MONITORING OF TREE SAP FLOW AND ESTIMATION OF BEECH STAND TRANSPIRATION AS THE MAJOR COMPONENT OF THE PASSIVE PART OF ECOSYSTEMS' WATER BALANCE

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Measurement of tree sap flow enables the analysis of derived forest transpiration and also the water state of the entire ecosystem. Transpiration is strongly influenced by the synergistic effect of numerous external factors, some of which are predicted to alter due to climate change. The study was carried out by in-situ monitoring sap flow and related environmental factors in the years 2014 and 2015 on a research plot in Bienska dolina (Slovakia). In the paper, we described the available method of tree sap flow monitoring using a tissue heat balance method and the basic way of scaling up of individual tree sap flow to the forest stand level. We described the relationship between derived transpiration of the adult beech (*Fagus sylvatica* L.) forest stand, environmental conditions, and soil water deficit. In conditions of middle Europe, the transpiration is significant component of terrestrial ecosystem evapotranspiration. Seasonal beech transpiration (from May to September) achieved 59% of potential evapotranspiration (PET) in 2014 and 46% in 2015. We observed as the soil water deficit leading to a radical limitation of transpiration and fundamentally affects the relationship between transpiration and environmental drivers. The ratio of transpiration (E) against PET was significantly affected by a deficit of soil water and in dry September 2015 decreased to the value of 0.2. The maximum monthly value (0.8) of E/PET was recorded in August and September 2014.

METHODS AND DATA

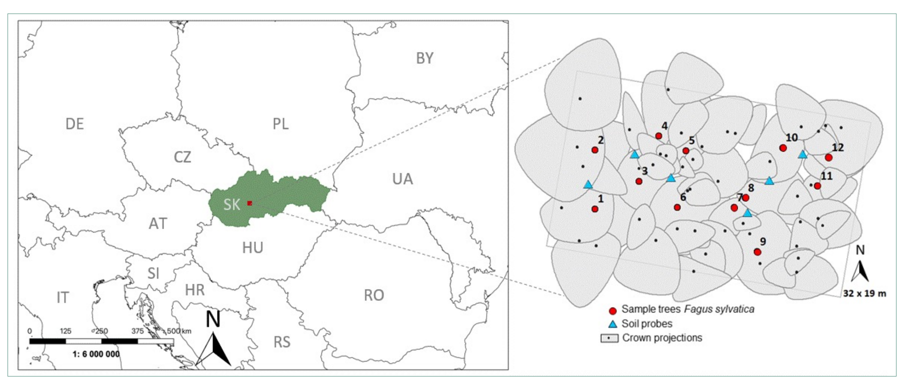

Figure 1 Location of the experimental plot Bienska dolina in central Slovakia (SK) (left) and design of the experimental plot showing crown projections of all beech trees, position of selected sample trees and soil probes (right)

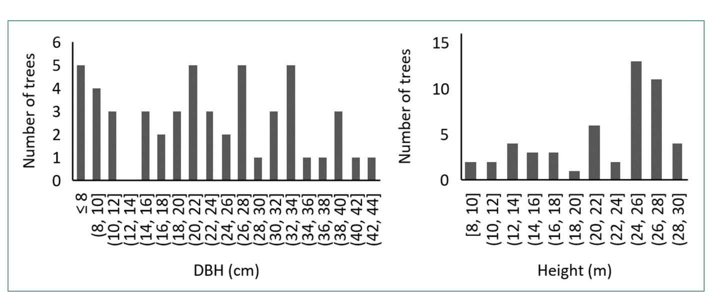

Figure 2 Number of trees in DBH and height classes (interval of the class is 3 cm and 3 m, respectively) within the experimental plot area (608 m²)

Bienska dolina experimental plot with an area of 608 m²

- 69-year-old European beech forest, which is dominated by *Fagus sylvatica* L.
- 3rd oak-beech altitudinal forest zone
- Haplic Cambisol (Humic, Eutric, Endoskeletic, and Siltic) formed on volcanic parent material (andesite and andesitic tuffs)
- relative stocking density of the stand 0.85, total stand volume of beech is 282 m³
- slightly warm and moderately humid climate
- mean annual air temperature and annual sum of precipitation are 7.3 °C and 690 mm (normals)

- *56 trees* - tree height, diameter at breast height (DBH) and crown projection measured and documented (Figure 1,2). The measured DBH of beech trees at the plot varied from 5.7 to 42.3 cm, and heights were from 8.4 to 29.3 m.

- 12 sample trees ---> sap flow systems
  mean tree height of 26.3 m ± 1.3 m (from 24.7 to 29.1 m)
  average diameter (DBH) of 32.4 cm ± 4.8 cm (from 27.1 to 42.3 cm)

Measured environmental variables

- Meteorological variables measured within an open grass area by an automatic meteorological station
  - air temperature (*AT*, °C) and relative humidity (*RH*, %) and global radiation (R_S, W m⁻²) - sensor EMS33 and EMS11; EMS Brno Ltd., Brno, Czech Republic, 2 m)
  - wind speed (*u*, m s⁻¹) - 034B Wind Sensor (Met One Instruments Inc., Grants Pass, OR, USA; 2 m above ground)
  - precipitation (*P*, mm) - rain gauge 370 placed at a height of 1 m above ground (Met One Instruments Inc.)
- Soil water potential (*SWP*, MPa) was continuously measured using measuring sets containing three calibrated gypsum blocs (Delmhorst Inc., Towaco, NJ, USA), and data were stored at 60-min intervals in a data logger (MicroLog SP3, EMS Brno Ltd., Brno, Czech Republic).

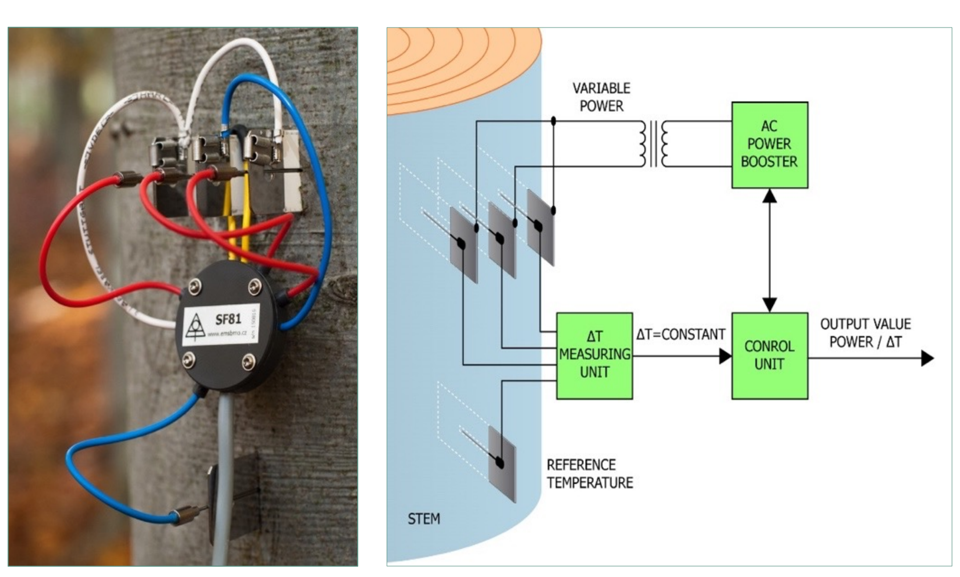

Figure 3. Installed Sap Flow System produced by EMS Brno Ltd. (Brno, Czech Republic) and the flows chart of measuring process (Nalevanková et al. 2020)

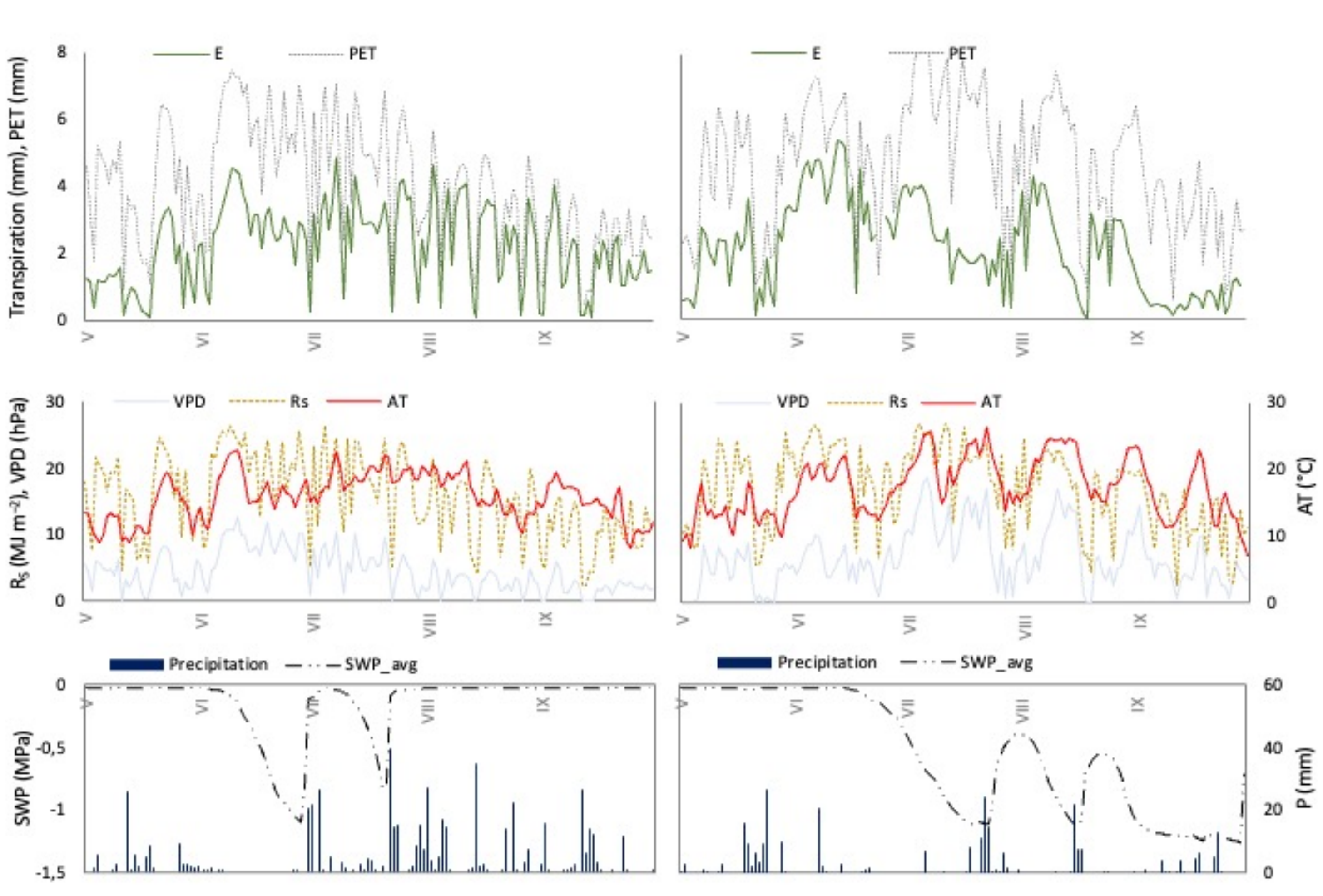

Figure 4. Seasonal dynamics of transpiration and potential evapotranspiration (*PET*) during vegetation season (top) of 2014 (left) and 2015 (right); daily values of global radiation (R_S) vapour pressure deficit (VPD) and average air temperature (*AT*) (middle); daily values of average soil water potential and precipitation totals (*P*) (bottom).

Table1. Monthly and seasonal (May–September) sums of transpiration (*E*) and potential evapotranspiration (*PET, Penman 1948*) in years 2014 and 2015; the ratio *E/PET*.

	2014			2015		
	E (mm)	PET (mm)	E/PET	E (mm)	PET (mm)	E/PET
May	46	119	0.4	58	123	0.5
June	86	165	0.5	106	156	0.7
July	90	149	0.6	72	187	0.4
August	81	104	0.8	73	153	0.5
September	55	72	0.8	19	96	0.2
Season	359	609	0.59	328	716	0.46

Sap Flow and Scaling up to Forest Stand Level

- *EMS51A Sap Flow system* connected to a 16-channel datalogger RailBox V16 (EMS Brno) instaled on 12 beech samples (within the experimental stand)

- The system uses a tissue heat balance method (THB; Čermák et al. 2004, Kučera et al. 1977) based on volume (three-dimensional) heating of the stem segment (Tatarinov et al. 2005) to measure the values of volumetric sap flow directly in kg of water per a specific period and per one centimetre of stem circumference.
- The system used is designed for large trees with a stem diameter larger than 12 cm, whereas its underlying theory is clear with the absence of uncertain empirical parameters and without the need for field calibration as stated by the manufacturer

- The **upscaling** from individual tree sap flow to the forest stand on the base of sap flow distribution at the diameter at breast height (DBH) classes (Čermák et al. 2004). The first step was to obtain the values of sap flow for mean trees ($Q_{mean;}$ kg h⁻¹) of *m* DBH classes by means of regression relating the sap flow of the measured sample tree ($Q_{sample;}$ kg h⁻¹) to the chosen biometric parameter—DBH. These regression analyses were performed with data obtained during a period of constant and sufficient soil water separately for the years 2014 and 2015. Derived Q_{mean} values were multiplied by numbers of trees in DBH classes (n_i) and then summarised within the stand area unit of 1 ha. The result represents the sap flow values of the entire forest stand (Q_{stand}).

$$Q_{stand} = \sum_{i=1}^{i=m} (Q_{mean})_i \, n_i \qquad S = \frac{\sum Q_{stand}}{\sum Q_{sample}}$$

By dividing gained stand sap flow (Q_{stand}) by the sum of sap flow (Q_{sample}), we determined the non-dimensional coefficient *S* (-). Finally, we multiplied the measured sap flow data (20-min) by the coefficient *S* and obtained stand-level values, which we considered to be equal to stand transpiration (*E*, mm h⁻¹ (kg m⁻² h⁻¹)).

CONCLUSIONS

This paper has evaluated the seasonal dynamics of transpiration as a component of potential evapotranspiration and described the environmental drivers' control of beech transpiration and the impact of water deficit on this relation. The experiment was based on the in-situ measurement of sap flow and accompanying measurement of environmental variables and soil water potential. It was found that seasonal beech transpiration (from May to September) achieved 59% of potential evapotranspiration in 2014, whereas in 2015, it was only 46%. During the studied growing seasons 2014 and 2015, soil water deficit led to the radical limitation of transpiration and affected the relationship between transpiration and environmental drivers. The ratio of transpiration (E) against potential evapotranspiration (PET) was significantly affected by the deficit of soil water and in dry September 2015 decreased to the value of 0.2. The maximum monthly value (0.8) of E/PET was recorded in August and September 2014. These months were characterised by above-normal precipitation totals and SWP values close to 0 MPa.

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