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THE INFLUENCE OF WEATHER CONDITIONS ON THE SAP FLOW OF *Brassica napus* L. DURING THE FRUCTIFICATION AND MATURATION STAGES

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Abstract

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Transpiration of arable crops is one of the basic components of their water balance. The sap flow in *Brassica napus* L. plants (Q; kg h^{-1}) was measured in fields in central Bohemia during the vegetation period in 2005. The selected measuring interval was that from the pod formation stage to the maturation stage. Q was observed using a sap flow meter T 4.2 (EMS, Brno). The decrease in actual Q values after BBCH 84 phase accession was documented by means of the calculated Q_{calc} values, which were estimated from the photosynthetic active radiation and the vapor pressure deficit values. The average daily Q value of a single *B. napus* plant achieved 0.33 kg day^{-1} within the BBCH 78–83 phase. Within the BBCH 84–89 phase, the average daily Q value was only 0.09 kg day^{-1}. The average water consumption of the whole plant cover was 2.8 mm for 51 plants per m^2.

Key words: sap flow rate, BBCH phase, photosynthetic active radiation, vapour pressure deficit; water consumption, *Brassica napus* L.

Introduction

The intensity of photosynthesis can be expressed by sap flow – that is, transpiration flux through the plant stem. Factors that influence photosynthesis will also influence the transpiration flow through the plant. One of the basic factors that affects the process of photosynthesis is PAR (photosynthetic active radiation). PAR supply is changeable during the year, depending on the angle of incident sunrays, weather conditions and a plant’s stand structure (Aufhammer et al., 2000; Stewart et al., 2003). Plants influence sunshine utilization, which then determines stand architecture, leaf area and growth (Zaffaroni, Schneiter, 1989). Photosynthetically active leaf area is expressed as leaf area index (LAI) and siliqua area index (SAI). A marked decline in leaf area occurs at the beginning of flowering and, concomitantly, silique area increases (Grosse et al., 1987). Pods participate in photosynthesis after the flowering phase (Singal et al., 1995). Successive physiological processes that are associated with the senescence process of plants – which are, for example, seen by changes in the hormonal level in pods (Bouille et al., 1989) affect the decrease in activities of photosynthetic and water consumption (Hauser et al., 1990). Water consumption of arable crops is one of the main parameters that is needed to determine the actual transpiration of phytocoenoses and the following water conditions influence crop structure. It is assumed that the transpiration values of individual arable crop species cultivated on arable land will vary, as has been shown by the differences that have been documented in the transpiration of trees (Schulze et al., 1985; Čermák et al., 1995 etc.). Transpiration is the main component of water balance in the soil–plant system during the vegetation period. Transpiration is difficult to quantify because it is influenced by the atmosphere, soil and plants (Merta et al., 2001).

The main aim of this work was to estimate sap-flow dynamics of *Brassica napus* L. plants under different weather conditions. In addition, the water consumption of plant stands was reviewed – from the point of view of the site water-use conditions in the period when the E_{pot} exceeds the amount of water supplied by precipitation. The experiments have enabled us to:

- consider the interactions between sap flow and weather conditions (PAR and VPD – vapour pressure deficit) on the basis of daily course and average daily values of these variables in the period observed
- determine the influence of the plant development stage on sap-flow values
- provide actual water consumption values of the plant stand of *B. napus* in relationship to the precipitation levels

Materials and methods

The experiment was undertaken in central Bohemia in an experimental plot in Červený Újezd at an elevation of 398 m above sea level; the average annual temperature is 7.9 °C and the average annual precipitation is 525.8 mm. The soil is a clay-loam. On the basis of water-use conditions, the monthly potential evapotranspiration values, which were estimated from the monthly average meteorological elements within the so-called 'normal period' (1961–1990) by Turc (1961), exceeds the monthly precipitation totals from the April to August period (Table 1).

The stand of winter oilseed rape *Brassica napus* L. variety Navajo was established in the autumn of 2004. The experimental plot area was 60 m^2. The seeding was carried out on 28 August 2004; rows were 125 mm in width (seeding rate: 4 kg ha^{-1}). Stands were fertilized and treated in the standard way. The sap flow was measured in five plants that were located in the centre of the experimental plot within the period from 22 June 2005 (BBCH 78) to 22 July 2005 (BBCH 87).

Measurement of sap flow and meteorological elements

The heat balance (HB) method of sap-flow rate measurement is based on the ratio between the heat input and the temperature rise in a defined space.

T a b l e 1. The average monthly precipitation totals (P) and average monthly potential evapotranspiration totals (E_{pot}) in the ‘normal period’ (1961–1990) for the Praha–Ruzyň locality and the same variables for in Červený Újezd (in mm) in 2005. E_{pot} was as estimated by Turc (1961).

	Monthly values (mm)											
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.
P (1961–1990)	23.5	22.6	28.1	38.2	77.2	72.7	66.2	69.6	40	30.5	31.9	25.3
E_{pot} (1961–1990)	0	0	17.8	50.5	89.3	104.7	111.3	96.7	60.8	31.6	8.1	0
P in 2005				22.2	91.5	77.3	141.4	70.6	24.2	14.2		
E_{pot} in 2005				57.9	83	94.6	101.5	82	64.8	35.2		

The HB method calculates the heat balance of a heating space. Basically, the input energy has to be split between the conductive heat losses and the warming of water passing through, according to the following simple equation:

$$IP = Q \cdot dT \cdot c_w + dT \cdot z, \tag{1}$$

where IP is the heat input power (W), Q is the sap flow rate (kg sec^{-1}), dT is the temperature difference in the measuring point (K), c_w is the specific heat of water (J kg^{-1} K^{-1}) and z is the coefficient of heat losses from the measuring point (W K^{-1}). Transpiration flux through the rape stem (Q, kg h^{-1}) was observed using a sap-flow meter T 4.2 for small diameters (6–20 mm; EMS, Brno) in a 10-minute interval. The principles involved are mentioned above.

Measured meteorological elements

Precipitation totals (P in mm; accuracy: 0.1 mm per tip) were collected by tipping a bucket rain gauge RS03 (Fiedler, CZ,) within a 1-hour interval. Air temperature (t, °C) and relative air humidity (r, %) were measured using a datalogger (Minikin TH; EMS Brno, CZ) every 10 minutes. Photosyntheticaly active radiation was recorded in the 10-minute interval using a Minikin QT quantum sensor (PAR, µmol m^{-2} s^{-1}; spectral range: 400–700 µm). Transpiration flux through the rape stem (Q, kg h^{-1}) was observed using a sap-flow meter T 4.2 for small diameters (6–20 mm; EMS, Brno). The principles involved are mentioned above.

Calculated meteorological elements

Vapour pressure deficit (VPD, hPa) was calculated using the following relationship:

$$\text{VPD} = E\left(1 - \frac{r}{100}\right), \tag{2}$$

where *E* = saturation vapour pressure (hPa), *r* = relative humidity of the air (%). The saturation vapor pressure algorithm was used (as proposed by Tetens):

$$\text{E} = c_1 \exp\left(\frac{c_2 t}{c_3 + t}\right) \ldots c_1 = 6.1078, c_2 = 17.558, c_3 = 241.88\,, \tag{3}$$

where c_1–c_3 are the coefficients and *t* is the air temperature (°C).

The Turc (1961) method, which uses global solar radiation and temperature as inputs, was chosen as the more suitable method for computation of potential evapotranspiration daily totals (E_{pot}, mm d^{-1}). One of the reasons for this choice was that non-standard global solar radiation was derived from standard measured sunshine duration. Another argument for using Turc's method was due to its principle, which is based on the input of energy and its effect on the thermal conditions of the environment. The algorithm is as follows:

$$E_{pot} = [\frac{K}{4.1868}(0.18 - 0.62\frac{h}{H}) + 50]\frac{0.013t}{(t+15)}, \qquad (4)$$

where K = extraterrestrial radiation [J cm^{-2} d^{-1}], h = actual sunshine hours, H = potential sunshine hours, t = air temperature [°C]. H was derived from the algorithm by Webb (1991) and Cooper (1969).

$$H = 12 + \frac{24}{180}\arcsin(\mathrm{tg}\varphi\ \mathrm{tg}(23{,}45\sin(360\frac{(284+d)}{365}))), \qquad (5)$$

where φ = latitude, d = number of days (1–365).

Estimations of sap flow (Q_{calc}) were realized using specialist software (Mini 32; EMS, Brno) after the following algorithm (Kučera, EMS Brno; C.Z., personal communication):

$$Q_{calc} = par1\frac{PAR}{(PAR + par2)}\frac{VPD}{(VPD + par3)}, \qquad (6)$$

where $par1$–3 = parameters, PAR = photosyntheticaly active radiation, VPD = vapour pressure deficit.

Evaluation of biological characteristics of Brassica napus L. *plants*

Developmental stages were evaluated during the period from 21 June 2005 to 27 July 2005 via the BBCH scale (Schwarz, 2003). A total of 20 plants were analyzed by stage assessment each time. Table 2 analyzes the developmental stages of *B. napus* plants within the time period: 51 *B. napus* plants per m^2 were determined on the experimental plot after measurements taken in the spring.

Statistical analysis was performed using Statgraphics®Plus, ver. 4.0, ANOVA, Tukey method ($P < 0.05$) and Simply Regression.

Table 2. Term of growth stage (BBCH) of *B. napus* plants in the period 21 June 2005 to 27 July 2005.

Term	21.6.	23.6.	27.6.	30.6.	1.7.	4.7.	7.7.	13.7.	15.7	18.7.	20.7.	23.7.	27.7.
BBCH	77	78	79	80	81	82	83	84	85	86	87	88	89

Results

Modification of the Q and Q_{calc} course of daily average values (Fig. 1), which was recorded on 14 July 2005 (BBCH 84-85), was evident throughout the observed period. Since that date, the average daily values of Q_{calc} exceeded the Q values. Up to this date, the Q_{calc} to Q ratio was the reverse. On the basis of this fact, the 10-minute values of Q_{calc} (dependent variable) to Q values (independent variables) were analyzed during the period from 22 June 2005 to 13 July 2005, and from 14 July 2005 to 22 July 2005. The linear regression dependency was determined as a result (Fig. 2). The close dependency between the 10-min values of Q_{calc} and Q was proved by the regression analysis results obtained for the period from 22 June 2005 to 13 July 2005 ($R^2 = 0.857$, n = 3312) (Fig. 2). On the other hand, the

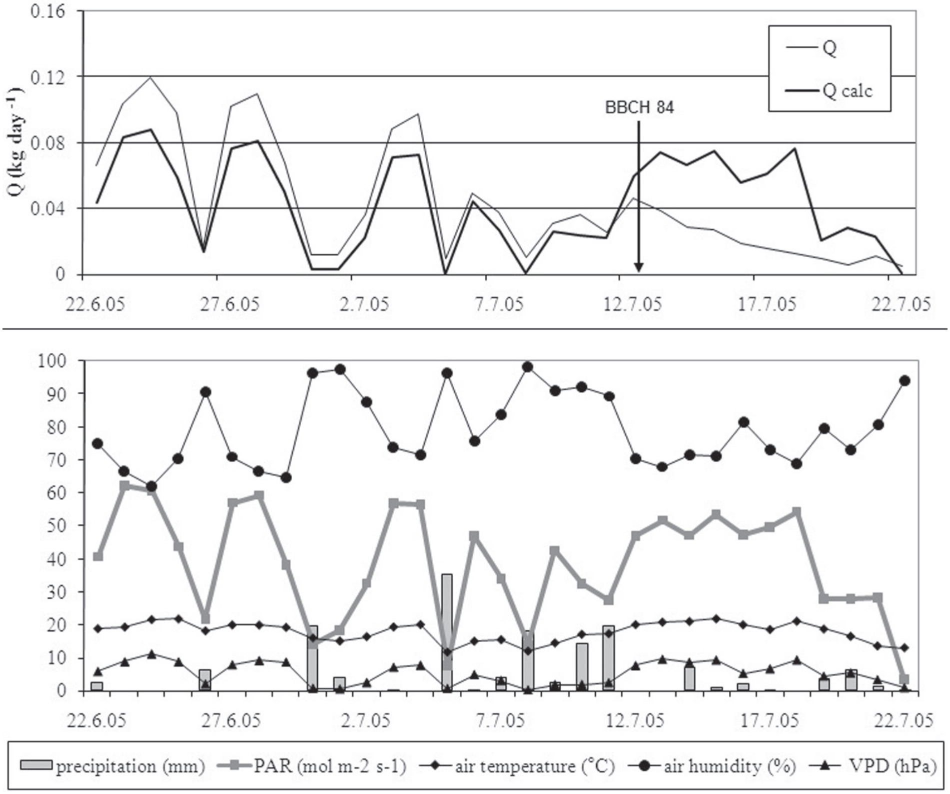

Fig. 1. Average daily values of Q, Q_{calc} (kg day^{-1}), precipitation (mm day^{-1}), PAR (mol m^{-2} d^{-1}), air temperature (°C), air humidity (%) and VPD (hPa) in the *B. napus* plants during the observed period of 22 June 2005 to 22 July 2005.

dependency between Q_{calc} and Q was not so close during the period from 14 July 2005 to 22 July 2005 ($R^2 = 0.601$, n = 1296) (Fig. 2). The average daily values of the measured and calculated meteorological elements are also documented in Figure 1.

Apparently, the daily course of the 10-minute values of Q_{calc} and Q on the two sunny days (one during the period between 22 June 2005 and 13 July 2005; and the other during the period between 14 and 22 July 2005) was dependent, in particular, on the course of PAR values (Fig. 3). The average 10-minute values of Q in the period from 23 to 29 June 2005 were higher compared with Q in the period from 14 to 20 July 2005 (Fig. 4). The differences were statistically significant (Fig. 4). On the contrary, the difference between the averages of the 10-minute values of PAR and VPD was not statistically significant in the studied periods (Fig. 4).

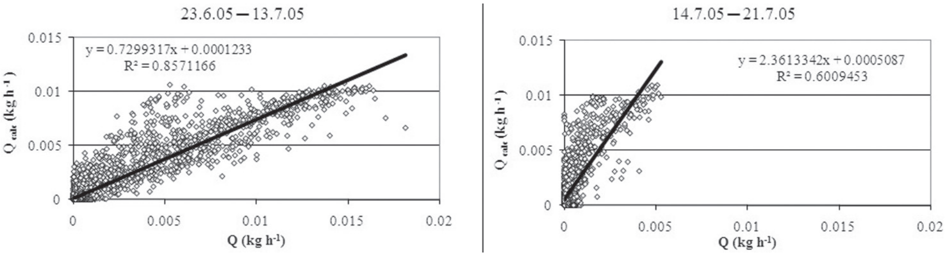

Fig. 2. Dependence of Q_{calc} on the actual Q (kg h^{-1}) in *B. napus* plants in the periods 23 June 2005 to 13 July 2005 and 14 to 21 July 2005.

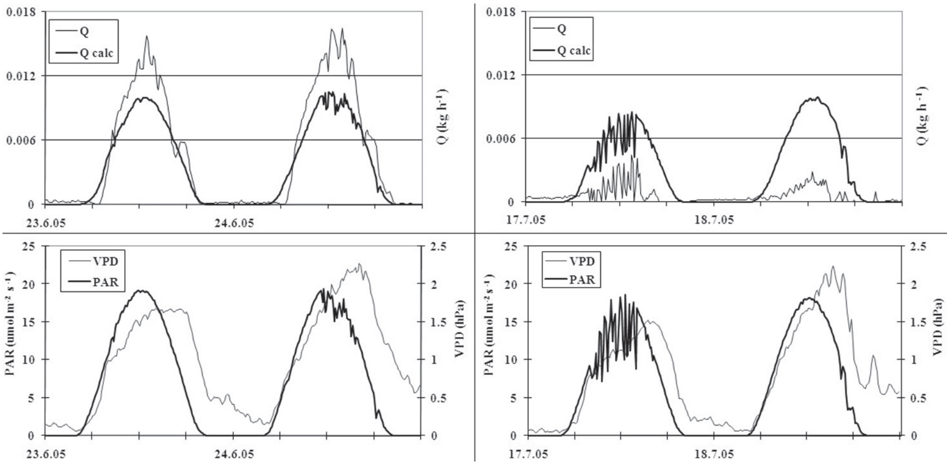

Fig. 3. Daily course of Q, Q_{calc} (kg h^{-1}), PAR (mmol m^{-2} s^{-1}) and VPD (hPa) in the fructification (23 and 24 June 2005) and maturation stages (17 and 18 July 2005) in *B. napus* plants on observed sunny days.

It is obvious, in agreement with the abovementioned results, that *B. napus* plants indicate higher values of Q in the BBCH 77-84 phase compared with the BBCH 85-89 phase. The average daily values of Q (kg day^{-1}) in the BBCH 77-84 phase were about 73% higher than the average daily values of Q in BBCH 85-89.

Figure 5 documents the relationship between the daily totals of precipitation and water demands of *B. napus* plant cover in the period from 22 June 2005 to 22 June 2005, with 51 *B. napus* plants per m^2. The total precipitation level was 149 mm and the total water consumption by the plant cover was 69 mm within the observed period (i.e. about 46% of total precipitation).

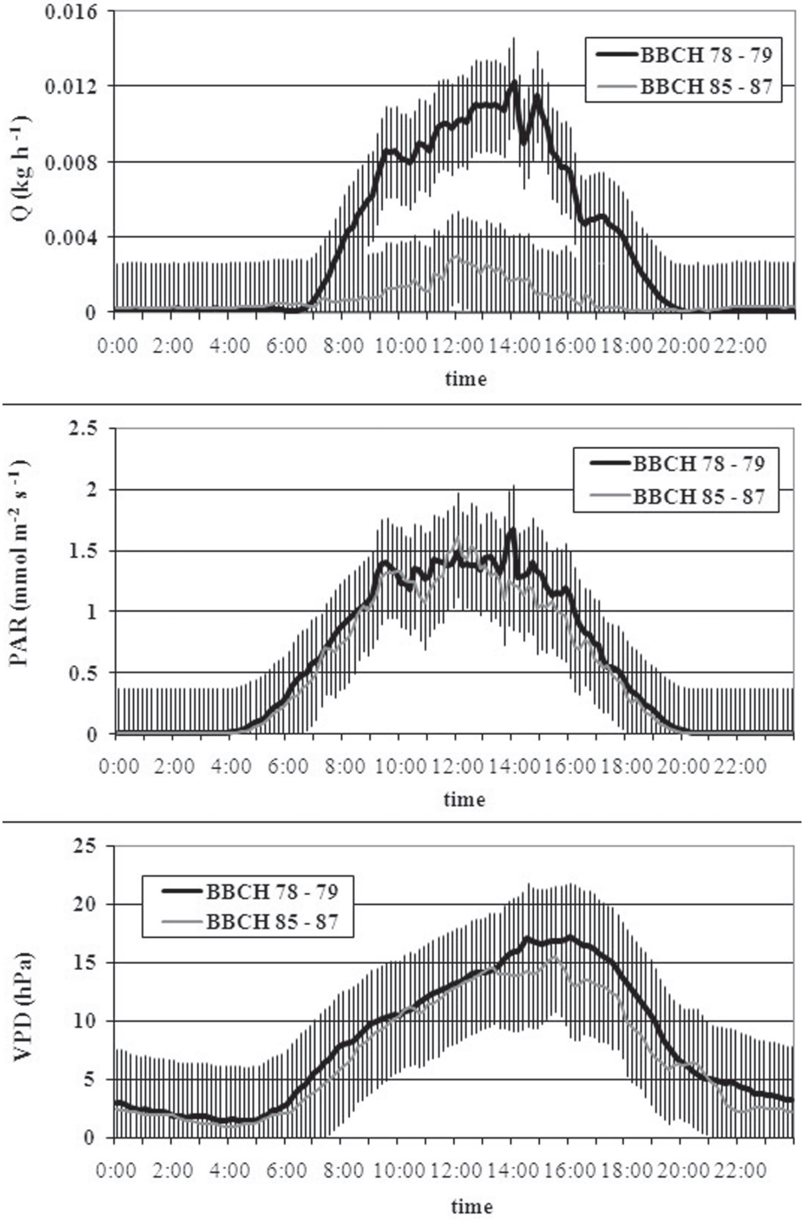

Fig. 4. Average daily course of Q (kg h^{-1}) in *B. napus* plants, PAR (mmol m^{-2} s^{-1}) and VPD (hPa) values within the BBCH 78–79 (23 to 29 June 2005) period and the BBCH 85-87 (14 to 20 July 2005) periods. Failure abscissa indicate +/– limit for $P < 0.05$.

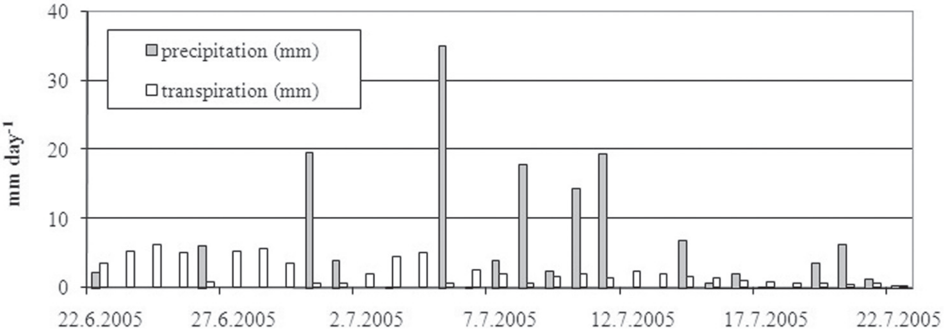

Fig. 5. Average daily water consumption by *B. napus* plant stand (mm d^{-1}) in comparison with precipitation daily totals (mm d^{-1}) during the observed period 22 June to 22 July 2005.

Discussion

On the basis of the estimated Q_{calc} values and by comparison of Q and PAR behaviour, it was shown that sap flow mainly depends on PAR values (Fig. 3). This has fully confirmed the general dependent relationship between PAR and photosynthesis intensity. The dependency of Q on global solar radiation (Rg) is evident from the spruce sap-flow measurement results of Čermák et al. (1992). More significant VPD influences on Q_{calc} values could be expected in the case of weeds and underseeding, closed by the main crop canopy. At the same time, the influence of the developmental phases of plants on Q values was proven. After *Brassica napus* transition to the BBCH 87 phase (40% matured seeds), a decrease in plant water consumption was observed as a consequence of plant senescence and seed maturation, even though PAR and VPD values were the same as before the BBCH 87 phase was achieved. This indicates that there is an increase in the pod phytohormones following photosynthesis inhibition (Bouille et al., 1989; Hauser et al., 1990). Singal et al. (1995) confirmed the decrease in pod photosynthesis inhibition of *B. campestris* L. as a result of the dependence on the seed maturation process.

In view of the water consumption (69 mm) and the available water – total precipitation (149 mm) – we assume that there were good water supply conditions within the observed period. In the case of lower values of available water, which is typical for this research site, we assume lower values of Q. If we take into account that the precipitation water level in June was 77.3 mm and E_{pot} 94.6 mm, then the *B. napus* cover water consumption that was estimated from the average daily water consumption was higher than both of the above-mentioned values (118.4 mm). This indicates that a higher amount of water is withdrawn by the plant cover than is supplied by precipitation. We consider the month of June as normal compared with monthly totals of precipitation and potential evapotranspiration E_{pot} within the normal period (1961–1990) values. Considering the precipitation (27.8 mm) and E_{pot} (30.4

mm) totals, the water consumption of *B. napus* crop exceeded both of the abovementioned values (35.5 mm) in the observed period (22 to 30 June 2005). This explains the particular demands, in this study, of the water balance of the arable crops and subsequent actual and potential evapotranspiration dependencies, as well as the estimation of the site evaporation and transpiration ratio, mainly in relation to the crop and soil cultivation. It is necessary to focus on the actual consumptive water use of arable crops within the growing season in relation to the site water conditions and consequently to stabilize the water balance of the landscape through the crop structure.

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