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Original article

Effect of shelter tubes on establishment and growth of *Juniperus thurifera* L. (*Cupressaceae*) seedlings in Mediterranean semi-arid environment

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Abstract – This paper evaluates the growth and survival of *Juniperus thurifera* L. seedlings planted using or not the shelter tube Tubex® in Mediterranean semi-arid agricultural lands (S.E. Spain). Biometrical data were recorded on the plants in the field during two years and several seedlings were extracted by random at the end in order to measure additional morphological parameters related to root system. Micrometeorological measurements were collected on the experimental site to characterize the microclimate induced by the treeshelters. A survival level of 100% was registered inside and outside the shelter. However, an increment of absolute maximum temperature and an important reduction of radiation detected inside the shelter, could make the plants grow higher and to increase their foliage surface with a significant negative effect upon the root biomass, quantity of fine and thick roots, length of the main root and root collar diameter, which constitute the key for its survival in climates in which hydric resources are scarce and the plants are subjected to long periods of xericity. Therefore, the use of the shelter tubes seems inadvisable, at least in these environments and for species with these characteristics.

semi-arid / treeshelter / radiation / root biomass / *Juniperus thurifera*

Résumé – Effets des tubes protecteurs dans l'installation et la croissance des plants de *Juniperus thurifera* L. (*Cupressaceae*) dans des zones semi-arides méditerranéennes. Le présent travail évalue la croissance et la survie des plantules de *J. thurifera* plantées avec ou sans tube de protection Tubex® en terrains agricoles semi-arides méditerranéens (S.E. de l'Espagne). Les données biométriques utilisées dans cette étude ont été récoltées in situ durant deux années. À la fin de cette période, on a prélevé un échantillon des plants d'une manière aléatoire pour mesurer des paramètres morphologiques en relation avec les systèmes racinaires. On a pris des mesures micrométéorologiques dans les parcelles expérimentales pour caractériser le microclimat induit par les tubes protecteurs. La réponse des plants a été excellente, enregistrant un taux de survie de 100 % dans et en dehors du tube protecteur. Néanmoins, une augmentation de la température maximale absolue et une importante réduction de la radiation enregistrée dans le tube protecteur ont stimulé la croissance des plants et ont augmenté leur surface foliaire au détriment de la biomasse racinaire, de la quantité des racines fines et des grosses racines, de la longueur de la racine principale et du diamètre au collet. Ces paramètres constituent la base de la survie des plants dans les zones déficitaires en eau avec une large période de sécheresse. À partir de ces résultats, on ne recommande pas l'utilisation de ce type de tubes protecteurs au moins dans des régions similaires du point de vue climatique et pour les espèces qui ont les mêmes caractéristiques.

zones semi-arides / tube protecteur / radiation / biomasse racinaire / *Juniperus thurifera*

1. INTRODUCTION

In dry and semi-arid Mediterranean environments, one of the factors which most influences the success of the planting, is the quality of the plant [35, 42]. Plant quality is understood according to the combination of morphological and physiological characteristics which are quantitatively related to satisfactory plant performance in the field [13, 20, 51]. Apart from the measurement parameters usually used to define the quality of the plant, such as height, root collar diameter, foliage biomass, etc., in diverse studies the importance of the root system following the transplant, has been highlighted as a decisive factor in plant rooting [17, 20, 30]. In semi-arid climates and soils that are water deficient, the quality of the plant will not only be related to the quality of its above-ground biomass, but also to the development of its roots, in which case, the root system may be a

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good indicator of the physiological condition of the plant. It is possible to relate strength and survival in the field, to the good root system in the nursery [52]. A profound, well developed root system may favour the establishment of seedlings in zones having semi-arid climatic conditions [10, 25].

There also exist other parameters and indexes, elaborated from the previous ones, which are recommended for studying plant quality. In this way, the relationship between the above and below ground biomass [47] expresses the balance between losses due to transpiration and the capacity to maintain gas exchange level through the leaves, and the absorption of water and nutrients through the roots. Plants with low values of this ratio survive much better than those which have high values, since they present a greater development of the absorption system with reference to transpiration. For *Pinus* sp., values between 1 and 2 are acceptable [20]. The narrowness index defined as the ratio between the above ground height and the root collar diameter [35], is useful in order to understand the plant´s capacity to confront stress and to compete with the existing vegetation [50]. Dickson evaluated a combination of morphological parameters which exhibit an intricate correlation between them (height, diameter and weight) which describe the plants' state of health, and therefore predict the field behaviour of specific species [53, 56]. Plants with greater thickness and development of the root system, will have a high Dickson index value, presenting greater capacity for survival. The first objective of this study was to analyse these parameters and indexes in a batch of thuriferous juniper (*Juniperus thurifera* L.) seedlings and compare them with the standard values of quality proposed in the literature for other Mediterranean species such as *Pinus halepensis* Mill. [53] and *Olea europea* L. var. *sylvestris* (Mill.) Lehr [35].

Moreover, the incidence on the seedlings protected by treeshelter tubes (Tubex®) was contrasted during the two years of field development. Some authors affirm that this device provokes a reduction of the specific foliage area, increasing the index of narrowness, morphological disproportion and poor growth, reduction of transpiration, together with the added economic cost which is incurred by its use [2, 3, 16]. Numerous works, most of them in agro-forestry systems with warm, rainy climates confirm that the survival of seedlings is better with the shelter Tubex® than without it, although there are some exceptions, and that it is advantageous against herbivores, application of herbicides and excessive ramification [1, 7, 15, 26, 27, 54, 58]. However, its use in dry and semi-arid Mediterranean environments is controversial and has not been well verified, due to the high temperatures which increase within the shelter in summer (up to 60 ºC, [32, 55]). There are also very few studies which analyse the effects produced on the plant´s root system under these conditions [37].

J. thurifera is a species which has been very little used in forestry research, and nothing is known about its field performance apart from specific instances [46], perhaps because it is a species that grows relatively slowly. It must be planted with at least two years of nursery growth in order to ensure its survival (nurserymen, comm. pers.), which therefore increases its price in relation to other species of the *Pinus* or *Quercus* genus with only one year of growth, traditionally used in Mediterranean environments.

The reason for choosing *J. thurifera* for this study is that it would be useful for use in forestation of agrarian lands, forest repopulation, ecological restoration, xero-gardening, etc., as it presents good physiological adaptation to the cold and to hydric stress [43], which means that successful planting is achieved in places with extreme ecological conditions [36]. The thuriferous juniper forests ("*sabinares*") constitute authentic relics of the Tertiary period, which are of enormous ecological, paleobiogeographical and fitosociological interest. In this areas, protection, conservation and research activities must be prioritary actions [11, 21]. In addition to that, *J. thurifera* wood is highly appreciated for several purposes (cabinet making, carpentry, ...) because it is compact, incorruptible and aromatic, and moreover, it has a high economic value [12, 24, 39].

In the face of this situation, the following questions were put forward as the objective of this study: (1) Is the commercial plant of *J. thurifera* used in this investigation of good quality in relation to those proposed for other similar Mediterranean species? (2) What will be its response in the field? (3) What effect does the treeshelter produce on the physical parameters and on the seedlings in semi-arid Mediterranean conditions?

2. MATERIALS AND METHODS

The thuriferous juniper (*J. thurifera* L., *Cupressaceae*) is a dioecious tree or bush with a more or less pyramidal shape, which presents escuamiform leaves and fruit of glaucous-green colour in its early stages, and black-purple on maturation [5, 14].

It is distributed throughout south and southeastern France, Italy (Alps), Corsica, Spain and North Africa [14]. There are two subspecies [19], *J. thurifera* L. subsp. *africana* (Maire) Gauquelin and *J. thurifera* L. subsp. *thurifera*. Of the latter, there are 3 varieties: var. *thurifera* on the Iberian Peninsula, var. *gallica* De Coincy in the Alps and var. *corsicana* Gauquelin in Corsica (Fig. 1A). On the Iberian Peninsula it appears in highly continental climates, cold and dry, between (200) 900–1200 (1800) m of altitude and in generally carbonated substrata [23].

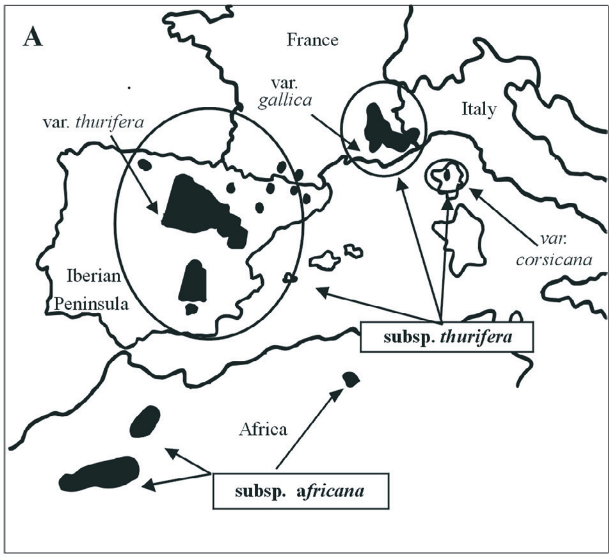
2.1. Study area

The experimental zone is located in "rambla de Becerra" (Guadix-Baza basin, Granada) in the Southeastern Iberian Peninsula. Its coordinates are 37º 26' N and 3º 5' W at 950 m above sea level. It is a zone which has a xeric-oceanic bioclimate, mesomediterranean thermotype and semi-arid ombrotype [48], very homogeneous topography, with an average annual rainfall of 320 mm in very irregular precipitations. The soils are calcic cambisoles with a pH of 7.5, they have a silt-clay-sand texture with great retention capacity [45].

This zone is found near the most southern and dry populations of *J. thurifera* on the Iberian Peninsula [31] (Fig. 1B), formations of great ecological and geo-botanical value which characterize, from the biogeographical view point [49], to the Baetic Province, Guadiciano-Bacense Sector and Guadiciano-Bastetano District.

During decades the trial surface was used for the extensive cultivation of cereals [18] but due to the socio-economical decline carried over from the 50s–60s decade, the land was sold to the Administration in 1993 and all agricultural activity ceased. Nowadays, a large section of this territory is used for forestry research projects.

A batch of 75 *J. thurifera* seedlings obtained from a commercial nursery close to the trial site, was used in this study. This plants was cultivated in containers of 250 cm^3 (Arnabat) with an anti-spiralling system, during 2 years.



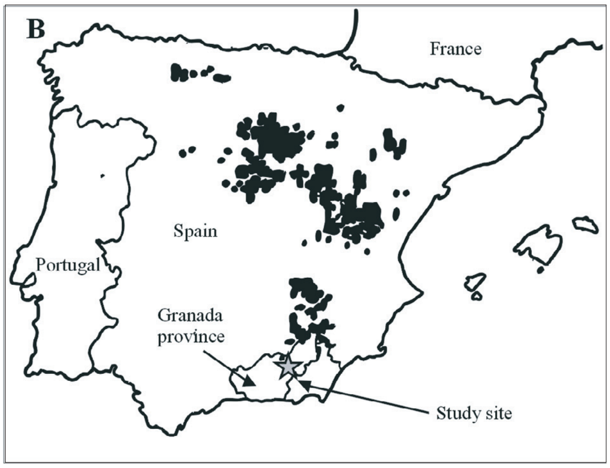


Figure 1. (**A**) General distribution area of *J. thurifera* [30], (**B**) Distribution of *J. thurifera* on the Iberian Peninsula ([22], modified), and localization of the study area.

2.2. Laboratory analysis of plant quality

The laboratory analysis was carried out on a set of 25 of this seedlings which were not planted. Root collar diameter (RCD) was measured with a digital calliper and height (H), with a millimetre ruler. The above-ground biomass (AGB) was separated from the root biomass (RB) in order to subject them to the drying process which was performed in a stove at 70 ºC during 48 h. At the same time the AGB was divided into leaf biomass (LB) and stem biomass (SB). Later, these were weighed on precision scales and the existent relationship between the two parts (AGB/RB) was calculated, as well as the index of narrowness (N = H/RCD), the Dickson index [ICD = AGB + RB/ N + (AGB/RB)], and the total biomass (TB), some ordinary morphological parameters in studies of plant quality [4, 33, 34, 38, 40, 41].

Finally, a correlation analysis was made between these variables in order to find predictive information about the choice of best quality plants in the nursery without the necessity of destructive samples.

2.3. Analysis of field performance

In the trial zone, where the ecological characteristics were very homogenous, 2 plots of 400 m^2 (20 × 20 m) were installed. twenty-five seedlings of the initial batch were planted in each one, at a distance of 5 × 5 m and with a regular frame, in February 2001. The procedure for ground preparation consisted of digging of a hole with a retro-excavator of 80 H.P., with a bucket of 50 × 80 cm. The seedlings placed in one of these plots were fitted with a Tubex® tree protector with a height of 80 cm, with a double layer of polypropylene, with no lateral ventilation and anchored by a stake. All the plants were measured H, RCD, N and the increments applied to the narrowness index (Ninc) in February, July, October 2001, and in February, July and October of 2002. In this latter sample (October 2002) the foliage surface (FS) was also estimated and the leaf water potential (Ψ) measured.

FS was calculated with a non-destructive estimator of the foliage area [9] based on the same principles used in spectroradiometry. This principles are based on the selective light absorption by chlorophyll. The dispositive used for the foliar surface estimation was a closed tube with reflecting walls and illuminated with a diffuse artificial light source. The spectra were sampled at the centre of the tube top by a Full Sky Irradiance Remote Cosine Receptor. The reflectance spectrum for each plant was calculated from the spectrum sampled with the plant inside the tube divided by the spectrum previously sampled in the tube without a plant. Normalized Difference Vegetation Index (NDVI) was calculated from the reflectance spectra as NDVI = $(R_{770} - R_{680})/(R_{770} + R_{680})$, where R_{770} and R_{680} are the relectances at 770 and 680 nm. Assuming a relationship between NDVI and plant green area, previously calculated in laboratory for *J. thurifera*, we can estimate the FS through the equation: FS = 1/(0.0118222 – 0.0434483 × NDVI), $r = -0.76$, $R^2 = 57.2\%$, Standar Error = 0.00103, $P = 0.0000$ ($n = 25$).

Leaf water potential (Ψ) was measured at the end of the maximum water stress period (September), at dawn (6.00 a.m.) and at midday (13.00 p.m.), in 3 seedlings from each plot, for which the Schölander Bomb was used. In all of these cases, the material used was a lateral stem of 6–8 cm, and 4 or 5 leaves, which was transversally cut with a blade and quickly introduced in the pressure chamber.

2.4. Final destructive analysis

In order to analyse the effect of the Tubex® shelter on the development of the root and above ground systems, these were extracted by random after 2 years from planting (Oct. 2002), 5 junipers with treeshelter (T) and 5 without treeshelter (WT). Before extracting them, measurements in the field were taken of H, RCD and FS.

The methodology followed in the extraction and processing of the samples consisted in extracting the plants using a retro-excavator 80 H.P. with a bucket of 50 × 80 cm, and once extracted, were transported to the laboratory where the roots were washed to eliminate soil and other rests. The maximum length of the main root (RL) was measured and later AGB differentiating LB and SB, and RB differentiating thick roots (TR, diameter > 2 mm) and fine roots (FR, diameter < 2 mm) were separated, in order to subject them to the drying and weighing process which is habitual in these kind of studies [8, 13, 57]. Finally the TB, the specific foliage area (SFA = LB/FS), N and ICD were calculated, and all the variables were correlated in order to find out the grade of dependency on one another, and also, the modifications produced by the treeshelter.

2.5. Measurement of microclimatic parameters

During this sampling period, the general climate was analyzed by means of the meteorological station, of the brand THIES mod. DL-15, located in the trial zone. Data about temperature and precipitation were registered every 30 min. Moreover, 2 temperature and humidity sensors with a datalogger were installed, of the "HOBO" brand, "Pro Series RH/Temp" type, which registered data every 30 min during 12 months, one inside and another outside the Tubex®. These sensors were rightly protected against rainfall and solar radiation. The existent radiation, outside and inside the shelter, was studied by means of 2 dataloggers of the same brand, "RH/Temp/2x External" type, connected to 2 sensors "Quantum", "QSO-SUN" model, which registered PAR type data (400–700 nm) every 15 min during 8 months.

All these sensors were fitted to 25 cm above soil (outside and inside the shelter) without any safety device.

2.6. Statistical analysis

The data obtained in the laboratory analysis and from the field measurements were analysed with the programmes Microsoft Excel 97 and SPSS 10.0 for Windows 98, with which different one way ANOVAs were made for the factor "treeshelter", with a confidence level of 95%. In the case of violation of the Levene test of variance equality, the non parametric test of Kruskal-Wallis was used [28]. Depending on the analysis made, the measurement comparison test LSD was applied, (assuming equal variances) or the Tamhane test (assuming unequal variances) [44]. Correlation analysis in order to obtain information about the level of dependency of the variables studied (r = correlation coefficient), was also made.

Table I. Comparison of the plant quality parameters (mean ± SE) of *J. thurifera* seedlings of two years of nursery growth (n = 25), with regard to the values proposed for *Pinus halepensis* [14] and *Olea europea* [2] from one year seedlings. H = height, RCD = root collar diameter, AGB = above ground biomass, RB = root biomass, TB = total biomass, N = narrowness index, ICD = Dickson index.

	J. thurifera	*P. halepensis*	*O. europaea*
	Morphological parameters		
H (cm)	21.1 ± 0.60	10.44 ± 0.38	22.42 ± 7.34
RCD (mm)	3.25 ± 0.12	2.05 ± 0.06	3.57 ± 0.82
AGB (g)	2.42 ± 0.10	0.69 ± 0.06	1.48 ± 0.49
RB (g)	1.66 ± 0.08	0.45 ± 0.04	1.53 ± 0.57
TB (g)	4.09 ± 0.15	1.14 ± 0.09	3.09 ± 0.95
	Morphological indexes		
AGB/RB	1.53 ± 0.08	1.68 ± 0.08	0.99 ± 0.27
N	6.63 ± 0.24	5.21 ± 0.11	6.30 ± 1.66
ICD	0.49 ± 0.03	0.16 ± 0.01	0.40 ± 0.13

3. RESULTS

3.1. Plant quality

The results obtained from the characterization of the plant is shown in Table I. The values and morphological indexes of *J. thurifera* were very similar, and even higher than those of *P. halepensis* and *O. europaea.* However, *J. thurifera* needed two years to obtain these characteristics.

From the correlation analysis done on the variables measured in *J. thurifera* seedlings, no significant correlation was found between RB and other morphological parameters because of numerous plants had similar RCD, H, etc., however they had very variable RB. A significant correlation was found between variables such as AGB-H (r = 0.46, P = 0.02), AGB-RCD (r = 0.60, P = 0.02), SB-RCD (r = 0.75, P = 0.000), etc.

3.2. Climatology and the physical effects of the treeshelter

The climate data collected in the meteorological station appear in Figure 2. The annual precipitation during the period

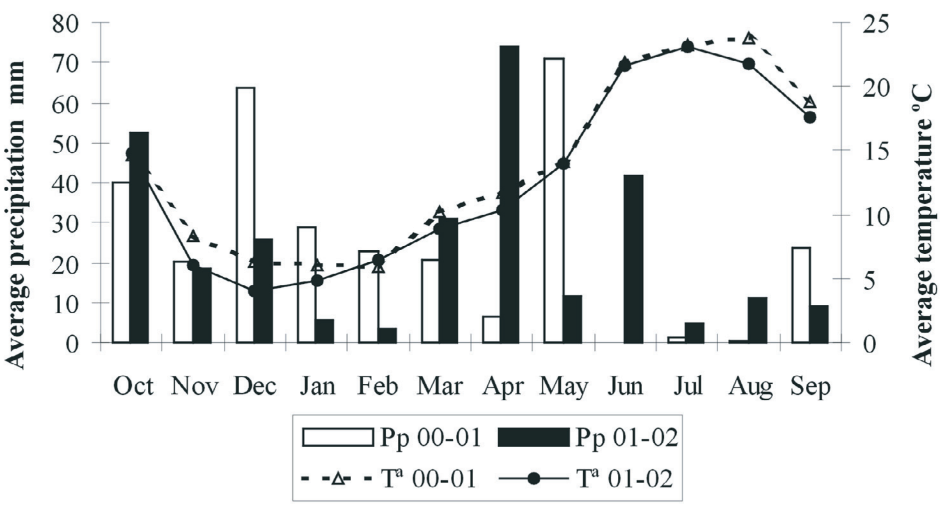


Figure 2. Average monthly temperature and monthly precipitation data during the periods Oct. 2000–Sept. 2001 and Oct. 2001–Sept. 2002, collected in the meteorological station located in the trial zone.

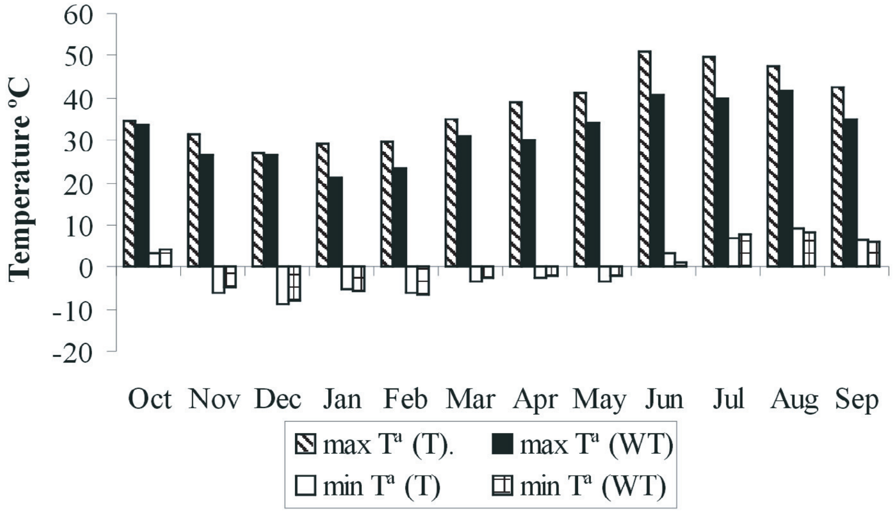


Figure 3. Absolute maximum and minimum temperatures inside (T) and outside (WT) the treeshelter (Tubex®), collected during the period Oct. 2001–Sept. 2002.

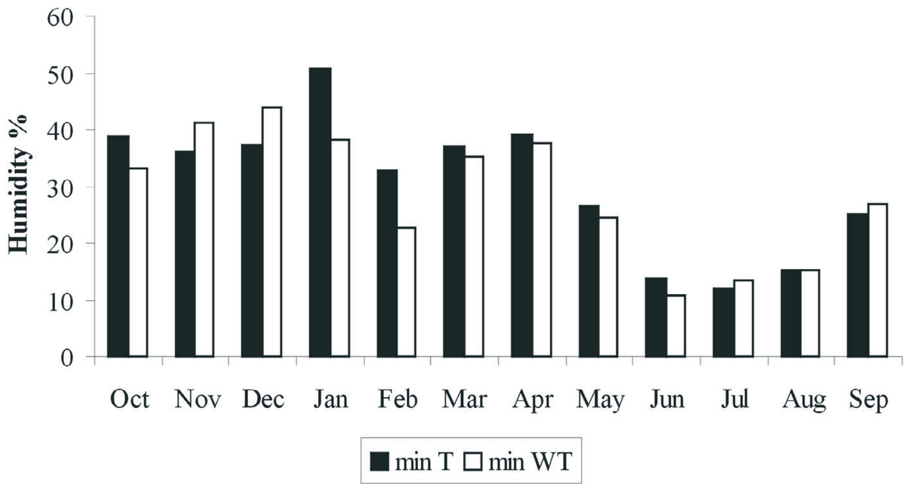


Figure 4. Average monthly minimum humidity inside (T) and outside (WT) the treeshelter (Tubex®) during the period Oct. 2001–Sept. 2002.

Oct. 2000–Sept. 2001 was 299.1 mm and during the period Oct. 2001–Sept. 2002 it was 288.7 mm. The mean temperature during Oct. 2000–Sept. 2001 was 13.7 °C and in Oct. 2001–Sept. 2002 it was 12.7 °C. The maximum temperature was 40.6 °C and the minimum –7.6 °C. The temperature data from the sensors installed inside and outside the shelter during the period Oct. 2001–Sept. 2002, showed important differences (Fig. 3). The absolute maximum temperature was much higher inside the shelter, reaching 51.2 °C in Jun. 2002, in relation to 40.6 °C from the exterior, while the absolute minimum was similar both inside and outside the shelter, although during the months of March, April and May, when the probability of late frost production exists, the temperature was lower inside the treeshelter.

Few differences were found between the minimum average relative humidity inside and outside the shelter (Fig. 4), although the average minimum was higher inside the shelter most part of the months. Figure 5 illustrates the data for mean and maximum radiation occurring inside and outside the treeshelter from Oct. 2001 to Jun. 2002. The presence of the shelter reduced the monthly maximum radiation (78.12% ± 4.69 SE), in some cases up to more than 90% (March 2002).

3.3. Survival and growth

The survival percentages during the study period were 100% both inside and outside the treeshelter.

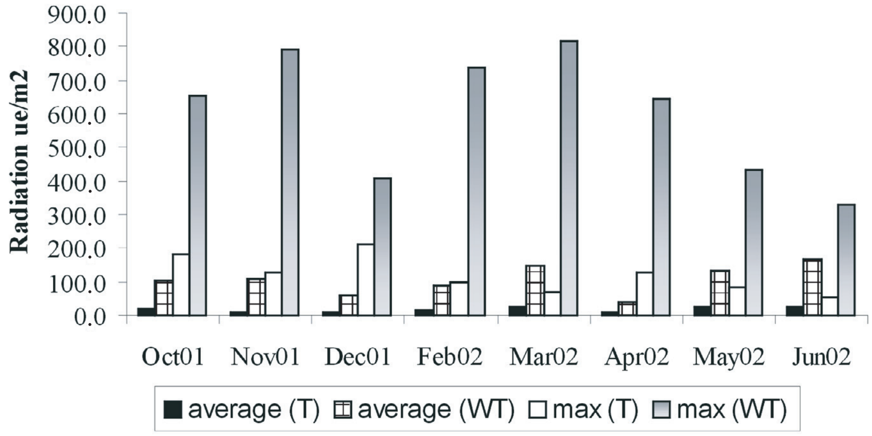


Figure 5. Monthly average and maximum radiation (PAR data) inside (T) and outside (WT) the treeshelter (Tubex®) from Oct. 2001 to Jun. 2002.

Table II. Performance in the field of *J. thurifera*, with protector (T) and without protector (WT) during the period Feb. 2001–Oct. 2002. The value mean ± SE for each parameter is shown. Different letters indicate significant differences between T and WT at 95% confidence level. H = height, RCD = root collar diameter, N = narrowness index, Ninc = increments applied to the narrowness index in each sample, FS = foliage surface, Ψ= leaf water potential. *n* = 50 for the different parametres except leaf water potencial (*n* = 10).

	Time					
	Feb. 01	Jul. 01	Oct. 01	Feb. 02	Jul. 02	Oct. 02
			H (cm)			
T	18.2 ± 0.40A	20.9 ± 0.51A	21.5 ± 0.57A	21.9 ± 0.59A	25.4 ± 0.85A	29.6 ± 1.05A
WT	16.5 ± 0.68A	17.7 ± 0.65B	18.1 ± 0.68B	18.4 ± 0.68B	20.0 ± 0.75B	21.6 ± 0.82B
			RCD (mm)			
T	2.87 ± 0.08A	3.17 ± 0.09A	3.34 ± 0.08A	3.61 ± 0.10A	4.20 ± 0.15A	4.60 ± 0.13A
WT	2.87 ± 0.10A	3.05 ± 0.12A	3.29 ± 0.13A	3.57 ± 0.16A	4.43 ± 0.22A	5.34 ± 0.25B
N						
T	6.40 ± 0.13A	6.67 ± 0.18A	6.49 ± 0.17A	6.16 ± 0.20A	6.16 ± 0.25A	6.50 ± 0.23A
WT	5.81 ± 0.21B	5.88 ± 0.16B	5.61 ± 0.19B	5.27 ± 0.18B	4.62 ± 0.16B	4.15 ± 0.14B
			Ninc			
T	0	0.26 ± 0.14A	–0.17 ± 0.13A	–0.32 ± 0.12A	–0.00 ± 0.15A	0.34 ± 0.15A
WT	0	0.06 ± 0.15A	–0.26 ± 0.14A	–0.34 ± 0.12A	–0.64 ± 0.12B	–0.47 ± 0.08B
			FS (cm^2)			
T						146.32 ± 5.80A
WT						116.88 ± 3.92B
			ψ6.00 a.m. (MPa)			
T						–0.79 ± 0.01A
WT						–1.09 ± 0.01B
			ψ13.00 p.m. (MPa)			
T						–2.14 ± 0.06A
WT						–2.14 ± 0.04A

The analysis of the average data obtained for the variables measured in the field are shown in Table II. The T presented greater H than those of WT, and significant differences existed between both of them from the first spring. With regard to the RCD, only significant differences existed between the T and the WT at the end of the trial (Oct. 2002), that was greater in the WT. From the beginning of the plantation, the N showed significant differences between the T and the WT. However,

Table III. Destructive analysis made at the end of the study period (Oct. 2002). It shows mean ± SE for *J. thurifera* (n = 10), with treeshelter (T) and without treeshelter (WT). Different letters indicate significant differences (* = 0.05 > P > 0.01, ** = 0.01 > P > 0.001, *** P < 0.001). H = height, RCD = root collar diameter, FS = foliage surface, RB = root biomass, TR = thick roots biomass, FR = fine roots biomass, AGB = above ground biomass, SB = stem biomass, LB = leaf biomass, TB = total biomass, RL = length of main root, SFA = specific foliage area, N = narrowness index, ICD = Dickson index.

Parameters	T	WT	*P*-value
H (cm)	28.10 ± 1.42A	22.62 ± 1.06B	0.022*
RCD (mm)	4.18 ± 0.12A	6.00 ± 0.51B	0.006**
FS (cm^2)	144.40 ± 7.13A	122.25 ± 3.96B	0.040*
RB (g)	3.67 ± 0.23A	6.20 ± 1.01B	0.029*
TR (g)	0.67 ± 0.08A	1.27 ± 0.20B	0.023*
FR (g)	2.99 ± 0.25A	4.93 ± 0.83B	0.043*
AGB (g)	7.51 ± 0.41A	11.61 ± 1.69B	0.034*
SB (g)	1.60 ± 0.14A	2.60 ± 0.42B	0.044*
LB (g)	5.90 ± 0.33A	9.00 ± 1.36B	0.043*
TB (g)	11.18 ± 0.54A	17.82 ± 2.69B	0.014*
RL (cm)	47.80 ± 2.18A	65.50 ± 6.97B	0.032*
SFA (g/cm^2)	0.041 ± 0.00A	0.074 ± 0.01B	0.023*
N	6.70 ± 0.23A	3,82 ± 0.26B	0.000***
ICD	1.28 ± 0.36A	3.18 ± 0.40B	0.001**

to avoid the initial existent differences between both groups of plants, the increases in the index of narrowness (Ninc) was calculated in each period, and it was observed that the T presented a higher increments than the WT, with significant differences in the periods of greater growth (Feb. 2002–Jul. 2002 and Jul. 2002–Oct. 2002). The T presented a greater FS, and the Ψ showed significant differences at dawn, but not at midday, when they suffered from the highest evaporative demand.

3.4. Final destructive analysis (Tab. III)

The T had an H which was significantly higher than the WT and there also existed significant differences with regard to the RCD, this being greater for the WT. The results of the analysis of the FS reflect that this was significantly higher in the T. Until now, the results are identical to those obtained for all the seedlings as a whole (Tab. II). However, the WT presented greater RB, both for TR and FR, greater AGB (SB and LB), greater RL and although the FS was less, they presented a greater SFA. The T had a greater N and the ICD was significantly lower than the WT. The correlation analyses between the parameters studied are presented in Table IV. From these, it is clear that the RL, H and FS have no correlation with any other parameter, with or without treeshelter. There were significant differences between T and WT with regard to the RCD, this was seen to be positively correlated in the WT with AGB, LB and TB. The TB also correlated with RB and SB; LB with RB and FR, and AGB with RB and FR. There were positive correlations for T and WT in the following cases: TB-LB, TB-AGB, TB-FR, LB-AGB and RB-FR. However, two cases showed a negative significant correlation for T, for the variables AGB-TR and LB-TR. Finally it must be pointed out that a negative correlation was found between N and ICD (r = –0.93, P = 0.000, n = 10).

Table IV. Correlation analyses made using different parameters of *J. thurifera* (Tab. III). It shows the coefficient of correlation (r) for *J. thurifera* seedlings with treeshelter (T) and without treeshelter (WT). RB = root biomass, FR = fine roots biomass, TR = thick roots biomass, AGB = above ground biomass, LB = leaf biomass, SB = stem biomass, TB = total biomass, RCD = root collar diameter. * = 0.05 > P > 0.01, ** = 0.01 > P > 0.001.

		FR	AGB	SB	LB	TB	RCD
RB	T	0.944*	–	–	–	–	–
	WT	0.987**	0.956*	0.885*	0.925*	0.981**	–
FR	T	–	–	–	–	0.882*	–
	WT	–	0.929*	–	0.917*	0.959**	–
TR	T	–	–0.905*	–	–0.914*	–	–
	WT	–	–	0.974*	–	–	–
AGB	T	–	–	–	0.952*	0.919*	–
	WT	–	–	–	0.987**	0.995**	0.945*
LB	T	–	–	–	–	0.925*	–
	WT	–	–	–	–	0.975**	0.955*
SB	T	–	–	–	–	–	–
	WT	–	–	–	–	0.882*	–
TB	T	–	–	–	–	–	–
	WT	–	–	–	–	–	0.925*

4. DISCUSSION

From the results obtained, the commercial plant of *J. thurifera* used for this trial can be considered to be of good quality. Both the parameters and morphological indexes applied were very similar to the standard quality values proposed for other Mediterranean species like *Pinus halepensis* and *Olea europaea*. However, two years of nursery cultivation were necessary in order to achieve similar characteristics to those obtained for *P. halepensis* and *O. europaea* in only a year. This places *J. thurifera* in a position of clear disadvantage regarding its commercial price. In laboratory, no correlation was obtained between the root biomass and other morphological parameters, which would have allowed us to discover the quality of the root system of the nursery seedlings without having to take destructive measurements.

Proof of this good quality of the seedlings used was the spectacular survival rate which was registered at 100%, with very low precipitations, less than the average, bordering on the limits that this species can withstand [43] and with negative temperatures during 7 months of the year. The high survival rate was also due to the favourable ground preparation, recommended by [6] for the rooting and establishment of seedlings in semiarid environments.

With regard to the treeshelter used, we can conclude that the maximum temperature increased, no important changes in minimum relative humidity were perceived and the monthly maximum radiation was reduced by 78%. This could provoke numerous changes in the protected seedlings, such as significant increase in height from the first Spring, low increase in diameter and consequently excessive narrowness which may cause problems of morphological disproportion and destabilization. Some authors found similar results for other species [2, 3, 16, 29]. The foliage surface was greater in seedlings inside the treeshelter, probably due to the diminished incidence of radiation. With regard to the water potential, there were no significant differences at the moment of the maximum evaporative demand (midday) while that at predawn the Ψ was significantly more negative for seedlings outside the shelter. This indicates insufficient re-saturation compared to seedlings in shelter and it can be explain by the ventilation effect outside the shelter.

However, the final destructive analysis and the correlation analysis of variables offer us crucial information for understanding the effects of the treeshelters upon the seedlings in the trial environment. The reduction of radiation inside the shelter could make the plants grow higher and to increase their foliage surface with a significant negative detriment upon the root biomass, quantity of fine and thick roots, and the length of the main root, which constitute the key for its survival in climates in which hydric resources are scarce and the plants are subjected to long periods of xericity. Therefore, the use of the shelter seems inadvisable, at least in these environments and for species with these characteristics.

Both N and ICD indicated a better response of the WT, however, N is easier to be calculated than ICD because it does not require the delicate and expensive harvest of the plants. Due to the high correlation found between both index, it is recommended to use N.

Finally, we conclude that this study constitutes one of the first field trials with *J. thurifera* in its natural distribution area. Special emphasis must be made on its viability even in extreme ecological conditions, which, together with the advanced methods that are being obtained for its reproduction in the nursery, widens the scene for the conservation, management and restoration of the *J. thurifera* formations.

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