Received: 06.05.2024; Revised: 02.08.2024; Accepted: 15.08.2024

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

Journal homepage: https://forestscience.com.ua/en
*Ukrainian Journal of Forest and Wood Science*, 15(3)

UDC 581.11(477.6)
DOI: 10.31548/forest/3.2024.148

# Comparison of transpiration activity of *Quercus robur* L. and *Acer campestre* L. trees under different conditions of moisture supply in the Viiskova ravine

**Valentina Bessonova**

Doctor of Biological Sciences, Professor
Dnipro State Agrarian and Economical University
49600, 25 Serhii Efremov Str., Dnipro, Ukraine
https://orcid.org/0000-0002-4310-0971

**Svitlana Yakovlieva-Nosar***

PhD in Biological Sciences, Associate Professor
Khortytsia National Academy
69017, 59 Naukove Mistechko Str., Zaporizhzhia, Ukraine
https://orcid.org/0000-0002-0935-0483

**Abstract.** Determining the role of trees in the water cycle and their impact on soil moisture and atmospheric humidity is crucial. This study aimed to investigate the patterns of leaf transpiration in *Quercus robur* and *Acer campestre* in a maple-oak forest under varying water supply conditions. The research was conducted in the lower third of the lower third of the north-facing slope and the middle third of the south-facing slope in the Viiskova ravine. A silvicultural and taxation survey of model trees was conducted on both sample plots, where the plantations are moderately dense. The diurnal course of transpiration patterns of these deciduous species was studied throughout the vegetation period. This physiological process reached its highest values in both species on the north-facing slope during the summer months, especially in *Quercus robur*. On the south-facing slope, in May and June, the average daily transpiration values in both species were almost indistinguishable. During the remaining months of the vegetation period, the intensity of water evaporation by *Quercus robur* leaves was statistically higher than that of *Acer campestre*. It was established that on the south-facing slope, under more arid conditions, this process is less active. This pertains to the daily transpiration loss of water by leaves per unit of their mass, monthly transpiration, and the intensity of this process per tree. The difference between the results of water loss by the leaves of a single *Quercus robur* and *Acer campestre* tree is significant and

***Suggested Citation:***

Bessonova, V., & Yakovlieva-Nosar, S. (2024). Comparison of transpiration activity of *Quercus robur* L. and *Acer campestre* L. trees under different conditions of moisture supply in the Viiskova ravine. *Ukrainian Journal of Forest and Wood Science*, 15(3), 148-164. doi: 10.31548/forest/3.2024.148.

**Corresponding author*

is attributed to the lower transpiration rate of *Acer campestre*, except in May and June under xerophytic conditions, as well as the smaller leaf mass of this species. Both *Quercus robur* and *Acer campestre* are hydrostable medium-transpiring species. The maple forest on the north-facing slope evaporates 30.6% more moisture per 1 ha per vegetation period than on the south-facing slope. The results obtained indicate that *Acer campestre* in a maple-oak forest, under fresh and dry forest-growing conditions, does not pose a significant competition for moisture for *Quercus robur* when they grow together. The results obtained can be used to develop effective forest management strategies in maple-oak forest

**Keywords:** lleaf water evaporation; common oak; field maple; forest-growing conditions; ravine forests

## Introduction

The increasing aridity of the climate and the decrease in water availability in certain areas lead to disruptions in the water regime of forest trees, including in Ukraine. This has a negative impact on their water and climate regulation functions. The water exchange of plants is influenced not only by environmental factors but also by the ratio of tree species in the phytocenosis. Competitive relationships between them can worsen the water supply of dominant species, reducing their resilience and longevity. *Quercus robur* is one such leading forest-forming species. Due to the discrepancy between the climatic conditions and the ecological requirements of this species in the steppe zone of Ukraine, oak phytocenoses are mainly concentrated in ravine forests. In this context, determining the water exchange of this dominant species and its companion species is relevant for the optimal construction of forest cenoses, and in natural forests, for regulating the density and ratio of species.

Considering water regime indicators in forestry practices and when creating forest plantations is a crucial factor that ensures the stability and balance of ecosystems. These characteristics are essential for enabling forest biogeocenoses to fully perform their vital resource functions. S.R. Weiskopf *et al.* (2020), investigating the impact of climate change on biodiversity and the ability of ecosystems to effectively perform their functions in the United States, concluded that the ability of forests to provide ecosystem services such as biodiversity habitat formation, climate mitigation, watershed protection, and erosion resistance is already gradually declining.

In a review article dedicated to analysing the existence of forests under drought and elevated carbon dioxide conditions, T.J. Brodribb *et al.* (2020) state the predicted further increase in the severity and frequency of droughts due to global warming. The review of the Fourth National Climate Assessment of the United States by A. Jay *et al.* (2018) consider the increased frequency of forest fires and outbreaks of diseases and pests in this context. Studies by A. Descals *et al.* (2023) using remote sensing methods have shown a progressive decline in the productivity of deciduous trees across Europe under drought stress, accompanied by early leaf shedding and the risk of tree death.

D. Ellison *et al.* (2017) emphasise the importance of forests in global hydrological and climate regulation, suggesting a transition from a carbon-focused approach to a water-regulating paradigm. G. Gao *et al.* (2022), assessing the contribution of transpiration to the magnitude of biogeocenoses evaporation and water cycle, indicated that woody plants replenish atmospheric moisture through evapotranspiration, promoting precipitation both locally and globally.

According to the IPCC's (Intergovernmental Panel on Climate Change) A1B scenario (moderate expected temperature rise with a decrease in precipitation) for most regions of Ukraine by the end of the century, significant warming and aridification are expected, along with a shift of moisture and heat supply zones towards the northwest. Consequently, I.F. Buksha *et al.* (2017), making a forecast for the existence and viability of *Quercus robur* on the plain part of Ukraine based on the A1B climate scenario, inform that already in the middle of the century, the area with conditions unsatisfactory for the existence of this species will cover 26% of the territory of Ukraine (in the south, partially in the centre and in the east), and the area of the zone unsuitable for its growth will be 56%. Under these conditions, oak stands will be preserved only locally in places with shallow groundwater, in floodplain areas, along rivers, and water bodies.

All of this underscores the relevance of studying the water exchange ecology of woody plants in phytocoenoses, with transpiration serving as a crucial indicator. However, these processes are mainly studied in trees within urban settings. For instance, D.V. Ganaba (2016) investigated the intensity of transpiration of woody plants in the dry period, which grew in different ecological zones of the Khmelnytskyi – within parklands and urban plantations. Nevertheless, research on water exchange issues in natural phytocoenoses of the steppe zone under current climate change conditions is practically absent.

The aim of this study was to compare the transpiration intensity of *Quercus robur* and *Acer campestre* leaves in a maple-oak forest under different water supply conditions and to determine the contribution of leaf mass of these tree species to water evaporation in these phytocenoses.

## Materials and Methods

The study was conducted in 2023 in a maple-oak forest on two experimental plots in the Viiskova ravine (Fig. 1), which belongs to a special geographical variant – the former rapids part of the Dnipro River. A.L. Belgard (1971) classified such ravines of this type as the southern outposts of natural ravine slope forests.


**Figure 1.** Map of the study area

**Note:** coordinates of the extreme points (48°11´08´´ N 35°07´45´´E; 48°10´41´´ N 35°10´12´´E)

**Source:** Google Maps

The research plots differed in location and hygrotopes. The first sample plot (SP1) is a maple-oak forest located on the lower third of a north-facing slope. The hygrotope is clay-loam soil ($CL_2$) (mesophytic, fresh soil). The second sample plot ($SP_2$) is a maple-oak forest located in the middle third of a south-facing slope. The hygrotope is $CL_1$ (xerophytic, arid). Both plots are characterised by atmospheric transit moisture. It should be noted that the south-facing slopes (light) and north-facing slopes (shadow) exposures differ in moisture and heat distribution. South-facing slopes warm up the most, receiving a greater amount of solar energy (Belgard, 1971). The subjects of the study were common oak (*Quercus robur* L.) and field maple (*Acer campestre* L.). The temperature and humidity of the air were measured using an electronic thermohygrometer TA-308 (Tcom, China). The values of these indicators are presented in Figure 2.

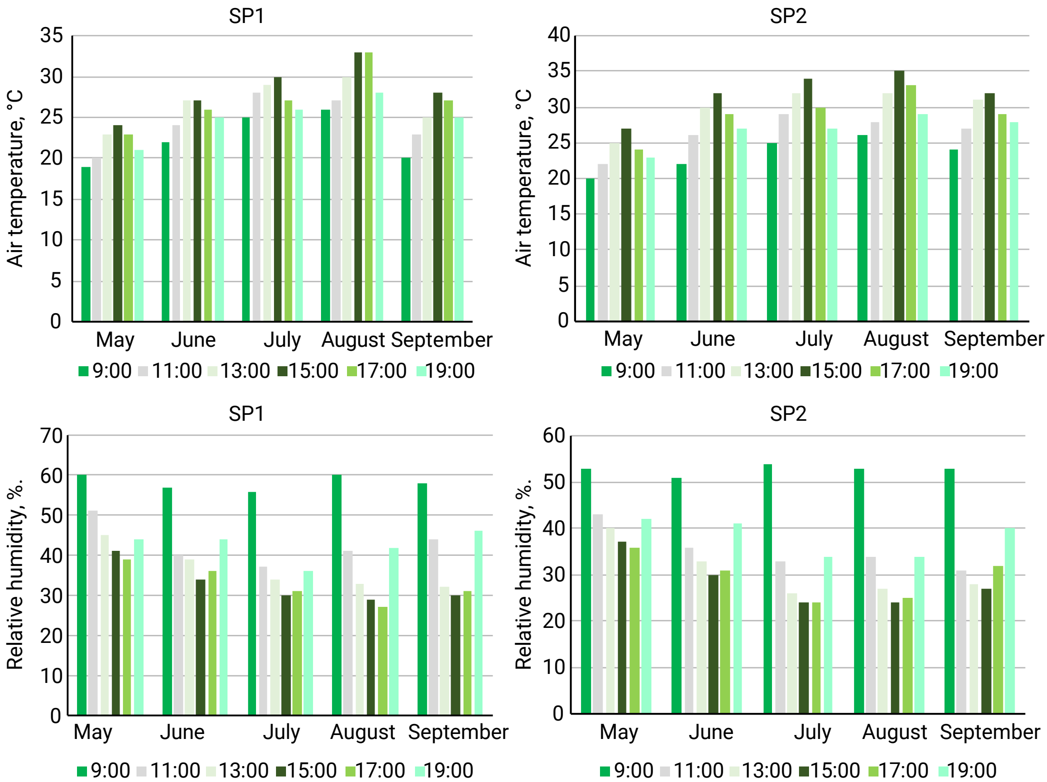


**Figure 2.** Temperature and relative humidity in the sample plots
**Source:** own measurements on the day of plant material collection

Plant material samples were collected using garden pruners from the southeast side of the middle part of the crown of the studied species during the vegetation period (May 15, June 21, July 14, August 16, and September 13) under identical lighting conditions. Leaves for determining the intensity of transpiration were plucked from branches of the same order of branching (third-fourth leaf from the base of the shoot of the current growth). The rapid weighing method according to Ivanov (Bessonova, 2006) was used with electronic scales TVE-0.21-0.001 (Technovagy, Ukraine). The experiment was conducted with five repetitions. The height of the trees was measured with an optical altimeter Suunto PM–5/1520 (Suunto, Finland), and their trunk diameter was measured with a calliper Codimex S-1 (Codimex, Poland). The leaf mass of the tree was established using the equation by M. Bibich (Urban ecology, 2017):

$$Y = -1.307 + 0.93x - 0.114x^2 + 0.01x^3,$$

where Y is the leaf mass, kg; x is the trunk diameter at a height of 1.3 m from the soil surface, cm.

The study was conducted in accordance with the ethical norms of the Convention on Biological Diversity (1992) and the Convention on the Trade in Endangered Species of Wild Fauna and Flora (1973). The results of the study were statistically processed using the standard software package IBM SPSS Statistics 22. A value of $P < 0.05$ was considered statistically significant.

## Results and Discussion

The stands on both sample plots are maple-oak forest of natural origin. The density of the plantations on the plots with different types of forest-growing conditions (FGC) was determined: they belong to the category of moderately dense (Table 1).

**Table 1.** Silvicultural and taxation characteristics of the plantations of the sample plots

| FGC | Stand composition | Species | $H_{avg.}$, m | $D_{avg.}$, cm | Stand density, units/ha |
|---|---|---|---|---|---|
| **SP1** | | | | | |
| $CL_2$ (mesophilic) | (Qu.ro)4(Ac.ca)6 | *Quercus robur* | 20.1 | 22.5 | 222 |
| | | *Acer campestre* | 16.5 | 17.4 | |
| **SP2** | | | | | |
| $CL_1$ (xerophilic) | (Qu.ro)3(Ac.ca)7 | *Quercus robur* | 18.8 | 21.4 | 251 |
| | | *Acer campestre* | 14.6 | 16.9 | |

**Note:** $H_{avg.}$ – the average height of the trees, $D_{avg.}$ – average diameter of the tree species in the sample plot
**Source:** developed by the authors

The basic taxonomic indicators of the model trees in the sample plots were determined since the value of the average diameter was used to calculate the transpiration parameters.

Leaf transpiration intensity is one of the most important indicators of plant water exchange. Studying this process in *Q. robur* leaves under mesophytic conditions ($CL_2$) showed that the patterns of the diurnal course of transpiration curves differ during the months of the study. In May, there is a significant increase in the intensity of transpiration evaporation of water from 9:00 to 13:00, after which the values remain almost unchanged until 15:00, followed by a decrease in activity. Lower values at 9:00 and 11:00, compared to the summer months, may be associated with high air humidity, which makes transpiration difficult. The same applies to the value of the process at 17:00, which is the lowest compared to all other months of the study, despite the moisture reserves in the soil. In June, the intensity of transpiration is expressed by a double-peaked curve, with peaks at 11:00 and 17:00, and with a minimum at 15:00. The onset of pronounced soil and air drought in July led to intensive evaporation of water already in the morning hours. The transpiration curve has two maxima: at 11:00 and 17:00. The highest values were recorded at 11:00 – 520 $mg \cdot g^{-1}$ of wet leaf mass, followed by a sharp drop in transpiration activity by 15:00 with the lowest values compared to other months of the study (245 mg·g$^{-1}$ of wet leaf mass). The second, smaller maximum of the diurnal course of transpiration in July occurs at 17:00. In September, the water evaporation by *Q. robur* leaves in the process of transpiration increases until 11:00, then there is no sharp change in the activity of this process. A significant decrease occurs at 19:00, as in all months of the study (Fig. 3).

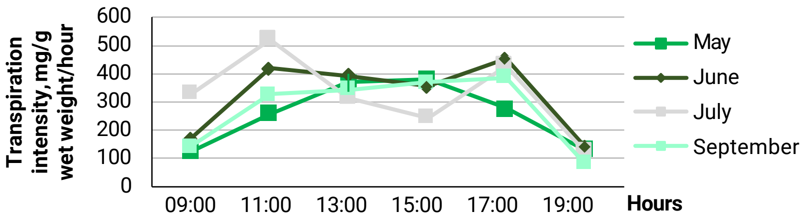


**Figure 3.** The diurnal course of transpiration of *Quercus robur* leaves under mesophylic conditions
**Source:** developed by the authors based on V.P. Bessonova *et al.* (2023)

The daily moisture expenditure by *Acer campestre* leaves in the process of transpiration under mesophytic growth conditions (north-facing slope) is the highest at 13:00 in May (Fig. 4). This is followed by a gradual decrease in the intensity of this process. In June, the daily fluctuations in transpiration activity are sharper. The maximum level of this process was recorded at 11:00. The second peak of water evaporation was determined at 17:00, which is 1.36 times smaller than the first peak. During the hottest hours (13:00 and 15:00), transpiration decreases, especially at 15:00 – by 1.82 times relative to the first maximum. The most significant fluctuations in water evaporation by *A. campestre* leaves were established in July. The diurnal course of transpiration in this month is expressed by a double-peaked curve, with maxima at 11:00 and 17:00.

Between these maxima, there is a significant drop in the intensity of this process, especially at 15:00, when the highest air temperature was recorded. In July, as in June, intensive water evaporation occurs already at 9:00 in the morning. The curve of the diurnal evaporation of water by *A. campestre* leaves in September differs from the curves of the summer months of June and July. As in *Q. robur*, there are no sharp changes in transpiration values from 11:00 to 17:00 (Fig. 4).

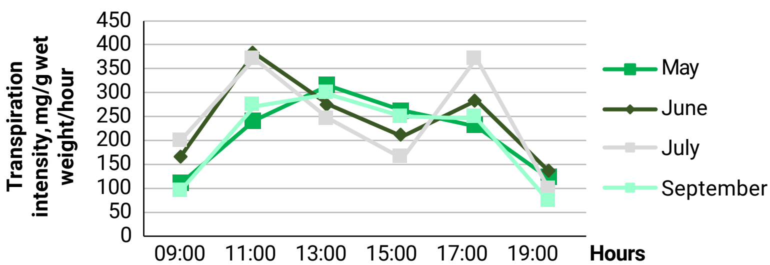


**Figure 4.** The diurnal course of transpiration of *Acer campestre* leaves under mesophytic conditions
**Source:** developed by the authors based on V.P. Bessonova *et al.* (2023)

The transpiration curves of the studied tree species in the maple-oak forest on the south-facing slope of the ravine (xerophytic growth conditions, $CL_1$) differ somewhat from those on the north-facing slope (mesophytic conditions, $CL_2$). In the spring month (May), the evaporation of water by *Q. robur* leaves increases significantly at 11:00 compared to the morning values (at 9:00), and then the intensity of its growth decreases. The most active transpiration occurs from 11:00 to 15:00, after which a decrease in this process is determined. More significant fluctuations in the level of transpiration of *Q. robur* leaves are observed in June. The curve reflecting the changes in the intensity of this process during the day is characterised by two peaks – at 11:00 and 17:00. A significant decrease in the activity of this process is noted at 15:00 (2.04 times relative to the first maximum) since this time is marked by the highest air temperature and low humidity. In July, the curve of the diurnal course of transpiration is similar to that in June, but the maximum values of the indicators at 11:00 and 17:00 are higher, as is the drop at 15:00. In September, a distinct increase in transpiration intensity is recorded at 11:00, with the value remaining almost at the same level at 13:00, followed by a decline at 15:00. A new rise in the evaporation of water by *Q. robur* leaves is observed at 17:00. This is followed by a significant decrease in the value of transpiration in the evening hours (Fig. 5).

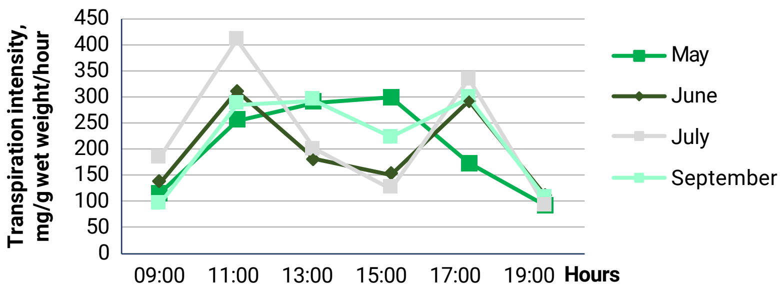


**Figure 5.** The diurnal course of transpiration of *Quercus robur* leaves under xerophytic conditions
**Source:** developed by the authors based on V.P. Bessonova *et al.* (2023)

The evaporation of water by *A. campestre* leaves in the maple-oak forest under xerophytic growth conditions (south-facing slope) gradually increases throughout the day until 15:00 in May. Then it remains at the same level with a sharp drop at 19:00. In the first summer month of June, a high intensity of transpiration is observed already in the morning – at 9:00. The curve of changes in the transpiration process in this month is double-peaked. The first peak occurs at 11:00 with insignificant changes in the indicator at 13:00, followed by a decline at 15:00. The second maximum, smaller than the first, is observed at 17:00. After that, the intensity of transpiration decreases.

The curve of the diurnal course of transpiration in July has a broken pattern with two maxima: a larger one at 11:00 and a smaller one at 17:00. A significant dip in the graph is observed between 13:00 and 15:00, which corresponds to the highest temperatures and the lowest relative humidity. Moreover, the transpiration values at these hours are the same. Apart from the morning (9:00) and evening (19:00) minima, the transpiration water loss curve in September is the highest level compared to the graphs in other months of the study (Fig. 6).

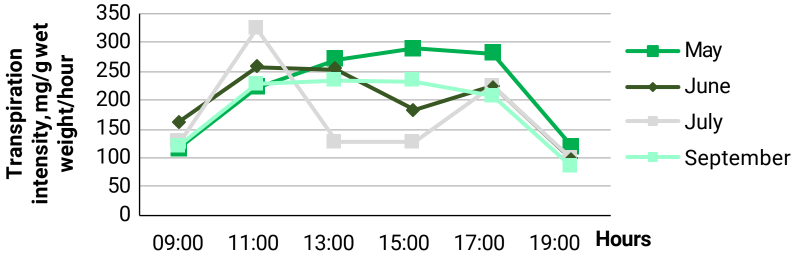


**Figure 6.** The diurnal course of transpiration of *Acer campestre* leaves under xerophytic conditions

**Source:** developed by the authors based on V.P. Bessonova *et al.* (2023)

The calculation of the average daily activity of water evaporation by the leaves of the studied tree species shows that the highest values are reached in both species on the north-facing slope in the summer months (Fig. 7). It should be noted that the higher average intensity of transpiration during the day is characteristic of *Quercus robur* leaves compared to the values of this process in *Acer campestre*.

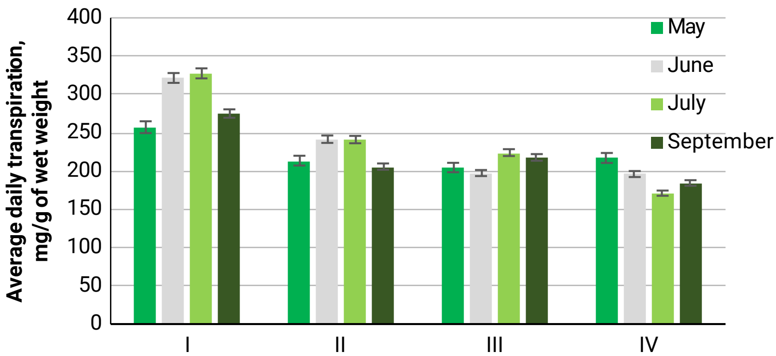


**Figure 7.** Average daily leaf transpiration of tree species under different forest growing conditions, mg·g$^{-1}$ wet weight

**Note:** I – *Quercus robur* on the north-facing slope; II – *Acer campestre* on the north-facing slope, III – *Quercus robur* on the south-facing slope; IV – *Acer campestre* on the south-facing slope

**Source:** developed by the authors

On the south-facing slope, the average daily transpiration values in both species are almost the same in May and June. Throughout the rest of the vegetation period, the intensity of water evaporation by *Quercus robur* leaves is statistically higher than that of *Acer campestre*. An analysis of the transpiration rates of *Quercus robur* in mesophytic ($CL_2$) and xerophytic ($CL_1$) growing conditions shows that this physiological process is 27.2% less active on the south-facing slope (CL1) compared to trees of the same species on the north-facing slope ($CL_2$).

For *Acer campestre*, this difference is 14.1%. The data obtained indicate the adaptive adjustment of *Quercus robur* to soil moisture deficit under more arid (xerophytic) conditions of SP2. A similar trend of change, but less pronounced, is also characteristic of *Acer campestre*. Table 2 shows the calculated transpiration rates of the studied tree species under different forest growing conditions – in fresh (SP1) and dry (SP2) maple-oak forest.

**Table 2.** Transpiration indicators of deciduous species in a maple-oak forest at different levels of moisture supply (2023)

| Months | SP1 ($CL_2$) | | SP2 ($CL_1$) | |
|---|---|---|---|---|
| | ***Q. robur*** | ***A. campestre*** | ***Q. robur*** | ***A. campestre*** |
| **Transpiration daily water loss by leaves, mg·g$^{-1}$*** | | | | |
| May | 2,880.6 | 2,391.2 | 2,290.4 | 2,430.4 |
| June | 3,600.8 | 2,704.8 | 2,209.8 | 2,195.2 |
| July | 3,668.0 | 2,699.2 | 2,508.8 | 1,915.2 |
| August | 3,080.0 | 2,303.8 | 2,438.2 | 2,064.2 |
| September | 3,071.2 | 2,301.7 | 2,421.3 | 2,079.9 |
| **Transpiration water loss by leaves per month, mg·g$^{-1}$** | | | | |
| May | 89,298.6 | 74,127.2 | 71,002.4 | 75,342.4 |
| June | 108,024.0 | 81,144.0 | 66,294.0 | 65,856.0 |
| July | 113,708.0 | 83,675.2 | 77,772.8 | 59,371.2 |
| August | 95,480.0 | 71,417.8 | 75,584.2 | 63,990.2 |
| September | 92,400.0 | 69,114.0 | 73,146.0 | 61,926.0 |
| **Water loss during transpiration by a tree per month, g** | | | | |
| May | 6,768,833.8 | 2,453,610.3 | 4,572,554.5 | 2,267,806.2 |
| June | 8,188,219.2 | 2,685,866.4 | 4,269,333.6 | 1,982,265.6 |
| July | 8,619,066.4 | 2,769,649.1 | 5,008,568.3 | 1,787,073.1 |
| August | 7,237,384.0 | 2,363,929.1 | 4,867,622.4 | 1,926,105.0 |
| September | 7,003,920.0 | 2,287,673.4 | 4,710,602.4 | 1,863,972.6 |
| **Water loss during transpiration by species per month from 1 ha, mm** | | | | |
| May | 59.6 | 32.9 | 34.3 | 39.9 |
| June | 72.1 | 35.9 | 32.0 | 34.9 |
| July | 75.8 | 37.1 | 37.6 | 31.5 |
| August | 63.7 | 31.7 | 36.5 | 33.9 |
| September | 61.6 | 30.6 | 35.3 | 32.8 |
| **Total, mm** | **332.8** | **168.3** | **175.7** | **172.9** |
| | **501.0** | | **348.6** | |

**Note:** * – the average weighted value of the period of the day during which water evaporates is 11.2 hours
**Source:** developed by the authors

As seen in Table 2, the overall transpiration water loss per unit leaf mass per day is greater in *Quercus robur* in all the months of the study at SP1. It decreases on SP2, with the difference between the indicators on the experimental plots growing more significantly in June and July. The daily water loss by the transpiring surface of *Acer campestre* is also greater under mesophytic growth conditions (SP1) than under xerophytic conditions (SP2), as is the case for *Quercus robur*, especially in June and July. However, under xerophytic conditions in May, when soil moisture is higher compared to the summer months, water loss by *Acer campestre* leaves is somewhat more significant on the $CL_1$ plot. The worsening of adverse hydrothermal conditions leads to an increase in the difference between the values of daily water evaporation by the transpiring leaf mass of *Quercus robur* and *Acer campestre*. The largest daily water loss by *Quercus robur* leaves on both experimental plots is observed in July, and for *Acer campestre* on SP1, it is in July and June, and at SP2, it is in May.

A similar pattern of water evaporation is characteristic of the results of monthly transpiration. Analysis of the data on the monthly water loss by leaf mass per tree shows the same pattern. More moisture is evaporated by both *Quercus robur* and *Acer campestre* under more favourable water supply conditions – mesophytic (SP2). However, the difference between the results of water loss by the leaves of a single *Quercus robur* tree is much greater than when calculating the total monthly transpiration loss per unit leaf mass. The difference in the values of this indicator between the studied tree species is especially large. Significantly less water is evaporated by the leaf surface of *Acer campestre*, which is due to both lower transpiration intensity compared to *Quercus robur*, except for May and June under xerophytic conditions, and lower leaf mass per tree.

The difference in water loss by leaves per hectare, taking into account the existing number of trees of each species, is quite significant between the species on SP1 on a monthly basis. It is the largest for *Quercus robur* and *Acer campestre* in the mesophytic maple-oak forest in July (Table 2). The quantitative indicators of water evaporation in the process of transpiration by *Quercus robur* leaves under mesophytic growth conditions (SP1) amount to 332.8 mm/ha, and for *Acer campestre* – 168.3 mm/ha. Under xerophytic conditions (SP2), these indicators are 175.7 and 172.9 mm/ha, respectively.

The leaves of one hectare of a *Quercus robur* plantation in a maple-oak forest on a shady slope (mesophytic conditions) evaporate 1.89 times more moisture than on a sunny slope (xerophytic conditions), even though the number of trees of this species in mesophytic conditions is only 1.17 times higher. Water loss by *Acer campestre* leaves on both the north-facing slope (SP1) and south-facing slope (SP2) is not significantly different, although the number of trees is 1.32 times higher on SP2. It should be noted that on SP1, the leaves of *Quercus robur* trees transpire 1.97 times more water per hectare than *Acer campestre*.

However, in the xerophytic maple-oak forest, the difference between the species in terms of the amount of water evaporated per hectare is small. This is explained by the fact that the ratio between the species on SP1 is 1.45 (formula of composition (Qu.ro)4(Ac.ca)6, *Acer campestre* prevails), and on SP2 – 2.33 ((Qu.ro)3 (Ac.ca)7), and the stand density in the mesophytic maple-oak forest is 222 trees/ha, and 251 trees/ha in the xerophytic one. These ratios lead to nearly equal transpiration water losses per hectare by maple and oak, which is not favourable for *Quercus robur* in such a mixed plantation on the south-facing slope. These results indicate the importance of regulating the ratio between the species to obtain optimal water evaporation indicators for the stand.

According to the data presented in Figures 3-6, the highest values of water evaporation by both *Quercus robur* and *Acer campestre* leaves in the process of transpiration are usually observed around 11:00. In the hottest summer months, this indicator decreases significantly when the highest temperatures and lowest relative air humidity are observed, and in the afternoon hours it again increases to a second maximum at 17:00. Thus, during the period of the highest temperatures, the intensity of transpiration decreases significantly, which indicates the ability of the studied plant species to regulate water exchange. Therefore, both species belong to the hydrostable category according to the classification given by W. Larcher (1978).

Such a decrease in transpiration activity under unfavourable hydrothermal conditions is a valuable adaptation that has developed in the process of evolution. However, on the other hand, a similar decrease in water evaporation by leaves leads to their overheating, which is very negative for plants with low heat resistance, as indicated by I.A. Vasilenko *et al.* (2017), who studied the drought resistance and water exchange of trees and shrubs.

According to their observations on the transpiration in twenty shelterbelt species regarding the intensity of this physiological process under the conditions of the Derkulskyi steppe, L.A. Ivanov *et al.* (1952) divided woody plants into three groups: strongly transpiring, moderately transpiring, and weakly transpiring. Based on the obtained indicators of the average daily intensity of leaf transpiration of *Quercus robur* and *Acer campestre* (Figs. 3-6), they can be classified as species with moderate water evaporation. The boundaries for this group, according to L.A. Ivanov *et al.* (1952), are 163-298 $mg \cdot g^{-1}$ wet mass/hour under very dry conditions of the Derkulskyi steppe and 374-480 $mg \cdot g^{-1}$ wet mass/hour in the Forest-Steppe zone, where the amount of precipitation is 1.5 times higher (420 and 650 mm, respectively).

V.I. Lyalko *et al.* (2012) studied the transpiration water losses of plant communities using remote methods and their combination with statistical estimates of water evaporation by certain phytocenoses over the vegetation period. As the authors emphasise, transpiration is one of the components of the water balance of the territory and is comparable in level to river runoff. In this case, the value of this process depends on the type of vegetation. In their article, researchers provided data on water evaporation by oak stands in the Donetsk and Kirovohrad Regions, which reach 405 and 520 mm per year, respectively. The data obtained in this study on the loss of water in the process of transpiration by the leaves of trees in a maple-oak forest over five months of vegetation were: under mesophytic conditions, evaporation amounted to 501.0 mm, and under xerophytic conditions, it was 348.6 mm. A.P. Krivoruchko (2019) determined the intensity of transpiration both in a mixed stand of *Quercus robur* and *Quercus rubra* with their ratio of 3:7 and in the growth of these species in single-species groups in the steppe zone of Ukraine. However, since the object of study was 11-year-old trees, the value of water evaporation by the leaf surface of these plantations per hectare cannot be used for comparison with the data obtained by the authors.

As can be seen from Figure 7, the average daily intensity of transpiration of *Quercus robur* and *Acer campestre* leaves under different hydrothermal conditions on the north-facing and south-facing slopes of the ravine Viiskova is higher under mesophytic conditions. Yu.L. Celniker (1958), studying the water regime of leaves of woody plants of the steppe zone, found that under drought conditions, moisture loss decreases with increasing stress of environmental factors. However, the study of the water-salt regime of plants and their communities under drought conditions of the Caucasus by I.N. Beydeman (1957) indicates that under optimal soil moisture, the intensity of plant transpiration increases simultaneously with increasing air dryness and temperature.

The value of water loss per day in the process of transpiration by the leaves of a maple-oak forest per 1 hectare in July-September under mesophytic conditions is within 3.64-3.07 mm, and under xerophytic conditions, it ranges from 2.23 to 2.24 mm. M. Landblad & A. Lindroth (2002) analysed the transpiration of forest stands depending on weather, soil moisture and stand characteristics (pure and mixed with *Pinus sylvestris*, *Picea abies*). They observed a wide range of values for this process (from 0.95 to 4.64 mm per day). The authors found that the average transpiration values for different stands varied from 1.30 to 4.64 mm per day during July-September.

As mentioned above, when the main and companion species grow together, the question arises of their competition for such resources as water supply and soil fertility. The optimal combination of tree species in a phytocenosis determines not only the environmental impact of forests, but also their productivity, stability, and longevity. V.I. Karpenko (2013), studying the forestry properties of such companion species for *Quercus robur* as *Acer platanoides*, *Carpinus betulus*, and *Tilia cordata* in mixed stands of the Forest-Steppe zone, found that it is little leaf linden that does not displace the roots of common oak from the upper soil layers to the lower ones, therefore it is its best companion species. N.P. Shpak *et al.* (2017) studied forest plantations of *Quercus robur* with the participation of several companion species in their composition. As the authors proved, the presence of *Tilia cordata* increases soil fertility and stand productivity. Moreover, the root systems of *Tilia cordata* and *Quercus robur* complement each other in the rhizosphere, promoting better growth of both species. *Sorbus torminalis* also possesses such properties in relation to *Quercus robur*.

Several researchers draw attention to the need to consider the role of certain tree species in the water cycle of forest ecosystems and their optimal combination, taking into account possible competition for water. Thus, H. Asbjornsen *et al.* (2007) underscore the importance of evaluating the interception of water by *Ulmus americana* when grown together with *Quercus macrocarpa* in American oak forests. Such studies are especially relevant in the context of the arid climate of the Ukrainian steppe. In particular, several authors highlight competitive relationships between *Quercus robur* and *Fraxinus excelsior*. For example, A.A. Silina (1958), analysing the influence of some tree species on the transpiration of others when grown together in the Steppe zone of Ukraine, found that under drought conditions *Fraxinus excelsior* is a dangerous competitor for *Acer platanoides* and, especially, for *Quercus robur*.

The studies of V.I. Obraztsova & N.P. Kotsyubinskaya (1976) also showed that the intensity of transpiration of *Fraxinus excelsior* on experimental plots with different water supplies in the riparian and floodplain oak forests of the steppe zone of Ukraine is higher than that of *Quercus robur*. Competition for water can lead to the suppression of the growth processes of tree species and, in general, to a decrease in the stability of phytocenoses. However, during the study of forest plantations of *Quercus robur* with the participation of native and introduced fast-growing species, Yu.D. Katsulyak (2009) found that in dry and fresh maple-oak forest with a share of *Fraxinus excelsior* not exceeding 30% with its even distribution across the area, exacerbation of competition with *Quercus robur* for soil-hydrological resources is not observed.

According to the results presented in this article, under mesophytic growth conditions, the intensity of transpiration of *Quercus robur* leaves is higher than that of *Acer campestre* during the vegetation period. In xerophytic conditions, it is also higher in July and September. In May, the transpiration values for *Acer campestre* are slightly higher, and in June they are almost the same for both species (Figs. 3-7).

Thus, *Acer campestre* leaf surface evaporates significantly less water, due to both lower transpiration intensity compared to *Quercus robur*, except for May and June under xerophytic conditions, and lower leaf mass per tree. Under mesophytic conditions, *Quercus robur* evaporates 1.97 times more per 1 ha than *Acer campestre*. It is also necessary to take into account the ratio of species on the sample plots. On the north-facing slope, there are 1.45 times more

*Acer campestre* individuals than *Quercus robur*, and on the south-facing slope, there are 2.33 times more. This leads to the fact that the total evaporation of water by *Acer campestre* plants under xerophytic conditions reaches almost the same values as those of *Quercus robur*, which further increases the stress of the water regime. The data obtained indicate the need to take this fact into account when constructing plantations in the steppe zone.

Therefore, *Acer campestre* is one of the optimal companion species for *Quercus robur*, since it belongs to the group with moderate transpiration activity and does not act as an aggressive competitor in water interception, given the appropriate ratio of trees in the plantation. It should be noted that *Acer campestre* thrives well in the second tier of oak phytocenoses, improving forest growing conditions in oak forests, as it belongs to acidifying species. In addition, as noted by V.E. Svyrydenko *et al.* (2004), the leaf litter of *Acer campestre* contributes to soil acidification, which benefits the growth of *Quercus robur*, a species with high mycotrophic requirements. A slightly acidic environment is optimal for mycorrhizal symbiosis.

According to P.F. Ffolliott (2008), who studied water evaporation by oak plantations (*Quercus emoryi*) on watersheds in New Mexico, USA, transpiration data are important for developing a general water budget for the studied ecosystems. This information, in combination with existing precipitation and water flow measurements, will contribute to a more accurate assessment of the ecosystem's water balance.

The data obtained as a result of the research carried out by the authors will bring greater clarity to understanding issues related to water use by both dominant and companion species in the maple-oak forest under different water supply conditions. The discussion outcomes indicate that the impact of companion species on the physiological characteristics of *Quercus robur*, including its water regime, requires further investigation.

## Conclusions

The stands on both sample plots are natural maple-oak forests, characterised by an average stand density of trees. The curves reflecting the diurnal course of the transpiration pattern of *Quercus robur* under mesophytic conditions in June and July have a double-peaked character with maxima at 11:00 and 17:00. In the rest of the vegetation period, the graphs have a smoother character. A similar pattern is observed in the fluctuation of water evaporation activity by *Acer campestre* leaves under mesophytic conditions. Under insufficient water supply (xerophytic conditions) in June and July, both species also show two peaks in the diurnal course of transpiration activity at the same hours of the day. In *Acer campestre*, the maximum intensity of transpiration is observed at 15:00 in May, its values approaching the value of July evaporation activity, which was recorded at 11:00.

Average daily leaf transpiration activity is maximum for both species on the north-facing slope under mesophytic conditions ($CL_2$) in the summer months, especially for *Quercus robur* compared to the values of this process in *Acer campestre*. On the south-facing slope under xerophytic conditions ($CL_1$) in May and June, the average daily transpiration values of both species are practically the same. Throughout the rest of the vegetation period, the intensity of water evaporation by *Quercus robur* leaves is statistically higher than that of *Acer campestre*.

Analysis of the diurnal course of transpiration of the studied species under the conditions of hygristotopes $CL_2$ and $CL_1$ showed that these woody plants are hydrostable and, according to the value of average daily activity of water evaporation, belong to the moderately transpiring species. On both sample plots with different levels of plant water supply, *Quercus* *robur* leaves, for the most part, transpire more actively than *Acer campestre*, although it was found that in some measurement hours, opposite results were observed.

The intensity of leaf transpiration of *Quercus robur* in the maple-oak forests under the conditions of hygristopos $CL_1$ in more arid growing conditions is less active (by 27.2%) than under conditions of better water supply ($CL_2$). This can be considered an adaptive adjustment of *Quercus robur* to soil moisture deficit. This is less characteristic of *Acer campestre*. On the north-facing slope, the average transpiration during the growing season is higher than on the south-facing slope. The maple-oak forest on the south-facing slope evaporates 30.6% less per 1 ha during the growing season than the stand on the north-facing slope under conditions of better water supply.

The results obtained indicate that *Acer campestre* in maple-oak forests under the conditions of fresh ($CL_2$) and dry ($CL_1$) hygristotopes will not be a serious competition for water for *Quercus robur* when they grow together. However, an analysis of the research results shows that it is important to consider the quantitative ratio between the species, especially in xerophytic growing conditions, in order to create favourable conditions for water exchange in oak stands. The prospect of further research is the analysis of morphophysiological indicators of different tree species when they grow together in phytocenoses under the influence of unfavourable hydrothermal conditions, which is typical for the summer months in the steppe zone of Ukraine.

## Acknowledgements

None.

## Conflict of Interest

None.

## References


[1] Asbjornsen, H., Tomer, M.D., Gomez-Cardenas, M., Brudvig, L.A., Greenan C.M., & Schilling, K. (2007). Tree and stand transpiration in a Midwestern bur oak savanna after elm encroachment and restoration thinning. *Forest Ecology and Management*, 247(1-3), 209-219. doi: 10.1016/j.foreco.2007.04.043.

[2] Belgard, A.L. (1971). *Steppe forestry*. Moscow: Forestry Industry.

[3] Bessonova, V.P. (2006). *Workshop on plant physiology*. Dnipro: IE A.L. Svidler.

[4] Bessonova, V.P., Yakovlieva-Nosar, S.O., Ivanchenko, O.E., & Aleksandrova, O.V. (2023). Characteristics of transpiration of Quercus robur L. and Acer campestre L. in the oak-field maple forest of Viyskova ravine. In *Proceedings of IX International scientific and practical conference "Modern problems of science, education and society"* (pp. 43-50). Kyiv: Scientific Publishing Center "Sci-conf.com.ua".

[5] Beydeman, I.N. (1957). Water-salt regime of plants and plant communities in desert areas of the Caucasus. *Congress of Botanical Society*, 2, 17-25.

[6] Brodribb, T.J., Powers, J., Cochard, H., & Choat, B. (2020). Hanging by a thread? Forests and drought. *Science,* 368(6488), 261-266. doi: 10.1126/science.aat7631.

[7] Buksha, I.F., Bondaruk, M.A., Tselyshchev, O.G., Pyvovar, T.S., Buksha, M.I., & Pasternak, V.P. (2017). Vitality forecasting for Scots pine and English oak in condition of climate change in the lowland of Ukraine. *Forestry and Forestry Melioration*, 130, 146-158. doi: 10.33220/1026-3365.141.2022.23.

[8] Celniker, Yu.L. (1958). On indicators of water regime of leaves of tree species of the steppe zone. In *Proceedings of the Institute of Forestry* (vol. 41, pp. 33-53). Moscow: Vysshaya Shkola.
[9] Convention on Biological Diversity. (1992, June). Retrieved from https://zakon.rada.gov.ua/laws/show/995_030#Text.
[10] Convention on the Trade in Endangered Species of Wild Fauna and Flora. (1973, June). Retrieved from https://zakon.rada.gov.ua/laws/show/995_129#Text.
[11] Descals, A., Verger, A., Yin, G., Filella, I., & Penuelas, J. (2023). Widespread drought-induced leaf shedding and legacy effects on productivity in European deciduous forests. *Remote Sensing in Ecology and Conservation*, 9(1), 76-89. doi: 10.1002/rse2.296.
[12] Ellison, D., *et al*. (2017). Trees, forests and water: Cool insights for a hot world. *Global Environmental Change*, 43(51), 51-61. doi: 10.1016/j.gloenvcha.2017.01.002.
[13] Ffolliott, P.F., Stroplu, C.L., Kauffman, A.T., & Gottfried, G.J. (2008). Transpiration of oak trees in the oak savannas of the southwestern borderlands region. *Hydrology and Water Resources in Arizona and the Southwest*, 38, 23-28.
[14] Ganaba, D.V. (2016). The intensity of transpiration of woody plants during the drought in different ecological zones of the city of Khmelnytskyi. *Scientific Progress & Innovations*, (1-2), 113-117. doi: 10.31210/visnyk2016.1-2.22.
[15] Gao, G., Wang, D., Zha, T., Wang, L., & Fu, B. (2022). A global synthesis of transpiration rate and evapotranspiration partitioning in the shrub ecosystems. *Journal of Hydrology*, 606, article number 127417. doi: 10.1016/j.jhydrol.2021.127417.
[16] Ivanov, L.A., Silina, A.A., & Celniker, Yu.L. (1952). On transpiration of field protective species in conditions of Derkul steppe. *Botanical Journal*, 37(2), 21-29.
[17] Jay, A., (2018). Overview. In *Impacts, risks, and adaptation in the united states: fourth national climate assessment* (pp. 33-71). Washington: U.S. Global Change Research Program. doi: 10.7930/NCA4.2018.CH1.
[18] Karpenko, V.I. (2013). Silvicultural properties of related species in oak forests of the Forest-Steppe of Ukraine. *Scientific Bulletin of NULES. Series: Forestry and Ornamental Gardening*, 187(1), 248-253.
[19] Katsulyak, Yu.D. (2009). Plantations of oak common participation aborigines that introducent duickness forest vegetation species of the Precarpathia Region. *Scientific Bulletin of UNFU*, 19(2), 31-40.
[20] Krivoruchko, A.P. (2019). Transpiration in *Quercus rubra* and *Quercus robur* mixed-species stand versus monocultures in the Steppe of Ukraine. *Problems of Bioindications and Ecology*, 24(1), 23-35. doi: 10.26661/2312-2056/2019-24/1-02.
[21] Landblad, M., & Lindroth, A. (2002). Stand transpiration and sapflow density in relation to weather, soil moisture and stand characteristics. *Basic and Applied Ecology*, 3(3), 229-243. doi: 10.1078/1439-1791-00099.
[22] Larcher, W. (1980). *Physiological plant ecology*. Berlin: Springer. doi: 10.1007/BF02851882.
[23] Lyalko, V.I., Levchik, O.I., & Sakhatsky, O.I. (2012). Estimation of transpiration using satellite images for regional water balance evaluation. *Geoinformatics*, 2(42), 60-66.
[24] Obraztsova, V.I., & Kotsyubinskaya, N.P. (1976). Transpiration of petiole oak and common ash in different forest conditions. *Issues of Steppe Forestry*, 6, 76-82.

[25] Shpak, N.P., Shlapak, V.P., & Leontyak, G.P. (2017). Some peculiarities of cultivation of common oak stands involving bereka medicinal in Southern Podillya. *Scientific Bulletin of UNFU*, 27(3), 71-74. doi: 10.15421/40270315.

[26] Silina, A.A. (1958). Influence of transpiration of some tree species on transpiration of others when growing together in the forest-steppe. *Proceedings of the Forest Institute*, 41, 96-103.

[27] Svyrydenko, V.E., Babich, O.G., & Kirichok, L.S. (2004). *Forestry*. Kyiv: Aristey.

[28] Vasilenko, I.A., Pivovarov, O.A., Trus, I.M., & Ivanchenko. A.V. (2017). *Urban ecology*. Dnipro: Accent.

[29] Weiskopf, S.R., *et al*. (2020). Climate change effects on biodiversity, ecosystems, ecosystem services, and natural resource management in the United States. *Science of the Total Environment*, 733, article number 137782. doi: 10.1016/j.scitotenv.2020.137782.

# Порівняння активності транспірації дерев *Quercus robur* L. і *Acer campestre* L. в різних умовах забезпечення вологою балки Військова

**Валентина Бессонова**

Доктор біологічних наук, професор
Дніпровський державний аграрно-економічний університет
49000, вул. Сергія Єфремова, 25, м. Дніпро, Україна
https://orcid.org/0000-0002-4310-0971

**Світлана Яковлєва-Носарь**

Кандидат біологічних наук, доцент
Хортицька національна академія
69017, вул. Наукове містечко, 59, м. Запоріжжя, Україна
https://orcid.org/0000-0002-0935-0483

**Анотація.** Важливим є визначення ролі дерев у водному циклі та їх вплив на вологість ґрунту й атмосферну вологозабезпеченість. Метою роботи було дослідити особливості перебігу транспірації листків *Quercus robur* і *Acer campestre* у пакленових дібровах за різних умов водозабезпечення. Дослідження проводилося в нижній третині схилу північної і середній третині схилу південної експозицій у байраці Військовий. Проведено лісівничо-таксаційне обстеження модельних дерев на обох пробних площах, насадження яких є середньогустими. Вивчено денний хід транспірації цих листяних порід протягом вегетації. Найбільших значень даний фізіологічний процес набуває в обох видів на схилі північної експозиції у літні місяці, особливо у *Quercus robur*. На схилі південної експозиції у травні і червні середньодобові значення транспірації в обох порід майже не відрізняються. Протягом решти місяців вегетаційного періоду інтенсивність випаровування води листками *Quercus robur* статистично вища, ніж у *Acer campestre*. Встановлено, що на схилі південної експозиції у більш посушливих умовах зростання дерев даний процес перебігає менш активно. Це стосується транспіраційної втрати води листками за день у розрахунку на одиницю їх маси, щомісячної транспірації й інтенсивності цього процесу у перерахунку на дерево. Відмінність між результатами втрати води листками одного дерева *Quercus robur* і *Acer campestre* є істотною і обумовлена як нижчим рівнем транспірації *Acer campestre*, за винятком травня і червня за ксерофільних умов, так і меншою масою листків цього виду. Як *Quercus robur*, так і *Acer campestre* є гідростабільними середньотранспіруючими породами. Пакленова діброва на схилі північної експозиції у перерахунку на 1 га за вегетаційний період випаровує вологи на 30,6 % більше, ніж на схилі південної. Одержані результати свідчать, що *Acer campestre* у пакленових дібровах за свіжих і сухих лісорослинних умов не виступає серйозним конкурентом за вологу для *Quercus robur* при їх сумісному зростанні. Отримані результати можуть бути використані для розроблення ефективних стратегій лісового господарювання в пакленових дібровах

**Ключові слова:** випаровування води листками; дуб звичайний; клен польовий; лісорослинні умови; байрачний ліс