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BRIEF COMMUNICATION

Tree water dynamics non-destructively assessed through sap flow measurements and potential evapotranspiration

R. BEQUET[1]*, J. ČERMÁK[2], N. NADEZHDINA[2], C. DE CANNIERE[3] and R. CEULEMANS[1]

Department of Biology, University of Antwerp, Universiteitsplein 1, B-2610 Wilrijk, Belgium[1]
Mendel University of Agriculture and Forestry, Zemědělská 3, CZ-61300 Brno, Czech Republic[2]
Ecole Interfacultaire de Bioingénieurs, Université Libre de Bruxelles, B-1050 Bruxelles, Belgium[3]

Abstract

Sap flow and potential evapotranspiration rates were analyzed for two coniferous tree species (Douglas-fir and Scots pine) and one broadleaf species (sessile oak) in a mixed *Carpineto-Quercetum* forest during the growing season 2005. The relationship between sap flow and potential evapotranspiration rates, effective crown area as a measure of the relative transpiration and daily relative proportion of the storage water used for transpiration were used as indicators of the tree water dynamics. These indicators were determined on four consecutive days and all three showed good reliability concerning tree water dynamics.

Additional key words: *Quercus petraea, Pinus sylvestris, Pseudotsuga menziesii*, transpiration rate, water balance, water deficit.

Water relations belong to the most important physiological processes in plants, because water is often growth limiting (Larcher 2003). Continuous sap flow measurements on sample trees provide a valuable background for the analysis of physiological processes and of the water balance (Nadezhdina 1999). Beside transpiration measurements, there is a certain lack of appropriate approaches to interpret the physiological behaviour of trees in relation to the water dynamics *in situ* (Ortuño *et al.* 2007). Because of the wide availability of sap flow measurements they could be used as a robust tool to analyze tree water dynamics in field conditions, especially under critical soil water availability.

The different indicators of tree water dynamics discussed in this article differ about the means of calculation and how they are characterizing the tree water status. First, water stress conditions can be characterized by a continuous decrease of the sap flow rate (Q_{wt}) under nearly constant diurnal potential evapotranspiration (PET) conditions (indicator 1). Changes in the slope of the linear regression between hourly fluxes of Q_{wt} and PET corrected for time shift give a specific idea of the tree water dynamics (Table 1). A decrease of the slope can be interpreted as an increase of the tree water deficit. Further, the effective crown area (A_{eff} - indicator 2) can be obtained from the ratio between daily rates of tree transpiration and PET: $A_{eff} = Q_{wt}/PET$. This indicator works when relating tree level sap flow with stand level PET data (Čermák *et al.* 1982). The A_{eff} on a reference day (DOY 231 in our study) gives the maximal A_{eff} involved in tree transpiration over the growing season. The ratio of A_{eff} on a particular day to the maximal A_{eff} provides the relative A_{eff}, an estimate of the tree hydraulic conductivity. Finally, the hourly course of PET is scaled-up to the sample tree level (PET_{tree}) by multiplying it with the effective crown area. Since the fluxes of sap flow and transpiration are lagged in time due to the primary use of the water stored in tree tissues, the daily integrated difference between hourly fluxes of Q_{wt} and PET_{tree} is applied to estimate the amount of used storage water. When Q_{wt} is lower than PET_{tree} (mostly in the early morning), the water used for transpiration is removed

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Abbreviations: A_{eff} - effective crown area; DOY - day of year; PET - potential evapotranspiration; PET_{tree} - PET extrapolated at tree level; Q_{wt} - tree sap flow rate.
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* Corresponding author; fax: (+32) 3 265 2349, e-mail: raphael.bequet@ua.ac.be

from the pool of water inside the tree. Indicator 3 is the ratio between daily contribution of storage water and daily sap flow rate (Čermák *et al.* 1982, 2007). The amount of transpired storage water compared with daily Q_{wt}, representing the water absorption by the roots, is of particular interest to understand which fraction of the particular water pool is involved in transpiration.

Specific indicators of tree water dynamics discussed in this article all rely on the same driving variable, PET (Kupper *et al.* 2006). The quantities Q_{wt} and PET can be quantitatively compared, if leaves are not wet (Nicolas *et al.* 2005). We used these indicators over the whole growing season. Here, we demonstrated them for each sample tree during a 4-d period (DOY 248 - 251) without rain events. Daily totals of PET over the 4-d period were similar [2.02 ± 0.11 kg(H_2O) m^{-2}(soil) d^{-1}]. However, 5 d prior to this period (DOY 243), tap water was locally applied around the two coniferous trees. This was done to enable the analysis of the three indicators under different soil moisture conditions.

The objective of this work was to evaluate the reliability and informative outcome of these three different indicators based on sap flow and potential evapotranspiration measurements on three mature trees in field conditions.

The study was done at the experimental site in a Brno suburban mixed forest located at an altitude of 360 m (latitude 49°18'N, longitude 16°36'E, Czech Republic). The subsoil is an illimerized forest soil on loamy aluvium and granodiorite with an inaccessible ground water table (Čermák *et al.* 1980). Long-term mean annual temperature is 7.8 °C and mean annual precipitation is 583 kg m^{-2} (360 kg m^{-2} over the growing season). Three tree species (*Quercus petraea*, *Pinus sylvestris* and *Pseudotsuga menziesii*) were chosen for their differences in morphological characteristics (crown area, root system) and for their different responses to available soil water (Bequet 2006). The measurements on one sample tree of each species provided a qualitative dataset, which was only used for a comparative analysis of the indicators of tree water dynamics. No assumptions are made on a species-specific tree water balance control.

Sap flow was measured during the growing season 2005 by the trunk heat balance method (Čermák *et al.* 2004). Two sets of sap flow sensors were installed on opposite sides of the stem at breast height of each sample tree. Sap flow data were measured each minute and recorded as hourly means over 15-min intervals by a data logger *Unilog EMS-12* (*Environmental Measuring Systems*, Brno, Czech Republic). Air temperature, relative humidity and global net radiation were used to calculate the potential evapotranspiration by the FAO modified Penman-Monteith equation (Allen *et al.* 1998). Statistical analysis (*ANCOVA*) was performed on daily data sets of Q_{wt} and PET. PET was treated as a fixed factor and Q_{wt} data were included as covariables. The regression coefficients (r^2) were calculated.

Diurnal records of both Q_{wt} and PET (indicator 1; Fig. 1) can provide valuable information about tree water dynamics. Drought stress was characterized by a continuous decrease of the slope of the regression between hourly values of Q_{wt} and PET corrected for time shift (not shown). A decrease of the slope indicated a decrease of soil water availability. Under a similar diurnal PET, both coniferous trees were not able to maintain the amplitude of their diurnal Q_{wt} (Fig. 1) and their Q_{wt} significantly ($P < 0.001$) decreased in the following days (DOY 249 - 251; Table 1). The oak tree known as a deep rooted species showed no significant decrease in Q_{wt} in the last 3 d of the period.

In line with the diurnal curve of the Douglas-fir sap flow rate, its relative effective crown area (as % of A_{eff} on a reference day, *i.e.*, 5, 22.5, and 82 m^2, respectively, for Scots pine, Douglas-fir and oak trees; indicator 2

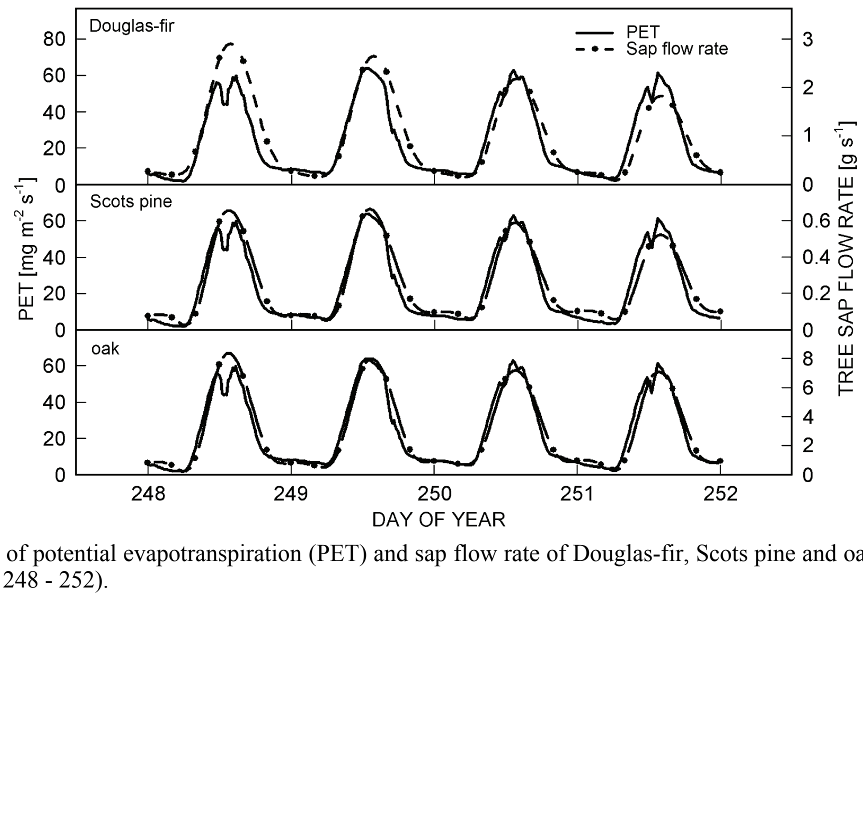

Fig. 1. Diurnal fluxes of potential evapotranspiration (PET) and sap flow rate of Douglas-fir, Scots pine and oak during development of water stress (DOY 248 - 252).

Table 1. Three indicators of tree water dynamics during the 4-d period (DOY 248 - 251) for sessile oak, Scots pine and Douglas fir. Sap flow (Q_{wt})/potential evapotranspiration (PET) ratio is based on the slope of linear regression (all r^2 are significant at $P < 0.001$). The relative (Rel.) effective crown area (A_{eff}) is expressed in % of the same area on the reference day (DOY 231). The daily contribution of storage water is expressed in % of tree transpiration.

Species	DOY	Q_{wt} /PET [m^2]	r^2	Rel. A_{eff} [%]	Storage water [%]
Sessile oak	248	120.0 ± 3.0	0.989	70.5	14.0
	249	117.9 ± 2.7	0.974	65.2	16.5
	250	117.6 ± 2.3	0.977	65.0	14.8
	251	115.1 ± 1.8	0.980	61.0	16.0
Scots pine	248	10.5 ± 0.2	0.985	96.6	14.4
	249	9.8 ± 0.1	0.988	92.2	16.1
	250	9.1 ± 0.1	0.991	87.8	14.5
	251	8.0 ± 0.1	0.989	81.4	16.5
Douglas fir	248	48.0 ± 0.7	0.964	99.0	14.5
	249	41.0 ± 0.7	0.950	82.4	18.9
	250	35.9 ± 0.4	0.970	69.0	16.8
	251	29.8 ± 0.3	0.983	58.1	18.5

decreased during DOY 249 - 251 due to the high evaporative demand (Table 1). A similar decrease also occurred in Scots pine and, less markedly, in oak. The high value of the relative A_{eff} of the two coniferous trees during DOY 248 - 252 was due to the high water availability in the soil after the local irrigation 5 d before. Oak had a lower relative A_{eff} area due to the absence of irrigation (Table 1).

Although the Douglas-fir tree showed the most significant decrease in Q_{wt} (Fig. 1), this was partly compensated by a substantial increase of the fraction of storage water (Table 1). Despite morphological differences (dense versus sparse crown) and physiologically contrasting behaviours (coniferous *versus* broadleaf), the Scots pine and the oak trees seemed to maintain a similar contribution of their storage water in the daily transpiration rate which was lower than in Douglas-fir (Table 1, indicator 3).

Indicators based on comparisons of sap flow and PET provided synthetic information on the tree water status. Indicators 1 and 3 have to be analyzed together because of the double source of water (by root uptake and from storage) utilized for tree transpiration. The effective crown area (indicator 2) enables intra- and interspecific comparisons among different trees. The analysis of the results compared to a reference day of maximal efficiency in transpiration is particularly valuable for the interpretation of tree water conductivity. Indicator 2 also has the advantage to include daily totals and, thereby, excludes the existing time lag between PET and Q_{wt} measurements.

References

Allen, R., Pereira, L.S., Raes, D., Smith, M.: Crop Evapotranspiration – Guidelines for Computing Crop Water Requirements. - Food and Agriculture Organization of the United Nations (FAO), Rome 1998.

Bequet, R.: Comparative study of the sap flow of coniferous and deciduous trees with different root systems and at a different water supply. - Master Thesis, Université Libre de Bruxelles, Bruxelles 2006.

Čermák, J., Huzulák, J., Penka, M.: Water potential and sap flow rate in adult trees with moist and dry soil as used for the assessment of root system depth. - Biol. Plant. **22**: 34-41, 1980.

Čermák, J., Úlehla, J., Kučera, J., Penka, M.: 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. **24**: 15-29, 1982.

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

Čermák, J., Kučera, N., Bauerle, W.L., Phillips, J., Hinckley, T.M.: Tree water storage and its diurnal dynamics related to sap flow and changes of trunk volume in old-growth Douglas-fir trees. - Tree Physiol. **27**: 181-198, 2007.

Kupper, P., Sellin, A., Klimánková, Z., Pokorný, R., Puértolas, J.: Water relations in Norway spruce trees growing at ambient and elevated CO_2 concentrations. - Biol. Plant. **50**: 603-609, 2006.

Larcher, W. (ed.): Physiological Plant Ecology 4th Edition. - Springer-Verlag, Berlin - Heidelberg - New York 2003.

Nadezhdina, N.: Sap flow index as an indicator of plant water status. - Tree Physiol. **19**: 885-891, 1999.

Nicolás, E., Torrecillas, A., Ortuño, M.F., Domingo, R., Alarcón, J.J.: Evaluation of transpiration in adult apricot trees from sap flow measurements. - Agr. Water Manage. **72**: 131-145, 2005.

Ortuño, M.F., Alarcón, J.J., Nicolás, E., Torrecillas, A.: Water status indicators of lemon tree in response to flooding and recovery. - Biol. Plant. **51**: 292-296, 2007.