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# Microclimatic specificity of a Mediterranean oak woodland (montado) in context of global change

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## Abstract

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The effects of oak trees on microclimatic parameters in *Quercus rotundifolia* Lam. woodland in Alentejo, Southern Portugal, are reported. The results show that oak trees create a marked differentiation in the grass matrix between open and tree-canopied habitats. Compared to open areas, oak canopy cover is associated with lower soil moisture content, lower soil temperature and lower photosynthetically active radiation (PAR). Soil temperature values outside the canopy shelter are generally higher than under the canopy, even two-fold during the winter. The decrease in soil water content is more rapid in areas not affected by tree canopy, but the recharge is earlier faster. PAR intercepted by tree canopy exceeds 60%, affecting dramatically production in herbs. Different climatic conditions at presence of trees, associated with higher variability in chemistry environment under the canopy, if combined with the IPCC forecasts for the Mediterranean region, pose new challenges in management of the montad*o* areas.

## Key words

montado, *Quercus rotundifolia*, PAR, soil water content, soil temperature

## Introduction

Mediterranean-type evergreen oak woodlands consisting of *Quercus rotundifoli*a Lam. (holm oak) and *Quercus suber* L. (cork oak) trees cover ample areas in Southern Portugal where they occupy 862.4 $10^3$ ha (D.G. F., 2006) – representing about 28% of the region. Anthropogenic activities have shaped these oak woodlands into savannah-type ecosystems or landscapes with scattered trees within a continuous grass matrix, in an agroforestry system called montado (David et al., 2004). The primary aim of this system is feeding livestock and cork extraction. The net effect of trees on grass production can be negative, neutral or positive, changing with tree age, size and density (Scholes and Archer, 1997).

Isolated individuals may alter chemical, physical and biological soil properties through their impact on energy and nutrient fluxes (Gallardo et al., 2000). In fact, soil organic matter quantity and quality are affected positively by the tree presence (Escudero et al., 1985; Rovira and Vallejo, 2007). Nitrogen mineralization rate and microbial biomass-N were observed higher in soils under tree canopy than in open areas (Gallardo et al., 2000; Gallardo, 2003), together with higher contents of organic C, N, base cations and values of cation exchange capacity (Zinke, 1962; Barth, 1980; Ryan and McGarity, 1983). The soil under tree canopy also exhibited more developed soil profiles and improved water regime (Koechlin et al., 1986). Zinke (1962) pointed out that individual trees have an influence proportional to their crown area projected onto the soil surface.

The interactions between the trees and the understorey environment may have an important role in the management of these systems in a multiple use perspective. Although the study of these interactions is of utmost importance, some uncertainty subsists in Southern Portugal regarding the role of trees in context of microclimatic and soil characteristics, especially soil water content, chemical characteristics and nutrient availability. The considerable economic and ecological importance of the montado silvopastoral multi-purpose systems and the considerable concern about their long-term sustainability has raised the relevance of studying their functioning, and their influence on nutrient cycling in a way facilitating recognition of management practices affecting the long-term sustainability of these ecosystems.

## Material and methods

The study was carried out in Southern Portugal at the Centro de Estudos e Experimentação da Mitra (CEEM), experimental campus of the University of Évora (38º32' N, 8º01' W, 243 m), during 2001–2002. The local climate is of the Mediterranean-type (Csa according to Köppen), characterized by wet-winter and dry-summer pattern. The mean annual rainfall is 665 mm, most of which falls from autumn to early spring (90%), in less than 75 days of rain per year (Inmg, 1991). The mean annual air temperature is about 15.4 ºC, ranging from 8.6 ºC in January to 23.1 ºC in August. The relative air humidity is about 70%. The dry period lasts up to 5 months.

The landscape is gently undulating. The slope at the study site has an inclination from 3 to 8%. The geological substratum consists of granites and gneisses (Carvalhosa et al., 1969). The prevailing soils are Eutric Leptosols developed on gneiss (*WRBSR*, 2006), with a maximum soil depth of about 1 m. The soil texture is sandy to sandy loamy.

The vegetation consists of open pastures with scattered trees of *Q. suber* L and *Q. rotundifolia* Lam. The tree density ranges from 35–45 trees ha$^{-1}$ with an average canopy cover of 21% (David, 2006). Major forbs include *Rumex bucephalophorus* L., *Silene gallica* L., *Ornithopus compressus* L., *Ornithopus pinnatus* (Miller) Druce, *Geranium purpureum* Vill., *Tolpis barbata* (L.) Gaertner, *Tuberaria guttata* L. Fourr. Common annual grass species are *Vulpia bromoides* (L.) S.F. Gray, *Bromus rigidum* Gaudin, *Hordeum murinum* L. and *Briza maxima* L. The herbaceous layer has been invaded by shrubs, mainly *Cistus salviifolius* L.

Microclimatic parameters (photosynthetically active radiation, soil temperature and soil moisture) were monitored under tree canopies and ouside their influence. Photosynthetically active radiation (PAR) was recorded by PAR sensors, placed at 0.30 m above the soil surface, at the upper limit of herbaceous layer. Average hourly soil temperature under tree canopy was recorded continuously, using copper-constantan thermocouples Delta-t placed on soil organic surface layers, between surface organic horizon and mineral profile (0 cm), and at 2.5 cm, 5 cm, 10 cm, 15 cm and 20 cm. In the open area, average hourly soil temperature was also recorded continuously with thermocouples placed at 2.5 cm, 5 cm, 10 cm, 15 cm and 20 cm. Soil moisture was monitored with 20 ThetaProbe sensors (ML2x, Delta-T Devices, Cambridge, UK). The sensors are designed to measure volumetric soil water content ($\theta_v$) using a simplified standing wave measurement to determine the impedance of a sensing rod array (Miller and Gaskin, n.d.). Ten sensors were installed in soil under an isolated *Q. rotundifolia* tree (crown radius was 7.2 m) for use in precipitation interception studies, and ten sensors were installed outside the crown projection. In both cases, half of the sensors were installed at 0.06 m depth, and the other half at 0.25 m depth. Soil volumetric water content was averaged and stored at half-hourly intervals. All sensors were connected to a DL2$_e$ data-logger (Delta-T Devices, Cambridge, UK).

## Results and discussion

The amount of solar radiation reaching the soil under tree canopy depends on multiple factors; the season, cloud cover, tree height, and density of tree cover. *Quercus rotundifolia* is an evergreen oak, therefore, the interception of solar radiation in this species does not display such a marked seasonality as in deciduous trees – there are only slight variations, around 5%, all year around.

The global solar radiation (G) and photosynthetically active radiation (PAR) during most of the daytime was higher in open areas than in areas influenced by tree canopy (Figs 1 and 2). The G and PAR interception by the tree and shrub layers attained 95% and 85%. The pattern of radiation decrease is in accordance with patterns recognised by other authors (Belsky et al., 1993) in savanna formations.

Soil temperature values observed during December 2001 and March 2002 at soil depth of 2.5 cm and 10 cm were always higher in the areas outside canopy influence (Figs 3–6). However, the differences in soil temperature found between these areas and at those canopy-influenced were still more accentuated during the summer months. A similar pattern was found by Rorison (1991), who compared north and south slopes, and by Belsky et al. (1993) in his studies with *Acacia*

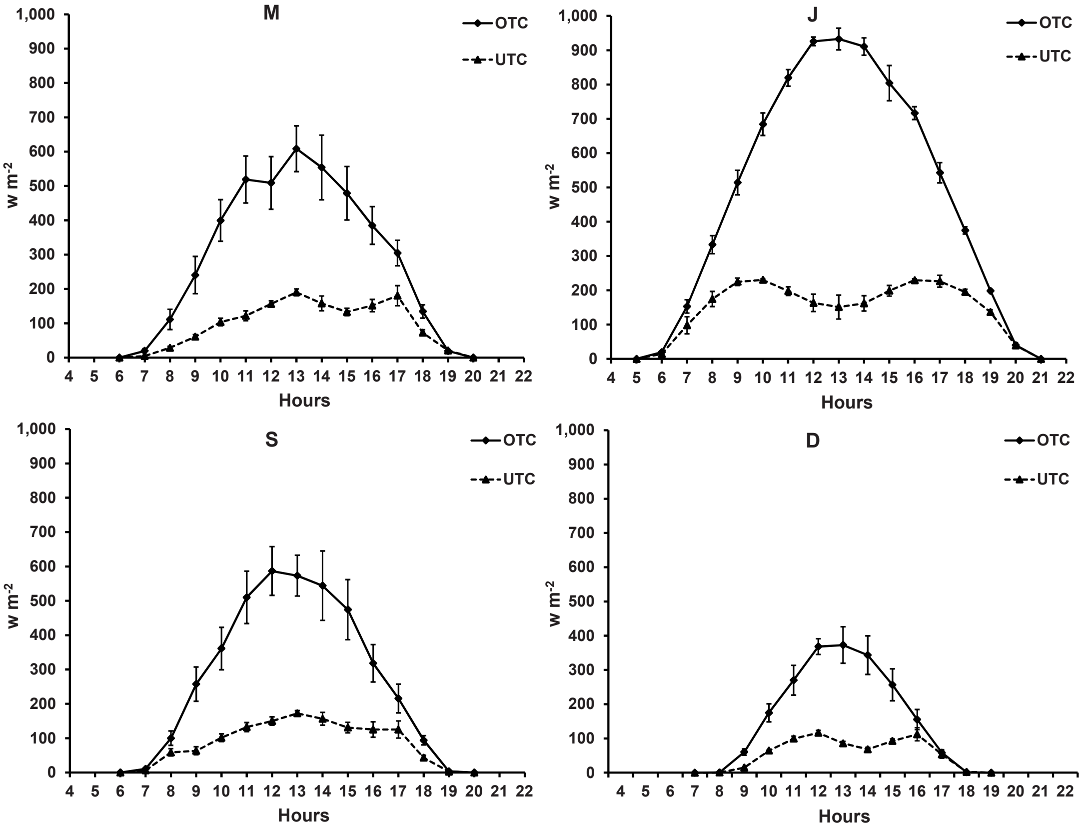

Fig. 1. Average time course of solar global radiation (G, w m$^{-2}$), under tree canopy (UTC) and outside tree canopy (OTC), during March, June, September and December 2002.

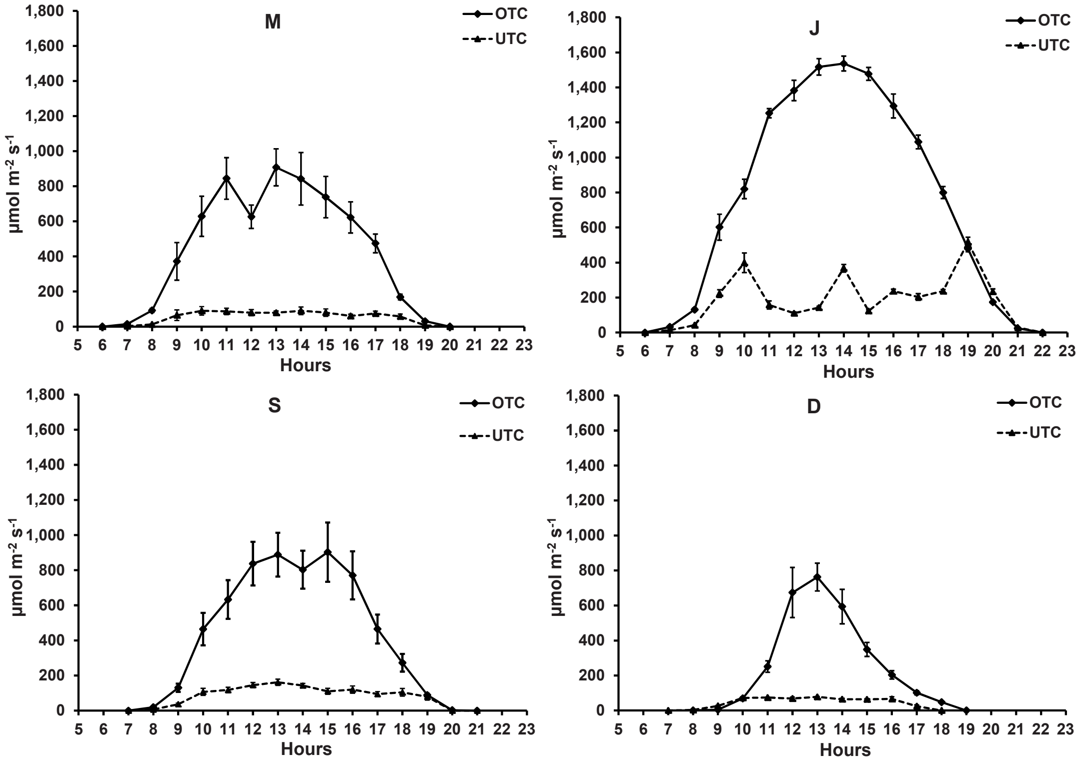

Fig. 2. Average time course of photosynthetically active radiation (PAR, µmol m$^{-2}$ s$^{-1}$), under tree canopy (UTC) and outside tree canopy (OTC), during March, June, September and December 2002.

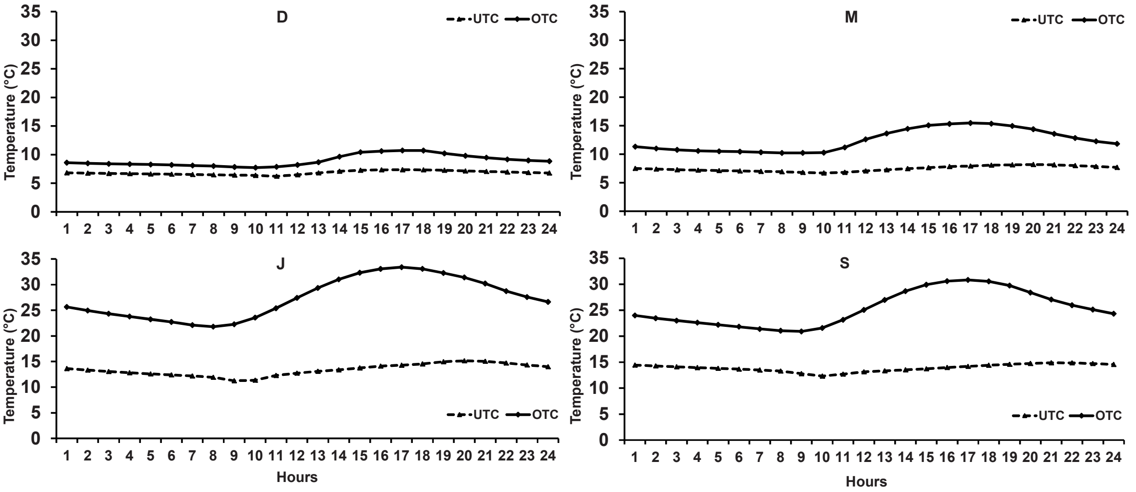

Fig. 3. Average time course of soil temperature (°C) at 2.5 cm depth, under tree canopy (UTC) and outside tree canopy (OTC), during December 2001 and March, June and September 2002.

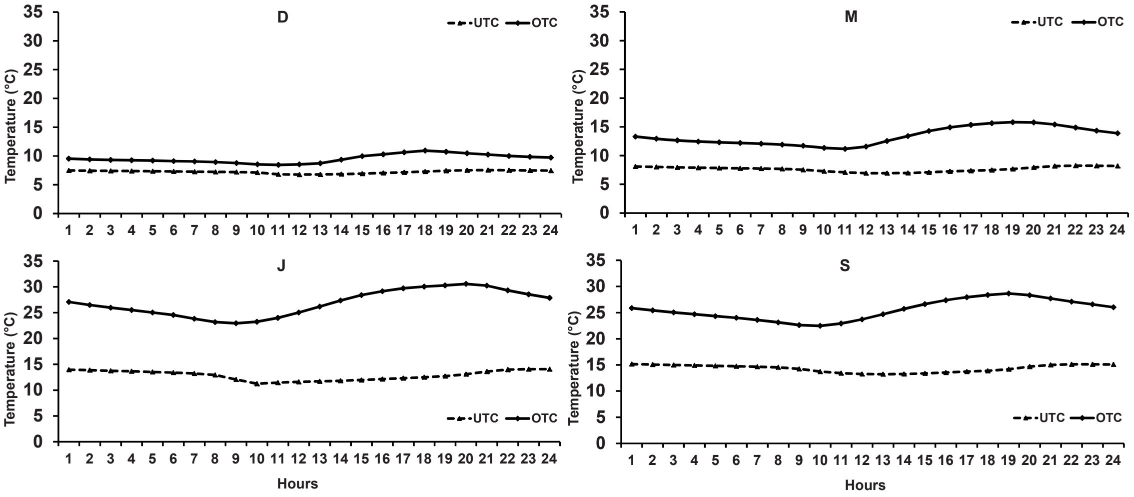

Fig. 4. Average time course of soil temperature (°C) at 10 cm depth, under tree canopy (UTC) and outside tree canopy (OTC), during December 2001 and March, June and September 2002.

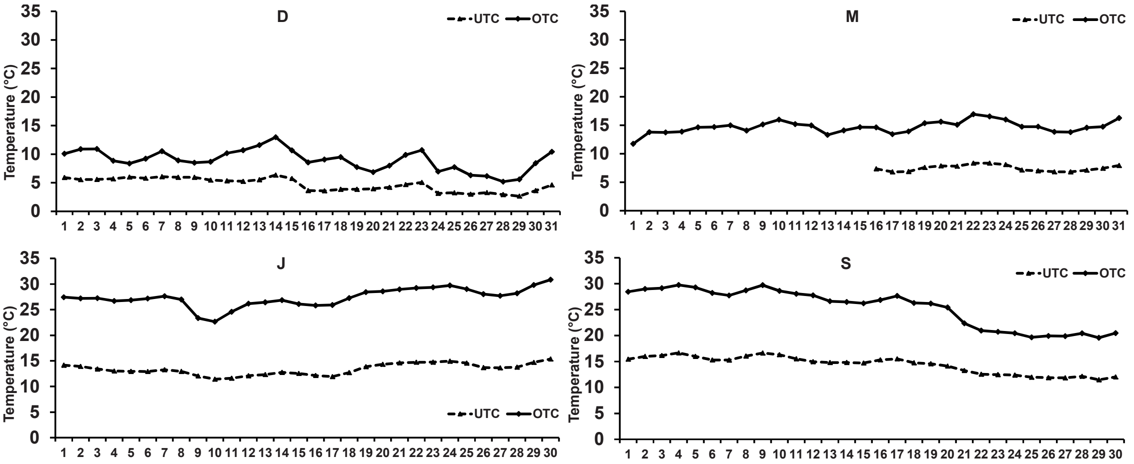

Fig. 5. Average daily course of soil temperature (°C) at 2.5 cm depth, under tree canopy (UTC) and outside tree canopy (OTC), during December 2001 and March, June and September 2002.

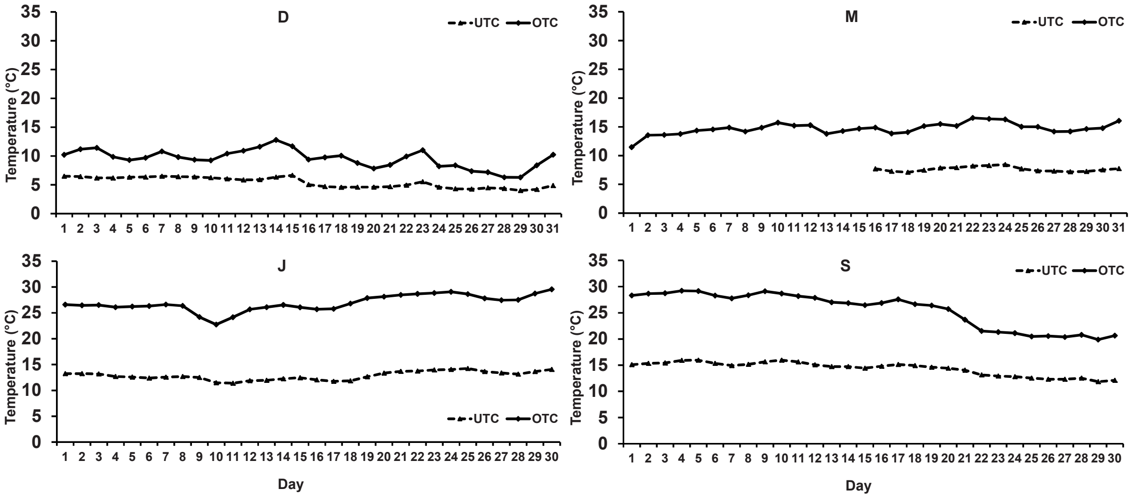

Fig. 6. Average daily course of soil temperature (°C) at 10 cm depth, under tree canopy (UTC) and outside tree canopy (OTC), during December 2001 and March, June and September 2002.

*tortilis* and *Adansonia digitata*. Haworth and McPherson (1995) in grasslands of semi-arid areas (South-Eastern Arizona, U.S.A) with *Quercus emoryi* trees, and Pereira et al. (2007) in a pasture land (Northeast of Portugal) with isolated ash trees (*Fraxinus angustifolia* Vahl), observed patterns similar to the present study in the summer period, with soil temperatures lower below tree canopy than in open area. Conversely, in the winter period, they observed just opposite patterns – with higher temperatures under tree canopy. This is in contradiction with our results, and may be explained by physiology (evergreen tree) and conformation of *Quercus rotundifolia* canopy. The crown of Holm oak has a homo-genizing effect on soil temperature, since the values of soil temperature in canopy-influenced areas show less marked variations, both in time and daily course (Figs 3–6).

The pattern of soil moisture variation during the dry period was similar for both areas, although the highest values were always obtained for open areas (Figs 7 and 8). The minimum moisture content observed in the topsoil during the summer was of the same order of magnitude in both areas. This indicates that the tree cover did not affect the minimum water content in soil, but only the rate of moisture loss, even during spring and early summer. In canopy-influenced areas, moisture content at 25 cm depth was generally higher than at the soil surface. The values of soil moisture at this depth did not reflect the occurrence of precipitation events as dramatically as the surface.

As the result of the first rains after the summer drought, the soil wetting rate at the two habitats was very similar, nevertheless, somewhat higher in open areas. After soil wetting by continuous autumn rains, both areas had the same soil water content on surface by the end of November to early December (Fig. 8). However, at 25 cm depth, soil water content at the end of this period, was higher in open areas than under the oak canopy. Nevertheless, there were found no statistically significant differences in soil moisture values between the canopy-influenced and open areas, for all the measured periods.

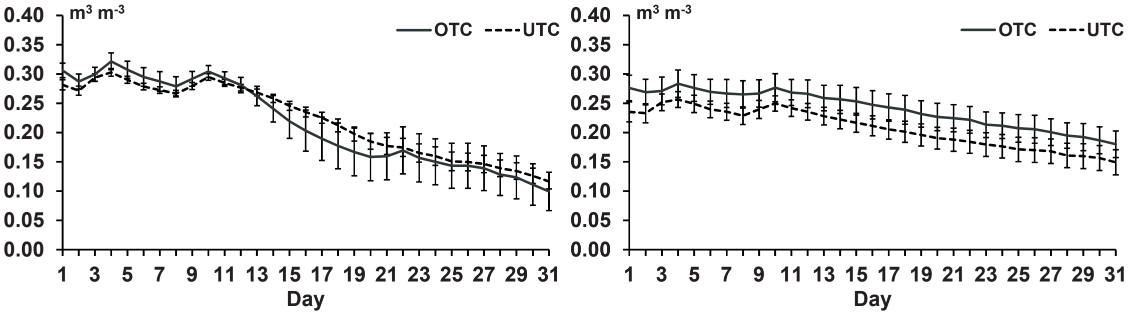

Fig. 7. Average soil water contents under canopy of *Q. rotundifolia* tree (UTC) and outside tree canopy (OTC) at 6 cm (Left) and 25 cm (Right), in May 2002.

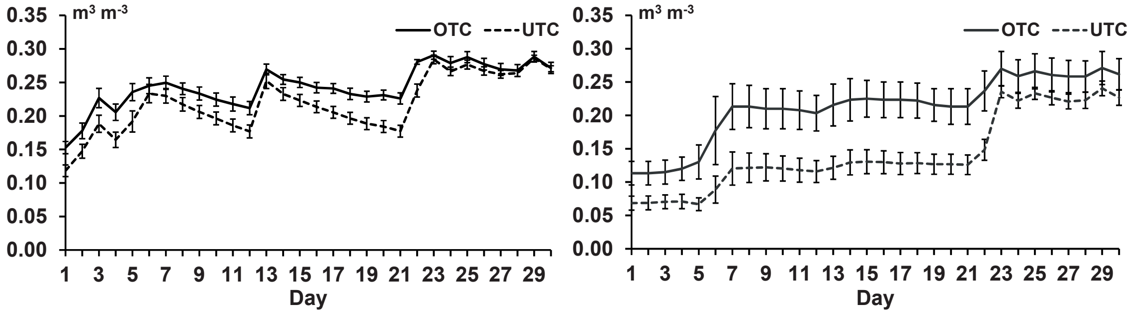

Fig. 8. Average soil water contents under canopy of *Q. rotundifolia* tree (UTC) and outside tree canopy (OTC) at 6 cm (Left) and 25 cm (Right), in November 2002.

Our results are in accord neither with those obtained for the same species in Spain (Joffre and Rambal, 1988, 1993), nor with those obtained for other species in similar savanna systems (Belsky, 1994; Belsky et al., 1989, 1993; Jackson et al., 1990), as we observed higher moisture content more frequently in open areas than in canopy-influenced ones. Nevertheless, Belsky and Amundson (1998) report that water content in soil under canopy shelter may be both higher and lower than in unsheltered soil. The pattern found in this study can follow from the fact that trees determine an interception loss of around 27% of the gross rainfall per unit of effective cover (David, 2006). The tree canopy cover ensures higher values of soil water content in dry periods, extending periods of water availability for plants.

In these agroforestry systems, Holm oak trees, more or less isolated, catch precipitation particles and redeploy them across the pasture in throughfall and stemflow. At the same time, they influence the microclimatic conditions, physical and chemical characteristics of soil and the rates of biogeochemical processes in the areas under the action of the trees. As a result of these changes, the production of pastures exhibits qualitative and quantitative differences between the two habitat types (Cubera et al., 2009), with carbon and nitrogen production / accumulation higher in the canopy-influenced areas (Nunes et al., 2007).

Given the scenarios of high variability in the precipitation and temperature patterns referred to the regions of Mediterranean climate (Miranda et al., 2002; Ipcc, 2007), the performance of this mosaic ecosystem may be strongly changed. The differentiation between areas with and without tree canopy in soil carbon and nitrogen cycles, and in herb production will probably be exacerbated, questioning the sustainability of the montado ecosystem. The animal support capacity may decrease, and tree susceptibility to diseases may increase.

## Conclusions

The canopy of *Quercus rotundifolia* trees causes dramatic changes to the microclimatic environment beneath: concerning namely photosynthetically active solar radiation, global solar radiation, soil temperature and soil moisture of the first layer. This differentiation is reflected in differences in herb production, nitrogen mineralization and carbon storage between under-canopy and without-ca-nopy areas. The expected climate change for Mediterranean region may seriously disturb the present equilibrium of the montado ecosystem – by sharpening the differences between canopy-sheltered and open areas, putting in question the sustainability of this ecosystem.

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# Význam mikroklimaticky špecifických systémov montado v agrolesníctve v kontexte globálnych klimatických zmien

## Súhrn

Práca sa zaoberá vplyvom duba *Quercus rotundifolia* Lam. na mikroklímu lesnatej krajiny v oblasti Alentejo v južnom Portugalsku. Výsledky ukazujú, že duby spôsobujú výraznú diferenciáciu trávnej matrice medzi otvorenými biotopmi a biotopmi clonenými korunami stromov. V porovnaní s neclonenými plochami, plochy pod clonou dubového zápoja vykazujú nižší obsah pôdnej vlhkosti, nižšiu teploty pôdy a nižšiu fotosynteticky aktívnu radiáciu (PAR). Teplota pôdy mimo clony je vo všeobecnosti vyššia ako teplota pôdy pod clonou, v zime dokonca dvojnásobne. Pokles obsahu pôdnej vody je výraznejší na plochách mimo clony, na druhej strane, doplňanie prebieha skôr a je rýchlejšie. Podiel fotosynteticky aktívnej radiácie zachytenej stromami je vyšší ako 60 %, čo má výrazný vplyv na produkciu bylinnej vrstvy. Odlišné klimatické podmienky v prítomnosti stromov spojené s vyššou chemickou variabilitou prostredia pod korunovou clonou spolu s predpoveďami IPCC pre oblasť Stredomoria nastoľujú nové úlohy v obhospodarovaní oblastí montado.

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