Seasonal pattern of physiological state in a cork oak *(Quercus suber L.)* stand in Huelva (Spain)

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Abstract

The seasonal pattern of the physiological state of *Quercus suber* is determined by different ecological factors, and it affects to the growth of the species. The main objective of this study is to know the seasonal pattern of water potential, photosynthesis and fluorescence in four *Quercus suber* L. trees and to relate these values with ecological factors during two years.

In this time there were three critical periods, the first one the end of the dry period where the water potential descends to values less than -3MPa and the photosynthesis to 0.781 µmol CO_2 $m^{-2}s^{-1}$. The second critical period is located in period of change of the leaf, between the months of March and May. The third critical period occurred due to the freezes and drought of the year 2005, that produced strong damages in the PSII.

Keywords: Quercus suber, physiology, water potential, photosynthesis, fluorescence.

Introduction

The cork oak (*Quercus suber* L.) it is one of the most important forest species in the Iberian Peninsula. In Spain it is the eighth forest species with more covered area (503.000 ha) (DGCONA, 1998) with 32% of their surface in protected areas.

The environmental importance of *Quercus suber* and economic value by the cork production, it is indispensable a correct management that should be based on technical approaches and in the knowledge of the ecology of the species. In this sense it is fundamental to know the influence that ecological factors and the management exerts in the physiological status and growth. This knowledge can be used later on for the development of growth and production models with ecological base and the possibility to apply these models for management purposes.

The ecological factors have a great influence in the growth and development of forest species. In the regions of mediterranean climate, the factors related with the hydric regime acquire an great importance because during a long period of the annual cycle exists a limited water resource and that coincides with a favorable time (high temperatures) for the growth development (Moreno, 2001). The shortage of water is considered the main restrictive factor for the plant development in this type of climates (Oliveira 1995) and for this reason there are many works that overcome the response of plant development under these ecological conditions (Lange *et al.*, 1987; Tenhunen *et al.*, 1984; Faria *et al.*, 1998; Oliveira, 1995).

The photosynthesis is the main process that gives chemical energy to the ecosystems (Lange *et al.*, 1987). The reception of the dioxide of carbon and loss of water are two processes that are intimately bound, as both are carried out by stomata way. The productivity of any plant depends on its capacity to maintain the photosynthetic tissues with an appropriate water status (Passioura, 1982), and for that plant species develop processes that allow the assimilation of the CO_2 minimizing the loss of water (Cowan, 1977). These processes are especially evident when the environmental conditions of the mediterranean ecosystems favor the leaf transpiration but they are limiting the supply of water to the vegetation (Oliveira, 1995).

Most of published studies that investigate the restrictive factors for the productivity in mediterranean species are centered in the spring and the summer seasons. However, in those species that maintain the leaf covering in the winter months, as the case of cork oak, the physiological behavior of the leaves in this time can play an important role in the global strategy of the plant (Tretiach, 1993). It is also known that the summer drought is not the only restrictive factor in the productivity and growth of the mediterranean species. In winter, for example, the thermal limitations can be important. But, apart of environmental factors, there are other conditions that influence photosynthesis like the age and the structure of the leaf and the growth rate that is directly dependent on the genotype.

The knowledge of the processes of the photosynthesis and assimilation of water in the plant will allow us to study the limitations in the vegetable productivity under stress conditions. It is also important the knowledge of the soil factors, since in most of the terrestrial plants the entrance of water is carried out through the roots and it can be affected by the water retention capacity and temperature of the soil, and size and distribution of the roots (Rambal, 1984).

In this study we analyze the seasonal variation along two years of photosynthesis, water potential and fluorescence of the chlorophyll of the leaves of four cork oaks in an open forest (dehesa) in Hinojos (Huelva).

Material and methods

Data have been collected in a plot located in the Montes Propios de Hinojos (Huelva). This plot is located in a flat cork oak open forest (dehesa) with scattered holm oak (*Quercus ilex* L.) trees, at an altitude of 100 m.a.s.l. The area of the plot is 1,8 ha with a density of 99,6 trees ha^{-1} and a basal area 8,1 m^2 ha. Climate is typical Mediterranean IV_2 (Allué, 1990) with mean anual precipitation of 579 mm and mean annual temperature of 18,9 ºC. The precipitation in the period July 2003 - June 2004 was of 826.4 mm and between July 2004 and July 2005 was 266.2 mm. 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. The superficial pH is of 5.5 and the content in organic matter of 1.5%. It is classified as Planosol (FAO, 1998). Inside the plot meteorological station was installed, that allows to know the climatic conditions when carrying out the physiological measurements.

For the study of the variation of physiological status, four trees of the plot were chosen (trees nº 13, 14, 51 and 68). The trees 13 and 14 are located in a water-course area and with higher density, while the trees nº 51 and 68 are in a flat area under less inter-tree competition. The competition index "Overlapping of areas of influence" (Vázquez *et al.*, 2001), considering a radius of influence (in m) of each tree Ri=0,2 * Dn (Dn, Diameter at breast height, in cm) and an exponent of diameters quotients k=1, takes the values 0, 0.66, 1.20 and 1.40 for the trees 68, 51, 14 and 13 respectively.

Measurements started in July 2003 and they had a bimonthly repetition until February 2004 where began to be monthly until July 2005 (20 measurements in total). These measurements were carried out in the central hours of the day between the 11.00 hours and the 13.00 hours

Measurements of the xylem water potential, parameter used as an indicator of the water deficit, branches of the external part were picked up from the half height of crown. Four branches were selected by tree, one for each orientation (N,S,E,W). Measurements were carried out by a pressure chamber (PMS Instruments, Model 1000, Corvallis, Oregon, USA).

Carbon dioxide uptake, that allow consider the net photosynthesis rate, was measured with a portable CO_2 IR analyzer (LCi, ADC®, UK). The leaves used were chosen with the same approaches and at the same time that the branches used in the water potential.

Measurement of chlorophyll fluorescence was carried out with a fluorimeter (1500 FIM®). Two leaves were selected in good state in the south exposition and two in the east exposition. They were maintained in darkness for 15 minutes and a ray of red light during 5 seconds to 50% of the equipment capacity was selected. The parameters that were measured were: the basal fluorescence (Fo), the variable fluorescence (Fv), the maximum fluorescence (Fm), the half time in reaching the variable fluorescence (Tm) and the relationship Fv/Fm that allows us to evaluate the photosynthetic efficiency of the photosystem II.

Parallel to these measurements we monitored the temporal and spatial variation of soil water, the crown phenology (following Díaz (2000) tipification), the production of reproductive and vegetative organs and litterfall (monthly), that allowed to discuss the variation of the physiological status in function of the environmental variables and phenology.

Results and discussion

Climate in the study period

One of the environmental factors that more affects to the physiological parameters of the plants is the climate. In Figure 1 we show the climodiagrams corresponding to the two years of study with data collected from the meteorological station installed in the plot

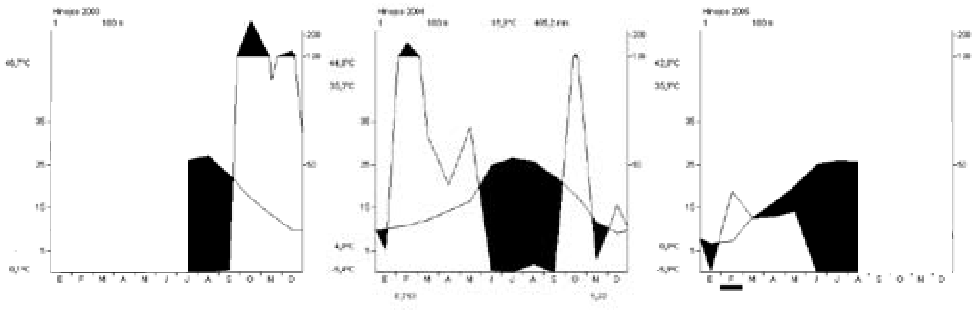

Figure 1. Climodiagrams corresponding to the meteorological station of the plot (July 2003-August 2005)

Large variability between years can be seen in the climodiagrams of Figure 1. The following events can be emphasize:

- August of 2003 with absolute maximum temperatures of 46.7 ºC and mean of the maximum temperatures 36.9 ºC.
- Severe frosts in January and February 2005, with mean of the minimum temperatures reaching 0.5 and 0.0ºC respectively, that is 5ºC less than the previous year with absolute minimum values of –5.9ºC.
- Severe drought in 2005. Precipitation in the period october 2003 - september 2004 was 828.8 mm, while in the period October 2004- September 2005 was only 266.2 mm.

Water status

The results have been clearly influenced by climate with very different hydrological years. In the years 2003 and 2004 with high precipitation, the water potential presents very marked seasonal variations (Figure 2) with minimum at the end of dry period with values of -3,3 MPa. These levels are similar to other studies of mediterranean species, as the one carried out by Moreno (2001) that presents minimum potentials in holm oak (*Quercus ilex* L.) of -3,4 MPa in the south of France.

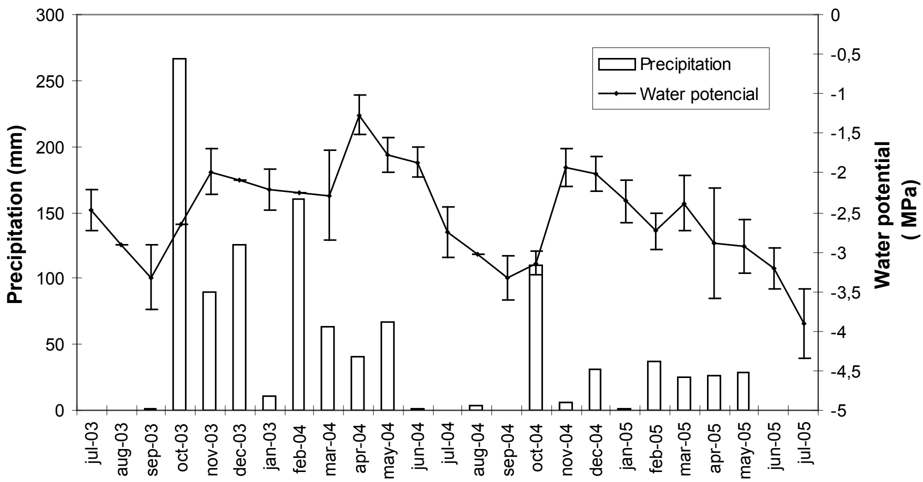

Figure 2. Evolution of the average water potential and monthly precipitation during the study period.

A gradual recovery of the potential exists with the precipitations of autumn, with a slight descent in winter months, due to the descent of the precipitation. A new increase of the potential registers starting from March 2004 that is when the vegetative activity begins. The maximum value, with -1.2 MPa, is reached in April 2004, when the trees are in full production of new leaves, a smaller covering of leaves exists and the soil water availability is high.

The high between-tree variability of the water potencial measured in the months of March and April, when the trees are producing the new foliage, could be influenced by the different phenological state of the trees, with leaves in different states of development, that indicate the differences in the beginning of the vegetative activity. This variability observed in the month of April was already described in Oliveira (1995) in Portugal. Nevertheless, this author measured homogeneous leaves previous to the leaf fall, which was occurring in May in that area of Portugal. Oliveira explains the high variability in the different response of different leaves under the same ecological conditions and in measurements errors.

The low precipitation registered during winter 2005, that reached only 0.8 mm in January 2005, produced a descent of the water potential in February to -2.7 MPa, similar to the value of July 2004. The slight increase in precipitation in February (37.4 mm) motivated the slight increase in the potencial, but starting from this month recovery no longer exists. This shortage of water caused that the sprout was delayed until April, and due to the absence of rain sprout was paralyzed in most of the trees.

In July 2005, the minimum values registered of the water potential from the beginning of the study were reached, with a mean value of - 3.9 MPa. It is interesting to highlight that in some of the branches this potential reached values below -4.6 MPa. In conditions of severe water stress individuals show noticeable differences in the physiological parameters that indicates the existence of genetic differences for drought resistance (Castro *et al.*, 2001).

Photosynthesis

The net photosynthetic rates (A) (Figure 3) are related the precipitations and also with the phenological state of the leaves. The lowest levels in the year 2003 are 0.781 μmol CO_2 $m^{-2}s^{-1}$ registered in September, at the end of the dry period. The recovery of the photosynthetic levels takes place when soil moisture contents recovers with autumn precipitation. The photosynthetic rate in autumn-winter is quite high with mean values between 5.6 and 6.6 μmol CO_2 $m^{-2}s^{-1}$. These data are logical as winter temperatures in the study area are warm (Figure 1), the photosynthetic system is not damaged (Figure 3), neither the leaf is in deep dormancy.

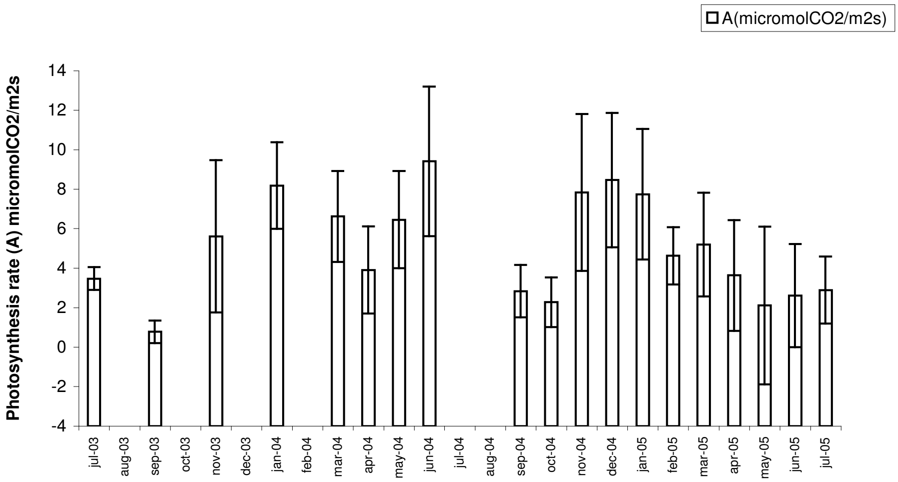

Figure 3. Evolution of photosyntetic rate (A) for the study period

In April 2004 a remarkable decrease of A is registered with values of 3.96 μmolCO_2 $m^{-2}s^{-1}$, because the measurements were carried out on new leaves. With the totally developed new leaves, the trees recovered their photosynthetic capacity, being reached the maximum in June with mean levels of 9.4 μmolCO_2 $m^{-2}s^{-1}$.

In winter 2005 the strong frost caused serious damages in the photosynthetic system causing the descent of the photosynthesis rates , with mean values in February of 4.62 μmolCO_2 $m^{-2}s^{-1}$. Since March of 2005, with severe drought continuing, the photosynthesis rates did not overcame the value of 3.5 μmolCO_2 $m^{-2}s^{-1}$.

Fluorescence of the chlorophyl

The measurement of the state of the photosynthetic nuclei through the photosynthetic efficiency (Fv/Fm) (Figure 4) shows the variation of the phenological state of the trees.

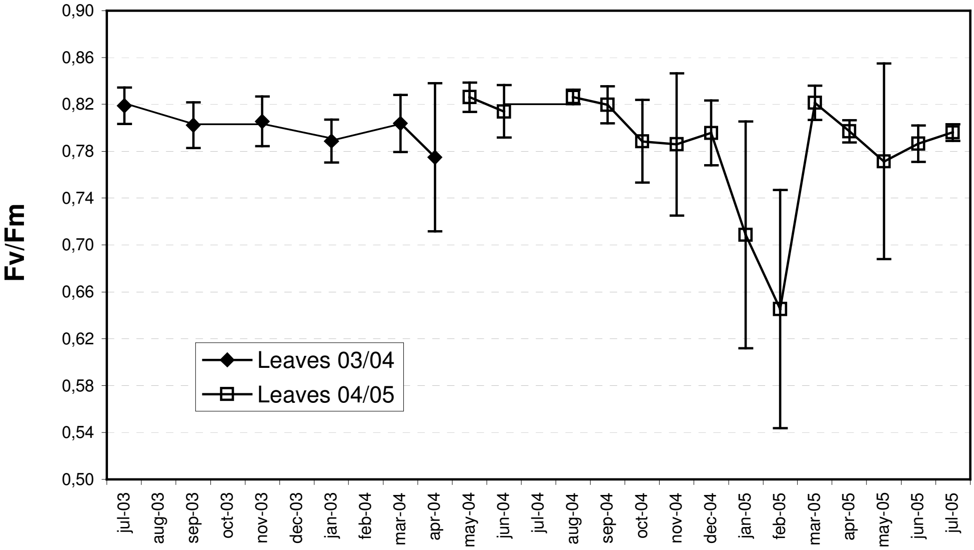

Figure 4. Variation of the mean photosynthetic efficiency (Fv/Fm) along the study period

In March all the measurements were carried out on leaves formed in the previous year. In April the trees 13,14 and 68 presented recently formed leaves, but not the 51. In April, coinciding with the formation of new leaves that do not have totally developed their photosynthetic tissues, the photosynthetic efficiency was the minimum of the year with Fv/Fm average values of 0.775, with a great variability between trees motivated by the different states of leaf development. The best photosynthetic efficiency was reached from May until August with values of Fv/Fm between 0.826 and 0.814. From September a descent begins until the month of January with minima of 0.788.

January 2005 was characterized by severe frosts (minimum temperatures of -5.9 ºC) and absence of precipitation. The photosynthetic apparatus suffered big damages with differences motivated for the geographical situation inside the plot: trees 13 and 14, situated in a more protected area of the plot with higher competition maintained levels of Fv/Fm of 0.78, while trees 51 and 68, growing in a more exposed area registered average values of 0.68 and 0.58 respectively. These damages were also more evident in the most external leaves in the crown, more exposed to freezing. These frost damages produced and abundant leaf fall and trees maintains only the leaves that suffered less damages.

In winter and spring 2005 the absence of precipitation continued and most of the trees in the plot did not produce new leaves in spring but with some variations in the studied trees: tree 68 was able to produce new leaves but trees 13 and 14 stopped the production of new leaves and maintained the old leaves in operation. Tree 51 that was not able to produce new leaves and maintained a reduced leaf biomass but with acceptable Fv/Fm levels. This data shows that leaves are not renewed if there is not enough precipitation and the trees, in an adaptive mechanism to the extreme environmental conditions, maintain part of the functional leaves of the previous year. Values presented by Faria (2001) for cork oak in the months of summer in Portugal for the photosynthetic efficiency have the same variation range that those we measured in Huelva.

Conclusions

Water potential presents very marked seasonal variations with minima at the end of drought period with values of -3,3 MPa. The maximum potential (-1.2 MPa) is reached when trees are in full production of new leaves, a small leaf biomass exists and the water content in soil is high.

The high variability of the physiological parameters measured in March and April is due to the different phenological state of the trees.

Under conditions of strong water stress the different individuals presented marked differences in the physiological parameters that indicates a high genetic variability The sprout and production of new leafs in spring does not occur in severe drought conditions. In that case trees maintain functional part of the leaves of the previous year as an adaptative mechanism to the extreme environmental conditions.

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References

Allue, J.L.; 1990. *Atlas fitoclimático de España.* Ministerio de Agricultura Pesca y Alimentación. Madrid.

Castro, L., Aranda, I., Gil, L., Pardos, J.A.; 2001. Relaciones hídricas en procedencias de Quercus suber L. Actas del III Congreso Forestal Español Granada, 1: 347-353.

Cowan, I.R.; 1977. Stomatal behaviour and environment. Adv.Bot.Res. 4: 117-288

DGCONA, 1998. Segundo Inventario Forestal Nacional. DGCONA. Ministerio de Medio Ambiente, Madrid.

Diaz, P.M.; 2000. Variabilidad de la fenología y del ciclo reproductor de Quercus suber L. en la península Ibérica. Tesis doctoral. Universidad Politécnica de Madrid. Madrid

FAO, 1998. Base referencial mundial del recurso suelo. Informes sobre recursos mundiales de suelo 84. FAO. Roma.

Faria, T., Silvério, D., Breia, E., Cabral, R., Cabral, A., Abadia, A., Abadia, J., Pereira, J.S., Chaves, M.M., 1998. Differences in the response of carbon assimilation to summer stress (water deficits, high light and temperature) in four Mediterranean tree species. Physiologia plantarum 102: 419-428.

Lange, O.L., Beyschlag, W., Tenhunen, J.D., 1987. Control of leaf carbon assimilation- Input of chemical energy into ecosystems. In : Schulze, D., Zwolfer, H. (eds.) Ecological studies, 61: 149-163. Springer, Berlin.

Moreno, G.; 2001. Efectos del déficit hídrico en el balance de carbono de la encina (Quercus ilex. L). Actas del III Congreso Forestal Español Granada, 2: 554-560.

Oliveira, M.G.; 1995. Autoecología do sobreiro (Quercus suber L.) em montados portugueses. Tesis doctoral. Universidad de Lisboa. Lisboa.

Passioura, J.B.; 1982. Water in the soil- plant-atmosphere continum. InEn: Physiological plant ecology II- Water relations and carbon assimilation. In: Lange,O.L., Nobel, P.S., Osmond, C.B., Ziegler,H. (eds). Encyclopedia of plant physiology, New Series, 12B: 5-33. Springer, Berlín.

Rambal, S.; 1984. Water balance and pattern of root water uptake by a Quercus coccifera L. evergreen scrub. Ecologia 62: 18-25.

Scholander, P.F., Hammel H.T., Hemmingsen, E.A., Bradstreet, E.D., 1964. Hydrostatic pressure and osmotic potential in leaves of mangroves and some other plants. Proceedings of the National Academy of Sciences, USA 52, 119–125

Tenhunen, J.D., Lange, O.L., Gebel, J., Beyschlag, W., Weber, J.A., 1984. Changes in the photosynthetic capacity, carboxylation efficiency and CO_2 compensation point associated with midday stomatal closure and midday depression of net CO_2 exchange of leaves of Quercus suber. Planta 162: 193-203.

Tretiach,M., 1993. Photosynthesis and transpiration of evergreen Mediterranean and deciduous trees in an ecotone during a growing season. Acta Oecol. 14, 341-360.

Vázquez, J., Lago, J., González, A.; 2001. INCO: programa para el cálculo de índices de competencia de especies forestales. Actas del III Congreso Forestal Español Granada, 5: 517-524.