FIRST-YEAR EFFECTS OF TREE SHELTERS AND MULCHING ON SURVIVAL AND GROWTH OF ZEEN OAK (\textit{QUERCUS CANARIENSIS} LAMK.) SEEDLINGS PLANTED IN NORTH-WESTERN TUNISIA

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RéSUMÉ. — Effets à un an des abris-serres et du paillage sur la survie et la croissance des plantules de Chêne zéen (\textit{Quercus canariensis} Lamk.) dans le Nord-Ouest de la Tunisie. — Dans le Nord-Ouest de la Tunisie, les plantations forestières sont souvent associées à des taux de mortalité élevés ou montrent un ralentissement de croissance assez prononcé en cas de survie. L’objectif du présent travail est d’évaluer la survie et la croissance des plantules de Chêne zéen (\textit{Quercus canariensis} Lamk.) plantés dans le Nord-Ouest de la Tunisie, en réponse aux abris-serres et au contrôle des mauvaises herbes à l’aide du paillage. Pour atteindre cet objectif, trois modalités d’abris-serres (abris-serres non aérés, aérés et témoins) ainsi que cinq modalités de paillage (Pin pignon, Lentisque, mélange de Pin pignon et de Lentisque (paillages organiques), gravier (paillage inorganique) et témoin) ont été ainsi testées. Un an après la plantation, le taux de mortalité des plants était très faible (2,36 %) et n’a été significativement affecté par aucun des facteurs étudiés. En revanche, les abris-serres ont permis d’améliorer de 50 % en moyenne la croissance en hauteur des plants par rapport aux témoins sans abris-serres. Cette forte croissance résulte d’un nombre plus élevé d’unités de croissance par pousse annuelle, ainsi que de plus longues pousses annuelles et unités de croissance. Le diamètre de la tige à la base a été cependant sévèrement réduit à l’intérieur des abris-serres, conduisant à l’obtention de plants étroits, incapables de se tenir verticalement après le retrait des abris-serres. Les plants témoins étaient de petites tailles et robustes avec des diamètres bien développés en réponse au manque de support physique. Le paillage n’a eu aucune influence tant sur le taux de survie que sur la croissance en hauteur et celle du diamètre à la base des plants. Toutefois, une amélioration du nombre d’entre-nœuds et de la longueur de l’unité de croissance a été constatée chez les plants plantés avec le paillage inorganique, ce qui laisse à penser que les conditions de croissance sous ce paillage ont été légèrement améliorées et ce comparativement aux autres paillages utilisés. Les résultats obtenus suggèrent que les abris-serres, en particulier ceux de type aéré, pourraient améliorer la croissance des plants de Chêne zéen dans les conditions du Nord-Ouest de la Tunisie.

SUMMARY. — Forest plantations in North-western Tunisia suffer high early seedling mortality and slow growth. The objective of this paper is to evaluate the survival and growth of planted Zeen Oak (\textit{Quercus canariensis} Lamk.) in response to tree shelters and mulching. Three tree shelters (non-vented tree shelter, vented tree shelter, and control with no shelters) and five mulch types (Italian Stone Pine, Lentisk, combination of Italian Stone Pine and Lentisk (organic mulches), gravel (inorganic mulch) and no mulch) were tested. One year after establishment, seedling mortality rate was very low (2.36 %) and was not significantly affected by any of the studied factors. Seedlings growing inside tree shelters responded with significant increases in height exceeding 50 % that of unsheltered seedlings. This enhanced growth is due to larger number of growth units per annual shoot, and longer annual shoots and growth units. In contrast, the stem diameter growth was severely reduced inside tree shelters, resulting in narrow stems with insufficient strength to support their weight. The unsheltered seedlings were shorter and sturdier, with significantly larger basal diameter in response to the lack of shelter. Mulching had no significant impact on early survival, basal

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stem diameter or height growth. However, a small beneficial effect, resulting in an increase in the number of internodes and the GU (growth units) length was observed under inorganic mulch suggesting that growth conditions under inorganic mulch were slightly improved. Our results suggest that tree shelters, especially the vented type, could improve the growth of Zeen Oak seedlings planted in North-western Tunisia.

Zeen Oak forests (*Quercus canariensis* Lamk.) are mainly located in N.-W. Tunisia, where they form a wooded area with a great ecological and socio-economical interest. They are aesthetically agreeable and provide food for wildlife and are used by local inhabitants for grazing. Traditionally, Zeen Oak stands in Tunisia are regenerated naturally. Unfortunately, regeneration is not achieved due to several factors including high seed predation, aging, Zeen Oak decline and adverse climatic conditions. The planting alternative has not been either successful because of high mortality in the early years, slow growth, mainly due to overgrazing (Hasnaoui, 1992) and inability of newly planted seedlings to successfully compete for available resources. Such situation demands specific research in order to improve seedling’s survival by using new techniques or improving the traditionally used methods of afforestation. Among the available techniques that are presently becoming a common practice in afforestation works is the use of tree shelters (Navarro *et al.*, 2005).

Tree shelters are polypropylene tubes of different shapes and colours, originally developed in Great Britain to shield newly transplanted seedlings from browsing animals (Sharpe *et al.*, 1999). It was observed that tree shelters also increased seedling survival and promoted increased height growth (Tuley, 1985; Potter, 1991; Burger *et al.*, 1992). These benefits have been attributed to microclimate changes inside tree shelters in relation to temperature, air humidity, radiation, vapor pressure deficit, CO$_2$ concentration and wind (Kjelgren *et al.*, 1997; Dupraz & Bergez, 1999). However, tree shelters often had negative effects in both diameter growth and the seedling’s ability to support itself without a stake (Burger *et al.*, 1996; Mayhead & Boothman, 1997). These effects were often interpreted as a result of a lack of ventilation inside tree shelters, thereby the use of ventilated tree shelters was described as a key issue (Bellot *et al.*, 2002).

In Tunisia, weed control is often limited to cultivation; mulching is not done and herbicides are not used for environmental reasons. However, weed control by mulching is proved to be equally or more efficient than weed control with mechanical cultivation (Bowersox & Ward, 1970). Mulches are known to buffer soil temperature (Greenly & Rakow, 1995), inhibit weed germination and suppress weed growth, prevent evaporative water loss from the soil and reduce erosion (Mayhead, 1992; Haywood *et al.*, 1997) which in turn enhances plant growth and survival (Davies, 1988a; Greenly & Rakow, 1995). Mulches can be either organic or inorganic (Duryea *et al.*, 1999). Organic mulches are very heterogeneous in both the type of tree species (i.e., eucalyptus, cypress, pine, and melaleuca) and plant parts used (leaves, branches, wood, and bark), while inorganic mulches include polyethylene film, pebbles or gravel.

Studies investigating the growth response of oak seedlings to either tree shelters or vegetative competition control (e.g., Burger *et al.*, 1992, 1996; McCreary & Tecklin, 1997; Navarro Cerrillo *et al.*, 2005) were often limited to height, diameter and biomass measurements. However, like other oak species (Reich *et al.*, 1980; Champagnat *et al.*, 1986; Harmer, 1990), Zeen Oak has a typically rhythmic pattern of height growth (Hasnaoui, 1992). Multiple shoot growth flushes can occur in the same growing season in response to favourable growth conditions (Chaar *et al.*, 2008). During each shoot flush, a distinct shoot portion called the growth unit (GU) is established along the main stem (Chaar & Colin, 1999). The study of the periodic height growth pattern of Zeen Oak allows the main stem to be divided on other morphological entities (GUs) and gives useful information on this growth response characterization. On the other hand, most previous experiments examining the growth response of oak seedlings to tree shelters, except Navarro Cerrillo *et al.* (2005), did not study the impact of the ventilation of tree shelters on seedlings growth. In addition, a few studies have included the combined effect of tree shelters and mulching on tree establishment (Dubois *et al.*, 2000).
Zeen Oak is a slow-growing Mediterranean species, with high site requirement demands and difficult to establish successfully. This situation is aggravated by the presence of aggressive weed communities and animal seed predation. Thus, the following hypotheses are addressed: (1) tree shelters especially those designed with holes as a ventilation system could promote growth and establishment success of Zeen Oak; (2) mulching could have an additional effect on seedlings growth. The aim of this paper was to test the effectiveness of using tree shelters and mulch for Zeen Oak habitat restoration in Tunisia. The specific objectives were to assess (1) both tree shelters and mulch effects on different growth traits and in the polycyclism rate and (2) the effectiveness of ventilation achieved with some holes at the bottom of tree shelter on early survival and growth attributes in a Mediterranean Zeen Oak (*Q. canariensis* Lamk.) plantation.

**MATERIALS AND METHODS**

**EXPERIMENTAL SITE**

The experiment was carried out at the M’hibeus national forest (9°07′52′′N, 37°06′05′′E, elevation 200 m a.s.l.) in North-western Tunisia (Sejnène forest subdivision). The climate is Mediterranean with an annual mean temperature of 18.2 °C (1975–2004). Maximum and minimum temperatures averaged 34.4 °C and 5.6 °C, respectively. The average annual rainfall is 912 mm, 77 % of the total rain falling in winter and autumn and only 4 % in summer.

The soil at the study site showed a balanced texture in horizon A, clay-sandy loam in horizon B and clay-silt loam deeper (horizon C) (Tab. I). Soil organic matter content was 5.35 %, 1.45 % and 0.98 % in horizons A, B and C, respectively. The site was cleared of maquis vegetation mainly dominated by *Calycotome villosa* L., *Cistus monspeliensis* L., *Myrtus communis* L. and *Pistacia lentiscus* L.

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**PLANT MATERIAL**

In February 2009, 300 one year old (1-0) seedlings were hand planted in the site at 4 m x 4 m spacing. Seedlings had been grown in a local Sejnène nursery, in 2000 cc container, filled with compost. Prior to planting, all vegetation in each line was cut close to ground level. Manual hoeing around each planted seedling levelled a surface of 1m² for the mulch sheeting. The prepared surface around each seedling was 3 cm deep in order to fix well the mulch and avoid their removal by wind or runoff. Seedlings were immediately watered after planting with 5 litres per seedling. Dead seedlings were replaced 2 weeks later. The experimental site was fenced by wires held up by 2.5 m wooden stakes to restrict herbivore access.
EXPERIMENTAL DESIGN AND TREATMENTS

A split-plot design with Whole Plots in Randomized Blocks with four replications (or blocks) was used. A set of 75 seedlings per block were distributed for plantation, allocated between the following treatments: five mulch and three tree shelter types, with 5 replicates for each type. Seedlings were planted in a rectangular block (64×24 m) following a spatial pattern distribution (15 columns x 5 rows). Mulch types were the whole-plots and tree shelter types were the sub-plots. Surrounding each whole plot, a one-row buffer strip was planted to minimize edge effects between treatments. Tested mulches were: 1) Italian Stone Pine (Pinus pinea L.); 2) Lentisk (Pistacia lentiscus L.); 3) combined mulch of Italian Stone Pine and Lentisk (50 %: 50 %) (organic mulches); 4) gravel (inorganic mulch) and 5) untreated control (no mulch). Organic mulches consisted of prunings, 20 to 40 cm long and 5 to 20 mm thick. They were not oven-dried before use due to the risk of their rapid disintegration during the major rainfall season, which may lead to accelerated rate of decomposition (Oelbermann et al., 2004). Moreover, use of fresh biomass is also more representative of natural decay processes when these mulching materials are applied to the soil surface (Fang et al., 2008). Inorganic mulch consisted of gravel (calibration: 4-16 mm). It was purchased at gravel quarry in Bizerte. Davies (1988b) found that the mulch benefit was correlated to the size of the sheet, and he recommended a minimum of 1 m² size for optimal results. Consequently, mulch materials were applied approximately in a 3 cm thick layer to an area of 1× 1 m square around individual seedlings (Fig. 1).

The three tree shelter types were: (1) ‘Non-vented’ tree shelter, (2) ‘Vented’ tree shelter, and (3) Control with no shelters. The non-vented tree shelters (Tubex ‘L’ Standard®) were translucent green, circular, 1.8-m tall, 8.0–12.0 cm...
wide, UV stabilized polypropylene with twin-walls (Tubex Co., South Wales, UK). The wall of the tree shelter is totally airtight and the entrance of fresh air is only possible through the top of the tree shelter (Fig. 1). The vented tree shelters (Tubex ‘E’ Equilibre®) were ventilated by ten 1-cm-wide round holes at their base, creating a “chimney effect”.

Tree shelters were buried 5 cm into the soil immediately after planting to prevent air movement through the shelter bottom which would dry out the plants. Tree shelters were then secured to a 1.8 m untreated eucalyptus stakes anchored 20 cm into the soil. Mesh caps were placed over them to keep birds out.

**GROWTH MEASUREMENTS**

Observations were made on all seedlings except border seedlings (44 per whole plot). Seedling height and basal diameter were measured just after planting. Initial seedling height and basal diameter just after plantation varied between 8.50 cm and 68.60 cm, and between 2.17 mm and 17.50 mm, respectively, with an overall mean of 26.72 ± 0.69 cm (± S.E.) and 7.77 ± 0.16 mm, respectively. They were not significantly different among the groups of treatments. Height and basal diameter were recorded again at the end of the growing season, together with mortality. Seedlings were counted as alive when at least part of the stem was still living. Resprouted seedlings coming from total stem die-back were also counted as alive. Heights were recorded from the base of the seedling to the end of the longest shoot held straight. Diameter measurements were taken at the base of seedling, approximately 2 cm above the ground. Browsing was also recorded during survival assessments.

After tree shelters were removed at the end of the experiment, seedling’s ability to support itself without a stake (its posture) was evaluated by determining whether the seedling would stand on its own (erect posture) or bend and touch the ground (bent posture).

Oak height growth occurs in a rhythmic pattern with periods of uninterrupted terminal bud growth (flushes) alternating with periods of bud development and apparent rest (Harmer, 1990). During each growth flush, a distinct portion of the stem called the growth unit (GU) is established. It is composed of nodes, on which are inserted basal scales or foliage leaves, and internodes (Chaar et al., 1997). GUs occurred during a given growth season form a portion of the stem named annual shoot. The following growth components were recorded at the end of the growing season: length and number of internodes per GU, number of flushes established by the main stem, length of the GU for each flush and annual shoot length. The shoot elongation period (growth flush) as well as the rest period was also determined.

**STATISTICAL ANALYSES**

Quantitative variables measured at the seedling level (final height, basal diameter) and calculated height-to-diameter (H/D ratio) were analysed as a split-plot arrangement with whole plots in randomized blocks and with repeated measures. An analysis of covariance (ANCOVA) was conducted (Littell et al., 2006), with the initial value of the variable-measured just after planting as a covariate measured on the small-size experimental unit (seedling); the two factors Tree shelter type and Mulch type and their interactions as fixed effects; and Block, Block x Mulch type as random effects.

Annual shoot length was analysed with the additional effect of the covariate number of flushes established per growing season. The length of the GU for each flush was analysed by introducing into the model the additional effects of both flush number (1st, 2nd, 3d or 4th), number of flushes (1, 2, 3, or more than 4), and possible interactions with other factor effects. Seedling state (dead or alive) and seedling posture (bent or erect) were binary variables that were analysed using a logistic linear model (Agresti, 2002):

$$\text{logit} (p_1) = \log \left( \frac{p_1}{1-p_1} \right) = \beta X$$

where $p_1$ is the rate of mortality or of bent seedlings (unable to support themselves without a stake). $X$ is a column vector of explanatory fixed variables and $\beta$ is a column vector of unknown coefficients.

An analysis of deviance (ANODEV) was performed in order to test the effects of the two factors Tree shelter type and Mulch type and their interactions. The random effects of Block and its interaction with Mulch type were not tested because of the problem of convergence by using generalized linear mixed models (SAS PROC GLIMMIX). Therefore, simple generalized linear models were performed by ignoring the hierarchical structure of the data.

The odds or probabilities ($= p_1/(1-p_1)$) and odds ratios were both calculated and tests of significance were performed using the ESTIMATE option of the GENMOD Procedure. The odds ratio compares the probability of whether a certain event is the same for two factor levels. Therefore, an odds ratio of 1 implies that the event is equally likely in both levels. An odds ratio greater than one implies that the event is more likely in the first level and an odds ratio less than one implies that the event is less likely.

In order to analyse the ordinal variable, number of flushes (1, 2, 3 or more than 4), a cumulative logit model was used. The probabilities of levels of the response having lower ordered values in the response profile table were modelled. That is, seedlings producing one, two or three flushes, with $p_1$, $p_2$ and $p_3$ proportions respectively, were compared with those producing four flushes ($p_4$) in the resulting odds ($((p_1 + p_2 + p_3)/p_4)$). The proportional odds assumption was tested. Likelihood confidence intervals at a 5 % level were calculated for the proportions. Statistical analyses were performed using PROC MIXED and PROC GENMOD procedures of SAS Version 9.1 (SAS Institute Inc., Cary, NC). Comparisons between treatment means and proportions (percentage) were made using Tukey-Kramer multiple comparison test and Chi² test, respectively, with an entry and exit significance of $p < 0.05$.

In no case was the effect of the block or its interactions with the studied factors significant.
RESULTS

MORTALITY

Overall mortality among all of the treatments was 2.36% during the study period. The odds of a seedling dying were 0.0240. On the other hand, mortality did not differ significantly among different treatments.

HEIGHT GROWTH

Final height varied between 17 and 302.5 cm (mean: 127.17 ± 4.07 cm). Some of the smaller seedling sizes found were due to dieback and resprouting.

After one year of field growth, the odds of seedlings coming out of the top of the tree shelters were 1.26 (55.79%) and 0.98 (49.49%) for non-vented and vented types, respectively, with an odds ratio of 1.2857 ($p = 0.3801$).

Seedlings height was significantly affected by both initial height ($p < 0.0001$) and tree shelter type ($p < 0.0001$). Taller seedlings at plantation establishment tended to be tall 1 year after. After one growing season, height growth for the control seedlings (69.92 cm) was 54.3% and 55.4% less than those in vented (152.9 cm) and non-vented (156.77 cm) tree shelters, respectively. There was no significant difference in mean height between sheltered seedlings (Fig. 2).

BASAL DIAMETER GROWTH

Basal stem diameter ranged from 5.43 to 26.10 mm (mean: 14.10 ± 0.24 mm). It was significantly affected by both initial basal diameter ($p < 0.0001$) and tree shelter type ($p < 0.0001$). After one year of field growth, seedlings in vented (13.9 mm) and non-vented (12.68 mm) tree shelters exhibited 11.1% and 18.9% less diameter growth than control seedlings (15.63 mm), respectively (Fig. 2).

HEIGHT-TO-DIAMETER (H/D) RATIO

The height-to-diameter ratio was used as an index to characterize the structural support provided by the seedlings and was compared to observations of seedling support made at the end of the study. Overall, this ratio varied between 13.03 and 198.08 with a mean of 91.96 ± 2.82 at the end of year. It was significantly influenced only by the initial height-to-diameter ratio ($p = 0.0004$) and tree shelter type ($p < 0.0001$). Seedlings inside non-vented tree shelters had the highest ratio (taller, thinner seedlings), followed by those inside vented tree shelters (Fig. 2). The lowest ratio was found in the control seedlings (shorter, thicker seedlings).

POLYCYCLISM RATE

During the growing season, seedlings had one to four flushes. The first, second, third and fourth flushes occurred during March–April, May–June, August–September, and October–November, respectively. The polycyclism rate was significantly affected only by the tree shelter type ($p < 0.0001$). Unsheltered seedlings were more likely to produce fewer flushes than those inside non-vented or vented tree shelters (odds ratio were of 0.1531 and 0.0717 for non-vented and control, and for vented and control, respectively) (Fig. 3). However, seedlings inside vented tree shelters were more likely to produce fewer flushes than those inside non-vented tree shelters (odds ratio: 0.4683).

LENGTH AND NUMBER OF INTERNODES

Internode length was significantly affected only by tree shelter type ($p < 0.0001$). Seedlings grown in non-vented tree shelters exhibited longer mean internodes, which did not differ significantly from those in vented tree shelters. The shortest internodes were associated with the control seedlings (Fig. 4C). Regarding the number of internodes, significant factors
included tree shelter ($p < 0.0001$) and mulch ($p < 0.0001$) types, flush number on the annual shoot ($p < 0.0001$) and number of flushes (polycyclism rate) established during the growing season ($p < 0.0001$). Seedlings inside non-vented tree shelters had the greatest mean number of internodes, followed by those inside the vented tree shelters, but the difference was not significant, whereas the control seedlings had the lowest value (Fig. 4D). As shown in Fig. 5B, the number of internodes was significantly increased under inorganic mulch, compared with unmulched control and organic mulches, although a positive trend was observed under Italian stone pine. However, there were no significant differences in number of internodes between

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Figure 2. — Height (A), basal diameter (B), and height-to-diameter ratio ($H/D$ ratio) (C) according to date of measurement just after planting (February 2009) and at the end of the growing season (December 2009) and tree shelter type (NV, non-vented; C, control; V, ventilated) and adjusted mean ± S.E. Means marked with different letters within each date were significantly different according to the Tukey-Kramer multiple comparison test, at $p = 0.05$ level.
Figure 3. — Frequency (in percent) of the number of flushes (polycyclism rate) established on the main stem during the growing season according to tree shelter type (NV, non-vented; C, control; V, ventilated): seedling percentage ± likelihood confidence limits, at 5% level. Values marked with different letters were significantly different at $p = 0.05$ level, according to the $\chi^2$-test.

Figure 4. — Annual shoot length (A), GU length (B), internodes length (C), and number of internodes (D) according to tree shelter type (NV, non-vented; C, control; V, ventilated): adjusted mean ± S.E. Means marked with different letters were significantly different according to the Tukey-Kramer multiple comparison test, at $p = 0.05$ level.
different types of organic mulches or even between these mulches and unmulched control. On the other hand, number of internodes was inversely proportional to the polycyclism rate; it tended to decrease as the number of shoot flushes per annual shoots increases (Fig. 6). Taking into account the flush number on the annual shoot, the number of internodes tended to increase from the proximal to the distal part of the annual shoot (Fig. 7A).

**GU: DURATION OF ESTABLISHMENT AND LENGTH**

Seedlings grown inside as well as outside tree shelters showed rhythmical growth, characterized by a succession of clearly visible flushes. Inside tree shelters, one flush lasted for 6.5 weeks: the first 3 weeks (average) were the active growth phase during which a GU is established and the last was the rest period. For unsheltered seedlings, one flush lasted for 7 weeks, but only the first 2 weeks (average) were the active growth phase and the last was the rest period.

The GU length showed an important variability of length; it varied between a minimum of 1.10 cm and a maximum of 220.5 cm, with an overall mean of 31.88 ± 0.93 cm. It was significantly influenced by the negative effect of the number of flushes \( (p < 0.0001) \); the more flushes a seedling produces, the shorter the overall mean GU length will be. Other significant factors included the flush number on the annual shoot \( (p < 0.0001) \), tree shelter

Figure 5. — GU length (A) and number of internodes (B) according to combination of tree shelter type (NV, non-vented; C, control; V, ventilated) and mulch type (G, gravel; L, Lentisk; L+P, Lentisk + Italian Stone Pine; P, Italian Stone Pine; C, control): adjusted mean ± S.E. Means marked with different letters were significantly different according to the Tukey–Kramer multiple comparison test, at \( p = 0.05 \) level.
type \( (p < 0.0001) \) and its interaction with mulch \( (p = 0.0059) \). The GUs established during the first two growth flushes were significantly shorter than those established during the subsequent growth flushes which showed about the same length. In a general way, there was a gradual increase in mean length for the successive GUs from the proximal to the distal part of the
annual shoot (Fig. 7B). On the other hand, mean GU length was significantly greater for seedlings grown inside tree shelters than for those outside. However, there was no significant difference in GU length between sheltered seedlings (Fig. 4B). These last ones exhibited shortest GUs under unmulched control, intermediate under organic mulch and longer under inorganic mulch. There was no significant difference in GU length under organic and inorganic mulches. However, compared to unmulched control, a significantly increase in GU length was observed only under the inorganic mulch (Fig. 5A). Generally speaking, seedlings showed more trends to express longer GUs under the combined use of tree shelters and mulch than their separate use.

**Annual Shoot Length**

The annual shoot length, all polycyclism categories combined, varied between 4.70 cm and 256.40 cm with a mean of 93.83 ± 3.60 cm at the end of growing season.

Significant factors for annual shoot length were the number of flushes \( (p < 0.0001) \) and the tree shelter type \( (p < 0.0001) \). The more growth flushes per growing season, the longer the annual shoot length was. Mean annual shoot length was significantly greater for the seedlings inside tree shelters than for those outside (Fig. 4A). However, no significant difference in annual shoot lengths was found among sheltered seedlings.

**Seedling Posture**

At the end of the growing season, a seedling’s inability to support itself without a stake was only dependent on tree shelter type \( (p < 0.0001) \). The odds of seedlings with bent posture were 0.3572 (26.32 %) in the non-vented shelters and 0.3026 (23.23 %) in the vented shelters, with an odds ratio of 1.1804. Therefore, the seedling’s inability to support itself was about the same between non-vented and vented tree shelters. In the unsheltered control, the odds of seedlings with bent posture were 0, indicating that all seedlings were self-supporting.

Seedlings with bent posture had larger height and basal diameter and height-to-diameter \( (H/D) \) ratio than erect seedlings, although the difference was not significant only for the mean of the diameter of the non-vented tree shelter type (Fig. 8).

**Discussion**

Mortality rate was overall very low during the growing season (2.36 %). The positive effect of tree shelter type on seedling mortality noted in other studies (Sharpe et al., 1999; West et al., 1999) was not observed during the first year after planting. The absence of the effect of the tree shelter on the seedling mortality found in this study supports previous findings that seedling mortality can be independent of the tree shelter (Potter, 1991; Burger et al., 1996; Bellot et al., 2002). Several studies reported that mortality during the first year depends on establishment (Mayhead & Boothman, 1997), seedling quality, and climate conditions during the growing season, and more specifically rainfall distribution (Bellot et al., 2002). In this study, seedling mortality was largely attributed to climatic stress factor, the most important one being summer drought.

As emphasized in previous studies conducted on various species of the genus *Quercus* (Bellot et al., 2002; Sharpe et al., 1999; Quilhó et al., 2003), stem diameter growth can be dramatically reduced inside tree shelters. Comparison between tree shelters clearly shows that this negative impact was significantly reduced inside vented tree shelters, presumably in response to the increase of the air circulation inside this tree shelter type (Bergez & Dupraz, 2000). These results confirm that ventilation in the tree shelters could have some benefit to growth for the assayed period (Bergez & Dupraz, 2000; Navarro et al., 2005).

Contrary to the diameter growth, non-vented as well as vented tree shelters resulted in seedling height growth increase. Similar results were reported by Quilhó et al. (2003) and Chaar et al. (2008) in Cork Oak, Kjelgren & Rupp (1997), Sharpe et al. (1999) and West et al. (1999) in other species. Besides, more than half of the seedlings emerged from the top of the
non-vented as well as the vented tree shelters during only one growing season after planting. This shoot elongation of the sheltered plants could be a response to radiation reduction, and, as a result of low ventilation, to increase in temperature, and most likely to increase in relative humidity (Holly et al., 1994; Bergez & Dupraz, 2000; Famiani et al., 2007), especially in non-vented shelters. These same growth characteristics can also be explained by the structural support, wind protection and reduction in mechanical stress provided by the shelter (Sharpe et al., 1999). The sheltered seedlings may put more resources towards shoot elongation and leaf growth than towards support structures such as stem diameter and root mass (Sharpe et al., 1999). Unsheltered seedlings subject to wind stress however exhibit an adaptive growth response with a larger basal diameter relative to height (Jaffe, 1973). Moreover, one of the benefits of tree shelters is their ability to conserve moisture by trapping transpiration water loss as condensation which drips back down into the soil, perhaps in turn improving shoot elongation.

Seedlings in the vented tree shelters were shorter than those in the non-vented tree shelters, although, the difference was not significant. This response could be explained by several possibilities, all due to the ventilation holes in the tree shelters: stimulation of both transpiration and photosynthesis (Bergez & Dupraz, 1997, 2000) causing water stress for the still-
frail seedlings; wind stress caused by air movement through the holes; or reduced moisture conservation of trapped transpiration water.

The combination of greater height and low stem diameter of sheltered seedlings resulted in an increase of the height-to-diameter ratio and of the proportion of seedlings unable to support their above-ground mass and bent to the ground after the removal of the shelter. In fact, the problem of morphological disproportion and destabilization affected especially individuals grown in non-vented tree shelters. The unsheltered seedlings had the lowest height-to-diameter ratio and, as a result, all of the seedlings were able to support themselves. Similar results were reported by Quilhó et al. (2003) in *Quercus suber*, by Jiménez et al. (2005) in *Juniperus thurifera* L. and by Burger et al. (1992) and Sharpe et al. (1999) in other species.

Rhythmic growth pattern was observed inside and outside tree shelters. Sheltered seedlings exhibited longer growth flush alternating with shorter rest periods, compared to unsheltered control seedlings. These results support the general idea that the tree shelters extend the growth flush (Bergez & Dupraz, 2000) and reduce rest period by increasing photosynthetic activity (Leroy & Caraglio, 2003). Therefore, it can be concluded that tree shelters improved GU length of all the shoot flushes as well as the annual shoot length in response to the extended shoot elongation period. On the other hand, the rest period reduction inside tree shelters conferred seedlings more chance to establish more growth flush per growing season resulting in marked increase in polycyclism rate. In contrast, the lengthening of rest periods at the expensive of the growth flush explains the poor shoot growth as well as the low polycyclism rate noticed in unsheltered seedlings. So, according to our results, the greater height of seedlings grown in tree shelters is the result to both longer GUs and a higher polycyclism rate per growing season. However, GU length in general tends to be shorter as the polycyclism rate increases. Actually, it seems that the polycyclism rate tends to control the GU length by influencing on the number of internodes per GU. On the other hand, the GU length tends to be longer from the proximal to the distal part of the annual shoot, which reflects the progressive seedlings adaptation to environmental conditions during the growing season. In a general way, the different properties of GU such as the length depend on its position on the annual shoot, the environmental conditions, the seedling age (Barthélemy et al., 1997) and the polycyclism rate.

The increase of both GU length and polycyclism rate gained from the use of tree shelters enables young trees to rapidly grow in height, which will be of particular benefit to their establishment especially where browse damage is intense (Taylor et al., 2006). This is, again, particularly important for the establishment of tree species, which have relatively slower growth rates (Lai & Wong, 2005).

During the study period, a low proportion (5 %) of unsheltered seedlings was injured by animal browse. However, none of sheltered seedlings were browsed, even though 51 % of them were emerged from the top of the tree shelters. This is because sheltered seedlings reached a height that makes them invulnerable to animal browse. In a general way, planting costs using tree shelters may be relatively higher especially in the case of large reforestation programs. However their use is justified economically and ecologically since they offer an excellent protection against animal browsing and promote rapid early height growth, even for a slow-growing species, thus reducing time to establishment (Taylor et al., 2006).

Some studies have noted increased seedling survival and early growth using mulch (see Davies, 1988a; Lambert et al., 1994; Greenly & Rakow, 1995). However, in this study, no detectable mulching effect was observed regarding survival, stem basal diameter or height growth. Only a small beneficial effect, resulting in increases in the number of internodes per GU and the GU length, was observed under inorganic mulch, suggesting that growth conditions beneath this mulch were improved but not to a level that could have great consequences on seedling growth. It is important to note however that inorganic mulch has no effect on the GU length if the plants are not protected by tree shelters. This is because the stresses from wind and transpiration, removed by the shelters, are more inhibitive to plant growth than competition for soil resources, controlled by mulching (Chaar et al., 2008). Moreover, positive response of unsheltered seedlings to inorganic mulch which resulted only in an increased number of internodes per GU, even though the GU elongation occurs by an increase in both number and
length of internodes, suggests that the internodes elongation was retarded, presumably as a consequence of wind stress; this mechanical stress results generally in inhibition of internodes lengthening (Neel & Harris, 1971). This could explain in part (1) why the internodes development was stimulated only inside tree shelters, in other words when seedlings were shielded from wind stress and (2) the poor growth of GU of unsheltered seedlings under inorganic mulch in spite of the enhancement in number of internodes per GU. On the other hand, it seems that the number of internodes per GU is less responsive than the internodes elongation to wind stress which could explain its positive response to both tree shelters and mulch. In a general way, it can be concluded that the good growth of GU found under combination of tree shelters and inorganic mulch is a result of simultaneous increases in number and length of internodes. Finally it is interesting to point out that the lack of significant seedling growth responses to mulching found in this study could be attributed especially to poor weed competition, since the soil was manually scalped around all the seedlings at planting which considerably reduced weeds for that year. In fact, until now the utility of mulching in forestry applications remains unclear due to mixed results in field trials with beneficial effects in certain cases (Gupta, 1991; Adams, 1997; Haywood, 1999), but not in others (McDonald & Helgerson, 1990; Lai & Wong, 2005). Therefore, more research is needed on the ecological effects of mulching, the effect of the material and size of the mulch, and the final cost-effectiveness of their use.

CONCLUSION

Results found in this study allowed us to conclude that protection of Zeen Oak with tree shelters could promote rapid initial height growth, but reduces stem diameter growth, resulting in tall narrow plants that could not support themselves once the tree shelter was removed. The greater height growth of sheltered seedlings results from an increase in GU length, and to a higher polycyclism rate of annual shoots. However, the effect of tree shelters on seedlings growth depended on their design. Indeed, seedlings grown with non-vented tree shelters grew taller than seedlings grown with vented tree shelters, although the difference was not significant, but this height increase came at the expense of stem diameter. On the other hand, the vented tree shelters offered some advantages which are linked in major part to ventilation holes at the bottom of tree shelters. Thus, seedling’s ability to stand upright after tree shelter removal and basal diameter were increased by 9.62 % and by 19 %, respectively, over non-vented tree shelters. The vented tree shelter could therefore be a good compromise for producing seedlings with a good height growth and larger basal diameter in comparison with the non-vented tree shelter.

Seedling growth response to mulching varies with the site quality (Davies, 1985), the type of mulch materials (Chaar et al., 2008) and amount of competing vegetation (Green et al., 2003). In this study, seedlings exhibited a small positive response to inorganic mulch when used alone or in combination with tree shelters, whereas no response was found under different organic mulches, suggesting that growth conditions provided by the inorganic mulch were relatively more conducive for seedling growth. On the other hand, these differences in growth response to organic and inorganic mulches, under the same site conditions, could suggest also that mulching benefits depend on the type of mulch materials. However, the general lack of growth response to mulching found in this study appears to be suited to poor weed competition, since vegetation was removed around all seedlings at planting which reduced apparently the role that should play the mulching.

Initial seedling size at plantation positively affects subsequent growth. This implies that, for a better establishment and growth response to shelters and mulches, the forest manager should plant vigorous seedlings. Therefore, since establishing a plantation using tree shelters and vegetation control is expensive, a better strategy would be to plant fewer and higher quality seedlings (Ward et al., 2000).

These conclusions were from a 1-year study after the plantation. Therefore, the different measurements should be continued in order to determine whether the effect of tree shelters on seedlings growth is persistent or temporary. Other measurements of root and shoot biomasses should also be taken in order to better study seedling posture.
Moreover, the relative economic benefits of using both mulch and tree shelters should be evaluated by taking into account their purchase, installation, and maintenance costs. The tree shelters used in this study do not require supplementary cost to be removed.

ACKNOWLEDGEMENTS

We would like to thank the Tunisian General Direction of Forests (DGF) and their staff in the district of Sejnène for their assistance in all phases of this research, including plant supply and plantation installation. Special thanks are given to Abel Hamid Smeti and Rabeh Marii for facilitating planting.

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