Influence of climate and soil conditions on cork oak diameter changes. An approach based on high resolution point dendrometers

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Abstract

In this work we analyse the influence of climate and soil conditions on cork oak stem growth with high resolution point dendrometers. Two experimental field plots were installed in Hinojos (Huelva, Spain) and Cortes de la Frontera (Málaga, Spain) in 2003. Inside each plot a meteorological station was installed and climate and soil variables were recorded each 15 min. Climate variables were air temperature, relative humidity, precipitation, leaf moisture, wind speed and wind direction. Soil variables were soil temperature at 30 cm depth and volumetric water content at four (Cortes de la Frontera) and five (Hinojos) different depths. Two electronic point dendrometers (extensiometric gauges with 2 µm accuracy) were attached to detect changes in diameter stem dimension in four trees in each plot, one of them over cork and other over cambium in an attempt to separate cork from wood growth.

High resolution data showed a main spring growth and an autumn growth, with last one highly dependent on autumn precipitation, and two rest periods: in winter due to low temperatures and at the end of summer due to very low soil water resources. The duration of summer inactivity is highly dependent on the soil moisture level of the year. A high variability in growth rates is observed between trees inside the same plot.

Keywords: stem growth, climate, soil, electronic point dendrometer, Quercus suber.

Introduction

Cork oak (*Quercus suber* L.) is one of the most important forest species of the mediterranean region in Spain. According to II National Forest Inventory it covers 409.025 ha that is 3,9% of the total forest tree cover of the country. They are usually forests with a high human intervention, mainly focused in providing food for cattle (acorns and pastures), firewood and cork. It is one of the few mediterranean forest species that could be preserved just taking into account its economical importance, due to the extraction of cork and the high added value of cork stoppers. It has also a very high ecological and landscape value and one of the most efficient mediterranean systems to couple with a limiting, diverse and highly interannual variable environment (Montero *et al.*, 1998).

Detailed knowledge about growth of this forest species and its relationship with climate and soil factors is very important at different levels:

- It allows a better understanding about the role of these forests in the CO_2 fixation process and its seasonal evolution.
- It facilitates the sustainable management of the species as it improves the knowledge about the development and evolution of forest and, then, the planning of regeneration and thinning treatments under technical criteria.
- It could improve the growth-climate functions that can be found in general ecosystem and forest dynamic models -p.e. JABOWA, in Botkin *et al.*, (1972), FORET, in Shugart (1984), FORENA, in Solomon (1986), FORSKA2, in Price and Apps (1996)-, that are usually empirical and with little ecophysiological basis.
- It allows the performance of growth simulations under different climate change scenarios.

The traditional dendroclimatological approach, based in the relationship between easy-to-measure climatic parameters, as temperature and precipitation, and growth rings width has an annual scale. In these studies, climatic parameters are usually obtained from meteorological stations situated far from the study sites and soil factors are not taken into account due to a lack in soil characterization. The simple analysis of growth rings sometimes is not sensitive enough to detect the influence of environmental factors on tree growth (Phipps, 1982). This approach is neither adequate if we are interested in the factors related with cambial activity activation and cessation, that is a key point to analyse the influence of climate change on tree growth.

A more detailed approach for climate-growth analysis is the use of dendrometers installed around the tree stem (band dendrometers) or on an specific point (point dendrometers) with manual recording of growth at certain intervals (bimonthly, monthly, quarterly..). This allows a more sensitive analysis with a shorter scale (monthly, quarterly). This approach is frequent due to the low cost (Costa *et al.*, 2003; Lagergren and Lindroth, 2004; Baker *et al.*, 2002; Miller *et al.*, 2001; Crossley *et al.*, 1997; Vose and Swank, 1994; Pereira da Silva *et al.*, 2002).

Evaluation of the relationship between environmental factors and growth is more efficient using continuous growth measurements and the installation of meteorological weather stations and soil sensors in the proximity of the study areas (Schweingruber, 1996). Nowadays, electronic dendrometers allow the continuous measurement of the cambial activity with micron accuracy in a temporal scale that can vary from seconds until days. There are basically two types (Tardif *et al.*, 2001): 1. Band dendrometers, that measure the changes in the tree perimeter and provide a good estimation of mean radial growth, regarding errors associated with termical dilatation and contraction of the material and 2. Point dendrometers, that measure changes in a specific point of the stem. Values obtained can differ significantly due to exposition or height (Bormann and Kozlowski, 1962) but they are more efficient to detect inner tree variations.

Electronic dendrometers can also detect daily variations in stem diameter that can be explained as variations in the stem water content (Kramer and Kozlowski, 1979). These daily variations have been later closely related to the transpiration and sap flow processes (Irvine and Grace, 1997) and negative growth values in stem diameter in several consecutive days with severe drought conditions (Worbes, 1999). This indicates the possibility to relate daily variation data obtained with electronic dendrometers with ecophysiological processes (Peramaki *et al.*, 2001; Sevanto *et al.*, 2001; McLaughlin *et al.*, 2003).

The main disadvantage of dendrometers is the interpretation of data: measurements cannot distinguish the phloem, xylem or peridermis growth and either growth, due the addition of new cells, from the stem daily variations (Tardif *et al.*, 2001). Periodical histological analysis with extraction of joint xylem-phloem-peridermis tissues can better establish the cambial activity period (Fraser, 1956), even if it is time consuming and it produces some damage to the tree in comparison with dendrometers (Pereira da Silva *et al.*, 2002). Due to the advantages and disadvantages of both methods (dendrometer vs. histological analysis) it is widely recognised the importance of using them simultaneously to have a detailed knowledge about the tree vegetative periods (Deslauriers *et al.*, 2003a).

Most of the studies related with the influence of climatic factors on stem growth in an intranual or daily scale are focused on boreal or taiga ecosystems, where temperature is the main limiting growth factor. There are studies focused on *Abies balsamea* (Deslauriers *et al.*, 2003b; Deslauriers *et al.*, 2003a; Tardif *et al.*, 2001), *Pinus sylvestis* (Peramaki *et al.*, 2001; Sevanto *et al.*, 2001; Sevanto *et al.*, 2002; Sevanto *et al.*, 2003; Antonova *et al.*, 1995; Antonova and Stasova, 1993; Schmitt *et al.*, 2004), *Betula papyrifera, Thuja occidentalis, Picea glauca, Picea mariana, Pinus banksiana, Pinus resinosa* (Tardif *et al.*, 2001), *Liriodendron tulipifera* (McLaughlin *et al.*, 2003), , *Chamaecyparis obtusa* (Kuroda and Kiyono, 1997), *Larix sibirica* (Antonova and Stasova, 1997), *Picea abies* and *Pinus cembra* (Deslauriers *et al.*, 2004). All these studies reflects the sensitivity of dendrometers to analyse the influence of climate on growth, its utility to relate the data obtained with ecophysiological variables related with tree water status (Sevanto *et al.*, 2001) and the interest of combining dendrometer data with histological analysis to characterise with higher accuracy the growth periods (Rossi and Deslauriers, 2003).

Detailed studies in mediterranean-type climates under natural conditions are scarce. In this environment the main limiting growth factor is not only temperature but water availability in the drought season so a detailed analysis require the acquisition of continuous soil water moisture data. In this study we analyse the influence of climate and soil conditions on cork oak stem growth with high-resolution point dendrometers.

Material and methods

Study sites

Experimental sites are situated in two areas with contrasting environmental conditions:

1. Hinojos (Huelva, Spain). It is a flat cork oak (*Quercus suber* L) stand with presence of scattered holm oak (*Quercus ilex* L.) trees at 100 m.a.s.l. Plot area is 1,89 ha, density is 99,6 trees ha^{-1} and basal area 8,1 m^2 ha^{-1}. Climate is typical Mediterranean IV_2 (Allué, 1990) with mean anual precipitation of 579 mm and mean annual temperature of 18,9ºC. Soil is a complex profile with a sandy loam to loamy sand upper layer of 25-40 cm thickness over an argilic horizon (with loam clay to sandy clay loam and clay texture) showing stagnic properties. It is classified as Planosol (FAO, 1998).

2. Cortes de la Frontera (Málaga, Spain). It is a *Quercus suber* L. stand with scattered *Quercus pyrenaica* Lam. trees at 830 m.a.s.l. situated in a 20% slope facing east exposition. Plot area is 0,67 ha, with a density of 345 trees ha^{-1} and basal area of 24,9 m^2 ha^{-1}. Climate is Mediterranean IV_4 (Allué, 1990) with mean annual precipitation of 1.400 mm and mean annual temperature of 14ºC. Soil is classified as Cambisol (FAO, 1998).

Experimental layout

Climatic and soil variables were gathered through a meteorological weather station installed inside each plot from May 2003 until June 2006. Data was registered each 15 min and included precipitation, air temperature, relative humidity, PAR radiation, wind speed and direction, leaf wetness, soil temperature at 30 cm depth and soil moisture (C-Probe® sensor) at 10, 30, 60, 90 and 120 cm depth at Hinojos plot and 10, 30, 60 and 90 cm at Cerro del Castillo.

To measure stem growth, two electronic point dendrometers (extensiometric gauges with 2 µm accuracy) were attached in four trees in each plot to detect changes in stem diameter, one of them over cork and other over cambium in an attempt to separate cork from wood growth. To attach the sensor to account only cambial and not phellogen activity we stripped a rectangular cork window of approximately 5 x 10 cm on each tree.

Results and discussion

Hinojos (Huelva) plot

Figure 1 shows the results of continuous growth monitoring in the four trees over cork and Figure 2 over wood from 15/5/2003 until 6/6/2005, with the representation of the maximum value of the sensor per day. There is a main growth period from mid March to mid July and one less stressed in autumn. There are also two clear rest periods: one in winter from mid November to mid March and a second one at the end of summer, from mid July to the starting of the autumn rain season. In autumn 2004 and spring 2005 growth was much more reduced in comparison to previous years due to the severe drought that was affecting the region. In the sensors attached to the wood some growth could be detected due to the activity of the new phellogen that was developed after the stripping in 2003. Also the contraction that is detected in winter 2005 from the sensor attached to cork is higher than in previous years due the low temperatures. Variations in stem diameter are much higher in sensors attached to the cork due to the hygroscopic properties and termical expansion and contraction of cork.

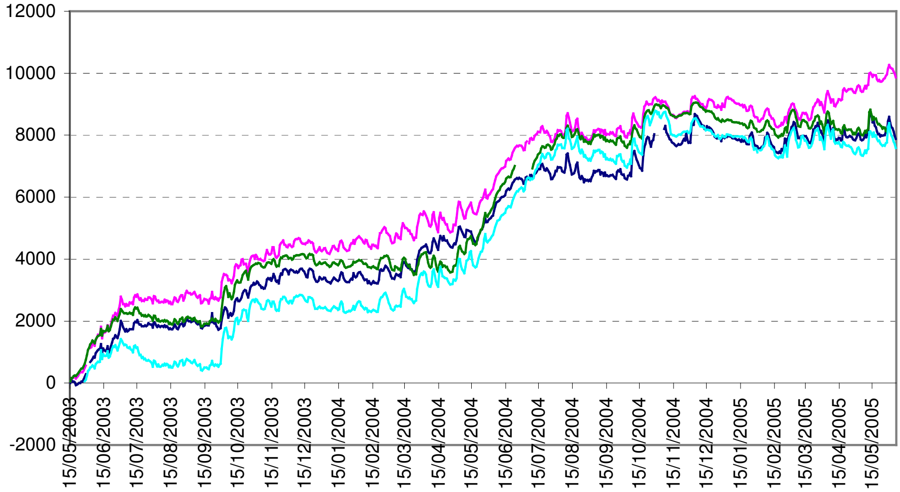

Figure 1. Continuous growth monitoring in Hinojos (data in microns). Results from sensors over cork

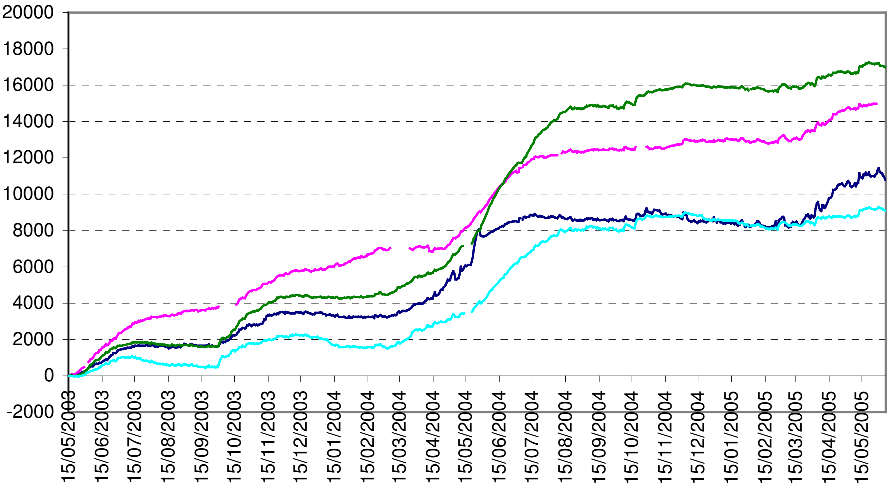

Figure 2. Continuous growth monitoring in Hinojos (data in microns). Results from sensors over wood

The influence of climate on tree growth can be done graphically observing Figure 3. The winter rest period is clearly related with a period with mean daily temperatures below 10-12 ºC. The activation of growth in spring is related with a period of continuous mean daily temperatures over 12ºC. The summer rest period is consequence of the low soil water availability with mean percentage values in the 0-120 cm layer below 10% in the plot. The activation of autumn growth due to hydration or production of new cells starts after the first rain event after the summer drought.

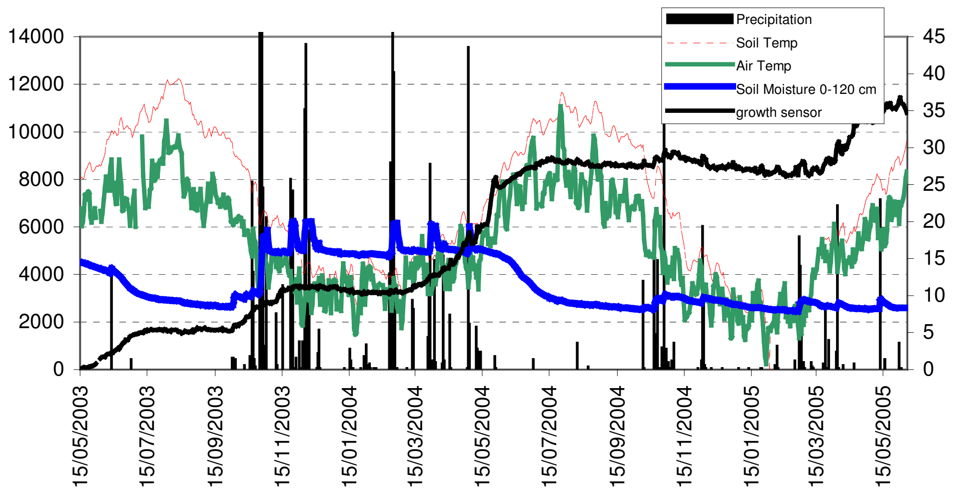

Figure 3. Daily mean values of soil temperature at 30 cm (ºC), air temperature (ºC), soil moisture content from 0 to 120 cm (%) and daily precipitation (mm) and growth of tree 51 (wood sensor) (in microns) in Hinojos plot

Comparison between growth rates are better shown in Figure 4, where moving average of 20 days for daily growth rates are presented. A maximum value of 130 microns per day can be observed in the period May-June 2004, where water availability and temperature was high. Negative values (contraction) are observed in summer, due to low water availability, and winter, due to low temperatures. Differences between trees are due to differences in phenology and microecological conditions.

Interannual variations in tree growth can be better detected in Figure 5, where the moving average of 20 days are shown for tree 51. The influence of drought on tree growth is clearly marked: growth rates in autumn 2004 and spring 2005 are less than in previous years. Growth in May 2005 is already negative while it was maximum in 2004.

Cerro del Castillo (Málaga) plot

Figure 6 shows the results of continuous monitoring in the four trees over wood and Figure 7 over cork from 2/9/2003 until 10/6/2005, with the representation of the maximum value of the sensor per day. Comparing with Hinojos plot, total growth over cork is higher in Cerro del Castillo but the mean values over wood are similar. Differences between trees inside the plot are also less stressed in Cerro del Castillo, specially taking into account over cork measurements, indicating more homogeneous site conditions inside the plot.

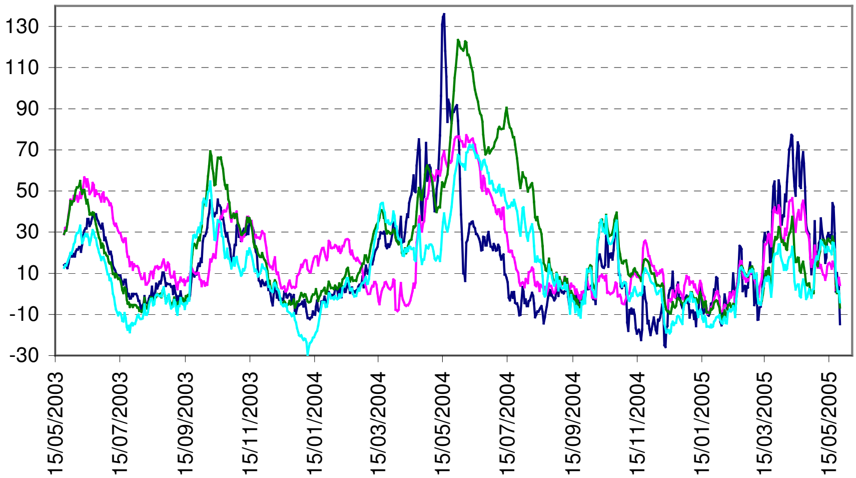

Figure 4. Moving average of 20 days for daily growth rates in Hinojos plot in microns per day. Data corresponding to sensors attached to wood.

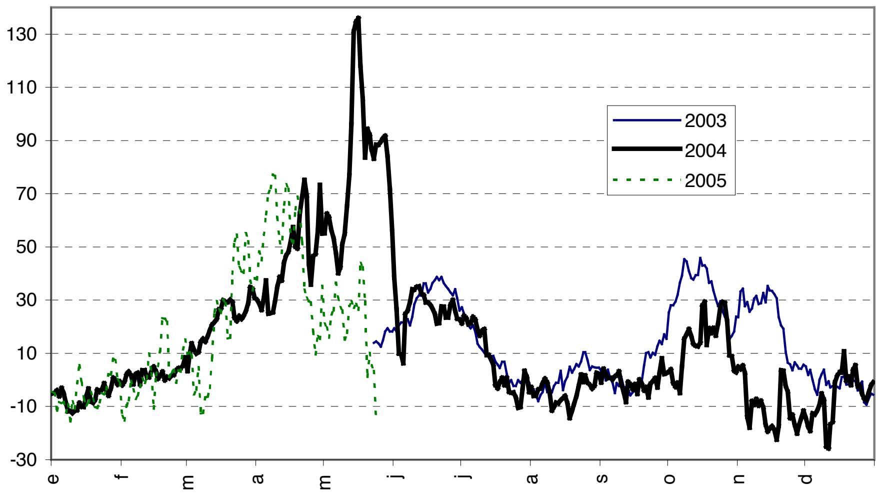

Figure 5. Moving average of 20 days for daily growth rates in Hinojos plot in microns per day for tree 51 (wood component)

In Cerro del Castillo, a longer winter rest period can be observed from beginning of November to beginning of May, due to lower temperatures. The summer rest period is almost no visible, as the growth continue, in most of the trees, until the beginning of November but with a lower growth rate. Autumn reactivation of growth after the first autumn precipitation is not visible either and the effect of the drought in spring 2005 on growth is almost negligible.

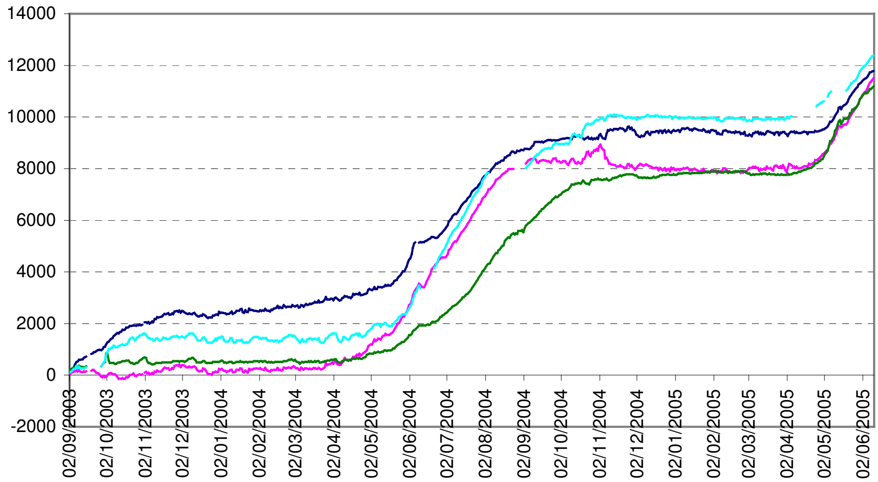

Figure 6. Continuous growth monitoring in Cerro del Castillo (data in microns). Results from sensors over wood.

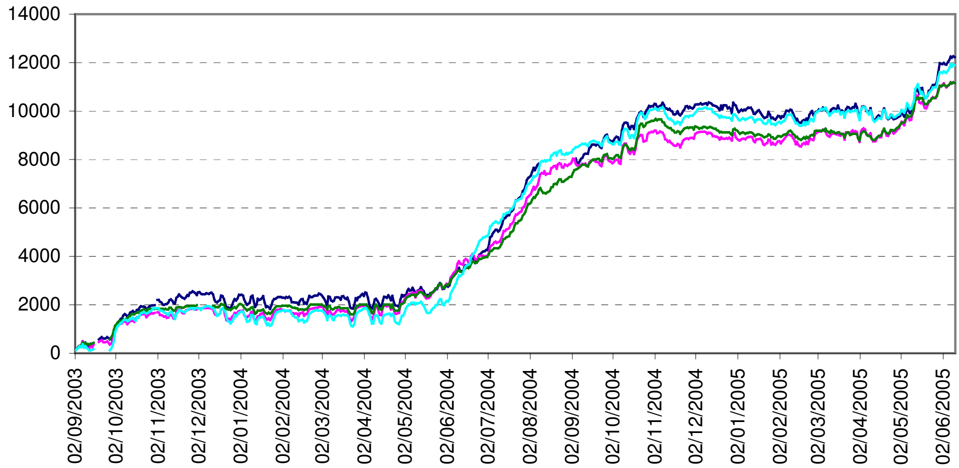

Figure 7. Continuous growth monitoring in Cerro del Castillo (data in microns). Results from sensors over cork

As in Hinojos plot, spring activation of growth (Figure 8) is related with a period where mean daily temperatures raise over 12ºC. The growth rate slow down when water availability is low (mean percentage values under 6% in the 0-90 cm layer) and growth cessation is reached when temperatures go down under 10-12ºC again.

Maximum growth rates in Cerro del Castillo plot reach 90 microns per day (Figure 9), that last for June and July considering centered moving average of 20 days. Some negative values can be detected in winter but an end of summer contractions due to drought are not observed in this case. The interannual variations are not so stressed as in Hinojos plot. Figure 10 shows the comparison of growth rates for tree 10 (sensor over wood).

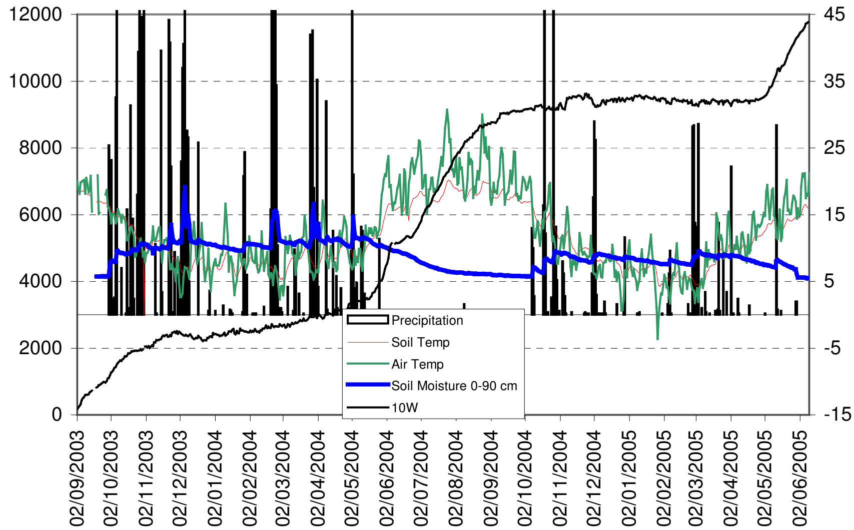

Figure 8. Daily mean values of soil temperature at 30 cm (ºC), air temperature (ºC), soil moisture content from 0 to 90 cm (%) and daily precipitation (mm) and growth of tree 10 (wood sensor) (in microns) in Cerro del Castillo plot

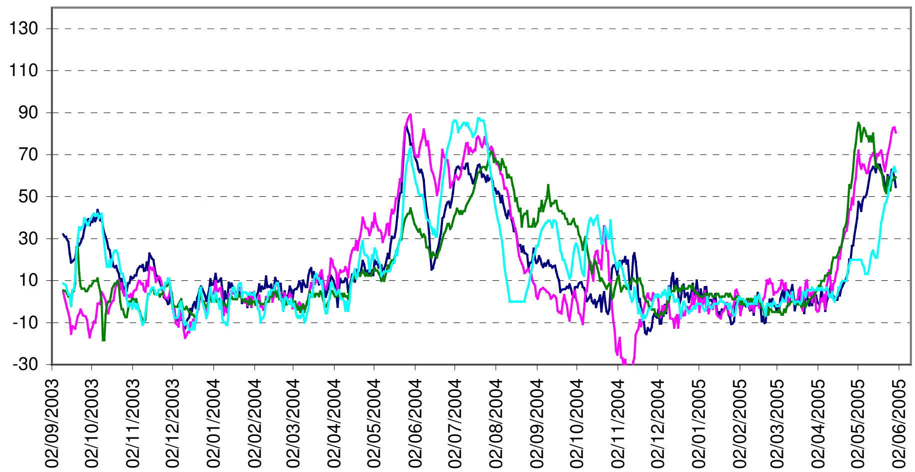

Figure 9. Moving average of 20 days for daily growth rates in Cerro del Castillo plot in microns per day. Data corresponding to sensors attached to wood.

The comparison of growth rates between Hinojos and Cerro del Castillo are better understood observing Figure 11. Hinojos shows highest growth rates but during less days than Cerro del Castillo. The spring growth activation occurs in Hinojos two months earlier than in Cerro del Castillo due to the higher temperatures in the first region. Activation of growth in autumn is more stressed in Hinojos, but with high interannual variability.

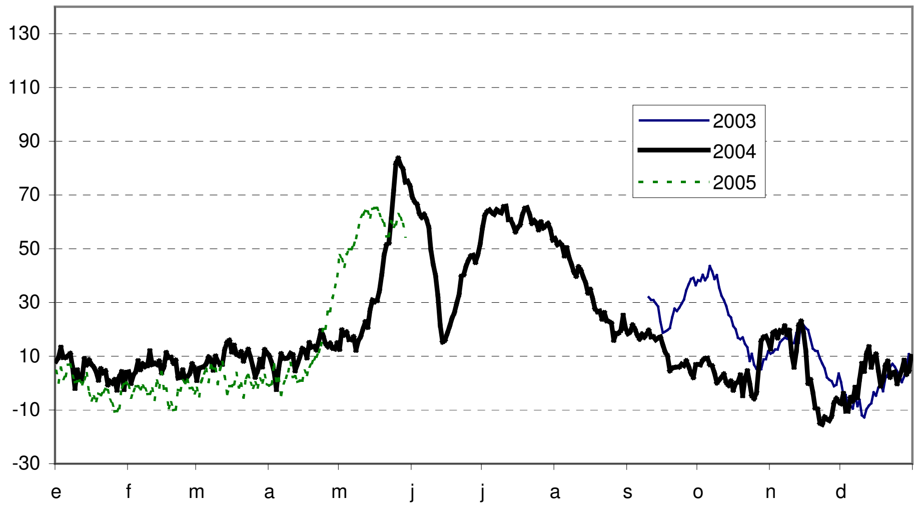

Figure 10. Moving average of 20 days for daily growth rates in Cerro del Castillo plot in microns per day for tree 10 (wood component)

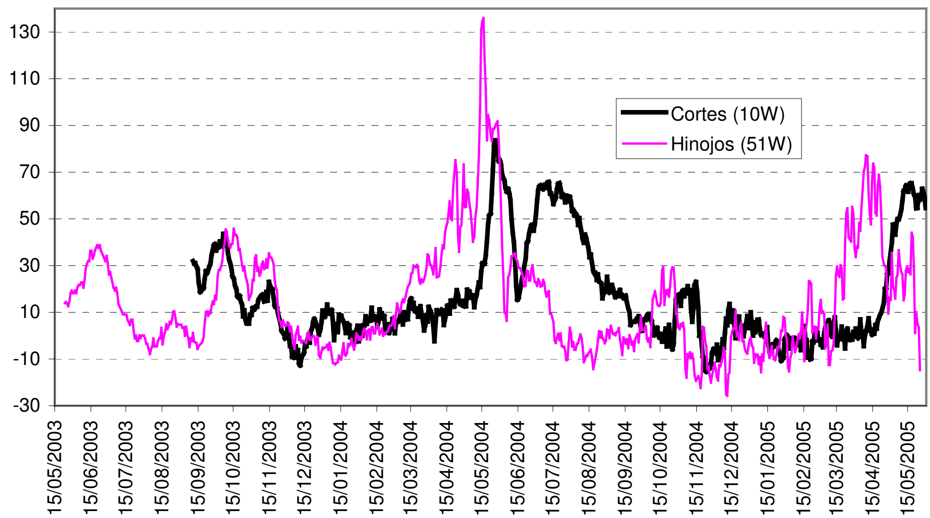

Figure 11. Comparison of growth rates using moving averages for 20 days between Cerro del Castillo (tree 10, sensor over wood) and Hinojos (tree 51, sensor over wood). Data in microns per day

Conclusions

Cork oak has a main growth period in spring when water availability and temperatures are high. Activation of cambium after winter occurs when mean daily temperatures are higher than 12ºC, giving a period of cambial inactivity of 4 months in Hinojos and 7 months in Cerro del Castillo. Water availability is a clear limiting factor for growth in Hinojos plot that leads to a period of cambial and phellogen inactivity at the end of the drought period when mean volumetric water content in soil is less than 10%. In Cerro del Castillo there is not a clear stop in cambial or phellogen activity due to drought but a reduction in growth rate can be observed when volumetric water content is less than 6%. Activation of cambial activity or hydration can be observed after the first autumn precipitation in Hinojos plot.

A high interannual variation in growth rates occurs mainly in Hinojos plot due to high interannual differences in precipitation.

High resolution point dendrometers are a very useful tool to analyse the influence of climatic factors on stem growth. A more detailed appreciation of the periods of cambial activity or a clear separation of cambial and phellogen activity will require a simultaneous histological analysis with periodical extraction of microcores.

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