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Proximity to riverbed influences physiological response of adult pedunculate oak trees

Lazar Kesić¹, Matjaž Čater^{2,3}, Saša Orlović¹, Bratislav Matović¹, Marko Stojanović⁴, Mirjana Bojović^{5*}¹ University of Novi Sad, Institute of Lowland Forestry and Environment, Novi Sad, Serbia² Slovenian Forestry Institute, Ljubljana, Slovenia³ Mendel University, Faculty of Forestry and Wood Technology, Brno, Czech Republic⁴ Global Change Research Institute of the Czech Academy of Sciences, Brno, Czech Republic⁵ Educons University, Faculty of Ecological Agriculture, Sremska Kamenica, Serbia

* Corresponding author: Mirjana Bojović; E-mail: mirjana.bojovic@educons.edu.rs

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Abstract: The pedunculate oak (*Quercus robur* L.) is economically and ecologically one of the most significant tree species in Serbia, however, little is known about the influence of the riverbed distance and its water supply on ecophysiological responses of this species. Given the limited information on the light-response curve of photosynthesis for oaks in southwest Srem, Serbia, the aim of this paper is to enhance understanding of their ecophysiological responses in this context. Maximum assimilation rate (A_{max}), the quantum yield (Φ), and light compensation point (LCP) were compared in adult trees situated along the transect from the river: (1) close to the river, (2) intermediate, (3) farthest from the river, and (4) forest reserve (second closest), with the first three transects being managed forests and the last one being an unmanaged forest reserve. The measurements were conducted in July during the first evidence of drought. The highest A_{max} rates were measured in all light intensities on the site closest to the river and the smallest on the site that was most distant to the water source. The most efficient were trees close to the river and the ones in the forest reserve. No significant difference between compensation points was confirmed for the studied groups of trees, although the forest reserve trees showed slightly higher values. The results demonstrated clear response between transects, which followed the distance from the riverbed. Pedunculate oak's reliance on groundwater is in tight relation with ecophysiological processes in trees; groundwater depletion may threaten its survival in areas distant from the river.

Keywords: *Quercus robur* L., floodplain forest, drought, light-response curves, transects.

1. Introduction

Climate variability and extreme weather events have major influence on forest ecosystems over time (Kostić et al. 2019), especially in climax tree species of floodplain forests (Klimo et al. 2013). Pedunculate oak (*Quercus robur* L.), a key tree species with a wide geographic distribution is predominantly influenced by water supply, which varies between different microsites (Netsvetov et al. 2017). In a temperate climate, pedunculate oak is undoubtedly a climate-sensitive species, affected by

several environmental factors such as drought, groundwater level, river water level, temperature precipitation (Stojanović et al. 2021).

Pedunculate oak forests in the Ravni Srem region have an important ecological role and high economic value in the Republic of Serbia (Stojnić et al. 2014; Rađević et al. 2020). The predominant problem that affects pedunculate oak in the abovementioned zone is decline of available water supply due to lowering of Sava River table, as well as the increasing temperatures, especially during last 30 years (Stojanović et al. 2015). Old trees are losing their adaptation ability; irreversible and declining processes are triggered due to constant stress conditions (Li et al. 2021). Water deficit stress is related to many physiological processes, such as photosynthesis, due to its principal function in determining plant fitness, survival and sensitivity to water scarcity (Flexas et al. 2006).

Although valuable and important tree species, studies related to photosynthesis light acclimation for mentioned species are scarce. Light-response curves of photosynthesis (LRCs), as an instrument to monitor plant ecophysiology, reflect the interaction of plant photosynthetic characteristics with the environment (Larcher 1995). LRCs proved to be efficient in determining the competitive strength between tree species (Čater et al. 2014), in comparing different silvicultural systems (Čater and Levanič, 2013), as a response trait after large-scale disturbances (Čater 2021), in determining the optimal sites within a larger geographical region (Čater and Levanič, 2019), etc.

Quantum yield (Φ) is an essential tool for studying plant physiology and understanding the factors that regulate growth and productivity in forests around the world (Berry and Goldsmith, 2020). Čater and Diaci (2017) found that as light intensity increased, so did the maximal assimilation rate and quantum yield of the trees. This indicates that high light availability enhances the efficiency of photosynthetic processes in trees (Liu et al. 2013). However, at very high light intensities, there was a decline in both maximal assimilation rate and quantum yield due to photoinhibition. This suggests that there is an optimal range for light intensity where tree growth is most efficient (Zivcak et al. 2015). By analyzing these responses, it could predict how climate change-related stressors such as drought or changes in groundwater levels will impact forest ecosystems (Hussain et al. 2020). In this study, the influence of the Sava River and its water supply on the area covered by autochthonous mature pedunculate oaks was investigated based on the physiological response of the mature trees and their distance from the riverbed. The first evidence of drought was assumed in the high growing season (July 20, 2015) with occurrence of extreme temperatures and stable riverbed conditions. Maximum assimilation (A_{max}), the quantum yield (Φ), and light compensation points (LCPs) for the light saturation curves were used to compare trees situated along the transect from the river: (1) close to the river, (2) intermediate, (3) farthest from the river, and (4) forest reserve. Considering the scarcity of data about the light-response curve of photosynthesis of the oaks in Serbia, this study aimed to give the first insight into the ecophysiological responses in that sense, on pedunculate oak in southwest Srem, Serbia.

2. Material and methods

2.1. Site description

Study was conducted in four pedunculate oak mature stands situated at the territory of PE Vojvodinašume, FE Sremska Mitrovica, FMU Višnjićevo (Figure 1). Adult trees were situated along the transect from the Sava river. The research localities were selected according to their accessibility by the road, as we wanted to fully access tree crowns by the truck elevator.

The first site (1 - close to the river) is characterised by forests of pedunculate oak, hornbeam and ash in the floodplain (*Carpino-Fraxino-Quercetum roboris inundatum*) on black-aluvial brown soils (semigley). The second site (2 - intermediate) is marked as a forest of pedunculate oak and ash (*Fraxino-Querceto roboris typicum*) on drier varieties of hydromorphic black soil (humosemigley). The third site (3 - farthest from the river) is characterised by a forest of pedunculate oak and ash with common maple and tartar maple and a rich shrub layer (*Fraxineto-Quercetum roboris aceretosum*) on the driest varieties of hydromorphic soils and meadow black soils with the signs of lessivage (humosemigley to eugley

with signs of lessivage). The fourth site (4 - Forest reserve) is marked as a forest of pedunculate oak, hornbeam and ash in the floodplain (*Carpino-Fraxino-Quercetum roboris inundatum*) on meadow-black alluvial brown soils (semigley) (Bojović et al. 2022).



Figure 1. Explored sites (1 - close to the river; 2 - intermediate, 3 - farthest from the river; 4 - forest reserve) (Source: Google Earth Pro 7.3.6.9345, Accessed on May 5th, 2023).

2.2. Climate data

The climate data (monthly average temperatures and sum precipitation) were taken from the Hydrometeorological Service of the Republic of Serbia - RHMZ, for the year 2015 (RHMZ, 2023). According to the World Climate Classification, the studied area is described as a temperate continental climate zone (Kottek et al. 2006). The coldest month was January, the warmest was June and the monthly average temperatures ranged from 2.5 to 23.3°C. The monthly precipitation total was highest in May (93.1 mm) and lowest in December (Figure 2).

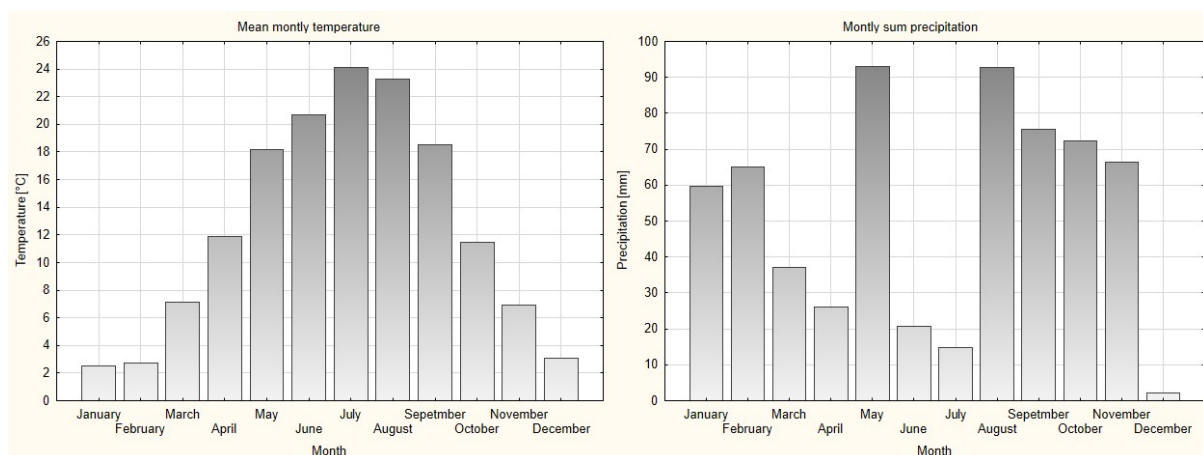


Figure 2. Monthly sum of precipitations (mm) and mean air temperature (°C) during 2015.

2.3. Maximal assimilation (A_{max}) and quantum yield (Φ)

With the advantage of transportable truck elevator, real time photosynthetic response was measured on adult pedunculate oak of each transect from 8:00-10:30 AM every day in the upper crown under comparable / controlled environmental conditions. The response was measured with an LI-6400

portable system (LI-COR Biosciences, USA) on at least eight sun leaves/locations per tree. Measurements were performed at a constant temperature of the measurement block (20°C), a CO₂ concentration of 380 µmol/l, flow 500 µmol/s and different light intensities: 0, 50, 250, 600, 800, 1200, and 1800 µmol/m²s. Maximal assimilation (A_{max}) rates and light compensation point (LCP) for the light saturation curves were established for trees on all studied transects. The light compensation points were established by linear extrapolation of value where light curve crossed x-axis. All assimilation values were recorded after they had held constant for minimal 2 minutes or until the coefficient of variability (CV, %) dropped below 5%.

3. Results

Response between transects was significant and followed the distribution of plots away from the riverbed. The highest A_{max} rates were measured in all light intensities on site which was closest to the river and smallest on the site that was most distant to the water source. In spite of similar distance between transects closest to the river and forest reserve, responses of trees in forest reserve were insignificantly smaller from the site close to the water, but still higher compared to other measured microsite responses (Figure 3).

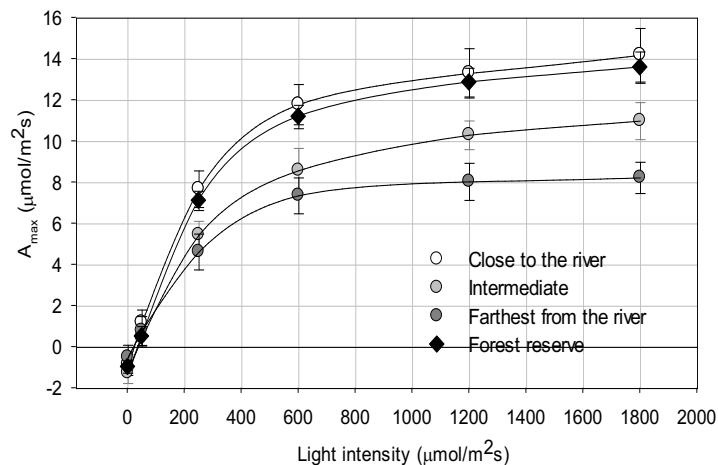


Figure 3. A_{max} in three managed forest groups and in the forest reserve (N=8/category). Average values \pm standard errors are presented.

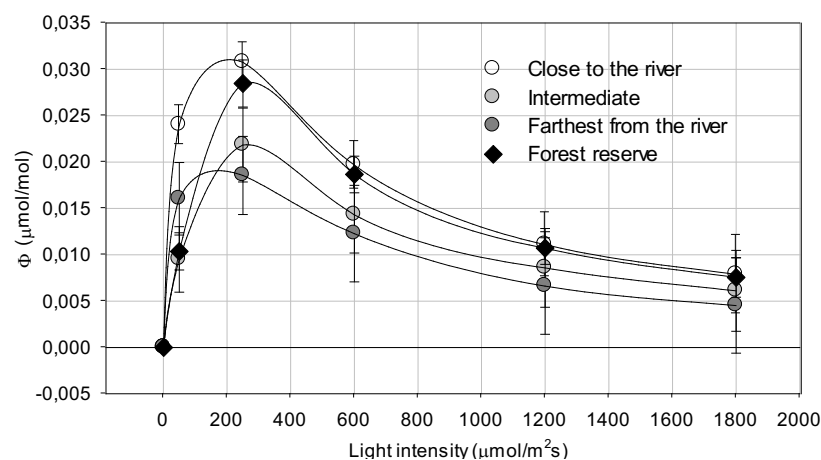


Figure 4. Quantum yield (Φ) in all four groups (N=8/category). Smallest dispersion of data was evidenced in managed plot close to the river, while the most variable was the response in forest reserve. Average values \pm standard errors are presented.

The most efficient were trees close to the river, as well as the ones in the forest reserve (Figure 4). Maximal efficiency in forest reserve-group was achieved at higher light intensities, similar to the intermediate group, while in the lower intensity values range, the microsite closest to the water had highest response, which might be contributed to the conservative character of the forest reserve - adaptation to higher light values or to physiologically older trees that require a higher threshold setting for the same efficiency as managed forests in the provided site-best conditions.

No significant difference between compensation points was confirmed for the studied groups of trees (19-24 $\mu\text{mol}/\text{m}^2\text{s}$), although the forest reserve trees showed slightly higher values (37 $\mu\text{mol}/\text{m}^2\text{s}$).

4. Discussion

The accessibility of water is the most powerful factor which affects leaf gas exchange and tree growth (Levesque et al. 2017). Many species maintain their maximum photosynthetic rates over a considerable range of water potentials in the field (Beadle et al. 1981). In this study, A_{max} was higher at sites 1 and 4 where water supply was optimal, while decrease in PWP (-1.56 MPa) (see Bojović et al. 2022) most severely affected the group furthest from the riverbed (site 3). We might assumed that recorded value for PWP on site 3 was potentially the main cause for parallel decline in A_{max} . Our results are in agreement with those of Grassi and Magnani et al. (2005), who showed that the decline of A_{max} in summer was proportional to the intensity of drought in ash and oak trees. According to Čater and Batič (2006), decrease of stomatal conductance and photosynthesis may lead to embolism in pedunculate oaks, when the pre-dawn water potential falls below -2.0 MPa. There is also a difference in pre-dawn water potential between planted and natural grown trees. Furthermore, Sanches and Silva (2013) analysed the changes in leaf water potential and photosynthesis of *Bauhinia forficata* under water deficit. They found that the maximum photosynthetic rates (A_{max}) of the plants under water deficit showed a high and significant correlation with soil moisture and leaf water potential, which is consistent with the statement about the dependence of photosynthesis of these plants on water availability. When plants have a steady supply of water, they are less likely to experience water stress, which can reduce photosynthetic efficiency (Stojanović et al. 2016). As such, in our study, the trees situated closest to river and second closest (forest reserve) demonstrated highest quantum yield (Fig. 4). In conditions of drought, stomata often close to prevent excessive water loss through transpiration (Szatniewska et al. 2022). When this happens, the intake of carbon dioxide is also limited, which in turn limits photosynthesis and reduces photosynthetic efficiency. Therefore, having access to groundwater can help plants maintain high photosynthetic efficiency.

Since the pre-dawn water potential characterizes both the water status of the accessible soil water and the degree of plant water stress (Pallardy et al. 1991), it was found that the group farthest from the riverbed (site 3) indicated the onset of reversible water stress (-1.56 MPa) (see Bojović et al. 2022). It could also be assumed that the mentioned degree of desiccation was related to the soil with the highest quality of barely available water. According to Galić et al. (2011), who studied the same forest types, the mentioned phenomena could be related to the lack of additional moistening by surface water and insufficient moistening by groundwater.

The light response of oaks is of particular interest because the regeneration of these species, either naturally or through silvicultural measures, is influenced by their shade tolerance and inter- and intraspecific competition for light (Welander and Ottosson, 2000). At all transects investigated in this study, the maximum assimilation of adult pedunculate oaks trees increased progressively with increasing light. However, values were always higher at sites close to the river (sites 1 and 4), indicating favourable influence of the water supply over sites further away from the river (sites 2 and 3). In their comparative study, Valladares et al. (2002) found that the maximum photosynthetic rate (A_{max}) increased with increasing light availability in the two species studied - *Q. robur* and *F. sylvatica* - but was always higher in oak than in beech. The same authors also concluded that greater tolerance to strong irradiation is associated with increased physiological plasticity (variables related to photosynthesis). Moreover, characteristics associated with photosynthesis, like the light compensation

point (LCP) and A_{max} , could be indicators of a plant's shade tolerance and its potential rate of growth (Spector and Puts 2006). In the context of our study, the observed higher LCP values in the forest reserve might suggest the need for more intense light levels. This intensity is required for older trees in forest reserve to sustain their larger biomass while compensating for the energy used respiration.

5. Conclusion

All the obtained results confirmed that the differences in the maximum assimilation rate (A_{max}) and the quantum yield (Φ) of the adult pedunculate oak depending on the distance of the Sava River can explain the adaptations of oaks to different sites within the same forest complex. The results obtained showed that the response between transects was evident. The oak stand closest to the river showed the highest values of A_{max} and Φ , while the other three sites showed a progressive decrease in both values as the distance from the riverbed increased. Obtained results may help to explain the difference between transects within the same forest complex, which may be related to the groundwater table, which probably becomes lower the further we move away from the riverbed. Our results may serve as the reference for the further investigation in adaptation of adult pedunculate oaks to changing environmental conditions. Adult oaks still preserve the response and adaptation ability, which decreases by the age and also by the increasing stress severity. Further depletion of groundwater and increased evapotranspiration due to rising temperatures may threaten the oak's existence in areas farther from the river.

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