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Sap Flux Simulation and Tree Transpiration Depending on Tree Position within Stand of Different Densities

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Summary

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Tree sap flow rate was measured using THB method in two trees of *Picea abies* at the experimental forest study site in the Beskydy Mts. during two time periods of three days in the autumn 1997. Sampled trees were affected by their location within plots of different stand densities. An exponential relationship between diameter at breast height and sapwood area was applied to scale up the specific sap flux data to the whole stand transpiration. Relations of specific sap flux and different microclimate factors were used for simulations of whole stand transpiration as well.

The specific sap flux data highly correlated with air temperature and relative air humidity measured at 5m height (canopy height equaled 6.6m), and incident global radiation with one hour time lag. The best simulation was based on multiple regression among all above mentioned factors (without the time lag) when constant night fluxes were presumed. The trees located in sparse plot transpired more than the trees in dense plot when incident global radiation up to 500 W. m^{-2}. Thus, daily sum of transpiration was greater in dense plot except sunny days when daily sum of incident global radiation overcome ca 14 MJ. m^{-2}. day^{-1}. The differences between experimental plots were 500 trees. ha^{-1} in stand density.

Introduction

Water regime of forest trees is influenced by many factors. For an individual tree, transpiration depends on age, structure, health status, as well as growing conditions (i.e. mineral supply, air temperature, amount of incident global radia-

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tion, air humidity, soil water availability, etc.) (LU & al. 1995, VERTESSY & al. 1995, GRANIER & al. 1996).

Among the factors influencing tree transpiration, stand quality and tree position within the stand are of the greatest importance. These factors can diminish or enhance impacts of external conditions, and are also crucial for the physiological properties development of an individual tree.

This paper presents some results about sap flow measurements performed on twenty-year-old Norway spruce (*Picea abies* (L.) Karst.) trees when affected by their location within plots of different stand densities. The values of specific sap flux and their relationships to different microclimatic conditions were used to simulate transpiration (i.e. total sap flux) at the stand level (GRANIER & al. 1996).

Materials and Methods

Site and stand characteristics

All measurements were carried out on two plots of different stand densities (Dense plot (D)- 2600 trees. ha^{-1}, and Sparse plot (S)- 2100 trees. ha^{-1}) on the Experimental ecological study site of Bílý Kříž located in the Beskydy Mts. in the Czech Republic (KRATOCHVÍLOVÁ & al. 1989). Mean stem diameter at breast height (1.3m, DBH) and tree height (H) were 8.2 cm and 6.62 m in D plot, and 7.1 cm and 5.63 m in S plot. Hemi-surface leaf area index was of 8.74 and 6.24 in D and S plots, respectively. Total sapwood area at 1.3m amounted to $3.05m^2$ in D plot and $2.08m^2$ in S plot.

Sap flow measurements

The heat pulse method (Sapflow Meter SF 300, Greenspan Technology, Australia) (HATTON & al. 1990) was used for the measurements of sap flow on two sampled trees in each plot (two different depths for each tree). The trees were chosen according to the following typical or similar standards: i) position within the plot respect of the stand density, ii) crown structure, and iii) stem diameter at 1.3m and tree height. Parameters of sampled trees were: D232- 8m H, 10.2cm DBH, D177- 6.9m H, 8.3cm DBH, S310- 8.5m H, 10.5cm DBH, and S274- 7.4m H, 9.3cm DBH. The sap flux values [l. hr^{-1}] obtained for the sampled trees and of sapwood area at each measurement point (estimated by translucent method) were used for calculation of the mean specific sap flux values on each plot [l. hr^{-1}. cm^{-2} of sapwood]. The sapwood area was calculated as following:

$$SA = 0.537 \,.\, DBH^{2.0791}, \; (r^2{=}0.99) \qquad (1)$$

where SA is sapwood area [cm^2] and DBH is stem diameter at breast height, n=23. This relationship was obtained from previous structure measurements in the studied stands (unpublished data). The sapwood area was calculated separately for each tree in the plot and the total sapwood area value for each plot is given by the sum of the individual sapwood areas.

Microclimatic conditions

Microclimatic characteristics of the D plot (air temperature [°C], relative air humidity [%] and wind speed [m. s^{-1}]) were determined for several canopy layers. In the central part of the D plot, the 12 m high meteorological mast comprised six sensors for air temperature and relative air humidity measurements (RHA 1, Delta-T, England) at 2, 5, 6, 7, 8, and 11 m high, and five sensors for wind speed measurements (AN 1, Delta-T, England). The sensor of global radiation (Kipp & Zonen Delf BV- CM5, Holland) was located on the nearby research station above all obstacles [W. m^{-2}] and its values were used for both plots. All the mean values from 30 seconds readings were recorded every 10 minutes by a data logger (Delta-T, England). From the observed air temperature and humidity, a water potential deficit (VPD) was calculated for the identical canopy levels [kPa], as well. Microclimatic canopy characteristics were not measured at the S plot.

Results and Discussion

The measurements were carried out during two periods in autumn 1997. Weather conditions during the measurements were relatively stable, typical for the mentioned season without any extreme cold or drought. Three sunny days for each measurement period (27. – 29. 9. and 6. – 8. 10.) were chosen for the calculations and comparisons.

Differences between individual trees in specific sap flux were found when incident global radiation was less than 200 $W.m^{-2}$ and over 500 $W.m^{-2}$. Incident global radiation was divided to the following intervals <0, 5); <5, 100); <100, 200); <200, 300); <300, 400); <400, 500) and <500, +). No statistically significant differences (Mann-Whitney U Test, Tukey HSD Test for unequal N) were found between trees D232 and D177, between S310 and S274 in <5, 500> interval, and among all trees in <200, 500> interval. Shapiro-Wilk's W Test was used for tests of normality. High statistically significant differences ($p<0.01$) were found between trees especially in intervals <0, 5) and <500,+). The interval <0, 5) represents night time. If the trees had similar stem and crown parameters and structure, the above mentioned differences appear probably owing to different stand densities (tree position) and different proportions of exposed and shaded part of crown.

The strongest linear relationships between mean specific sap flux values and incident global radiation in case of one hour time lag were:

$$SF_S = 4.10^{-5}\ GR + 0.0066,\ (r^2 = 0.84) \qquad (2)$$
$$SF_D = 2.10^{-5}\ GR + 0.0057,\ (r^2 = 0.87) \qquad (3)$$

where SF represents specific sap flux of trees in S and D plots [$l.\ hr^{-1}.\ cm^{-2}$ of sapwood], GR is incident global radiation [$W.\ m^{-2}$].

These linear equations were scaled to the stand level with the total sapwood area values to simulate transpiration for all the chosen days – I. Simulation. It is clear that this scaling was quite inaccurate, because not enough data (two measured trees per plot). HATTON & al. 1995 showed that the greatest potential source of error in estimating of the stand transpiration by the heat pulse method was in the measurement of the fluxes of individual stems rather than in scaling these measurements to a homogenous stand. The daily sums of total sap flux obtained for the D and S plots are described together with the summed values of incident global radiation for the individual days (Table 1.). Some differences in mean specific sap flux values between D and S plots were found. The intercept and especially the slope was higher in the equation concerning the S plot. This means a higher increase of sap flux when increasing global radiation.

In the D plot (Fig. 1a, 1b), some values of the other microclimatic conditions (air temperature, relative air humidity, wind speed and derived VPD) were collected and used to set up relationships between specific sap flux and individual microclimatic factors. The best relationships were found with air temperature at 5m height in the canopy level according to Person and Spearman ($r=0.91$, $r_s=0.76$), with the natural logarithm of air temperature($r=0.83$, $r_s=0.76$), with relative air humidity ($r=0.89$, $r_s=0.87$) at the same canopy level and with the incident global radiation ($r=0.70$). Thus, we determined a multiple linear regression to simulate the daily evolution of specific sap flux – II. Simulation (without time lag):

$$SF = 4.10^{-6}\, GR - 8.8.10^{-5}\, RH_5 + 1.1.10^{-3}\, T_5 + 0.006085, (r^2=0.94) \qquad (4)$$

where SF is specific sap flux [l. hr^{-1}. cm^{-2} of sapwood], GR is incident global radiation [W. m^{-2}], RH_5 is relative air humidity [%] at 5m height in the canopy level, and T_5 is the corresponding air temperature at 5m height [°C]. For a possible delay of sap flux response to changes in microclimatic conditions, we tested a time shift of about 20- 60 minutes. After a 20 minutes time lag, specific sap flux was still strongly related with stand climatic factors:

$$SF = 2.76.10^{-2}\, T_5 - 1.39.\, 10^{-2} \log T_5 - 1.10^{-6}\, RH_5^{\,2} + 0.0206, (r^2=0.93) \qquad (5)$$

where SF is specific sap flux shifted by 20 minutes.

The correlation factor r^2 for equation (4) was 0.92 at 20 minutes time shift. The correlation coefficient decreases with a longer time lag. Nevertheless, a linear relationship determined for both plots between specific sap flux and incident global radiation was the strongest link after one hour time shift.

The transpiration was estimated in each plot for the chosen three days. Simulations were done for three other days without any direct sap flow measurements for each plot, from the above mentioned equations concerning the relationship between sap flux and microclimatic factors. A problem with the sap flux simulation appeared during the night, where the specific sap flux was mostly underestimated when using the II. Simulation (eq. 4). Therefore, night fluxes were taken as a constant (intercept of eq. 3) from the I. Simulation when incident global radiation equals zero- III. Simulation. This third simulation appeared to be the best estimate. However, testing instrumental error measurements during the night needs to be investigated more deeply. Simultaneous measurements of sap flux in the studied plots were not carried out and the values of transpiration for both plots were compared on the basis of mathematical simulations. Transpiration per day was higher in the D plot except during sunny days with a high amount of incident global radiation and also with a daily sum of global radiation higher than ca 14 MJ. m^{-2}. day^{-1}. Results are shown in Table 1.

Table 1. Daily sums of total sap flux. Differences in percent for the simulations are presented between brackets.

Day	Global radiation [MJm^2day^{-1}]	Real sap flux [$mm.day^{-1}$] D plot	Real sap flux [$mm.day^{-1}$] S plot	I. Simulation [$mm.day^{-1}$] D plot	I. Simulation S plot	II. Simulation [$mm.day^{-1}$] D plot	III. Simulation [$mm.day^{-1}$] D plot
27.9.	6.94	2.14	-	2.14 (+0.2)	1.96	2.01 (-5.9)	2.08 (-2.7)
28.9.	6.85	1.95	-	2.14 (+9.5)	1.95	1.80 (-7.8)	2.03 (+3.9)
29.9.	14.67	2.98	-	2.67 (-10.4)	2.68	2.93 (-1.5)	2.87 (-3.5)
6.10.	13.99	-	2.77	2.62	2.61 (-5.6)	-	
7.10.	8.97	-	2.11	2.28	2.15 (+1.8)	-	
8.10.	8.11	-	1.89	2.22	2.07 (+9.2)	-	

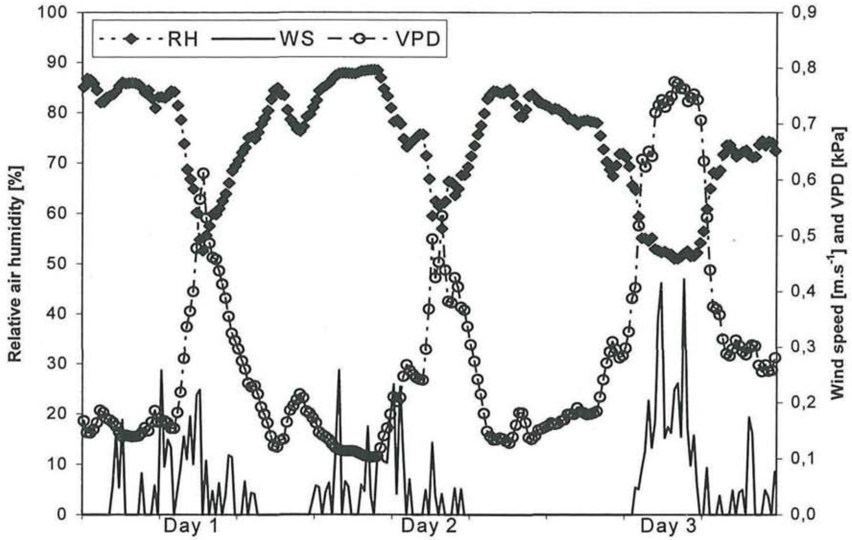

Fig. 1a. Daily courses of different climate factors in D plot. RH- relative air humidity at 5m height in canopy, WS- wind speed at 5m height in canopy, and VPD- water potential deficit at the same canopy level.

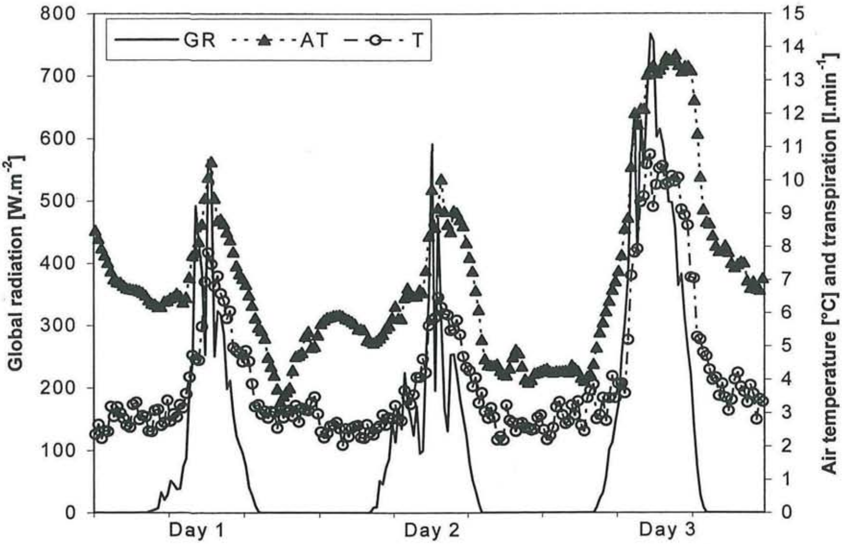

Fig. 1b. Daily courses of different climate factors and stand transpiration in D plot. GR- incident global radiation, AT- air temperature at 5m height in canopy, and T- stand transpiration.

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