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Reasons and Limitations of Transpiration Measurements in Mountainous Areas

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ABSTRACT

Paper presents the up-to-date method of measurement of the transpiration, its application and also limitations in mountainous areas.

The relationship of measured transpiration to meteorological characteristics, particularly net radiation and air temperature over the canopy is discussed and for diurnal courses of transpiration recommended. A simple multiregression model for calculation of hourly transpiration is then presented.

The use of model for long term seasonal calculation is limited due to the absence of data on soil moisture content and the natural vegetational cycle within the studied catchment.

INTRODUCTION

Water balance computations in mountainous catchments are often reduced on counting differences between two directly measurable components the precipitation and runoff. Resulting amount of water called "losses" is than composed of two basic components the evapotranspiration and infiltration or water storage. Thus, the water balance is limited to the question which of those two related components is easier to determine in mountainous areas. Infiltration processes depend on various orographical characteristics as well as type of vegetation and heterogeneous soil profile. Therefore, the actual evapotranspiration is considered as a key for possible solution (Molnár et al. 1988).

The actual distribution of potential evapotranspiration could be calculated by heat balance considering the elevation and exposition of the slopes. Results presented by Miklánek (1992) are giving hope also for determination of the actual evapotranspiration. However, the subject approach does not satisfy much needed requirement for determination of the role of transpiration by vegetation.

METHODS

Transpiration as the most decisive part of the actual evapotranspiration depends on type, age and condition of vegetation and it is affected by meteorological characteristics and limited by disponsible soil moisture. This brief account of influencing parameters clearly proves the reason for direct measurements of transpiration.

For the measurement of transpiration the heat balance method by Čermák et al.(1973, 1982) and Kučera et al. (1977) was used and modified for mountainous conditions by Rášo (1989). The measuring device consists of a power generator, two series of needle thermometers (8 sensors for one measured tree), electrodes (5 electrodes for one tree) and recording instruments. There is needed a heat insulation around the measured segment of the tree. The automatic recorder is than registering differences in temperature of the heated and unheated row of thermometers. The obtained differences ΔT are indirectly related to the speed of sap flow which is in fact considered as a cooling medium. Cooling effect together with the power input, distance and number of electrodes, and including the circumference of the tree, serve for calculation of the intensity of transpiration according to Equation (1).

$$Q_{wt,rec} = \frac{P \;.\; \Delta t}{\Delta T . C_w} \;.\; \frac{O_{bk}}{d(n-1)} \qquad (1)$$

where P - power input /W/

ΔT - temperature difference /°C/

Δt - time interval /s/

C_w - specific water heat /4186,8 $J.K^{-2}.kg^{-1}$/

O_{bk} - circumference of the tree /cm/

d - distance of the electrodes /cm/

n - number of electrodes.

Net intensity of transpiration Q_{wt} is calculated by the Equation (2)

$$Q_{wt} = Q_{wt'rec} - Q_{wt,sep} \qquad (2)$$

where $Q_{wt,sep}$ are heat losses from measured segment, obtained by separation of minimum values during the night. The sap flow Q_{wt} in Equation (2) is calculated in the same time steps as measuring of input data. Figure 1 shows diurnal course of selected meteorological data and transpiration.

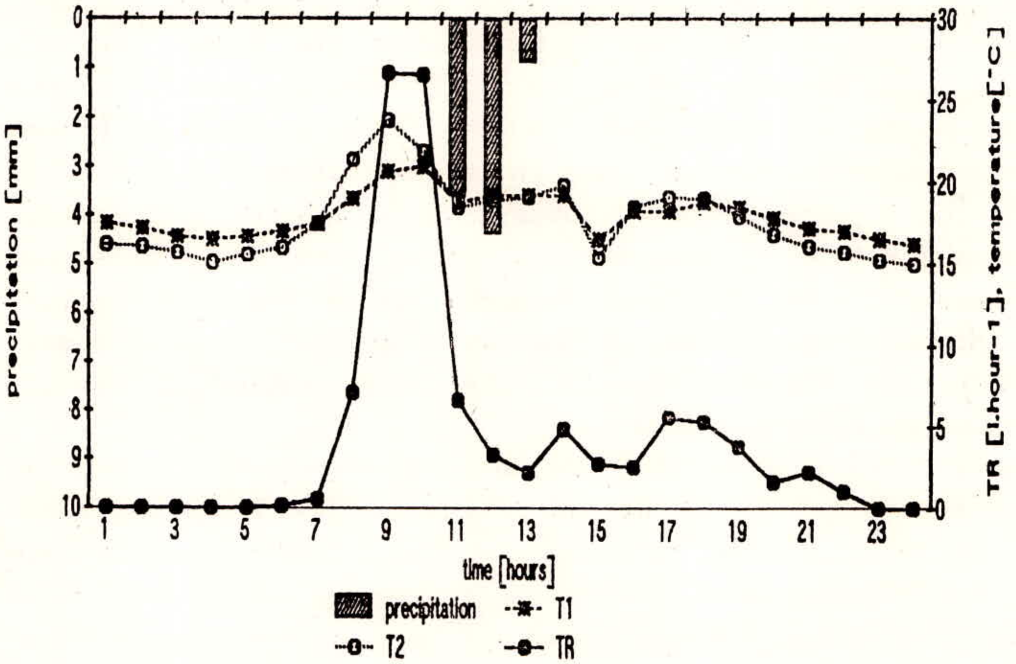
One of the most needed assumption for further utilization of transpiration measurements is the representativeness of the measured tree. Various, taxonomy methods and characteristics of studied vegetation are not a subject of this paper. However, the adequate attention to this matter is usually required and always paid off.

Nevertheless, even well selected representative trees do not serve a sufficient information about the areal distribution of transpiration. Thus, if we would like to extrapolate the point measurement of transpiration an additional data related to transpiration processes are needed. Among those data are counted the global and reflected radiations, the air temperature and humidity under and over the canopy. All those data together with resulted transpiration in hourly intervals are shown on Figure 1. Complete set of meteorological data should include also the wind speed which is more variable and much less influencing transpiration. Finally, according to the results presented by Molnár and Mészároš (1990), as the most related parameter for areal transpiration is usually considered the surface temperature of vegetation. This parameter as well as the soil moisture are closely related to transpiration but often limited by rare disposal of the remote sensing technology in mountainous areas.

RESULTS

The basic task of study has been to classify the relation of meteorological data to transpiration. Those data are rather evenly distributed over the area of catchment and they are easy measurable by standard equipment.

Regression analysis of different meteorological data and transpiration should be divided into two groups according to the time interval used. The Table 1 shows relationships between the hourly data of measured transpiration (TR) and global radiation over the canopy (GR), reflected radiation over the



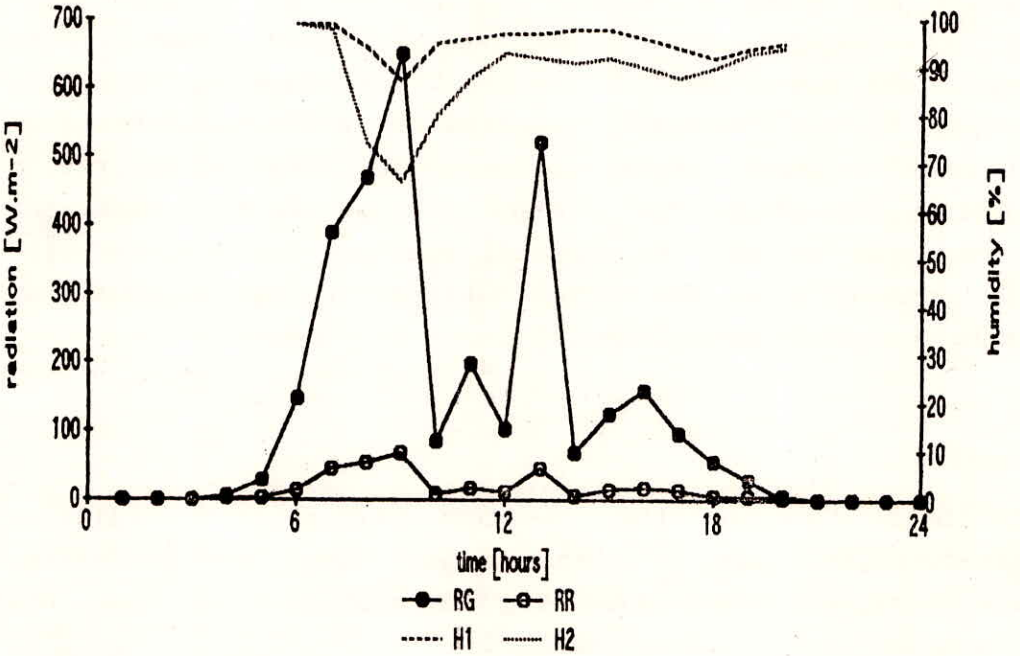


Figure 1 Diurnal courses of meteorological data including rainfall and measured transpiration.
RG - global radiation, RR-reflected radiation,
H1, H2 - ait humidity under and over canopy,
T1, T2 - air temperature under and over canopy,
TR - transpiration

canopy (RR), air temperature under the canopy (T1) and over the canopy (T2).

Table 1

Relation	Dep.var.	Indep.var.	St.dev.	Corr.coeff.
Linear	TR ($l/hour^{-1}$)	GR (W/m^{-2})	3.9235	0.7080
Linear	TR ($l/hour^{-1}$)	RR (W/m^{-2})	4.2894	0.6356
Linear	TR ($l/hour^{-1}$)	T1 (°C)	4.2617	0.5906
Linear	TR ($l/hour^{-1}$)	T2 (°C)	4.2763	0.6274

The Table 2 shows relationships between the daily totals of measured transpiration (TR), global radiation (GR), reflected radiation (RR), net radiation over the canopy (GR-RR) and daily means of air temperature over the canopy (T2) and air humidity in the meteorological station (HM).

Table 2

Dep.var.	Indep.var.	Lin.corr.coeff.	Nonlin.corr.coeff.
TR (l/day^{-1})	GR ($Whm^{-2}.day^{-1}$)	0.6092	0.6205
TR (l/day^{-1})	RR ($Whm^{-2}.day^{-1}$)	0.4342	0.4541
TR (l/day^{-1})	GR-RR($Whm^{-2}.day^{-1}$)	0.6223	0.6326
TR (l/day^{-1})	T2 (°C)	0.4969	0.4900
TR (l/day^{-1})	HM (%)	-0.5113	-0.5176

Presented results counted for one vegetational season in 1989 have confirmed the assumption that the hourly meteorological data are more closely related to the diurnal variation of transpiration. On the other hand the Table 2 clearly shows that the net radiation (GR-RR) over the canopy is the most related parameter to transpiration. The Table 1 proves that conclusion, and moreover confirms the dominant importance of air temperature over the canopy (T2) against that collected over the ground (T1). Lack of data on air humidity over the canopy in hourly time intervals has not allowed to include this parameter in the regression model used for calculation of transpiration in hourly steps presented by Molnár et.al. (1991).

The multiregression linear analysis was applied for diurnal estimation of transpiration in two alternatives (whole period,

and sunny days only).
Results are shown in Table 3.

Table 3

Period	Dep.v.	Independent variables	Coeff.corr.	
Whole	TR =	0.0185(GR-RR) + 0.3069 T2 - 2.2386	0.7920	(3)
Sunny	TR =	0.0167(GR-RR) + 0.5407 T2 - 4.7164	0.8283	(4)

The Figure 2 shows the measured and calculated values of transpiration in hourly intervals using the Equation (3). As the independent variables, the net radiation and air temperature over the canopy are used. The results on Figure 2 justify the applicability of the simple regression model.

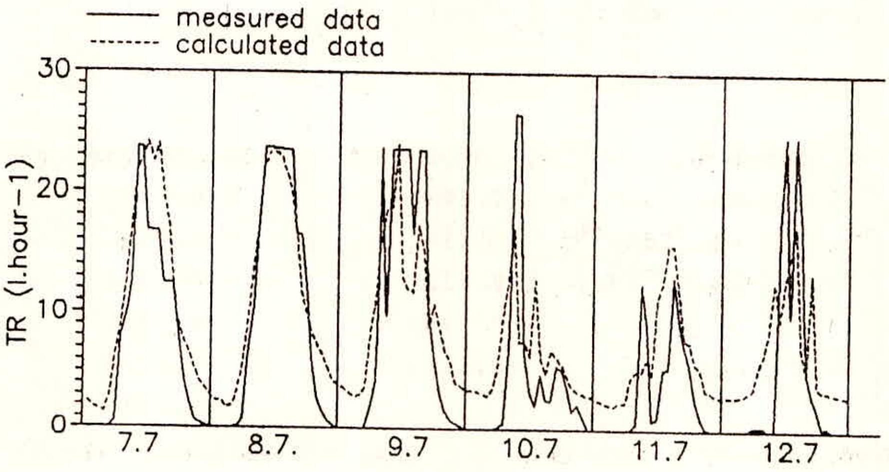


Figure 2 Measured and calculated values of transpiration of the Carpinus Betulus tree in hourly intervals from 7th to 12th July, 1989

The use of regression model for longer periods or whole vegetational season is limited by absence of input data about soil moisture and vegetation conditions within the catchment. As it was already proved by regression analyses in Tables 1 and 2, the seasonal course of transpiration depends much more on disponibility of water in the root zone and natural vegetational cycle. Anthropogenic influences on vegetation and considerable climate changes could also play a significant role.

CONCLUSIONS

The need to determine the actual evapotranspiration from mostly forested mountainous catchments is the main reason for transpiration measurements in those areas. Direct measurement of transpiration is reliable method but heavily depending on representativeness of selected trees.

Point measurements of transpiration should be extrapolated over the area. In this respect the use of surface temperature measurement of the forest is recommended though usually not available.

The relationship of transpiration to meteorological characteristics is documented and justified for diurnal courses of transpiration. The most common parameters, the net radiation and air temperature over the canopy are tested. A simple multiregression model for calculation of hourly transpiration is than applied.

The use of presented model for long term seasonal calculation is limited, as the seasonal course of transpiration depends much more on soil moisture disposal and the natural vegetational cycle within the studied catchment.

The areal distribution of transpiration in mountainous areas requires the further use of remote sensing and digitalized terrain modelling methods.

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