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TRANSPIRATION AND SOIL WATER SUPPLY IN FLOODPLAIN FORESTS

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Abstract

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Transpiration of mature floodplain forest stands in the alluvium of the Dyje river in South Moravia has been monitored for more than three decades. The monitoring was carried out both under original natural conditions and after the water management measures. The transpiration (actually sap flow measured by the trunk heat balance method) was monitored in pedunculate oak (*Quercus robur* L.), European ash (*Fraxinus excelsior* L.) and small-leaved lime (*Tilia cordata* Mill.) during growing seasons of ten years. Tree transpiration represented over 80% of potential evapotraspiration under conditions of non-limited soil water. Actual transpiration decreased significantly under limiting soil water conditions following the major groundwater level decline after the canalization of the Dyje river.

Key words: floodplain ecosystem, potential evapotranspiration, actual transpiration, water balance, ground water

Introduction

Floodplain forests are relatively rare but very valuable forest ecosystems found in the Czech Republic. The impact of anthropogenic interventions into the specific conditions on which these forest ecosystems are dependent threatened their structure, stability and eventually their existence. Conservation of these ecosystems requires the monitoring, understanding and the effort to optimize primarily the floodplain forest trees water relations, which is vital to the water balance of these ecosystems.

Methods

The transpiration of mature floodplain forest stands growing on alluvial soils (modal Fluvisol including a number of subtypes) in the floodplain of the Dyje river in South Moravia has been studied for three decades under variable climatic conditions and under the impact of the groundwater level changes due to the water management measures implemented in the region (Penka et al., 1972, 1979, 1983; Čermák et al., 1982, 1987, 1991, 2001; Čermák, 1995a, b; Hadaš, 2003). The study covers the situation during the last natural floods in the early 1970s, followed by twenty-year long transient period without floods and the recent years when the groundwater level increased again as a result of controlled flooding.

Transpiration was determined by continual measurements of sap flow rate during entire growing periods, using the trunk heat balance method (Čermák et al., 1982, 2004), which was applied to series of sample trees of differing social classes in several experimental stands. The studied species included dominant pedunculate oak (*Quercus robur* L.), partially also European ash (*Fraxinus excelsior* L.) and small-leaved lime (*Tilia cordata* Mill.). Greater part of the study was focused on a stationary experimental site and forest stands near the town of Lednice, other parts of the study were focused on sites near the towns of Lanžhot and Pohansko.

Results and discussion

Floodplain forests growing under conditions of high evaporation demands and non-limiting soil moisture transpired high amounts of water, reaching over 80% of potential evapotranspiration (Fig. 1). Roughly up to 70% of this amount of water was supplied from underground water sources, the remaining part was supplied by the local precipitation. Transpiration was sometimes limited by both: periodical short-term droughts and in contrast the water-

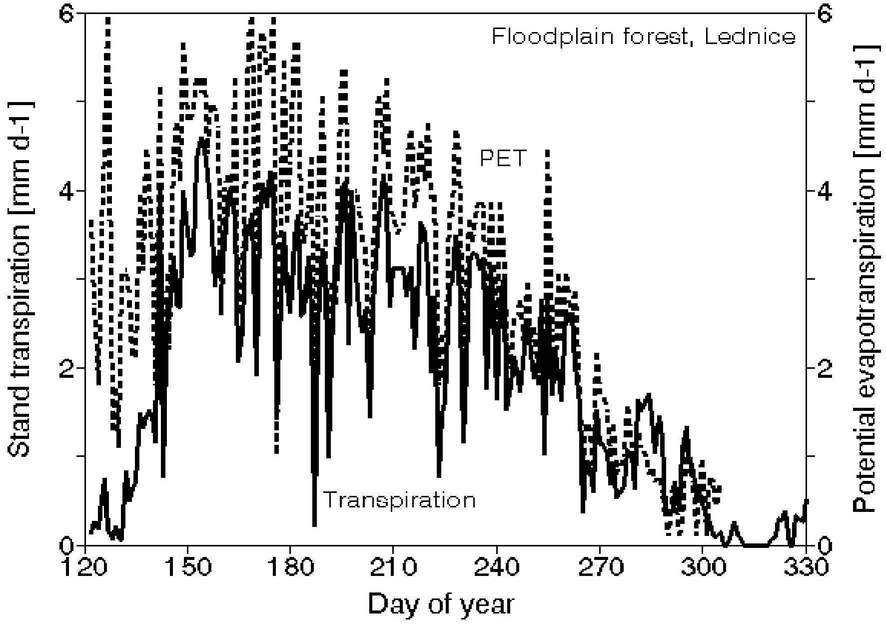

Fig. 1. Example of a seasonal course of transpiration of entire floodplain forest stand near Lednice (composed mostly of pedunculate oak, also ash and lime) and potential evapotranspiration (PET).

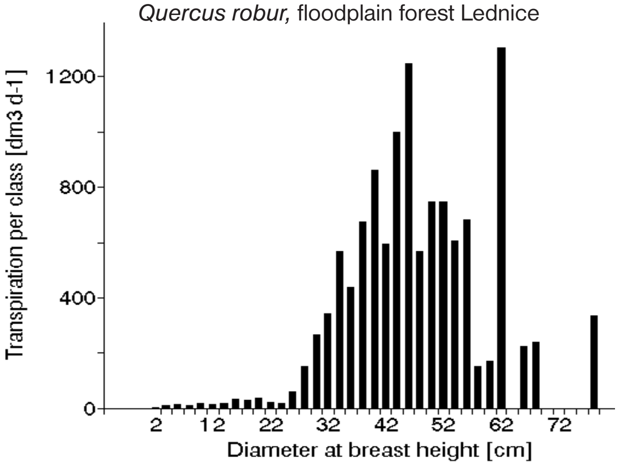

Fig. 2. Example of daily transpiration of trees in different diameter classes over the whole range of tree size in the floodplain forest "Horni Les".

logging of soil. This took place in trees that were subject to long-term flooding and thus the active water absorption was strongly limited due to lack of soil aeration and following soil and root hypoxia. Water consumption in stands dropped significantly after the water management measures applied in the region after which the consequent significant drop of underground water level occurred. Therefore trees could absorb only a small amount of water (or no water) from underground water level under such conditions and had to rely on local precipitation only. Although there was still significant soil water storage in about 2 m deep layer of heavy soil, transpiration decreased by about 50%. Small-to-medium size trees with disbalanced root to leaf area ratio were declining during this period. Stand transpiration increased again when started artificial controlled watering.

Large trees transpired much more than small trees, when considering 1/3 of tree number per ha, they represent about 2/3 of entire stand transpiration (Fig. 2). Principal tree species of the floodplain forest show a considerable disproportion between the massive biomass of the above-ground part of a tree and the relatively small biomass of its root system, which was developed for conditions of non-limiting soil water supply. Individual components of water balance in the floodplain forest under conditions of different water supply from soil from the underground water (Čermák, Prax, 2001) based on a good knowledge of tree structure and root distribution in soil (Vyskot, 1976; Tatarinov et al., 2008) are shown on the scheme (Fig. 3). The situation during mild and fine weather in the period of regular floods, and that following the unfavourable water management measures was characterized this way. The decline of the groundwater level and water supply into the uppermost soil layers resulted in drought stress in the floodplain forest stands and consequently in a significant decline in the actual water transpiration.

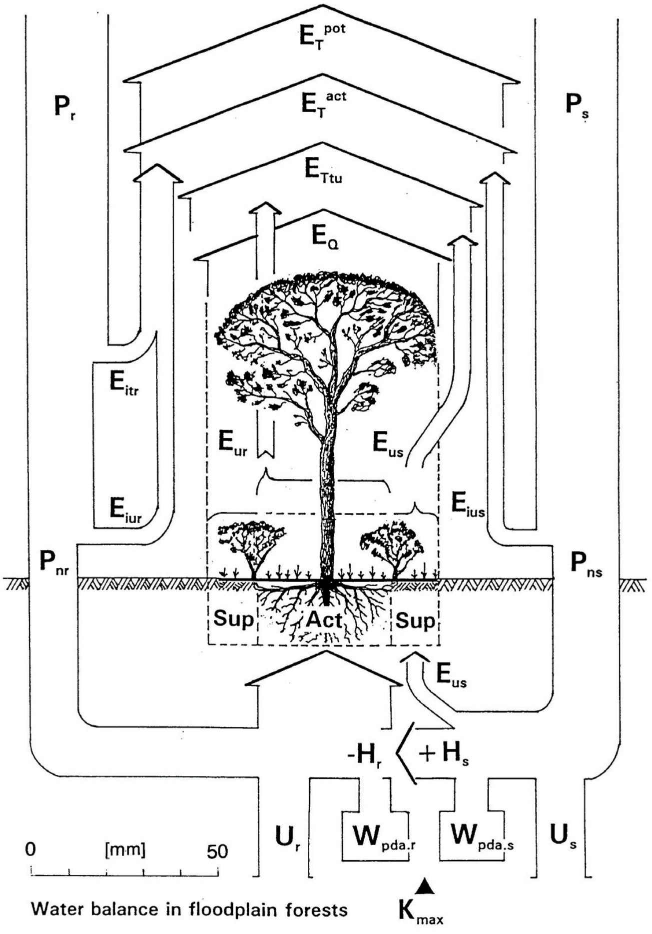

Fig. 3. General scheme of the water balance components of a floodplain forest in South Moravia (near the town of Lednice). Width of arrows represents magnitude of water flows during the growing period.
Symbols without index – values valid for the entire stand, s**ymbols with index r** – values valid for the soil compartment with roots, index **s** – additional "supplementary" soil volume compartments (i.e. timber land without the roots of the dominant stand component), $\mathbf{P}_r \mathbf{P}_s$ – precipitation over soil with roots and over the additional soil volume, $\mathbf{P}_{nr}$ $\mathbf{P}_{ns}$ – stand precipitation, $\mathbf{E}_{pot}$ – stands for potential evapotranspiration, $\mathbf{E}_{act}$ – stands for actual evaporation. $\mathbf{E}_{T.act}$ – actual evapotranspiration (i.e. evaporation without interception), $\mathbf{E}_Q$ – transpiration of the principal species of the stand (determined by direct measurements of the transpiration stream), $\mathbf{E}_{ur}$**,** $\mathbf{E}_{us.}$ $\mathbf{E}_{iur}$ and $\mathbf{E}_{ius}$ – interception of the closed stand of principal stand and the undergrowth, $\mathbf{dW}_{pda.r}$**,** $\mathbf{dW}_{pda.s}$ – water supply in soil up to the soil-moisture constant of the limited water availability (pda), $\mathbf{U}_r$, $\mathbf{U}_s$ – water coming from the groundwater level, **H** – horizontal water transport between the additional and soil volume with roots ($-\mathbf{H}_s$ – run-off from the additional volume, $+\mathbf{H}_r$ – influx into the soil volume with roots), $\mathbf{K}_{max}$ – maximum soil hydraulic conductivity (limits water transport from the supplementary to the rooted soil volume).

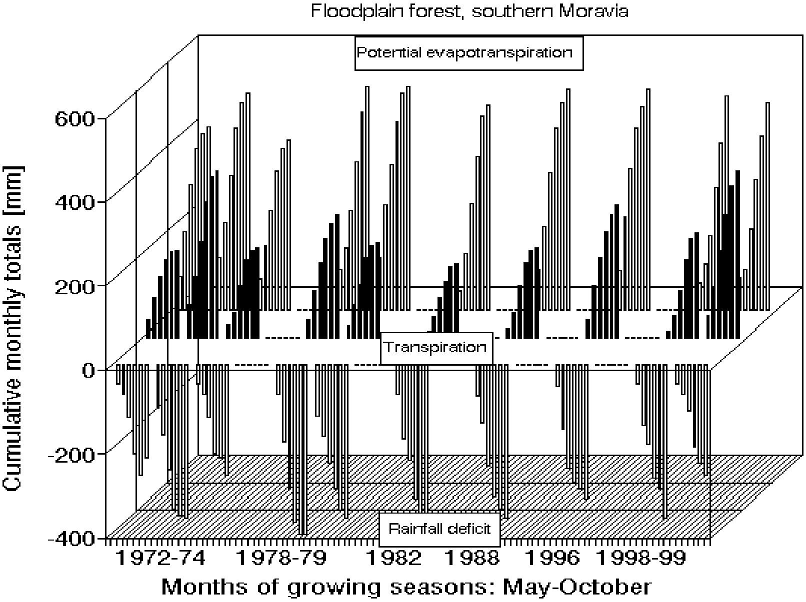

Fig. 4. Seasonal courses (cumulative monthly values) of main variables measured during 10 years over the period of 27 years (24 years in the experimental plot of "Horni Les" near Lednice and last 2 years in the experimental plot of "Dlouhy Hrud" near Pohansko) at the stand level. These are: potential evapotranspiration (E_T), rainfall deficit (precipitation minus potential evapotranspiration), floodplain forest stand transpiration derived from sap flow data (E_Q).

Over two decades the forest stands partly adapted to the changed conditions by developing additional roots and thus managed to absorb about 30% of the transpired water from the underground supplies. At present (i.e. about 30 years after the original regular inundation had stopped) the monitored floodplain forests are functionally and structurally adapted (among other things, significant changes in both the undergrowth and dominant stand density have taken place) and survived over the critical period in the 1980s (Čermák et al., 2001). The stands have a better chance that they will survive now (Fig. 4). It can be expected that controlled flooding will improve the water supply into soil. However, we must make allowance for the readjusting of tree root systems to wetter soil conditions after passing a period of drier conditions, which took place over the twenty years there.

A detailed study of the water balance of forest stands, whose soil profile was divided into compartments with roots and without roots, showed that soil moisture in floodplain forests remained relatively high over the entire monitored period. However, the trees suffered from drought due to low hydraulic conductivity of the heavily textured alluvial soils. Horizontal water transport plays an important role in this. A minor drop of moisture content in soil (tiny percentage by volume) resulted in a significant decline of hydraulic conductivity in heavy soils. Consequently, in case of increased evaporation demand even water present in the water profile in seemingly ample quantity cannot be transported to the trees quickly enough through the thin layer of soil adhering to the roots. As a result, even in times of mild short-term drought trees with unfavourable ratio between the root and foliage areas (ratio between the entire root ball area of root systems and the area of sun-exposed foliage) suffered from drought and consequently died. Hydraulic conductivity of heavy soils becomes a limiting factor in water supply even before the reduced water potential of a soil becomes apparent. This can have both local and widespread impact.

The floodplain forest ecosystem has been considerably disrupted by human activity. Owing to its sensitivity to ill-considered intervention, it requires constant attention of both forest managers and research workers.

Conclusion

Floodplain forests transpire one of the largest amounts of water (if compared to other forest ecosystems) under high evaporation demands when growing under non-limiting soil water conditions, i.e., with permanently high underground water table. However, during the 20-year-long period of limiting soil water supply (which was caused by inappropriate water management measures in the region), their transpiration decreased by about one half. This happened due to substantially lower hydraulic conductivity of heavy soil, after its water content decreased partially. The situation changed again in early 90ties, when forests started being watered artificially. Fortunately trees were able to readapt to such changes and renewed their water consumption almost to the same level as under the period of regular natural floods. However, some changes of floodplain forests already occurred. They can be jeopardized by climatic changes, particularly in cases of prolonged periods of drought.

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References

Čermák, J., Úlehla, J., Kučera, J., Penka, M., 1982: Sap flow rate and transpiration dynamics in the full-grown oak (*Quercus robur* L.) in floodplain forest exposed to seasonal floods as related to potential evapotranspiration and tree dimensions. Biol. Plant. (Prague), 24, 6: 446–460. doi:10.1007/BF02880444

Čermák, J., Kučera, J., Štěpánková, M., 1987: Water consumption of fully grown oak in floodplain forest during transient period after cessation of floods (in Czech). Acta Universitatis Agriculturae (Brno), Ser. C, *56*, 1–4: 5–25.

Čermák, J., Kučera, J., Štěpánková, M., 1991: Water consumption of full-grown oak (*Quercus robur* L.) in a floodplain forest after the cessation of flooding. In Penka, M., Vyskot, M., Klimo, E., Vašíček, F. (eds), Floodplain forest ecosystem II. Elsevier (Developments in Agricult.& Managed Forest Ecology 15B), Amsterdam-Oxford-N.York-Tokyo, p. 397–417.

Čermák, J., 1995a: Water consumption by floodlain forests in southern Moravia, its changes due to decreasing soil water table and possibilities of its systematic control.(in Czech). In Proc. „Ochrana lužních lesů jižní Moravy – specifika lesního hospodářství“. Židlochovice –zámek, April. 6-7, 1995. MZČR Praha, LČR and CVVS Czech Republic and EFI Joensuu, Finland, p. 100–114.

Čermák, J., 1995b: Long-term monitoring of transpiration of floodplain forests in southern Moravia (in Czech). In Workshop „Zvelebení lesních ekosystémů“, VÚLHM-SB-NLK, Opočno, 5–9.11.1995.

Čermák, J., Kučera, J., Prax, A., Bednářová, E., Tatarinov, F., Nadyezhdin, V., 2001: Long-term course of transpiration in a floodplain forest in southern Moravia associated with changes of underground water table. Ekológia (Bratislava), *20*, Suppl. 1: 92–115.

Čermák, J., Prax, A., 2001: Water balance of floodplain forests in southern Moravia considering rooted and root-free compartments under contrasting water supply and its ecological consequences. Ann. Sci. For., *58*: 1–12.

Čermák, J., Kučera, J., Nadezhdina, N., 2004: Sap flow measurements with two thermodynamic methods, flow integration within trees and scaling up from sample trees to entire forest stands. Trees, Structure and Function, *18*: 529–546.

Hadaš, P., 2003: Temperature and humidity conditions of the floodplain forest with respect to stand microclimate and mesoclimate. Ekológia (Bratislava), *22*, Suppl. 3:19–46.

Penka, M., Štěpánek, V., Čermák, J., 1972: A study of the water regime in oak (*Quercus robur* L.). Acta Universitatis Agriculturae (Brno), Ser. C, *42*: 121–137.

Penka, M., Čermák, J., Štěpánek,V., Palát, M., 1979: Diurnal courses of transpiration rate and transpiration flow rate as determined by the gravimetric and thermometric methods in a full-grown oak tree (*Quercus robur* L). Acta Universitatis Agriculturae (Brno), Ser. C, *48*, 1–4: 3–30.

Penka, M., Čermák, J., Prax, A., Úlehla, J., Žídek,V., 1983: Water consumption of oak (*Quercus robur* L.) in the alluvium of the Dyje river in non-limiting moisture conditions (in Czech). Lesnictví, *29*, 6: 481–496.

Tatarinov, F., Urban, J., Čermák, J., 2008: The application of „clump technique“ for root system studies of *Quercus robur* and *Fraxinus excelsior*. Forest Ecology and Management, 255: 495–505. doi:10.1016/j.foreco.2007.09.022

Vyskot, M., 1976: Tree story biomass in lowland forests in South Moravia. Academia Praha, Rozpravy ČSAV, 10, 186 pp.