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Research Paper

Comparative study among experimental plantings and phenotypes of cork oak (*Quercus suber* L.), Northern Greece: 18 years later

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Abstract: Comparative studies on growth, wood and cork production, survival and germination between two treatments and among three phenotypes of Quercus suber were studied, in experimental plots. In 1992, two-year old saplings of cork oak were planted in northern Greece. Significant differences between the two treatments and among the three phenotypes in quantitative growth parameters (diameter, height, wood and cork production) were identified. Three regression models (linear, logarithmic and quadratic) were used to correlate precipitation and growth of cork oak over the last decade. The quadratic model shows the highest correlation, providing a reasonable prediction of annual tree growth, given the mean annual precipitation for the tested three phenotypes. Marginal climatic parameters (in particular drought and frost) negatively affected the survival and growth of oak saplings.

Keywords: Cork, germination, growth, *Quercus suber*, planting, phenotypes

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Introduction

Plant core natural populations, in woodlands particularly, depend on many factors such as site quality, silvicultural treatments, genetic heredity, climatic and soil conditions (Panetsos 1980, Spanos et al 2001, Hampe & Petit 2005). Furthermore, peripheral and small marginal populations may be highly sensitive to global changes in climate, disturbance regimes and pathogen agents (Lesica & Allendorf 1995, Thomas et al 2004, Hampe & Petit 2005).

In the Mediterranean region, more than 20 oak species are grown in natural stands. One species (Quercus suber L.) is very interesting due to its cork production. Natural forests of cork protected by the European Union (Habitat Directive 92/43/EEU), mainly occur on acidic soils in the center and western half of the Iberian Peninsula (core population). However, along the eastern Mediterranean coast, where calcareous soils are dominant, Q. suber occurs in several peripheral populations which show genetic differences from the core population (Panetsos 1980, Jimenez et al 1999).

Cork oak (Q. suber) is naturally found only in the western Mediterranean basin and adjacent areas on the Atlantic coast. Cork oak is an evergreen tree rarely reaching 20 m in height, with sclerophyllous leaves and a thick, rugged, corky bark, resistant to wildfires (Borges et al 1997, Pausas 1997, Pausas et al 2004). The geographical range extends from Iberian Peninsula, North Africa (Marocco, Algeria and Tunisia) to western Italy and the large islands between Italy and Spain (Tutin et al 1968-80, IPGRI 2000-05). The main wood product is cork that is harvested in sheets from the tree when the bark is thick enough. The bark is no longer a living part of the tree hence can be removed without greatly affecting the tree. Cork has been used for many centuries, and continues to have many uses, most notable of which is as a stopper or "cork" on bottles of wine. Today, the main uses of cork are bottle stoppers, gaskets and flooring. Other less notable products that use cork include: shoes, handles of fishing rods, bulletin boards and various uses in insulation. Harvesting begins when the tree is around 20 years old, and 20cm in trunk diameter, when the outer, dead, layer of bark is first removed from the tree. This cork is of relatively low standard and would be irregular, hard and have deformities (Montero & Canellas 1999). After the first stripping the tree will have its bark harvested every 8 to 10 years and the quality of this cork will improve and be at a premium after the third harvest (Caritat et al 1996). The interval between the subsequent harvests will vary depending on the growth of the cork, which is slower in the older trees.

Dendrochronology is a biological science that uses the width of tree rings and climatic parameters, enable us to predict growing models and climate changes (Morgan 1975, Fritts 1976, Huges et al 1980, Glerk 1986, Briffa et al 1990, Cook & Kairioukstis 1990, Banks 1991, Schweingruber 1996). This is also called tree-ring dating. Tree-ring dating is based on the principle that the growth rings on certain species of trees reflect variations in seasonal and annual rainfall. Trees from the same species, growing in the same area or environment will be exposed to the same conditions, and hence their growth rings will match at the point where their lifecycles overlap. It is known that climatic factors (precipitation, temperature, etc.) influence tree growth and cork growth (Oliveira et al 1992, Caritat et al 1996, Caritat et al 2000, Costa et al 2002).

Germination and regeneration success, survival and seedling vigour of Q. suber depends on various ecological and genetic factors, as climate and soil conditions, phenotypes, etc.(Branco et al 2002, Coca & Pauss 2009). Leaves (length, width, colour, shape, etc.), wood and cork parameters (qualitative and quantitative) and the shape of the tree are the main morphological characteristics that define the phenotypes of Q. suber(Petrov 1984, Nikolov et al 1987, Borges et al 1997, Montero & Canellas 1999).

In Greece, there are no extant natural stands or plantations of Q. suber in woodlands or fields (except for occasional trees in gardens), even though, there are extensive woodlands and fields in this country with favorable soil and climatic conditions for this species. A Greek program to introduce and test cork oak was initiated in 1990 within a national Greek project, entitled "New plant species testing for reforestations, applied new methods". Three experimental plots were established in three different areas in northern Greece. Experimental plots were established within a field of the Forest Research Institute (FRI) on the outskirts of Thessaloniki region and within public woodlands in the Halkidiki region-Ierissos and Thessaloniki region-Vrasna. Three phenotypes were tested and two treatments were applied.

In this investigation, we will discuss preliminary results from plots that are situated in the field of FRI. The main objectives of this study were:

- to monitor and compare the cork oak's establishment, 14 years after planting.
- to compare the main growing quantitative parameters among the three phenotypes (diameter, height, wood and cork stock).
- to correlate growth of cork phenotypes with precipitation, using three regression models.
- to identify critical ecological parameters that influence bark and wood production.
- to compare the seed germination among three phenotypes.

Materials & Methods

Study area

The study area is situated in north Greece, 20km east of Thessaloniki city, within a field owned by the Forest Research Institute (FRI), (latitude 40o 30΄ 27΄΄, longitude 23o 04΄ 58΄΄, altitude 10m). Acording to the data of meteorological station situated close to experimental plots the ombrothermic climatic diagram for the period 1978-2010 (figure 1) shows a typical Mediterranean climate, with a, relatively low, mean annual precipitation (437mm) and the xerothermic period (4.5 months) starts May and lasts until September. According to the formula of Emberger (Emberger 1971) and the pluviothermic quotient Q, the climate can be characterized Mediterranean and classified to the cold and semiarid variant. The most xerothermic year was 1993 (annual precipitation 225mm).

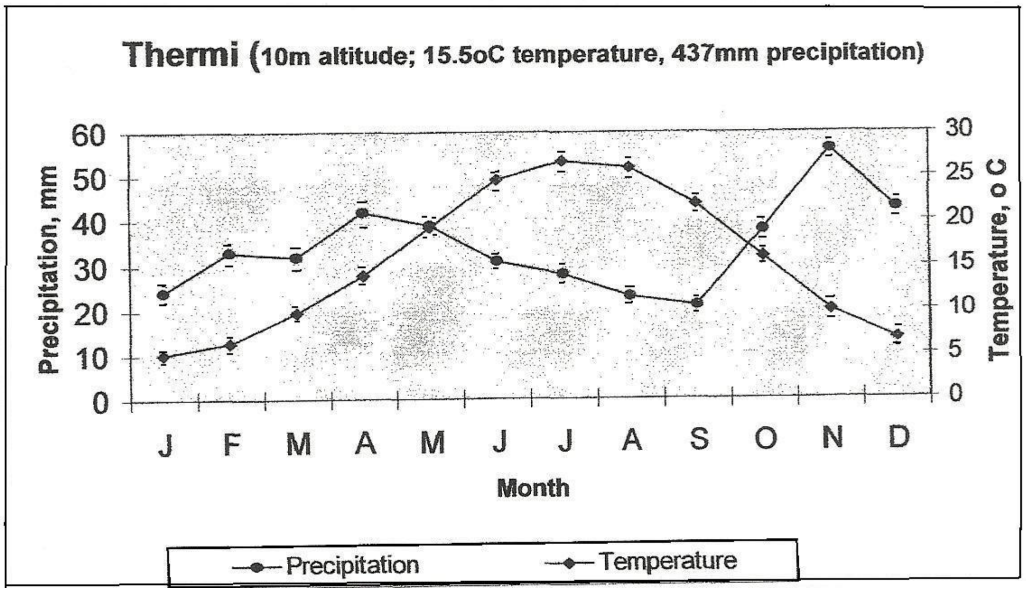

Figure 1: The ombrothermic climatic diagram of the meteorological station of the Forest Research Institute for the period 1978-2006.

The soil is derived from alluvians of the Holocene fourth-gene period. It is included in the dark colluvians iron-pyritical group with deep fertile depositions (100cm up to 120cm), pH 7.7 near the surface and 8.0 in the deeper strata. Granulometric analysis fluctuates from sandy to clayey (Gogos 1985).

Plant materials

In 1992, two permanent plots selected in the field of the FRI (Plot 1 was 0.715 ha; 50 m x 143 m and Plot 2 was 0.625 ha; 50 m x 125 m). Consequently (Nov. 1992), 540 (two-year old) seedlings of Q. suber were planted into the two plots (288 and 252 seedlings respectively) in a 5m x 5m grid. The growing space of each seedling was 25 m2 (5 m x 5 m). The seedlings were produced from seeds (collected in 1990) from mature stands of Q. suber (25 years old) situated in southern Bulgaria (Petritsi), 100 km from the study area. The seedlings were classified into three sub-species (phenotypes) as following: phenotype 1; Q. suber ssp. eusuber A. Camus, phenotype 2; Q. suber ssp. occidentalis (Gay) A. Vamus, phenotype 3; Q. suber ssp. occidentalis f. heterocarpa Globa-Mikhailenki and, consequently, were planted. The nomenclature of plant species follows Flora Europea Tutin et al 1968-80).

The seedlings were in plot 1 (treatment 1) were not treated before planting, while seedlings of plot 2 (treatment 2) were pruned and the lateral shoots were removed. All seedlings of both treatments were not irrigated for the next years after the planting. Three years after planting (1995) the lower shoots at two treatments were removed. Pruning was repeated biannually (1997, 1999, 2001, 2003, 2005). After the last pruning, the main quantitative parameters (diameter at breast height-DBH, height, circular area and wood overbark volume) of all trees were recorded (Oct. 2006). In the same year, 30 tree-rings were extracted randomly from selected trees in treatment1 (un-pruned) from a height of 130cm above-ground, using Pressler's instrument taken tree-ring cores as samples (ten tree-rings per phenotype).

On November 2009 we collected 1,800 seeds from selected trees in plot 1 (600 seeds per phenotype) to compare the germination among the three phenotypes. The seeds were tested (during the period November 2009-May 2010) into a greenhouse of FRI under control conditions (averagge day/night temperature, average day duration, artificial light intensity if any, soil temperature, soil moisture) without heating (since the germination success is generally higher in the cool greenhouse than outdoors) (Pausas et al 2004). Seeds were put in 12 intimate plastic containers (filling with mixed soil material; peat and sand), randomly established on a table (n = 50 replications per phenotype).

Statistical analysis was accomplished using the SPSS statistical program for Windows. The variables between treatments and among phenotypes, were analyzed using analysis of variance (ANOVA) and means were compared with Student's (t-test) and Tukey's multiple comparison tests. All tests for significance were conducted at $P<0.05$, unless otherwise indicated. Three models (linear, logarithm and quadratic) were used for regression analysis.

Results

Fourteen years after planting, the seedling survival of un-pruned treatment was higher than those of pruned treatment (85 % and 68 % respectively).

The main quantitative parameters (DBH, height, circular overbark area and wood overbark volume) among phenotypes and between treatments, 14 years after planting are presented on Table 1. In the first treatment (un-pruned), the average DBH was statistically significantly ($P<0.05$) higher than the second treatment for all phenotypes (type1, 6.3 cm and 5.3 cm; type2, 4.8 cm and 2.4 cm; type3, 6.1 cm and 3.1 cm respectively), as well as the average height (type1, 323 cm and 265 cm; type2, 281 cm and 181 cm; type3, 336 cm and 219 cm respectively).

Monitoring of precipitation and width of annual tree ring for the years between 1997 and 2006 are shown on Table 2. The lowest precipitation was registered in 2000 (257 mm yr-1 and 49 mm yr-1 in summer) and 2001 (291 mm yr-1) among phenotypes for all years, except 1998. No statistical differences were observed between phenotypes 2 and 3).

For un-pruned (plot1) treatment only, the main growing parameters of tree ring are analyzed using regression analysis for the different phenotypes using three models, linear, logarithmic, quadratic (Table 3). The quadratic model (quadratic) was shown the most significant correlation between total annual precipitation and width of annual tree ring growth, compared to the linear and logarithmic models. These quadratic equations are as following:

Y=5.5887 x X^2 – 0.0138 x X + 0.000018, (R^2 = 0.92) for phenotype 1,

Y=3.4475 x X^2 – 0.0077 x X + 0.000013, (R^2 = 0.93) for phenotype 2,

Y=3.4475 x X^2 – 0.0122 x X + 0.000017, (R^2 = 0.88) for phenotype 3, where X= the independent parameter (mean annual precipitation), and Y=the dependent parameter (annual tree ring width).

The observed and theoretical rates of regression models (linear, logarithmic and quadratic) are shown on figure 2. The figure displays the correlation of mean annual precipitation (mm) and the width of annual growth (mm) of cork oak. The sub-figures (a, b, c) graphically represent the three phenotypes respectively.

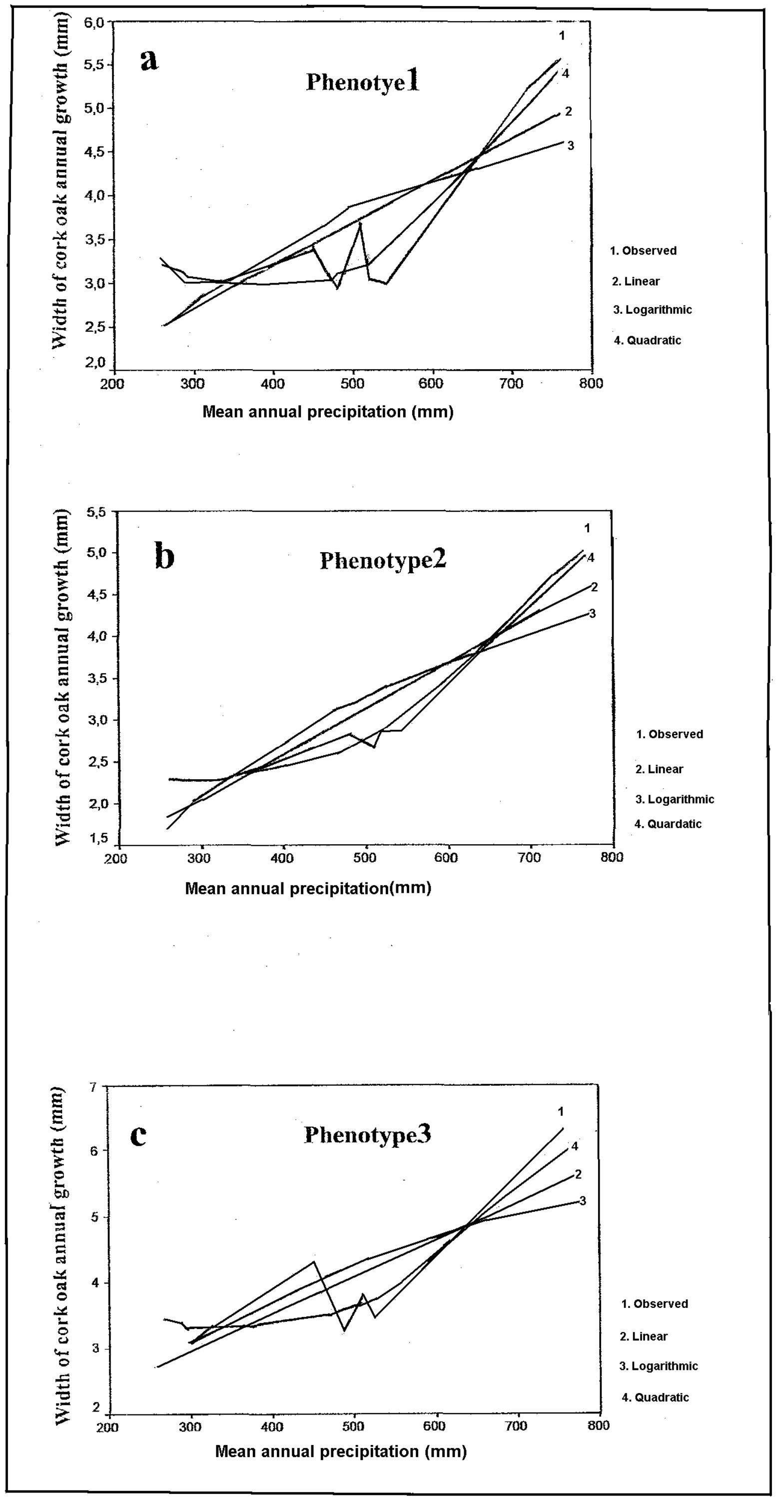

Figure 2: Graph of three regression models (linear, logarithmic and quadratic) that show the correlation of mean annual precipitation (mm) and the width of annual growth of cork oak, using SPSS (10.0 for Windows) statistical program. The three sub-figures (a,b,c) represent the three phenotypes respectively.

The average main bark characteristics based on tree-rings measurements (which were extracted from 30 randomly chosen trees in un-pruned treatment; ten tree-rings per phenotype) are shown on Table 4. Average bark volume per hectare (m3 ha-1) is very low for all phenotypes (0.054; 0.035 and 0.063 respectively) because the trees are still juvenile (14 years old).

Monitoring of germination (in percentage) among the three phenotypes is shown on Table 5. Six recordings were taken place (15 days intervals), three months after the sowing date (30 Nov. 2009). At the first observation (1 Mar. 2010) the percentage germination was low in all phenotypes (7.73; 3.33 and 1.67 in phenotypes 1, 2 and 3 respectively) and increases gradually. At the final observation (14 May 2010) the percentage germination was very high in all phenotypes (77.50; 80.00 and 75.97 in phenotypes 1, 2 and 3 respectively).

Discussion

The survival of seedlings from un-pruned treatment was considered more successful compared to those of pruned, since the seedlings in pruned were more negatively affected by the drought of 1993 than those of un-pruned. The lateral shoots of the second plot were pruned before planting and, consequently, many plants suffered and died from sun stress, during the summer of 1993 in particular. The saplings from second (pruned) treatment were negatively affected more than those in un-pruned from the summer dryness of 1993 (where mean annual precipitation was only 225 mm, which is the lowest for the preceding 27 years) as well as by the frost and very low temperatures during the winters of 2000 and 2001 (minimum air temperature -11^{o}C).

In our study area, the three phenotypes of *Q. suber* were monitored, 14 years after planting. The phenotype of *Q. suber* ssp. *eusuber* adapted better to soil and climatic conditions compared to *Q. suber* ssp. *occidentalis.* The same phenotypes were found in mature stands of *Q. suber* plantations (25 years old) in Bulgaria (Petritsi region), close to the Greek border and not far from the study area (100km north), that is the woodland from which the oak seeds were collected and introduced into Greece. A study of these phenotypes (forms) in the Bulgarian area (Petritsi), showed that the first phenotype (*Q. suber* ssp. *eusuber*) was characterized by higher wood density, static bending strength and modulus of linear deformation of the wood (Nikolov et al 1987).

Table 1: Comparison of means (±s.e.) of the main quantitative parameters (DBH, height, circular area, wood overbark volume), 14 years after planting. Means, followed by the same superscript letter among phenotypes (^{a},^{b},^{c}) of the same treatment (Tukey's test, P<0.05), and between treatments (^{d},^{e}) (t- test, P<0.05) of the same phenotype are not significantly different.

Phenotypes	Number of trees N	Diameter DBH (cm)	Height H (cm)	Circular area per tree G_o (cm^2)	Wood overbark volume per tree V_o (m^3)	Circular area per hectare G_o (m^2 ha^{-1})	Wood overbark volume per hectare V_o (m^3 ha^{-1})
Plot1							
Q. suber ssp. *eusuber*	122	6.31^{ae} (±0.29)	323.08^{ae} (±8.53)	36.47^{ae} (±2.82)	0.059^{be} (±0.009)	1.46^{ae} (±0.11)	23.60^{be} (±3.52)
Q. suber ssp. *occidentalis*	43	4.82^{be} (±0.38)	281.35^{be} (±12.00)	22.97^{be} (±3.01)	0.020^{ae} (±0.005)	0.92^{be} (±0.12)	8.00^{ae} (±2.00)
Q.suber ssp. *occidentalis f. heterocarpa*	73	6.18^{ae} (±0.32)	336.31^{ae} (±10.67)	36.14^{ae} (±3.23)	0.061^{be} (±0.01)	1.45^{ae} (±0.13)	24.4^{be} (±4.00)
Plot2							
Q. suber ssp. *eusuber*	46	5.35^{ad} (±0.55)	265.60^{ad} (±18.04)	33.33^{ad} (±5.47)	0.016^{ad} (±0.002)	1.33^{ae} (±0.22)	6.40^{ad} (±0.40)
Q. suber ssp. *occidentalis*	26	2.41^{bd} (±0.36)	181.66^{bd} (±13.06)	4.56^{bd} (±2.28)	0.006^{bd} (±0.001)	0.18^{bd} (±0.09)	2.40^{bd} (±0.40)
Q.suber ssp. *occidentalis f. heterocarpa*	51	3.11^{cd} (±0.35)	219.47^{cd} (±9.96)	$12.48c^{d}$ (±2.74)	0.010^{cd} (±0.003)	0.50^{cd} (±0.11)	4.00^{cd} (±1.2)

The mean annual precipitation plays a significant role in the establishment and survival of cork oak plantings. The drought of 1993 and the frost of 2000 and 2001 negatively affected the survival and growth of *Q. suber* plantings. In the study area, the maximum air temperature was registered in July 2000 (42.8^{o}C) with two minimum air temperatures occurring in the winter of 2001-2 minimum in December 2001 (-11.2^{o}C) and January 2002 (-11.0^{o}C). However, many saplings from both plots died one year after planting in 1993, since the juvenile trees of *Q. suber* were affected by the frost and low temperatures during the winter of 1992-3. Analogous observations took place in Portugal, Spain and Bulgaria (Nikolov et al 1987, Oliveira et al 1992, Caritat et al 1996). Water stress of *Q. suber* was found to be moderate and winter cold stress due to low air and soil temperatures appeared to have an influence on plant water balance through their effects on flow resistances [25]. Many trees of *Q. suber* died due to low temperatures, below -5^{o}C (Pertov 1984, Nikolov et al 1987, Caritat et al 1996, Montero & Canellas1999).

In a neighbouring woodland, 10km from the FRI at Mount Lanari-Thermis, thousands of pine (*Pinus pinaster* var. *maritime*) saplings (that were planted during the years 1982 to1985) died in1993, due to the long summer drought [33]. In Greece, precipitation and moisture (air and soil) are the main climatic parameters that affected the planted species since the available beneficial water (water-capacity minus permanent wilting point) is very low during the summer months, this is demonstrated in many neighbouring woodlands of the Forest Park of Thessaloniki, 15km NW of the study area (Tsitsoni et al 2004, Ganatsas & Spanos 2005, Raftiyannis & Spanos 2005) and Halkidiki (Tsitsoni 1997, Zagas et al 2004, Spanos et al 2005).

Three regression models (linear, logarithmic and quadratic) were tested to correlate annual precipitation and tree ring growth. The quadratic model provides an excellent prediction of correlation between annual tree growth and annual precipitation for all phenotypes. The correlation between the precipitation of the summer dry period and the annual growth of the tree ring was very low for all models (R<0.15) which indicates that the lower precipitations during the dry season did not affect the growth of *Q. suber*. In southwestern Portugal the average tree annual diameter increment of cork oak was 0.95 cm per year but significant inte-annual growth differences were observed. Smaller annual diameter increments could be related to climatic factors such as drought periods with low winter rainfall (Costa et al 2002). Statistical differences in DBH and height were registered among the three phenotypes in our study area. In contrast, in Bulgaria (Petritsi region) no statistical differences were found in DBH and height among the same three phenotypes of cork oak (ssp. *eusuber*, ssp. *occidentalis*, f. *heterocarpa*); in a mature stand (30 years old) DBH was 20.5cm, 19.5cm and 19.5cm, and height was 9.0m, 9.5m and 10.5m respectively (Nikolov et al 1987). This probably can be attributed to the climatic conditions (precipitation and air humidity in particular) of the Petritsi region are more favorable compared to the Greek study area.

Table 2: Data list of mean precipitation (annual and dry period) for ten years (1997-2006), and means (±s.e.) of annual tree ring width for the same years (1997-2006). Means, followed by the same superscript letter among subspecies (of the same date) are not significantly different (Tukey's test, P<0.05).

Year	**Annual precipitation (mm)**	**Precipitation during dry period (mm)**	**Width of annual wood growth (mm) (per phenotype)**		
			Q. suber ssp. *eusuber*	*Q. suber* ssp. *occidentalis*	*Q.suber* ssp. *occidentalis f. heterocarpa*
1997	322	73	2.98^a(±0.11)	2.28^a (±0.11)	3.33^a (±0.57)
1998	454	32	3.42^a (±0.20)	2.74^a (±0.36)	4.41^b (±0.98)
1999	513	126	3.72^a (±0.31)	2.68^a (±0.19)	3.90^a (±0.45)
2000	257	49	3.30^a (±0.16)	2.30^a (±0.18)	3.57^a (±0.85)
2001	291	14	2.98^a (±0.15)	2.28^a (±0.14)	3.00^a (±0.46)
2002	730	319	5.32^a (±0.54)	4.77^a (±1.0)	5.87^a (±0.63)
2003	784	73	5.73^a (±0.30)	5.16^a (±1.15)	6.47^a (±0.86)
2004	544	191	2.97^a (±0.20)	2.87^a (±0.26)	3.70^a (±0.59)
2005	482	218	2.95^a (±0.23)	2.84^a (±0.17)	3.12^a (±0.25)
2006	520	231	3.05^a (±0.24)	2.89^a (±0.12)	3.35^a (±0.24)

Table 3: Regression analysis of precipitation and annual tree growth in un-pruned treatment, classified in three subspecies. regression (of the last decade; 1997-2006) between mean annual precipitation (X=independent parameter, mm) and width of annual tree ring growth (Y=dependent parameter, mm), using three mathematical equations (linear, logarithm and quadratic).

Phenotypes	**Models**	**(R^2)**	**F**	**Sign.**	**Coeff. α (alpha)**	**Coeff. β (beta)**	**Coeff. γ (gamma)**
Q. suber ssp. *eusuber*	Linear ($Y_1=\alpha X_1+\beta$)	0.65	15.03	0.05	1.3045	0.0048	-
‘’	Logarithm ($Y_1=\alpha \mathrm{Log}X_1+\beta$)	0.50	7.96	0.022	8.3924	1.9620	-
‘’	Quadratic ($Y_1=\alpha X_1^2+\beta X_1+\gamma$)	**0.92**	42.43	0.000	5.5887	-0.0138	0.000018
Q. suber ssp. *occidentalis*	Linear ($Y_2=\alpha X_2+\beta$)	0.85	45.33	0.000	0.4143	0.0054	-
‘’	Logarithm ($Y_2=\alpha \mathrm{Log}X_2+\beta$)	0.71	19.95	0.002	-11.3060	2.3453	-
‘’	Quadratic ($Y_2=\alpha X_2^2+\beta X_2+\gamma$)	**0.99**	248.10	0.000	3.4475	-0.0077	0.000013
Q.suber ssp. *occidentalis f. heterocarpa*	Linear ($Y_3=\alpha X_3+\beta$)	0.69	17.89	0.003	1.2957	0.0057	-
‘’	Logarithm ($Y_3=\alpha \mathrm{Log}X_3+\beta$)	0.56	9.97	0.013	-10.5730	2.3874	-
‘’	Quadratic ($Y_3=\alpha X_3^2+\beta X_3+\gamma$)	**0.88**	25.78	0.001	5.4275	-0.0122	0.000017

Table 4: Means of bark characteristics of *Q. suber*, using tree-rings, extracted from 30 of the taller trees of the un-pruned treatment (six tree-rings per subspecies) at a height of 130cm above-ground, 14 years after planting (2006). Means (±s.e.), followed by the same superscript letter among subspecies (of the same parameter) are not significantly different (Tukey's test, P<0.05).

Subspecies	Number of tree-rings N	Width of bark (cm)	Height of trees H (cm)	Bark volume per tree V_b (m^3)	Bark volume per hectare V_b (m^3 ha^{-1})
Q. suber ssp. *eusuber*	10	1.51 [a] (±0.43)	445.0 [a] (±33.0)	0.00081[a]	0.054 [a]
Q. suber ssp. *occidentalis*	10	1.28 [b] (±0.36)	355.0 [b] (±47.6)	0.00058 [b]	0.038 [b]
Q.suber ssp. *occidentalis* *f. heterocarpa*	10	1.70 [a] (±0.30)	438.2 [a] (±56.3)	0.00096 [a]	0.063 [a]

Table 5: Monitoring of germination (%) among three phenotypes. Means (±s.e.), followed by the same superscript letter among subspecies (of the same date) are not significantly different (n=50, Tukey's test, P<0.05).

Date	Phenotypes		
	Q. suber ssp. *eusuber*	*Q. suber* ssp. *occidentalis*	*Q.suber* ssp. *occidentalis* *f. heterocarpa*
1 Mar.2010	7.73 [c] (±2.5)	3.33 [b] (±1.4)	1.67 [a] (±0.9)
15 Mar. 2010	23.03 [b] (±4.1)	10.55 [a] (±3.8)	12.22 [a] (±4.4)
1 Apr. 2010	40.45 [b] (±3.8)	32.89 [a] (7.0)	31.66 [a] (±5.3)
15 Apr. 2010	58.88 [a] (±3.4)	60.55 [b] (±5.6)	58.33 [a] (4.9)
30 Apr. 2010	69.61 [a] (±2.7)	75.55 [b] (±4.5)	70.14 [a] (±4.6)
14 May 2010	77.50 [a] (±2.4)	80.00 [b] (±3.5)	75.97 [a] (±3.4)

The concept that annual wood production is controlled to some extent by climate has recently been shown to apply also to cork (Caritat et al 1996, Costa et al 2002). Annual cork-ring width variability of *Q. suber* depends strongly on the temperature and precipitation (Caritat et al 2000, Moreira et al 2007). In relation to the wood growth, only very limited information is available for *Q. suber*, partly resulting from difficulties in distinguishing annual rings in the trees under sustained cork production (Borges et al 1997, Gourlay & Pereira 1998,). In Portugal, Costa et al. (2002) showed that cork oak trees increased their over cork circumference annually which corresponds to annual diameter increments between 0.41 and 1.44 cm. Bark thickness, a key variable determining post-fire tree survival, usually increases with tree diameter. The cork oak is an exception to this, as it is the only European tree was the commercial exploitation of bark (cork) occurs. In the study area, harvesting of the first stripping of bark for cork production could be start many years later (more than ten), when the DBH of trees will exceed 20cm (Nikolov et al 1987, Costa et al 2002).

Additionally, a main objective is to obtain seeds with high percentage and rapid and uniform seedling emergence. The germination success is generally higher in the cool greenhouse than outdoors.

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