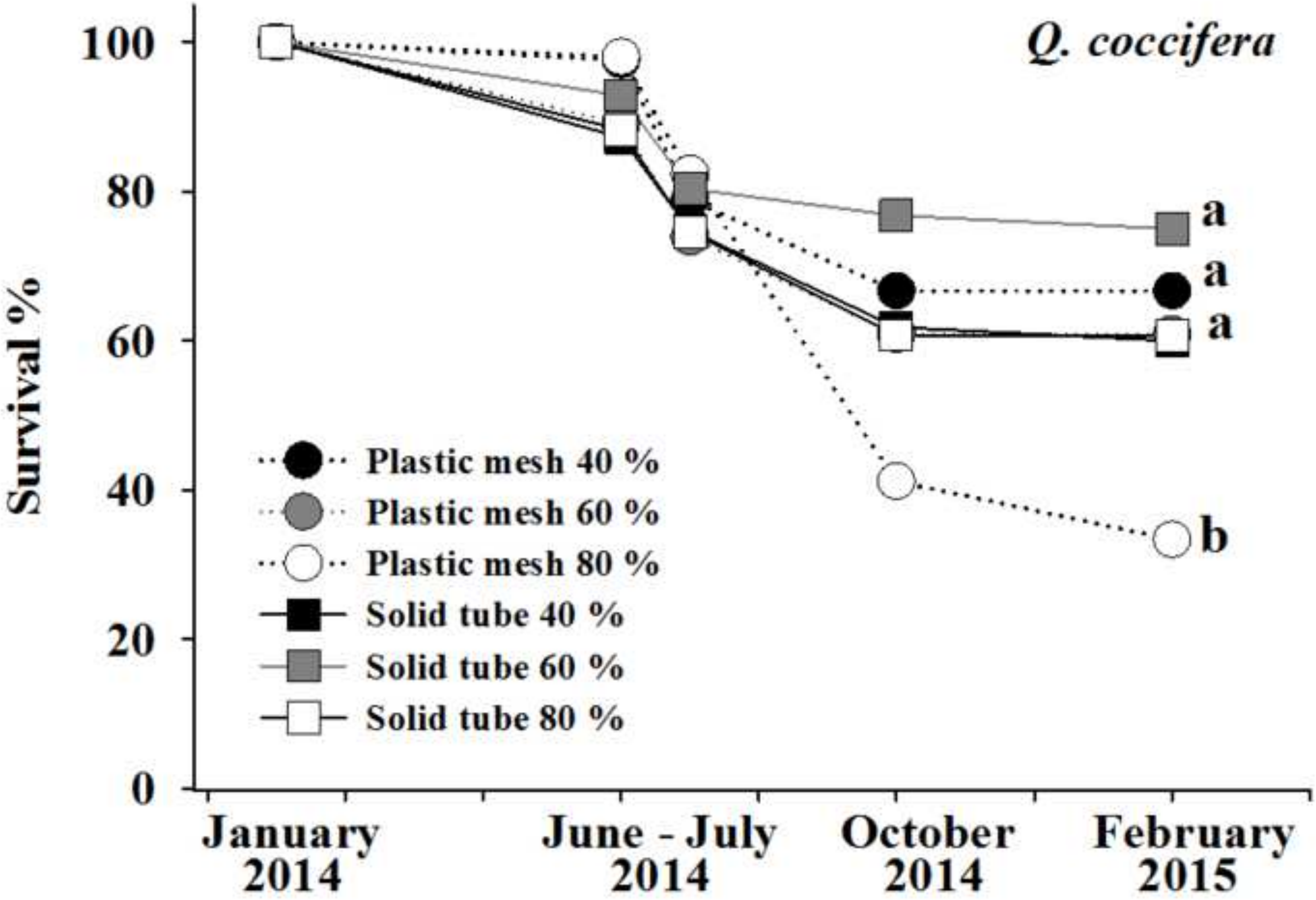

Predawn
Protector
Predawn
Transmissivity
A
Fv/Fm
1.0
0.9
0.8
0.7
0.6
0.0
a
b
a
a
b
Plastic mesh
Solid tube
T40%
T60%
T80%

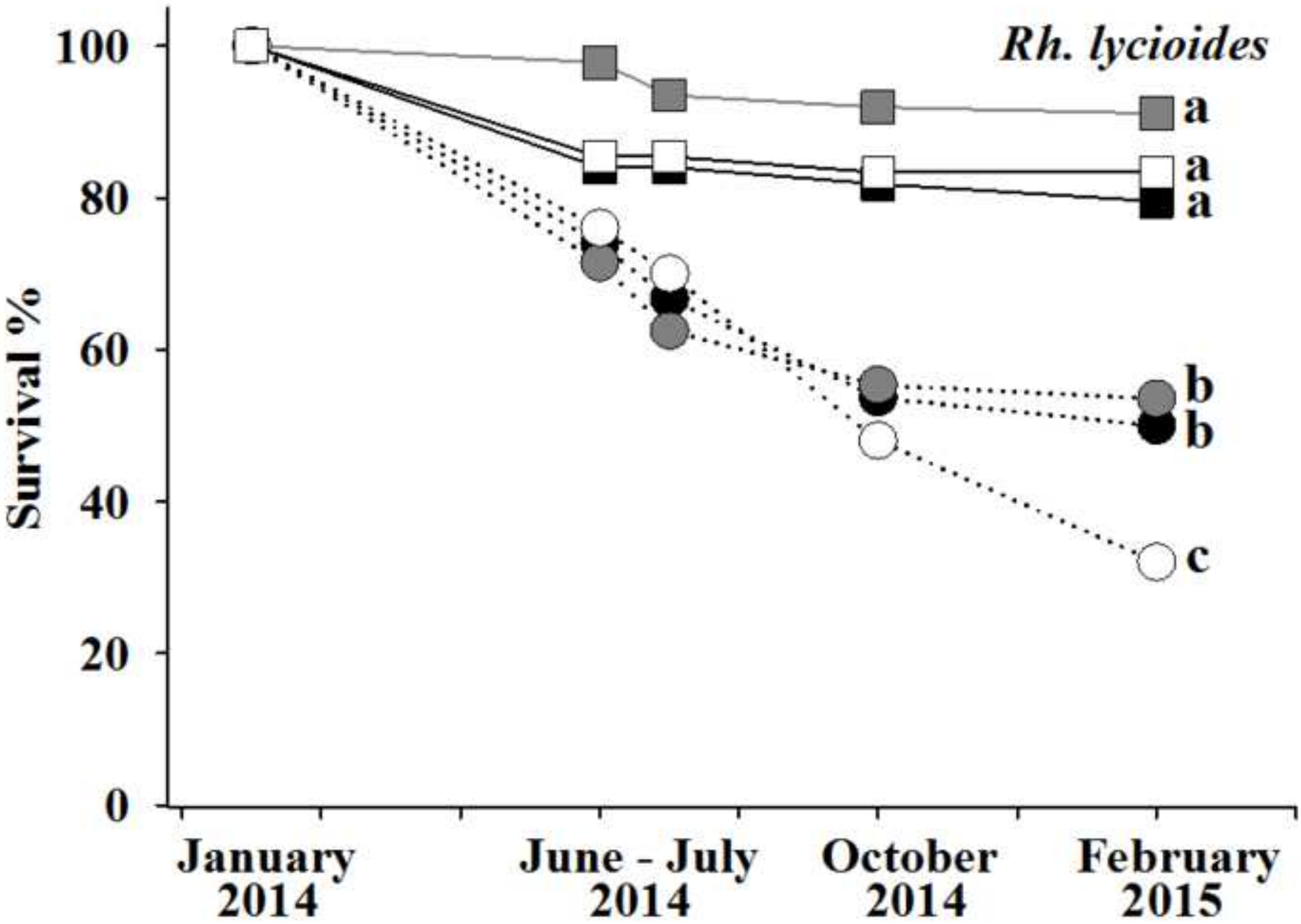

Midday
Protector
Midday
Transmissivity
B
Fv/Fm
1.0
0.9
0.8
0.7
0.6
0.0
a
b
a
b
b
Plastic mesh
Solid tube
T40%
T60%
T80%

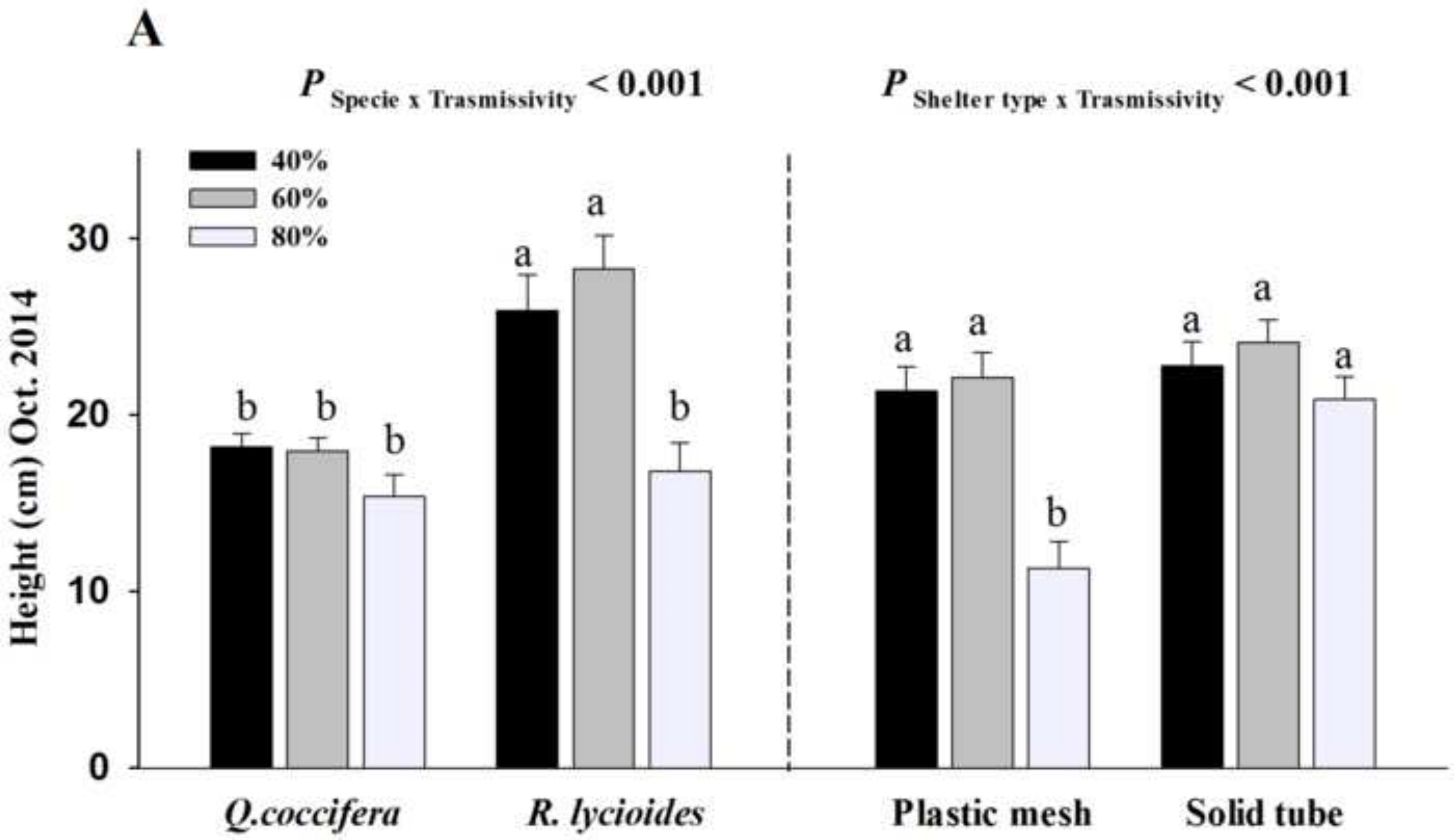

Temperature (°C)
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Day hours

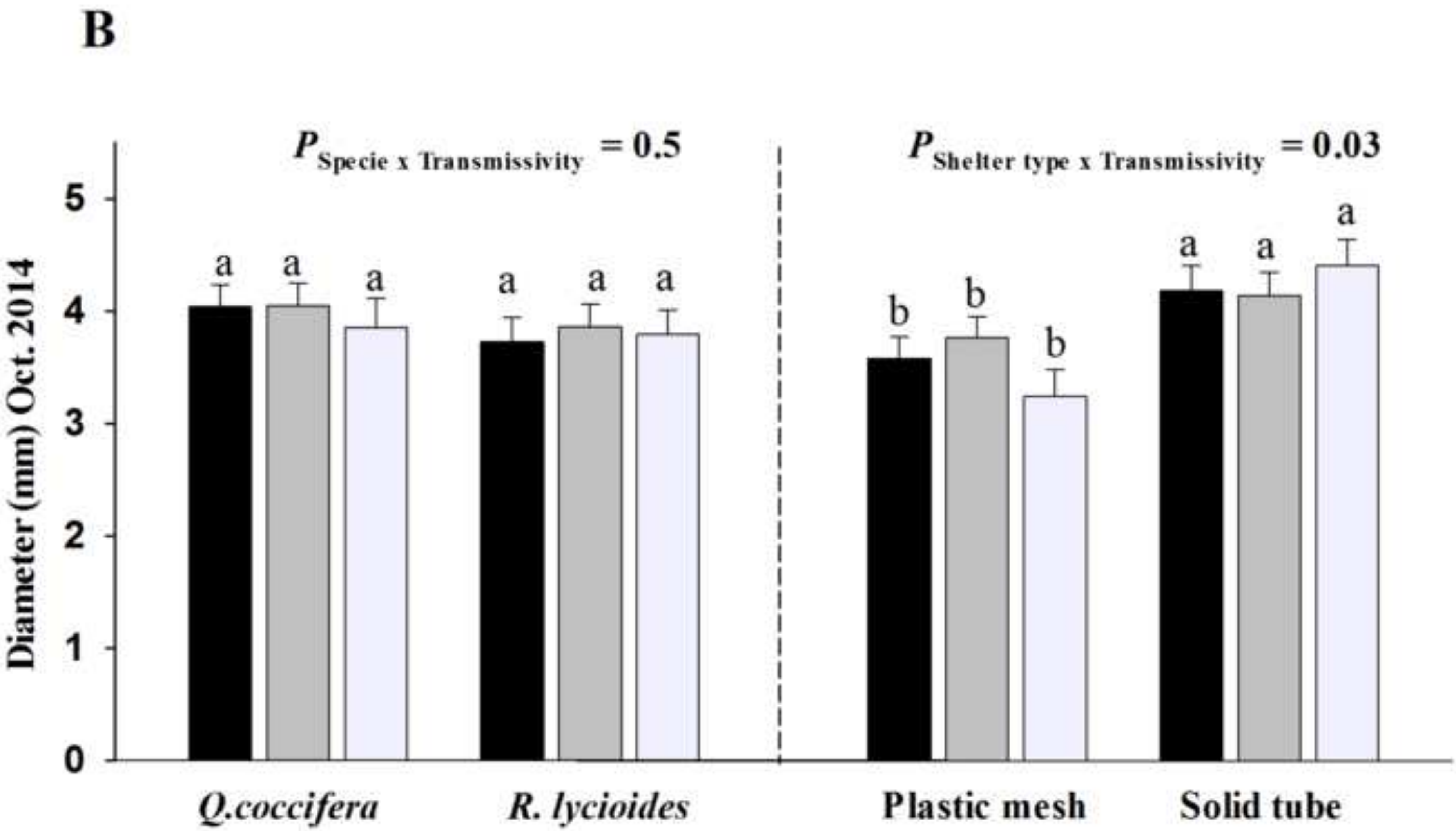

RH (%)
100
80
60
40
20
0
Solid tube 40%
Solid tube 60%
Solid tube 80%
Mesh 40%
Mesh 60%
Mesh 80%
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Day hours


VPD (kPa)
0
2
4
6
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
Day hours


Q. coccifera
Survival %
100
80
60
40
20
0
January 2014
June - July 2014
October 2014
February 2015
a
a
a
b
Plastic mesh 40 %
Plastic mesh 60 %
Plastic mesh 80 %
Solid tube 40 %
Solid tube 60 %
Solid tube 80 %


Rh. lycioides
Survival %
100
80
60
40
20
0
a
a
a
b
b
c
January 2014
June - July 2014
October 2014
February 2015


A
$P_{\text{Specie x Trasmissivity}} < 0.001$
$P_{\text{Shelter type x Trasmissivity}} < 0.001$
40%
60%
80%
Height (cm) Oct. 2014
0
10
20
30
b
b
b
a
a
b
a
a
b
a
a
a
Q.coccifera
R. lycioides
Plastic mesh
Solid tube


B
$P_{\text{Specie x Transmissivity}} = 0.5$
$P_{\text{Shelter type x Transmissivity}} = 0.03$
Diameter (mm) Oct. 2014
0
1
2
3
4
5
a
a
a
a
a
a
b
b
b
a
a
a
Q.coccifera
R. lycioides
Plastic mesh
Solid tube

MANUSCRIPT NEFO S 17 00259

Journal: New Forests

Title: Should we use meshes or solid tube shelters when planting in Mediterranean semiarid environments?

Juan A. Oliet1, Raul Blasco1, PatricioValenzuela2, María Melero de Blas3, Jaime Puértolas4

1 Departamento de Sistemas y Recursos Naturales, Universidad Politécnica de Madrid, 28040 Madrid, Spain. E-mail address: juan.oliet@upm.es. Phone: +34 913366412. ORCID 0000-0001-7719-9327. Corresponding author

2 Center of Applied Ecology & Sustainability (CAPES), Pontificia Universidad Católica de Chile, 4860 Macul, Santiago, Chile.

3 World Wildlife Foundation-España. 28005 Madrid, Spain

4 Lancaster Environment Centre, Lancaster University, Lancaster LA1 4YQ, UK. ORCID 0000-0002-6132-0679

Supplementary material.. Post summer height and basal diameter of tested species (*Rh. lycioides* and *Q. coccifera*) in October 2014 as affected by shelter type (plastic mesh or solid tube) and light transmissivity (40-60-80 %).

	Q.coccifera		*Rh. lycioides*	
	Plastic Mesh	Solid Tube	Plastic Mesh	Solid Tube
	Height (cm)			
Transmissivity 40 %	17.60 ± 0.72	18.58 ± 0.73	24.91 ± 2.03	26.95 ± 2.03
Transmissivity 60 %	17..52 ± 0.82	18.40 ± 0.70	26.74 ± 1.98	29.81 ± 1.86
Transmissivity 80 %	12.57 ± 1.62	18.17 ± 0.87	10.08 ± 1.39	23.58 ± 1.75
	Diameter (mm)			
Transmissivity 40 %	3.60 ± 0.2	4.47 ± 0.1	3.56 ± 0.1	3.9 ± 0.3
Transmissivity 60 %	3.83 ± 0.1	4.26 ± 0.2	3.70 ± 0.2	4.02 ± 0.2
Transmissivity 80 %	3.31 ± 0.3	4.40 ± 0.2	3.17 ± 0.2	4.41 ± 0.2