

Growth Dynamics of Cork Oak Under Different Water Regimes

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Abstract. The influence of irrigation regime on root and shoot growth was assessed over four and a half months in cork oak (*Quercus suber* L.) seedlings, grown individually in rhizotrons under three water regimes ([FC]: field capacity; [MW]: medium water availability; [LW]: low water availability). Root and shoot elongation, new secondary roots and number of leaves were recorded every 2-3 days. At harvest, root collar diameter, root volume and dry weight (wt.) were measured. Water supply had a significant and positive effect on shoot growth, number of leaves, dry weight, root collar diameter and leaf area. Plant dry weight at the [LW] treatment was less than 50% the value in the other treatments. The ratio of root system to seedling biomass increased as water availability was reduced. Root volume was ca. 70% greater in the [FC] and [MW] treatments in comparison with the [LW] treatment. S/R was drastically reduced at the [LW] treatment, where root biomass was almost twice shoot dry weight. Root system grew continuously, but growth was reduced during shoot growth, which showed multiple flushing. Root distribution at field capacity was different to that of the [MW] treatment: a distinct tap root vs a branched root system.

Key words: *Quercus suber* L.; rhizotron; water availability; root and shoot dry wt.; root system pattern

Sumário. A influência do regime de rega no desenvolvimento das raízes e da parte aérea de plantas de sobreiro (*Quercus suber* L.), criadas em rizotrótes individuais, foi avaliada durante quatro meses e meio. Foram testados quatro regimes hídricos ([FC]: capacidade de campo; [MW]: disponibilidade hídrica média; [LW]: disponibilidade hídrica baixa). O crescimento das raízes e da parte aérea, a formação de novas raízes secundárias e o número de folhas foram registados cada 2-3 dias. Após a colheita, foram avaliados o diâmetro, o volume e o peso seco. A rega teve um efeito positivo e significativo sobre o crescimento da parte aérea, o número de folhas, o peso seco, o diâmetro das raízes e a área foliar. O peso seco total das plantas submetidas ao tratamento [LW] foi inferior a 50% do apresentado pelas plantas dos restantes tratamentos. Verificou-se um aumento da razão entre a biomassa radical e a biomassa total com a diminuição da quantidade de água fornecida. O volume das raízes das plantas submetidas aos tratamentos [FC] e [MW] foi cerca de 70% superior ao apresentado pelas plantas submetidas ao tratamento [LW]. A razão S/R foi drasticamente reduzida no tratamento [LW], que apresentava uma biomassa radicular quase duas vezes superior à biomassa da parte aérea. Observou-se um crescimento contínuo do sistema radicular, embora com abrandamentos durante os períodos de alongamento da parte aérea, que apresentou múltiplos surtos de

crescimento. A distribuição das raízes das plantas criadas, relativamente à capacidade d campo, apresentou um padrão distinto do evidenciado pelas plantas submetidas ao tratament [MW]: uma distinta raiz principal vs um sistema radical ramificado.

Palavras-chave: *Quercus suber*; rizotróo; disponibilidade hídrica; peso seco da raiz; peso seco d parte aérea; tipo de sistema radicular

Résumé. L'influence d'un arrosage sur la croissance aérienne et souterraine de jeunes plante de chêne liège (*Quercus suber* L.), élevés en rhizotrons et soumises à trois régimes d'arrosag ([FC]: capacité au champ; [MW]: disponibilité en eau moyenne; [LW]: faible disponibilité en eau a été étudiée pendant quatre mois et demi. Le développement racinaire et aérien, les nouvelles racines secondaires, ainsi que le nombre de feuilles ont été analysés tous les 2 à 3 jours. A l récolte, le diamètre au collet, le volume racinaire et la matière sèche ont été mesurés. La disponibilité en eau a un effet significativement positif sur la croissance aérienne, le nombre d feuilles, la matière sèche, le diamètre au collet et la surface des feuilles. La matière sèche de plantes en régime [LW] est inférieure de 50% par rapport aux autres traitements. Le rapport d la biomasse du système racinaire sur la biomasse des jeunes plants a augmenté avec l diminution de la disponibilité en eau. Le volume racinaire a été de 70% supérieur pour les traitements [FC] et [MW] en comparaison avec le traitement [LW]. Le rapport S/R a été fortement réduit lors du traitement [LW], pour lequel la biomasse des racines était presque double de la matière sèche de la partie aérienne. Le système racinaire croît continuellement mais la croissance a été réduite durant la croissance aérienne, ce qui a montré des vagues de croissance. La distribution racinaire à la capacité au champ a été différente de celle observée pour le traitement [MW]: un pivot évident vs un système racinaire ramifié.

Mots clés: *Quercus suber* L.; rhizotron; disponibilité en eau; matière sèche des parties racinaires et aériennes; morphogénèse du système racinaire.

Introduction

Cork oak, a xerophytic and endemic species of the western mediterranean area, has a special relevance in the forestry and the rural economy of the Iberian Peninsula. It covers in Spain over 0.5 million hectares both as forests and silvopastoral ecosystems ("dehesas" or "montados") (MONTERO *et al.*, 1994; DÍAZ-FERNÁNDEZ *et al.*, 1995; MONTERO and CAÑELLAS, 1999), and plays an important role in the afforestation of former agricultural land (PARDOS, 1999). An adequate knowledge of different morphological and growth attributes of the species will improve seedling quality, and will lead to a better cork production, which is its principal income source.

Different *Quercus* species (*Quercus robur* L.; *Q. pedunculata* L., *Q. ilex* L.); exhibit a common pattern of root growth,

consisting of a main and long tap root which shows rapid and continuous growth in the seedling stage, and a variable number of secondary roots that are mainly involved in nutrient uptake. The secondary roots show a subhorizontal growth that is usually more limited in duration of elongation and growth rate in comparison with the tap root (CHAMPAGNAT *et al.*, 1974; PAGÉS, 1992; LÓPEZ *et al.*, 1998). Under optimal conditions (controlled temperature and soil moisture content) the root system grows continuously, always in advance from the beginning of shoot development (HARMER, 1990). Meanwhile, shoot growth follows a rhythmic pattern, with periods of fast stem extension and leaf expansion and other periods when growth is not so evident. The start of a flush seems to be under photoperiod control, but the cessation of growth is

more under internal control (AXELSSON *et al.*, 1979). As root growth and flushing are interdependent, both cease when soil moisture tensions are high (JOHNSON, 1979) because water availability is a factor in root distribution and mass (MARSHALL and GILMAN, 1997).

It is well accepted that plant height is reduced during water stress. Root growth has been shown to be less sensitive to water deficit than shoot growth, since root development may continue although at a reduced rate, when shoot growth is strongly limited by water stress (BALL *et al.*, 1994). A greater drought tolerance has been associated with a smaller investment in shoot growth compared with root growth in numerous species (PALLARDY and RHOADS, 1993). Shoot growth can be measured with relatively little difficulty; however, the measurement of root growth is more difficult (HARRIS *et al.*, 1995). In addition, little information exists on the growth pattern of evergreen oaks, particularly root growth response to different water supply (PARDOS, 1998).

The present study was designed to analyze the influence of water supply on root and shoot growth of cork oak (*Quercus suber* L.) seedlings. For this purpose seedlings were grown in rhizotrons, a transparent wall technique that allows the researcher to observe the roots growing in soil. Successive measurements are easily made on the same individual root or the visible part of the root system (TAYLOR *et al.*, 1991). Processes like root production, elongation, and mortality can be measured separately and sampled repeatedly (MAJDI, 1996), thereby minimizing the spatial component of experimental error (HENDRICK and PREGITZER, 1996). The

rhizotron is a convenient method for comparing how water supply affects root density and depth distribution (HANSSON and ANDRÉN, 1987).

The specific objectives of this study were: 1) to determine the influence of water supply on root and shoot growth of cork oak; 2) to describe shoot and root dynamics in seedlings under different water supplies; 3) to verify if the root system in cork oak follows the same growth pattern as in other oak species.

Materials and methods

Twelve rhizotrons 100 cm long, volume 10.5 liter, with cross section in the form of a circular sector (radius 10 cm, chord 6.67 cm), were placed in an iron framework constructed so that the tubes were tilted at 45° from vertical to force roots to grow along the bottom side. The circular wall was made of PVC pipe and the flat wall of metacrylate, covered with a black paper to exclude light. This structure allowed the monitoring of the root system at the interface between the soil and the transparent wall. Growing medium, consisting of a mixture of cork oak grove sandy soil from the first 40 cm (eutric cambisol; pH 7.23, low to medium productivity, CEC, 1985) and perlite (1:4 v:v), was submitted to an initial thorough drying in the oven at 100°C for a week, followed by addition of a known amount of water, which was fixed for each treatment.

Acorns of *Quercus suber* L. were collected from 30 parent trees of a selected stand in Parque de los Alcornocales - Serranía de Ronda provenance (Southern Iberian Peninsula). One pregerminated acorn with a radicle 0.5 cm long was planted 1 cm deep in each rhizotron. The rhizotrons were placed (13 March

1998) in a heated greenhouse with a minimum temperature of 10°C (night) and a maximum of 30°C (day), under 14-16 h photoperiod, 200-250 μ Einstein. $m^{-2}.s^{-1}$ of light intensity at midday.

Three water regimes were used, with four rhizotrons per treatment: field capacity (250ml H_2O added per liter of growing media) [FC], medium water availability (50% of field capacity) and [MW] low water availability (25% of field capacity) [LW]. One rhizotron in [MW] treatment was deleted from the study because the seedling died in the course of the experiment. At the middle of the experimental period (d74) water supply in [MW] and [LW] treatments was reduced to half of their initial values to increase possible differences between treatments.

Individual rhizotrons and their seedlings were weighted weekly and watered to refill the water loss up to their original weight. Root and shoot elongation, newly formed secondary roots and number of leaves were recorded per seedling every 2-3 days over 142 days. The position of the root apices was marked on the transparent wall with a different color pen for each date. Root elongation and shoot height were measured to the nearest mm. Periodic change in root system length (ΔRSL), tap root length (ΔTRL) and shoot length (ΔSL) for each replicate was determined by subtracting the previous length from the current length and calculating the mean. Periodic increase in leaf production (ΔLP) was also calculated by subtraction. At the end of the experiment, the rate of increase in root system length (RSL), tap root length (TRL), shoot length (SL), and leaf production (LP) for each measurement day was calculated for each replicate by:

$$RSL = \frac{\Delta RSL}{T_{RSL}} * 100 (\% \cdot day^{-1})$$

$$TRL = \frac{\Delta TRL}{T_{TRL}} * 100 (\% \cdot day^{-1})$$

$$SL = \frac{\Delta SL}{T_{SL}} * 100 (\% \cdot day^{-1})$$

$$LP = \frac{\Delta LP}{T_{LP}} * 100 (no.leaves \cdot day^{-1})$$

where ΔRSL = increase in root system length between measurements (cm); T_{RSL} = total increase in root system length for the experimental period (cm); ΔTRL = increase in tap root length between measurements (cm); T_{TRL} = total increase in tap root length for the experimental period (cm); ΔSL = increase in shoot extension between measurements (cm); T_{SL} = total shoot extension for the experimental period (cm); ΔLP = = number of new leaves counted (cm); T_{LP} = total number of leaves over the entire period (cm); t = time (days) between measurements.

Also total root length (Σ (tap root + secondary roots)) was recorded. At the end of the experiment each seedling was harvested and the following measurements were made: root collar diameter (in mm, with the use of a digimatic caliper), leaf area (in cm^2 , with the use of a Delta-T image analyzer), root volume (in cc, by displacement of the cleaned root system dipped into a vessel of water standing on a top-loading balance (BURDETT, 1979)) and dry weight (shoot, tap root, secondary roots and leaves; in g, in the oven, 72 h, at 70°C). Specific root length (total root length/root dry wt, $cm \cdot g^{-1}$) was calculated.

The experimental design was a

randomized incomplete block having three moisture treatments. Data were subjected to an analysis of variance (ANOVA). Statistical Analysis System (SAS INSTITUTE, 1992) software was used for analysis of all data. Planned contrasts were used to determine the response of the seedlings to the moisture-stress treatments (MIZE and SCHULTZ, 1985)

Results

Dry weight, root collar diameter, leaf area, root volume

Water supply regime significantly affected nearly all parameters measured (Table 1). Root system and tap root dry wt. were highest in the [FC] treatment. Decreasing soil water content reduced leaf, shoot and plant dry wt., and root collar diameter and leaf area. Plant dry wt. in the [LW] treatment was less than 50% the value in the other treatments. Leaf dry wt. was 59.5% of shoot dry wt. for all seedlings, while the ratio of leaf dry wt. to plant dry wt. decreased as water availability diminished. The ratio of shoot dry wt. to plant dry wt. also decreased when water regime was reduced. The opposite significant trend was shown in the ratios of fine roots dry wt. to total root system dry wt., and fine roots dry wt. to plant dry wt. Root system contributed the most to plant dry wt. in all three treatments; it increased its contribution as water supply decreased, and was at its maximum under low water availability [LW]. However, root volume was 79.4% and 73.5% greater in the [FC] and [MW] treatments, respectively, than in the [LW] treatment. Shoot to total root system dry wt. ratio (S/R) was also significantly influenced by the water regime supply. At the lowest soil water

content [LW], S/R was drastically reduced. Under these conditions, root biomass was almost twice shoot dry wt.

Growth dynamics

Root

Tap root growth began between d5 and d25, initially with no production of lateral roots. The 10 cm region of root behind the tip remained free of laterals. The highest appearance of laterals occurred as a whole between d18 and d74. Their final length varied from 0.3 cm (2 days elongation time) to 71.7 cm (up to 114 days elongation time). Lateral roots were less thick than the tap root and clearly differentiated from it. In some seedlings one or two lateral roots grew the same length as the tap root and exhibited a relatively orthogeotropic tendency, thus behaving like secondary taproots.

Total root system length was not significantly different among treatments, due to a large within-treatment variation. However, a marked trend was observed: treatment [MW] > treatment [FC] > treatment [LW] (Figure 1 (iii)). Total root system length increased by about 134% from the [LW] to the [MW] treatment. On the other hand, specific root length for root system and tap root was significantly lower in the [FC] treatment (Table 1), while total root length/leaf area ratio was higher in the [LW] treatment.

Mean tap root length did not differ significantly among treatments (Figure 1(iii)). A different trend was shown in tap root length in comparison with total root system length; the longest tap root were found in the [FC] treatment and the shortest in the [MW] treatment. Again, within-treatment variation was high.

Table 1 - Performance of seedlings of *Quercus suber* L. grown in rizhotrons after 142 days at different water availability levels

Parameter	Treatments			Pr>F	Test of contrast		
	[FC] (1)	[MW](2)	[LW](3)		(1) vs rest	(2) vs (3)	(1) vs (3)
Leaf dry wt. [L] (g)	2.6±0.2	2.5±0.9	0.7±0.2	0.0226 **	ns	0.0221 **	0.0124 **
Shoot dry wt. [S] (g)	4.4±0.3	4.3±1.6	1.2±0.2	0.0243 **	ns	0.0230 **	0.0134 **
Tap root dry wt. [TR] (g)	3.5±0.5	1.4±0.1	1.6±0.3	0.0056 ***	0.0017 ***	ns	0.0047 ***
Fine roots dry wt. [FR] (g)	0.4±0.1	0.6±0.1	0.6±0.1	ns			
Lateral roots dry wt. [LR] (g)	0.7±0.4	2.5±1.1	0.5±0.2	0.0927	ns	0.0441 **	ns
Root system dry wt. [R] (g)	4.6±0.3	4.5±1.0	2.7±0.1	0.0270 **	0.0776	0.0327 **	0.0127 **
Plant dry wt. [P] (g)	9.1±0.6	8.8±2.6	3.9±0.3	0.0304 **	ns	0.0284 **	0.0167 **
Shoot to root ratio [S/R] (g.g ⁻¹)	1.0±0.02	0.9±0.2	0.4±0.07	0.0094 ***	0.0364 **	0.0136 **	0.0043 ***
Specific root length [SRL] (cm.g ⁻¹)	24.7±4.9	52.2±10.2	46.0±3.8	0.0286 **	0.0100 **	ns	0.0314 **
TR/R (%)	75.7±10.1	36.2±9.9	61.4±11.2	ns			
FR/R (%)	9.0±1.6	13.5±1.6	21.6±3.6	0.0216 **	0.0271 **	0.0670	0.0076 ***
L/P (%)	29.1±1.4	27.2±2.9	18.3±3.1	0.0321 **	0.0735	0.0437 **	0.0142 **
S/P (%)	48.9±0.5	45.8±6.1	30.2±3.3	0.0098 ***	0.0322 **	0.0161 **	0.0043 ***
TR/P (%)	38.6±5.1	20.6±7.5	42.9±8.7	ns			
FR/P (%)	4.6±0.8	7.5±1.7	15.0±2.5	0.0095 ***	0.0187 **	0.0257 **	0.0035 ***
R/P (%)	51.5±0.5	54.2±6.1	69.8±3.3	0.0098 ***	0.0322 **	0.0161 **	0.0043 ***
Root caliper (mm)	0.6±0.04	0.56±0.06	0.4±0.01	0.0079 ***	0.0297 **	0.0125 **	0.0025 ***
Root volume (cc)	9.9±0.8	10.3±4.2	5.7±0.3	ns			
Leaf area (cm ²)	211.2±24.7	202.4±75.1	79.4±14.8	0.0685	ns	0.0614	0.0359 **

[FC], field capacity. [MW], medium water availability. [LW], low water availability. Values are means ± SE. n=4 in the [FC] and [LW] treatments, n=3 in the [MW] treatment. Analysis of variance and test of contrast per treatment are included. *** significant at 99%, ** significant at 95%, ns: non-significant.

There was a significant supply regime on mean (P=0.0053) (data not shown) the [MW] treatment had length. In addition, secondary roots were high treatment.

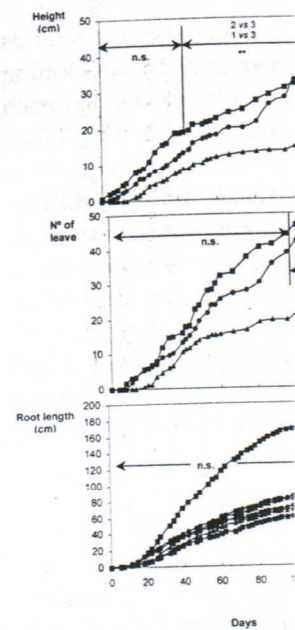


Figure 1 - Cumulative (i) of leaves, and (iii) root length of cork oak seedlings in response to The level of significance variance and the test of contrast: —[FC], field capacity; - water availability; — availability; ** significant; -significant.

There were considerable differences in the rate of total root growth increase between treatments which ranged from 1.6 to 3.7%.day⁻¹, re

There was a significant effect of water supply regime on mean fine root length ($P=0.0053$) (data not shown). Seedlings in the [MW] treatment had the shortest length. In addition, total sum of secondary roots was higher in the [MW] treatment.

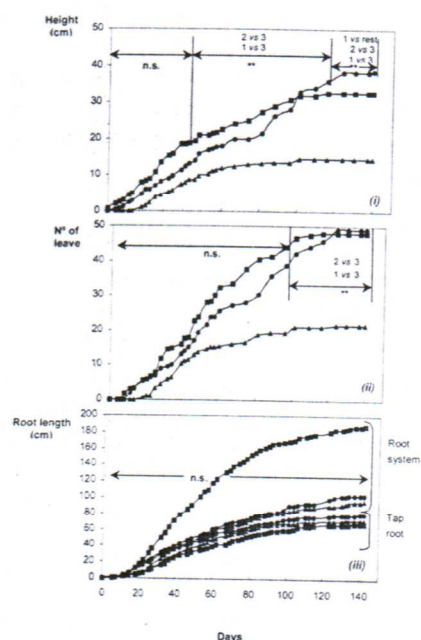


Figure 1 - Cumulative (i) height, (ii) number of leaves, and (iii) root system and tap root length of cork oak seedlings grown in rhizotrons, in response to water regime.

The level of significance of the analysis of variance and the test of contrast are shown.

—[FC], field capacity; —■[MW], medium water availability —▲[LW], low water availability; ** significant at 95%; ns: non-significant.

There were considerable differences in the rate of total root system and tap root growth increase between seedlings, which ranged from 1.6 to 3.8 %·day⁻¹ and 1.5 to 3.7%·day⁻¹, respectively. These

differences made construction of the pattern of growth for a treatment difficult, but that shown in Figure 2, which is an average for the three treatments, reflects the pattern for all seedlings. The peak growth occurred between d32 and d39. There was no clear relationship for any treatment between changes in the daily rate of root elongation and the time of irrigation.

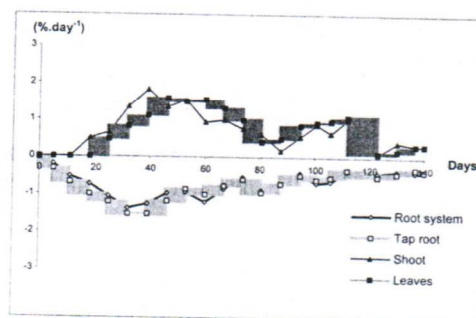


Figure 2 - Mean root system, tap root, shoot and leaves growth rates of cork oak seedlings grown in rhizotrons over the experimental period for the three treatments.

(n=4 in the [FC] and [LW] treatments, n=3 in the [MW] treatment).

Shoot

Shoot height growth and number of leaves were significantly different among treatments after d46 and d95, respectively (Figure 1 (i) and (ii)). An important decrease in both parameters was recorded in the [LW] treatment. At the end of the experiment shoot growth and number of leaves in the [FC] treatment were 258.8% and 229.3% greater, respectively, than in the [LW] treatment.

Shoot growth began slightly later (between d18 and d32) than root growth for all three treatments. Leaves commenced to emerge after d20. The peak

growth of shoot occurred in d39, while that of the leaves was delayed to d46. The three treatments showed a recurrent shoot growth, and two new flushes of growth, markedly shorter than the first one, followed after a short period of bud rest (Figure 2). The overall duration of the first flush was 77d, and 35d for the second one, comprising 2-7d of apparent inactivity and the rest, of active stem extension and leaf expansion and production.

Discussion

Seedling biomass was significantly reduced with decreasing soil water content. Tap root dry wt. in the [FC] treatment was over 200% that of the [LW] treatment, and differences were even greater in shoot and leaf dry wt. MARSHALL and GILMAN (1997) showed that irrigation could be a factor in root distribution and size, so root dry wt. increased in the soil layers with more water available. Total root system accounted for up to 69% of the seedling biomass in the [LW] treatment, in comparison to 51% in the [FC] treatment, which means an increase in the ratio as water availability decreased. CANADELL and RODÁ (1991) found that a limited availability of water favoured allocation of photosynthate to roots in holm oak (*Quercus ilex* L.), an evergreen species close to cork oak. HILBERT and CANADELL (1995) reported a root to seedling biomass ratio of up to 83% in 13 Mediterranean woody communities. Root collar diameter and leaf area were also significantly influenced by the water availability; many individuals in the nursery thus exhibit rapid shoot elongation and leaf area development, as long as soil moisture is nonlimiting

(JOHNSON, 1979).

The early formation of lateral roots was shown mainly under moderate water supply ([MW] treatment); this reveals a similar pattern to that described in a more mesic species, *Quercus robur*, by PAGÉS (1992). A different pattern was found under either abundant or limiting water supply, where a thick and deep tap root was evident. At early stages of seedling development, cork oak spends the acorn reserves mostly in developing a prominent tap root, in order to reach the deep water table (VIEIRA NATIVIDADE, 1950; CHAMPAGNANT *et al.*, 1974; VERDAGUER and MOLINAS, 1992; BRAGG *et al.*, 1993). This structure of root system growth is common in water-limited Mediterranean ecosystems, where roots are among the deepest of all biome-types (CANADELL *et al.*, 1996), and are thought to be a mechanism for surviving summer droughts (CANADELL *et al.*, 1999).

Tap root length was higher at field capacity ([FC] treatment). In contrast, mean secondary root length and dry weight were higher under moderate water availability ([MW] treatment). This led to a maximum total root system length in seedlings at the [MW] treatment, so it seems that the greatest root system development often occurs under suboptimal conditions (TESKEY and HINCKLEY, 1981). In addition, a lower specific root length in the [FC] treatment was joined to a greater root diameter; a similar finding has been reported by CROOKSHANKS *et al.* (1998) in *Quercus petraea*. These results may suggest two strategies in cork oak seedlings: (i) growth of a deep and thick tap root when water supply is abundant; (ii) a more branched root system to explore more soil volume, under moderate water

stress.

Rate of root system and tap root elongation varied between seedlings. There is some evidence that the rate declined whilst stem and leaves were actively growing. Similarly, REICH *et al.* (1980) and NOUR and RIEDACKER (1984) found that elongation of roots was also depressed during periods of shoot growth in 1 and 2 year old oaks (*Quercus marilandica* Muenchh., *Q. alba* and *Q. pedunculata* Ehrh.) grown in experimental chamber. On the contrary, BELGRAND *et al.* (1987) and HARMER (1990) for *Quercus robur* found no evidence of rhythmicity in root growth. What seemed clear is that the root system grew continuously over all the experiment, even during the periods of bud rest, whilst the shoot showed the rhythmic growth typical of oak, with multiple flushing, which is common in the spring when environmental conditions are not limiting (REICH *et al.*, 1980). Growth of cork oak roots was evenly distributed over the experimental period, and suffered a slow down in the rate at the middle of the experiment. Similar pattern was observed by HARRIS *et al.* (1995) in tree lilac (*Syringa reticulata* (Blume) Hara 'Ivory Silk').

Shoot growth and number of leaves were significantly reduced with decreasing soil water content. Moisture stress has been found to affect seedling growth in many species. Studies with cotton plants grown in rhizotrons (BALL *et al.*, 1994), red oak (*Quercus rubra* L.) and white oak (*Q. alba* L.) (LARSON and WHITMORE, 1970; LARSON and PALASHEV, 1973; TOMLINSON and ANDERSON, 1998), tilonj oak (*Q. floribunda* Lindl.) (RAO, 1988), Doulgas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) (KHAN *et al.*, 1996), etc., indicate that low

water availability often reduces seedling growth. It is suggested that aerial parts are more affected by drought than the root system and that under water-stressed conditions carbon reserves tend to support preferentially the root growth. Furthermore, in the present study well-watered cork oak seedlings exhibited relatively less root length per unit leaf area than the treated seedlings, as occurred in seedlings of several deciduous angiosperms (PALLARDY and RHOADS, 1993). It appears reasonable to consider internal water deficits as the most likely physiological basis for the reduction of shoot growth (BORCHERT, 1975).

Conclusions

The growth of the root system was coupled to the activity of the shoot, which showed a rhythmic growth. The maximum value in the different growth rates followed the same sequence as the appearance of the different parts, that is, root, shoot and leaves. The rate of the root system declined whilst stems and leaves were actively growing, and suffered a slow down from the middle of the experiment. Two strategies in the root system growth of cork oak seedlings may be suggested: (i) a deep and thick tap root when water supply is abundant; (ii) a more branched root system, under moderate water availability. In any case, the aerial part was more affected by water availability than root; so that a limited availability of water favoured allocation of photosynthate to roots.

This study can provide useful guidelines for afforestation purposes. Rhizotrons have proved useful for a detailed monitoring of root growth, under conditions similar to those found in the field. A better knowledge of root

and shoot dynamics in cork oak under different water regimes when grown in rhizotrons will allow foresters to choose those seedlings that as a whole will adapt better to the special conditions of the planting site. Control of the planting stock to promote satisfactory development after planting provides a means of improving establishment success. Additional work involving greater replication and more research on the physiological function of the different types of roots is encouraged.

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