

The 2nd International Geography Symposium GEOMED2010

Eco - physiological behaviour of two woody oak species to combat desertification in the east Mediterranean-a case study from Lebanon

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Abstract

The Millennium Ecosystem Assessment scenarios as well as other global assessments have revealed that factors like climate change, land use changes, biotic interferences and atmospheric CO₂ will be the major drivers of future biodiversity loss. This loss is important because it will lead to a loss of valuable genetic diversity as well, which is of paramount importance for well being of humans. The local species losses and extinctions are expected to take place at an even faster rate, which will directly affect local ecosystem functioning. However, the land- use change may play a more dominating role in the species loss at the global level during next 5 decades. This loss can vary between 7-25 percent depending on different biomes.

Due to her existence in the Mediterranean Basin Lebanon is among one of the countries which has been severely suffering from changes in the land use and desertification, and will be affected much in future. Attempts should thus be made for obtaining detailed projections for the country. One of the ways to be followed is monitoring the efficiency of water use. Therefore in this study adaptation strategies of two typical woody oak species *Quercus infectoria*; a deciduous species; and *Q. calliprinos*; an evergreen species; to drought prone environments was studied in two different sites in Lebanon with high and low rainfall, during spring and autumn seasons. The water relations and photosynthetic behaviour of these species were investigated by conducting experiments in the field in order to assess their ecophysiological responses to water stress caused by increased drought. The leaves of *Q. infectoria* were bright green and larger than leaves of *Q. calliprinos*, allowing higher rates of photosynthesis and transpiration, but also resulting in low water use efficiency, regardless of site and season. Water stress reduced the rates of photosynthesis and transpiration in the course of the drying period in correspondence with an increase in vapour pressure deficit. The recovery of these two parameters in the autumn was correlated with a lowering of the air temperature and the saturation deficit of the atmosphere, for the same range of intercepted PAR. In all seasons, a mid-day depression in the photosynthesis and transpiration curves was due to stomata closure in response to water stress during the hottest hours of the day. These results are expected to enlighten the possibilities for future reclamation of degraded areas in the country.

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Keywords: Lebanon; East Mediterranean; Drought; Transpiration; Photosynthesis; *Quercus calliprinos*; *Quercus infectoria*; Water Use Efficiency

1. Introduction

Progressive degradation in Mediterranean Basin, due to increasing anthropogenic pressure, including over grazing, frequent fires and/or unplanned and rapid urbanisation, contributing impoverishment of forest and grasslands and hence leads to increasing aridity [1, 2]. The perpendicular disciplines (long hot and dry summer period and cold winter season) of Mediterranean climate increase the pressure of drought on vegetation cover [3]. Increase in evapotranspiration, and decrease in the water availability develop stressful conditions for plants with decrease in transpiration and physiological demands. Generally, plants adapt different strategies to withstand water stress by water-saving or water-spending strategies [4]. The first strategy induces plants to save water in specialized tissues and limit transpiration to a minimum by a number of anatomical and functional adaptations, or by restricting their water spending to a short period [5]. As many of the Mediterranean evergreen trees sclerophyllous species show this kind of water stress avoidance [6] characterized by an increase in leaf consistence and turgidity, i.e. leaves are hard and coriaceous [5], breaking when folded [7]. Many *Quercus* species, mainly *Q. coccifera*, *Q. ilex* and *Q. calliprinos* are sclerophylls [8]. Gas exchange measurements under water stress conditions show greatly reduced rates of assimilation in different species. Analysis of these measurements permit a closer examination of water use efficiency in water-limited environments.

It is long standing controversy as to whether drought mainly limits photosynthesis through stomatal closure, or by metabolic or ATP synthesis (even under mild drought) impairment [9]. According to Flexas et al., 2002, an early effects of drought consisting partial closure in stomata, and following this reduction of RuBP-regeneration. Further progressive increase in drought lead to reduced photochemistry and carboxylation efficiency and creates photoinhibition under very severe drought condition, when stomata are completely closed [9].

Prompt closure of stomata in moderately stressed leaves may be advantageous in regions where drought is of short duration, but detrimental where drought lasts for a longer period of time, since photosynthesis is reduced by cutting off the supply of CO₂ before the photosynthetic machinery has been inhibited by water stress [10, 9, 11]. The daily patterns of CO₂ exchange in water efficient plants grown in highly evaporative demanding habitats show pronounced midday depression due to stomatal closure, therefore stomatal conductance and net photosynthesis decline at peak irradiance in species grown under water stress conditions [9]. Oliviera *et al.* [12] has observed an alight midday depression of stomatal aperture in adult trees of *Q. ilex* and *Q. suber*. Furthermore, decrease in the stomatal conductance of deciduous oaks is significantly faster than evergreen oaks at higher drought degrees [13]. This paper underlines the ecophysiological responses of two typical Mediterranean oaks, *Quercus calliprinos* Webb and *Quercus infectoria* Oliver, under drought conditions at different experimental sites in Lebanon.

2. Material and Methods

The selection of the species and the experimental sites was done upon considerations of different environmental features. The plots were selected on the basis of gradient analysis of climate and soil of the area and factors related to the vegetation cover. Sampling plots in the experimental sites were approximately 20 m x 20 m area.

Gas exchange measurements were made in the field on sunlight leaves of single trees of *Quercus calliprinos* Webb. and *Quercus infectoria* Oliver. The selected species represented more than 50 percent of the woody plants in the study areas. This allowed us to interpolate their behaviour to other species in each

area and consequently scale up ecophysiological results from the single-species to the vegetation level.

It extended from the eastern slopes of the Mount-Lebanon mountainous chain to the western slopes of the Anti-Lebanon mountainous chain, at an altitude of 1350 m a.s.l, crossing the central Bekaa Valley in width (Fig. 1). Two sites were selected for the measurements. In particular, the reference site was selected in the Mazraat Beit Slaibi, located in west-central part of the Bekaa Valley (eastern edges of the Mount-Lebanon mountainous chain; 35° 59' E; 33° 58' N; Altitude: 1315 m) showing optimal, disturbed development of vegetation. This site was considered as “healthy” around 200 inhabitant with 75 settlements). This site shows typically Mediterranean climate with less than 1000 mm of annual precipitation and little biotic interference. The other site, considered as “degraded”, is Raite, located in east-central part of the Bekaa Valley (western edges of the Anti-Lebanon mountainous chain; 36° 31' E; 33° 49' N; Altitude: 1350 m). These, showed scarce development of vegetation cover under climatic factors (with an average rainfall of 600-800 mm) and anthropogenic pressure- subjected to heavy grazing and wood cutting- (around 3000 inhabitant with 200 settlements). *Quercus calliprinos* was dominant species for both sites.



Fig. 1. Map showing studying areas (Slaibi and Raite).

In both sites, *Q. calliprinos* covers the vegetation zone upto 1000 m, while from 1000 m to 1500 m it is mixed with *Q. infectoria*, a deciduous predominant in the higher part of this zone. The co-dominant species associated with *Q. calliprinos* were *Pistacia terebinthus* ssp. *palaestina*, *Crataegus azarolus*, *Arbutus andrachne*, *Phillyrea media*, *Ceratonia siliqua*, *Pyrus syriaca*, *Styrax officinalis* and *Juniperus oxycedrus*. In addition to these we also come across *Amygdalus korschinkii* and *Prunus ursina* in the area.

Variations in the photosynthetic behaviour and transpiration were recorded on daily and seasonal bases to assess the desertification monitoring attitudes of different species. Measurements of gas exchange and environmental parameters were conducted at the beginning (May) and the

end of the drought period (September), using a LI-COR (Lincoln, NE) LI-6000 Portable Photosynthesis System [4, 3, 14]. Sampled leaves were chosen in full sunlight. Attached leaves remained in their natural orientation for approximately 45-60s inside the cuvette. One single leaf per tree was selected for measurements and two replicates of diurnal patterns of the ecophysiological parameters were made at hourly basis from sunrise to sunset in order to examine the tree response to different levels of daily stress, and to characterize hourly variability of environmental conditions. Same individual trees of all species were measured in May and September. Data were discharged and treated using the C6000 software program available from LI-COR [15].

3. Results

A perusal of our findings concerning the diurnal variation of air temperature, leaf temperature, relative humidity and PAR around the experimental sites during the measurement days (Fig. 2) reveals that highest

air temperature on *Q. calliprinos* site was recorded in July and lowest in May, whereas on *Q. infectoria* site it was highest in July but lowest in September. Leaf temperatures showed similar behaviour being highest in July and lowest in May on both sites. On the other hand relative humidity percentage and photosynthetically active radiation (w/m^2) were highest in May and lowest in September. In general degraded site shows higher values of PAR, air temperature and leaf temperature than healthy site. Geomorphological structure of the sites can explain more clearly the climatic situations. The healthy site-Slaibi experiences a rain shadow effect. This area was drier and exposed to east site. The Rait Site was located opposite to the Slaibi site. This site is more humid and exposed to west and sun set is late. Under these circumstances a higher photosynthesis is obtained on the Rait (D) site in comparison to the Slaibi (H) site (Fig. 3). A midday depression is evidenced for both *Quercus* species. Photosynthesis reaches a maximum value sometime early in the morning, and shows a continuous declining trend throughout the whole day. Obviously diurnal patterns established for herbaceous species need to be employed with greater caution when an attempt is made to use them in order to explain behaviour of extremely drought-tolerant species. In some species/ environment combinations and under more thoroughly executed sampling, we can identify the photosynthetic maximum, realized much earlier within the day.

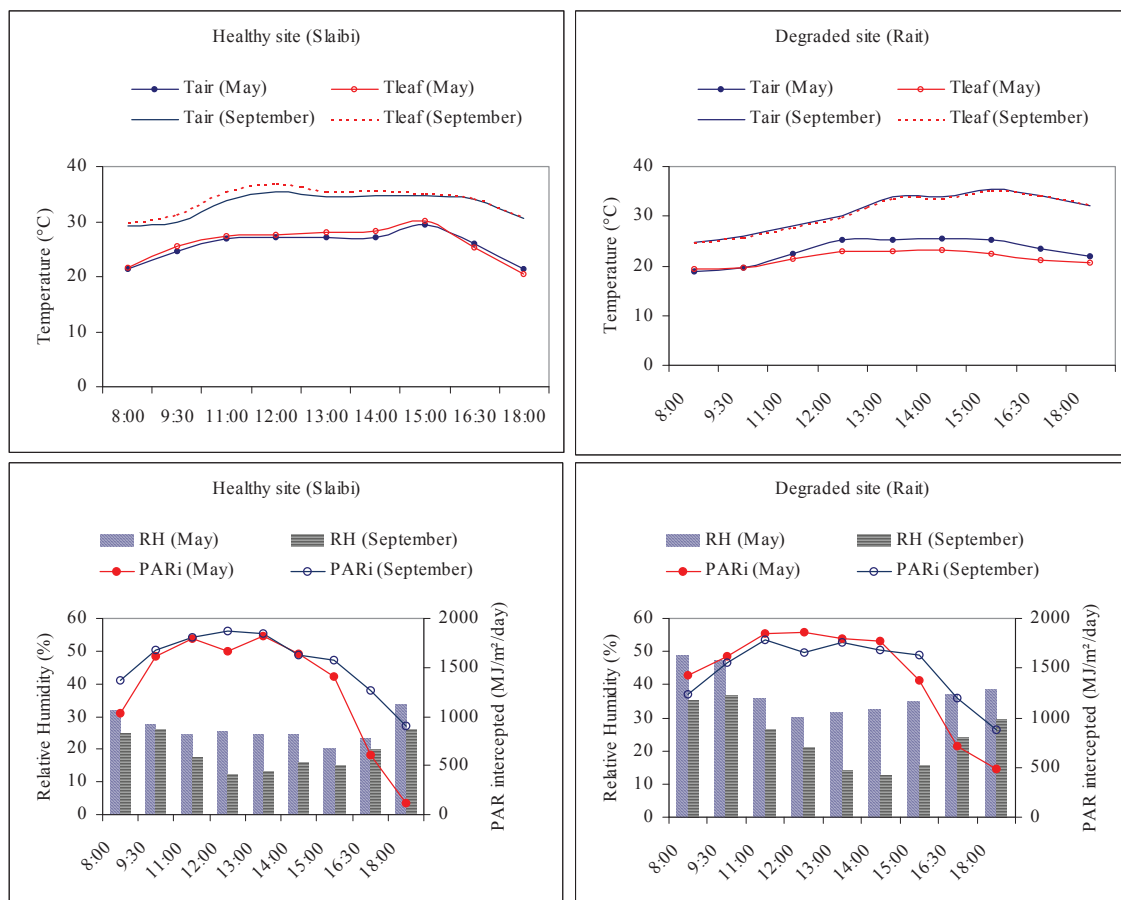


Fig. 2. Seasonal variation of climatic parameters during the measurement days

Highest values of daily transpiration are measured at midday in both species (Fig. 4). Fully expanded sunlight leaves of both species exhibit high transpiration rates in the degraded site than in the healthy one which can be attributed to the low competition among trees for water extraction in degraded environments. This can also be verified by comparing the daily values of transpiration on both sites. While in the degraded site transpiration pattern tends to increase gradually during the day to reach the maximum at noon, but on

healthy site it reduces the fluctuations during the day to a constant rate.

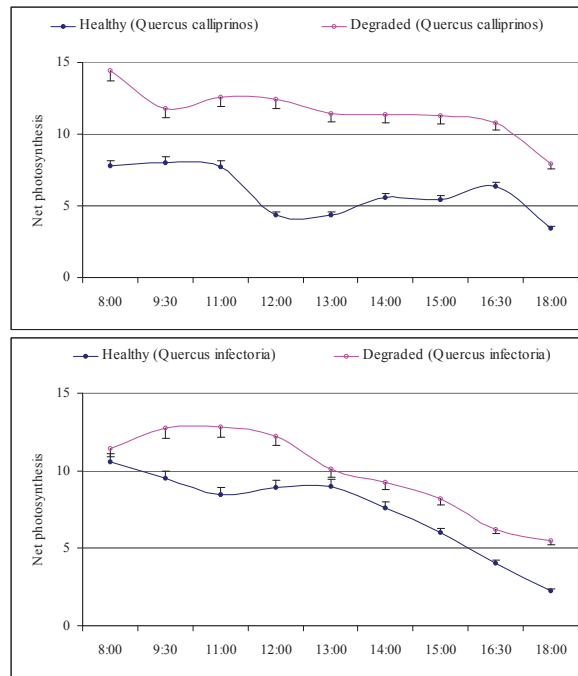


Fig. 3. Daily pattern of net photosynthesis: comparison among species from different sites (unit of measurement: $\mu\text{mol CO}_2/\text{m}^2/\text{s}$).

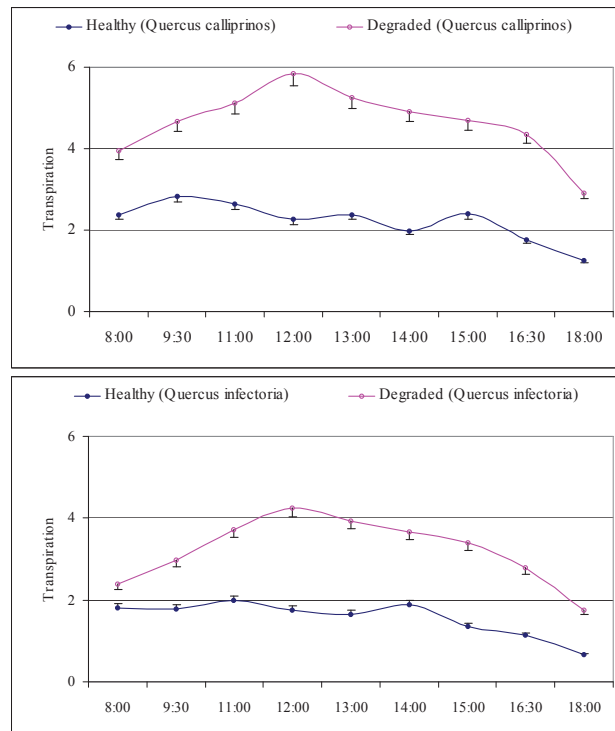


Fig. 4. Daily pattern of transpiration: comparison among species from different sites (unit of measurement: $\text{mmol H}_2\text{O}/\text{m}^2/\text{s}$).

Concerning seasonal effect, some differences are observed between the two *Quercus* species. Deciduous *Q. infectoria* shows higher rates of photosynthesis in May, in comparison with *Q. calliprinos*, but in September, the rate of photosynthesis of *Q. infectoria* decreases and becomes almost the same as in *Q. calliprinos* (Fig. 5). Both species tend to decrease slightly to maintain an equal rate of photosynthesis late in the season, where the environmental factors have a major involvement in the photosynthetic adaptation in a limited framework, compared to the conditions in May, when adequate soil water availability permits plants to produce large leaves and exhibit high growth rate, allowing thus high carbon gain.

A comparison between the species shows; *Q. infectoria* transpires twice the amount of water transpired by *Q. calliprinos* in May, but in September no consistent differences were found between the two species (Fig. 6). In May, the evergreen *Q. calliprinos* transpires less water than deciduous *Q. infectoria*, where the new leaves start to appear. This is in agreement with the results of the photosynthesis, which have been shown to have more consistent differences in *Q. infectoria*, with reference to seasonal effect, in comparison to *Q. calliprinos*. This means that for the same range of intercepted PAR, the first species has higher capacity of CO₂ fixation than the second one. Water use efficiency is higher for *Q. calliprinos* than *Q. infectoria* (Fig. 7).

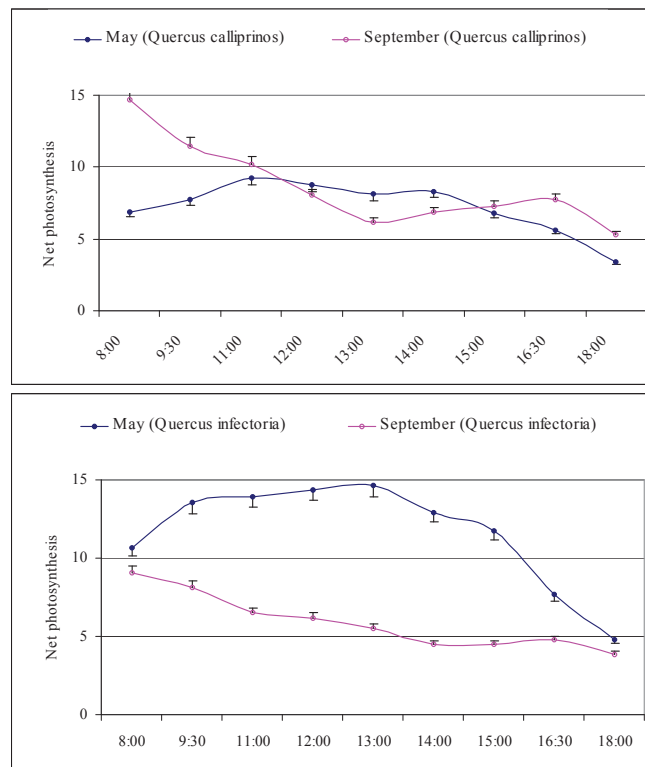


Fig. 5. Daily pattern of net photosynthesis: comparison among species on seasonal basis (unit of measurement: $\mu\text{mol CO}_2/\text{m}^2/\text{s}$)

Seasonal photosynthesis and transpiration rates are shown in Fig. 8. Differences in the photosynthesis in *Q. calliprinos* occur because in September the leaves are enough mature to resist the drought stress and to maintain high rates of photosynthesis, than in May. Contrarily, in September, leaves of *Q. infectoria* are different in age and young leaves are no more able to resist to the drought stress, leading thus to a decrease in the photosynthesis and transpiration rates. This shows how *Q. infectoria*, in dry surrounding environments, uses different physiological mechanisms to overcome the drought stress. Although mechanisms are different, their efficiency varies with sites. The degraded site, for example, shows higher photosynthesis and transpiration rates than the healthy site.

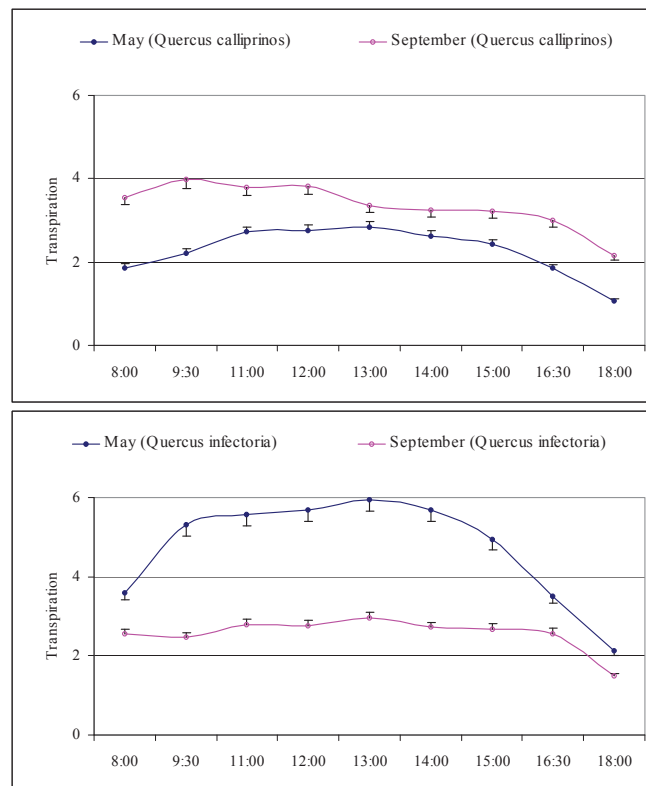


Fig. 6. Daily pattern of transpiration: comparison among species on seasonal basis (unit of measurement: mmol H₂O/m²/s).

Table 1. Seasonal water use efficiency for the species under study (mmol H₂O/m²/s).

| | Healthy site | | Degraded site | |
|-----------|-----------------------|----------------------|-----------------------|----------------------|
| | <i>Q. calliprinos</i> | <i>Q. infectoria</i> | <i>Q. calliprinos</i> | <i>Q. infectoria</i> |
| May | 3.84 | 2.16 | 4.71 | 3.46 |
| September | 2.30 | 2.08 | 3.64 | 2.55 |
| Average | 3.07 | 2.12 | 4.17 | 3.00 |

Seasonal values of water use efficiency of the species under study are presented in Table 1. Seasonal variation of photosynthesis and transpiration indicate the lower water use efficiency of *Q. infectoria*, in comparison with *Q. calliprinos*. Latter may compete successfully with other evergreen sclerophylls. In spring, the soils are still wet after the rainy season and climatic conditions are mild. Soil water content mainly affects the transpiration and photosynthesis rates more than it does in early and late summer when water in the soil decreases in response to the high evaporation rates imposed by the atmosphere. Water is not considered to be limiting factor in September since climatic factors such as temperature and relative humidity of the air become the key factors controlling both transpiration and photosynthesis.

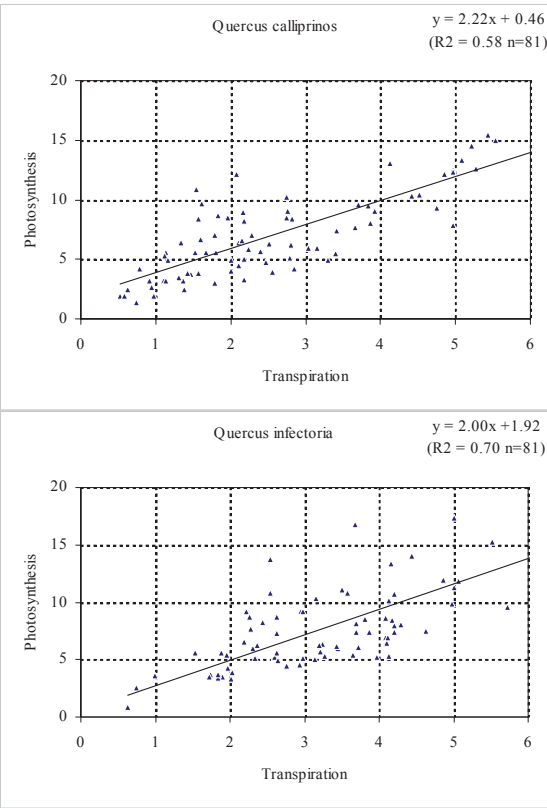


Fig. 7. Photosynthesis ($\mu\text{mol CO}_2/\text{m}^2/\text{s}$) versus transpiration ($\text{mmol H}_2\text{O}/\text{m}^2/\text{s}$): comparison between species (unit of measurement: $\mu\text{mol CO}_2/\text{mmol H}_2\text{O}$).

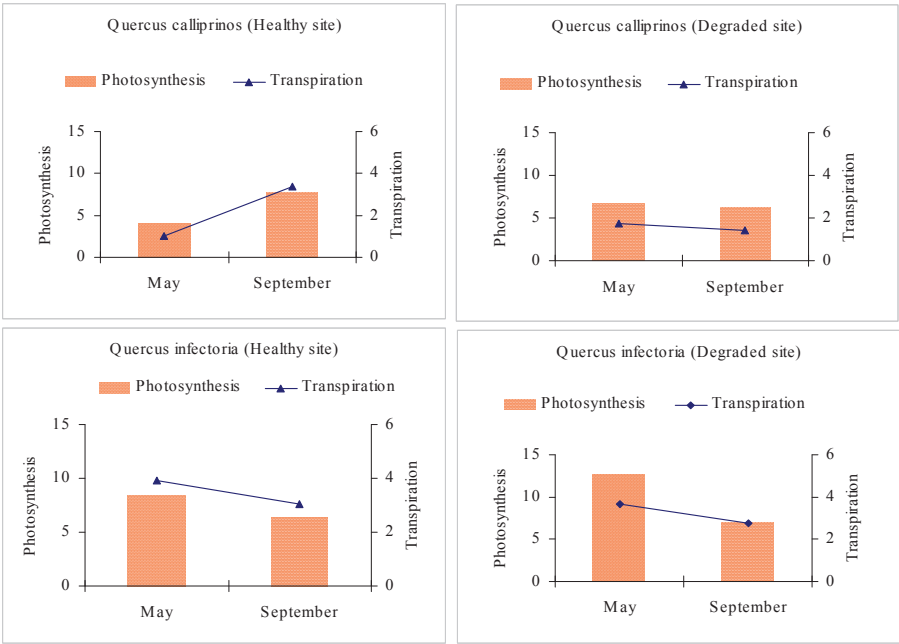


Fig. 8. Average seasonal net photosynthesis ($\mu\text{mol CO}_2/\text{m}^2/\text{s}$) and transpiration ($\text{mmol H}_2\text{O}/\text{m}^2/\text{s}$): comparison among species with emphasis on site and season

4. Discussion

Data collected in the field enabled us to assess the different levels of drought resistance of the species studied. *Q. calliprinos* is a drought resistant species, while *Q. infectoria* is quite vulnerable to environmental aridity. The diurnal and seasonal trends of the measured parameters, with regard to site and seasonal variation reveal that; differences between species are evident and explain different responses to the environmental pressure, based on proper physiological demand. In particular, differences help to discriminate between drought avoiding or resistant species like *Q. calliprinos* and drought tolerant or species vulnerable to aridity *Q. infectoria*. This means that different species can be used differently with regard to desertification monitoring attitudes.

An analysis of the daily trends of photosynthesis reveals in some cases differences between the healthy and degraded sites, where higher rates were obtained in September in the Rait. This area faces man-induced degradation like many other sites in the Mediterranean ecosystems. As a consequence, photosynthesis parameters are not so reliable as water relations to estimate and monitor degradation states, instead they are useful to estimate and compare potential productivity of species and vegetation where no other surveys are performed.

Evergreen oaks have to maintain a relatively high transpiration rate during periods of intense drought, whereas deciduous oaks have to assimilate, in a relatively short time, the amount of carbon they require for the conservation of their tissues and foliage renewal as observed by Acherar and Rambal [13] too. Summer period is a limiting factor for deciduous oaks since water stress induces stomatal closure early in the season and they have to make use of the most of their water resources during periods of available water, whereas evergreens govern their water resources throughout the year.

Significant differences in the water spending strategies were observed for the two different *Quercus* species. Although both species quickly respond to drought stress either at different periods of the day or in different seasons, *Q. infectoria* seems to need more water to resist water stress. This species may hence be considered as a water spender. Furthermore, *Q. infectoria* shows more sensitivity to drought and different type of stresses. *Q. infectoria* tends to be pushed upwards to higher elevations where water availability is usually higher and other stress factors are reduced. *Q. calliprinos* on the other hand, acts like water saver and it can more easily resist drought and other types of stresses.

It seems that *Q. calliprinos*, a drought resistant species, has the privilege to have an efficient water loss control with respect to *Q. infectoria*, a drought susceptible species. A similar behaviour was observed in *Q. ilex*, a typical Mediterranean sclerophyllous species, by Fleck *et al.* [16]. Such behaviour can result from the reduced plant competition in degraded sites, which increases the availability of water and other nutrients [16]. Another explanation can be that there is a reduced leaf area index in fire-exposed plants [18], and the result is an increase of net assimilation rate per unit of leaf area. In spite of the higher photosynthesis and transpiration rates measured in *Q. infectoria*, both *Q. calliprinos* and *Q. infectoria* exhibited relatively higher rates of photosynthesis and transpiration in the degraded site than in the healthy one.

Rate of seasonal variations in the water use efficiency (WUE) values of both species can be used as an indicator for more tolerant to drought and other factors. From May to September, the WUE decreases upto 40 percent in *Q. calliprinos* but in *Q. infectoria* it is 7 percent in Healthy site. In degraded site *Q. calliprinos* and *Q. infectoria* the decrease rates of WUE are 33 percent and 27 percent respectively. Under seasonal drought conditions either on degraded or healthy sites, the deciduous *Q. infectoria* behaves more constantly than evergreen *Q. calliprinos*. *Q. infectoria* seems to be a suitable candidate for reforestation of bare areas. *Q. calliprinos* also can be used as an indicator for degraded areas induced by climate or antropogenic factors.

Acknowledgement

We greatly acknowledge the help rendered to us by P. Akl and T. Shahsuvaroglu in the field. Our thanks go to Prof. M. Hamze, Chairman, National Council for Scientific Research-Beirut, Mr. A. Nikolaidis, Director, Mediterranean Agronomic Institute, Chania, 73100 Crete, Greece, Prof. Dr. S. Salleo, Prof. E.

Feoli, Dr. A. Nardini and Dr. M. Scimone (Dept. of Biology, Univ. of Trieste, Italy) for their helpful discussions during the course of this investigation. This project was supported by the European DEMOS programme.

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