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Original article

The relative importance of cork harvesting and climate for stem radial growth of *Quercus suber* L.

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Abstract – Growth of cork-oak (*Quercus suber* L.) in Iberian stands may depend not only on climate but also on recurrent cork harvesting and stand management. In this work, trees from sites with different managements were studied for 3–6 years. Radial increments were enhanced following harvesting (4.0–8.2 mm yr^{-1}), and decreased afterwards (< 4.3 mm yr^{-1}). Time after harvesting was the primary factor affecting radial growth of *Q. suber*, but trunk growth also correlated negatively with Autumn-Winter precipitations and minimum temperatures, and positively with Spring rainfall. Spring radial increment varied significantly between sites.

climate / cork harvesting / montado / *Quercus suber* / growth

Résumé – Importance relative de la récolte du liège et du climat sur la croissance radiale de *Quercus suber* L. La croissance du chêne liège (*Quercus suber* L.) des peuplements ibériques peut dépendre non seulement du climat mais aussi de la récolte du liège et de l'aménagement du peuplement. Dans ce travail, des arbres provenant de sites caractérisés par divers types d'aménagement ont été étudiés pendant 3 à 6 ans. L'accroissement radial était accrû après la récolte (4,0–8,2 mm yr^{-1}), et diminué ensuite (< 4,3 mm yr^{-1}). Le temps depuis la récolte était le facteur primordial affectant la croissance du tronc de *Quercus suber*, mais celle-ci était aussi corrélée négativement avec les précipitations et températures minimales de l'automne et de l'hiver, et positivement avec la pluviométrie printanière. L'accroissement radial au printemps varie significativement entre les sites.

climat / récolte de liège / montado / *Quercus suber* / croissance

1. INTRODUCTION

Low-density stands of *Quercus suber* L. (*montados*) are economically important in Portugal because of cork production, often associated with livestock or cereal cropping. Climate determines tree growth [4], but in cork-oak other factors may also be involved: the periodical cork harvesting, which implies considerable tissue regeneration [6]; and agrosilvicultural practices, which change stand characteristics such as tree density and regeneration, competition between trees, and availability of resources. The relative weight of all these

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factors is unknown. Experimental approaches are complicated by the slow growth of *Q. suber*, its large heterogeneity (size, form, age) and the recurrent cork harvesting. Here we present a first study of the effects of cork harvesting and climate on stem radial growth of mature cork-oaks in differently managed *montados* of SW Portugal.

2. MATERIALS AND METHODS

Two sites were chosen: a pure stand of *Q. suber* (81 trees ha^{-1}), at Cruz de João Mendes (CJM – 38º 05' N, 8º 39' W, elevation 290 m), used for cork production and occasional sheep grazing; and two neighbouring pure stands at Herdade do Pinheiro (HP – 38º 28' N, 8º 42' W, elevation 27 m), with an improved pasture for livestock at HPp ("pastured", 79 trees ha^{-1}), and no fertilisation nor grazing at HPu ("undisturbed", 88 trees ha^{-1}). Meteorological data (1990–1995) are from the nearest weather stations (*figure 1*). Summer rainfalls were negligible (< 8 mm yr^{-1}).

In Portugal, cork is harvested in early Summer every nine years. In a given *montado*, cork-oaks are generally unevenly aged and developed because they were not deliberately planted. As a result, not all the trees have the same cork thickness, and are not all harvested on the same year. Considering this, as well as the low density of stands, the selection of a homogeneous sample of trees was limited to 7–12 trees at each site (*table I*). According to year of the last cork harvesting, the trees were grouped into "86", "88", "90" and "92".

Radial stem growth was assessed with a depth micrometer (Series 129-Mitutoyo, MGF Co. Ltd., Tokyo, Japan), measuring the distance between a frame attached to the cork and a lag screw embedded in the wood [7]. Data refer to the south side of the trunk at breast height (1.30 m), and are presented as radial increments (wood plus cork) over March-late June (Spring) and March-February (annual). These periods were defined according to the phenology of this species [7].

Principal component analyses included the whole data set to identify the general relationships among variables related to growth, climate, time after cork harvesting, and management. Values were log transformed to give equal weighting to each variable. Comparisons between *montados* were made with one-way ANOVAs ($P < 0.05$) and Tukey HSD tests for unequal sample sizes. All analyses were done with the Statistica package (StatSoft, 1995, Tulsa, USA).

3. RESULTS

Stem radial growth of *Q. suber* occurred primarily in Spring at CJM (*table II*), but at HP a considerable increment was recorded in Autumn.

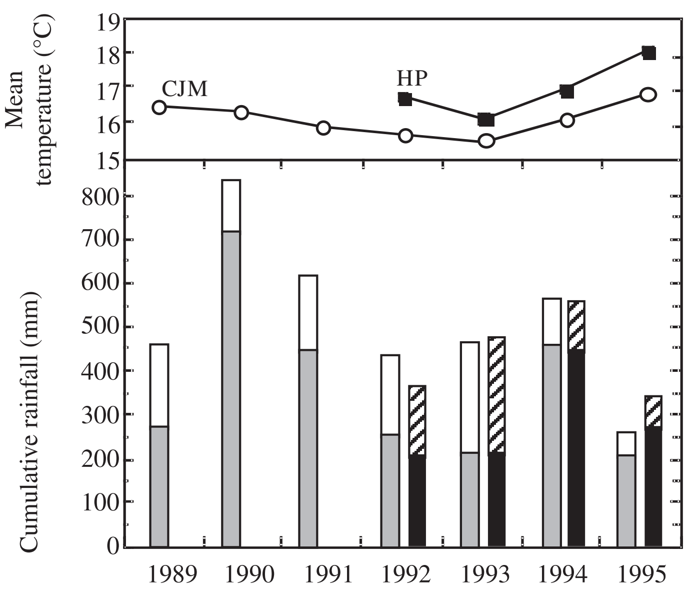


Figure 1. Climatic characteristics concerning the years of study at each site – CJM (1989–95, grey and white bars) and HP (1992–95, black and stripped bars). Cumulative precipitation from October (previous year) to February (darker bars) and March to September (lighter bars). Average annual air temperatures are displayed for CJM (circles) and HP (squares).

Table I. Characteristics of the selected cork-oaks in each stand. Values at the beginning of the study (1989 at CJM; 1992 at HP).

Stand	Last cork harvesting	Cork age (yrs)	Number of trees	dbh[#†] (m)	Tree height[#] (m)
CJM	1990	0[§]	2	0.42 (0.01)	7.5 (0.5)
	1988	1	4	0.42 (0.04)	8.0 (0.6)
	1986	3	6	0.42 (0.09)	9.9 (0.9)
HPu	1992	0	3	0.57 (0.06)	11.3 (0.9)
	1988	4	4	0.37 (0.06)	7.9 (0.7)
	1986	6	1	0.42	6.0
HPp	1992	0	3	0.46 (0.01)	8.9 (0.1)
	1988	4	2	0.38 (0.08)	8.0 (0.5)
	1986	6	2	0.34 (0.03)	7.2 (1.4)

[#] means and standard errors; [†] dbh – trunk diameter at 1.30 m; [§] in 1990.

Table II. Proportion (%) of Spring relative to annual radial increment at the three stands – CJM, HPu and HPp.

Years after cork harvesting	CJM	HPu	HPp
1	25 ± 15 (2)	53 ± 14 (3)	42 ± 2 (2)
2–3	69 ± 3 (12) [a]	41 ± 4 (5) [b]	51± 3 (6) [b]
4–9	66 ± 2 (44) [a]	47 ± 4 (14) [b]	53 ± 5 (8) [b]

Values are averages ± SE, and sample sizes. Different letters on a line represent significant differences ($P < 0.05$).

The principal component analysis revealed a strong association of climatic variables with the first axis, which accounted for 37% of data variability (*figure 2*). Growth variables were not well represented by this axis but tended to correlate negatively with Winter precipitation and with temperature variables, and positively with Spring rainfall. Radial growth was well and inversely correlated with time after harvesting; this group of variables was well described by axis 2 (27% of total variance). Factor 3 explained 13% of total variance, and was strongly associated with management, though rather poorly with growth variables.

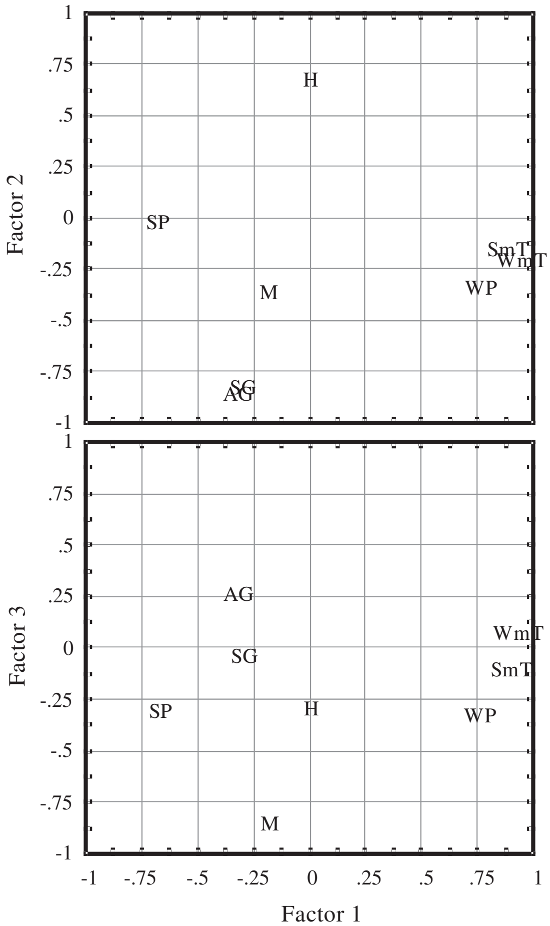
The growth rate was high during the first two years (4.0–8.2 mm yr^{-1}), as a new cork layer was being formed (*figure 3*). Afterwards, radial increments decreased (< 4.3 mm yr^{-1}, trees "88" and "86"). On the first Spring after harvesting, radial increment was rather small at CJM (*table II*) as compared to the following years. In contrast, at HP radial growth on the first Spring after harvesting roughly halved the annual value, similarly to the following Spring increments (*table II*).

4. DISCUSSION

The relative proportion of Spring and Autumn growths varied among the *montados* (*table II*). Intense Spring growth results in a thicker cork through increased number of cell layers [6]. It would be interesting to study whether the similarity between the two increments at HP derived from comparable numbers of new cell layers, or from distinct morphological characteristics of the new cells.

Thickening of cork is enhanced on the first years after harvesting, and decreases afterwards [6, 8]. Our study extends this conclusion to the whole radial growth, i.e. wood plus cork. Some authors found no effect of cork harvesting on wood growth [1], but cork extraction induces physiological reactions which may affect tree productivity [3], and this may be expected to affect wood-ring width.

Precipitation influences radial growth of *Quercus ilex* [5, 9] and the growth of cork in *Q. suber* [2, 6]. Spring (but not Winter) precipitation seemed to correlate



positively with stem increment (*figure 2*). Although Autumn-Winter and Spring temperatures also influence radial growth [5, 9], the results (*figure 2*) agree only with the finding that cork growth correlates positively with Spring temperatures, and is hindered by warm late Springs and Autumns [2].

No consistent differences in annual growth were found between different *montados* (*figures 2* and *3*). However, growth was more evenly distributed throughout the year at HP, whereas at CJM Spring growth prevailed (*table II*), suggesting different seasonalities in resource availability at the two sites.

The results showed that cork extraction is the primary determinant of radial increment in *Q. suber*. However, great stem growth does not necessarily reflect a good cork production because of the significant irregularity of cork quality [8]. The high variability in most growth parameters [this study; 7, 8] indicates that each tree is able to perform quite differently to the availability of resources, and this may be a key feature for the survival and productivity of *Q. suber*.

Figure 2. Results from a principal component analysis of the studied variables: radial increments – Spring growth (SG) and annual growth (AG); climate – cumulative precipitation of October-February (Autumn-Winter precipitation, WP) and of March-June (Spring precipitation, SP), and minimum air temperatures (Autumn-Winter, WmT and Spring, SmT); years after cork harvesting (H); and level of stand management, M (0 for HPu, 1 for CJM, and 2 for HPp). *n* = 95.

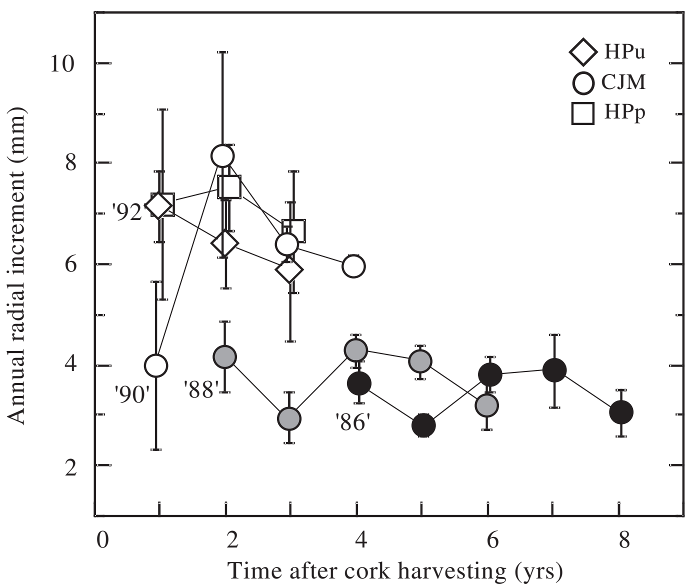


Figure 3. Variation of annual radial increment with time after cork harvesting. Values are shown for recently harvested trees (white symbols; "90", at CJM; "92", at HPu and HPp), and for trees harvested in 1986 and 1988 (grey and dark circles, CJM). Each symbol represents the mean ± SE of 2–3 ("90" and "92") or 4–6 ("86" and "88") trees.

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REFERENCES

[1] Caritat A., Molinas M., Oliva M., El crecimiento radial del alcornoque en cinco parcelas de alcornocal de Girona, Sci. ger. 18 (1992) 73–83.

[2] Caritat A., Gutiérrez E., Molinas M., Influence of weather on cork-ring width, Tree Physiol. 20 (2000) 893–900.

[3] Correia O., Oliveira G., Martins-Loução M.A., Catarino F.M., Effects of bark-stripping on the water relations of *Q. suber* L., Sci. ger. 18 (1992) 195–204.

[4] Fritts H.C., Tree Rings and Climate, Academic Press, London, 1976.

[5] Nabais C., Freitas H., Hagemeyer J., Tree-rings to climate relationships of *Quercus ilex* in NE-Portugal, Dendrochronologia 16–17 (2000) 41–48.

[6] Natividade J.V., Subericultura, DGSFA, Lisboa, 1950.

[7] Oliveira G., Correia O.A., Martins-Loução M.A., Catarino F.M., Phenological and growth patterns of the Mediterranean oak *Quercus suber* L., Trees 9 (1994) 41–46.

[8] Ferreira A., Lopes F., Pereira H., Caractérisation de la croissance et de la qualité du liège dans une région de production, Ann. For. Sci. 57 (2000) 187–193.

[9] Zhang S.H., Romane F., Variations de la croissance radiale de *Quercus ilex* L. en fonction du climat, Ann. Sci. For. 48 (1991) 225–234.