

We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900

Open access books available

186,000

International authors and editors

200M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



Evapotranspiration and Transpiration Measurements in Crops and Weed Species by the Bowen Ratio and Sapflow Methods Under the Rainless Region Conditions

J. Pivec, V. Brant and K. Hamouzová
*University of Life Sciences Prague,
 The Czech Republic*

1. Introduction

The aim of this chapter is to provide a systematic description of the measurements of total evapotranspiration and transpiration of selected agricultural crops and weeds, results of investigation, and perspectives of these methods for agricultural usage. This study provides a contribution towards increased knowledge on the consumptive water use of arable crops and weeds within the temperate climatic zone under specified weather conditions and actual crop structure given by biometric observation. The water consumption of plants represents a significant part of the landscape water balance (Merta et al. 2001). An important factor influencing the water balance of the plant stands on agricultural soil and thereby in the countryside is the species composition of phytocoenosis. Within the framework of phytocoenosis, the cultivated plants and weeds take share in influencing the water balance (Pivec & Brant 2009). Competition between plants to capture the resources essential to plant growth (i.e. light, water and nutrients) is one of the key processes determining the performance of natural, semi-natural and agricultural ecosystems (Kropff & van Laar, 1993). The issue of evapotranspiration and transpiration demands of field crops is a subject of intensive study especially in arid and semi-arid areas. In terms of eliminating the negative impact of agriculture on the environment and in terms of increasing the efficiency of the production systems, its monitoring is important for the temperate climate as well.

2. Used methods of actual evapotranspiration and transpiration measurements

The sensible heat flux (H) and the latent heat flux (λE) were measured by Liu & Foken (2001) using the eddy covariance method (EC) and the Bowen ratio/Energy balance method (BREB). The results indicate that H (BREB) is about $30 \pm 20 \text{ W m}^{-2}$ higher than H (EC) and λE (BREB) is about $180 \pm 40 \text{ W m}^{-2}$ higher than λE (EC) during the daytime. Liu & Foken (2001) proposed a modified Bowen ratio method (MBREB) to determine sensible and latent heat fluxes without using the surface energy balance equation. Their findings are to the contrary to the findings of Brotzge & Crawford (2003), who comment that the EC system favours latent heat flux and the BREB system favours sensible heat flux. Perez et al. (1999) show that,

if advection is considered negligible, the BREB method is able to determine correctly the surface flux partitioning or the flux values when certain conditions, consistent with the flux-gradient relationship, are fulfilled. San José et al. (2003) postulates, that different architecture of the canopy had a minor effect on the flux densities of net radiation as well as the partitioning of available energy into sensible and latent heat. His results indicate that the phenological trend of the daily λE was controlled by the leaf area index (LAI) development. When LAI reached its maximum value at the flowering and pod-filling stages, λE was controlled mainly by the available energy and temperature. The BREB method (eq. 1) was used to measure latent heat fluxes above the *Zea mays* canopy as well as between the soil surface and the canopy by Zeggaf et al. (2008). Then, the latent heat flux from *Z. mays* transpiration was calculated by the difference between that of the *Z. mays* field and soil surfaces. In method 2, a weighing lysimeter and sap flow gauges were used to measure latent heat fluxes from the maize field and *Z. mays* transpiration, respectively. Then, latent heat flux from the soil surface was calculated by the difference between that of the *Z. mays* total evapotranspiration and *Z. mays* transpiration. The coefficient of determination between latent heat fluxes by the two methods was 0.72 from the *Z. mays* field and 0.77 from the *Z. mays* transpiration. However, results indicated a low correlation between the latent heat fluxes from the soil surface by the two methods (coefficient of determination = 0.36).

Sap flow measurements (the heat balance method) may be used in determining plants' water demands. A survey of the literature has shown that information about the moisture requirements of herbal species, particularly their determination under natural conditions, is relatively much less abundant. Kjelgaard et al. (1997) and Jara et al. (1998) reported that sap flow measurements at the same plant were practicable for one week in dependence on weather conditions and stem thickening. For both the gas exchange and sap flow methods, scaling up from leaf to plant and to canopy is difficult to carry out because measurements with this method reflect only the reactions of single plants (e.g. Köstner et al. 1996). Data on weeds' water consumption represent a basic parameter for determining the ecological and economic functions of agriculture.

2.1 BREB measurement method

The BREB method is based on the precondition of the coefficients of the apparent and latent heat being equal (1), when it is possible to determine the ratio of the sensible and latent heat by measuring the gradients of the air temperature and humidity above the evaporating surface (Woodward & Sheehy 1983):

$$\beta = \frac{H}{\lambda ET} = \gamma \frac{dt}{de} \quad (1)$$

in which H is the flow of sensible heat, λ is the specific heat of the water vapour, ET is evapotranspiration, γ is a psychrometric constant 0.66 hPa °C⁻¹, dt/de is a temperature/humidity gradient of air at two levels above the evaporating surface. Fig. 1 documents the instruments settings.

2.2 Sap flow method

The use of the heat balance method is based on the relation (2) between the entering heat amount and the increase in temperature within a defined space (Kučera et al. 1977, Tatarinov et al. 2005):

$$P = Q \cdot dT \cdot c_w + dT \cdot z$$

(2)



Fig. 1. BREB installation over winter rape-seed field: radiation balance gauge on left, pair of temperature/relative humidity sensor in the middle (upper with global radiance gauge), anemo-indicator on right. Locality: Červený Újezd 2006, photo by authors.

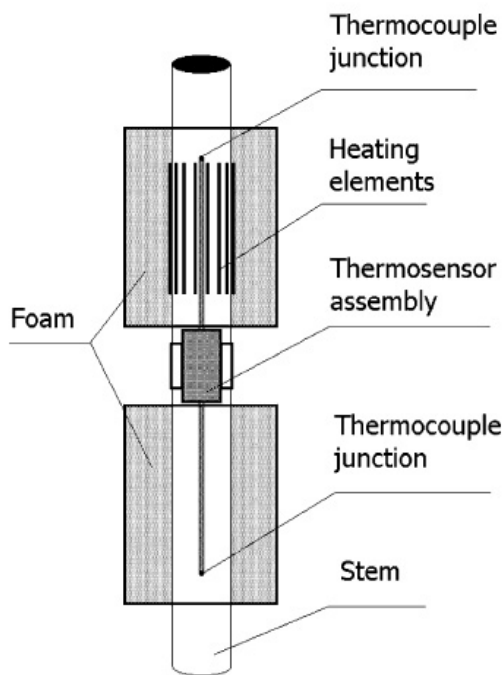


Fig. 2. Diagram of the EMS “baby sensor” for shoots or small stems (adapted from Čermák et al. 2004).

in which P is the heat energy input (W), Q is the sap flow (kg s^{-1}), dT is the temperature difference within the measured space (K), c_w is specific heat of water ($\text{J kg}^{-1}\text{K}^{-1}$) and z is a coefficient of the heat losses in the measured space (W K^{-1}). During our experiments that had taken place from 2005 to 2010, the sap flow values were evaluated in selected cultivated and weed plants under field conditions. The Q values were measured by a 12-channel T4.2 flow meter for the stems of 6 to 20 mm diameter, made by the EMS Brno (CZ) firm (see the diagram in Fig. 2). The values obtained during the measurements were recorded at 10 minute intervals during the entire period of individual measurements. The measurements point was always located at the base of the plant or stalk of the plant.

3. Evapotranspiration of field crops

Knowledge of the arable crops evapotranspiration is the **basis** of the understanding of the influence of agriculture on the environment and the basis for the elimination of the agricultural activities negative influences on the landscape water balance. The exchange of water vapour and CO_2 between the crops and surrounding air can also be perceived as an important factor for the photosynthetic assimilation and, consequently, for the biomass production. From the practical point of view, the knowledge of the evapotranspiration demands can be used for the water balance optimization through the finally structured crop and growing phases duration and growth access periods (San José et al. 2003).

3.1 Actual values of evapotranspiration

The crop transpiration depends on the management, such as a supply of nutrients (Shepherd et al. 1987), seeding days (Connor et al. 1992) and the plant species or cultivars (Eastham & Gregory 2000). Additionally, the energetic fluxes and the water use efficiency (e.g. Corbeels et al. 1998; Asseng et al. 2000) as well as the dissipation of the energy within the landscape (Ripl 1995) are evaluated. The energy balance components are strongly affected by the leaf area index and plant height during all developmental stages of the canopy, especially the sensible heat flux. Table 1 demonstrates the average values of the ET_c , ET_0 and Bowen ratio (β) on the Budihostice site for selected field crops from 2007 to 2010. The site is situated at an altitude of 220 m a.s.l. and the soil type is Haplic chernozem. Potential evapotranspiration slightly exceeds the precipitation totals (P/ET_0), and in the normal period (1961-1990) this ratio ranged from 0.7 to 0.8 (Pivec et al. 2006). ET_0 values were determined by an algorithm used by FAO (Allen et al. 1998).

3.2 Reference evapotranspiration and its relationship to the actual evapotranspiration

Also important for the estimation and verification of the crop coefficients values is the actual evapotranspiration assessment (Inman-Bamber & McGlinchey 2003; Hanson & May 2006; Kato & Kamichika 2006). Crop coefficients are classified as single coefficients or dual coefficients (Allen et al. 1998). Single coefficients include both, evaporation from the soil and plant transpiration. Dual crop coefficients consist of basal crop coefficients and coefficients that describe evaporation from the soil. The basal coefficients reflect the conditions of a dry soil surface and sufficient soil water to maintain maximum plant transpiration (Allen et al. 1998; Hanson & May 2006). No limitations are placed on crop growth or evapotranspiration from soil water and salinity stress, crop density, pests and diseases, weed infestation or low fertility. ET_c is determined by the crop coefficient (K_c) approach whereby the effect of the various weather conditions is incorporated into the reference crop evapotranspiration (ET_0)

(Allen et al. 1998). Values of K_c determined for most agricultural crops will typically vary in relation to the changes in vegetative growth until effective full cover is attained (Hunsaker et al. 2003). After full cover, the K_c will tend to decline, the extent of which is primarily dependent on the particular growth characteristics of the crop (Jensen et al. 1990).

Year	Crop		Period of DOY																		
			81-90	91-100	101-110	111-120	121-130	131-140	141-150	151-160	161-170	171-180	181-190	191-200	201-210	211-220	221-230	231-240	241-250	251-260	261-270
2007	<i>Hordeum vulgare</i> 1	β				0.9	0.8	0.7	1.1	1.0	1.8	1.9	1.7	1.8							
		ET_0				4.4	3.4	4.1	4.1	4.3	4.9	4.2	4.0	4.7							
		ET_c				3.9	3.5	4.0	2.7	3.0	2.1	2.2	2.2	2.3							
2008	<i>Beta vulgaris</i> var. <i>altissima</i> 2	β										0.7	0.7	0.5	0.6	0.9	0.5	0.9	0.9	1.0	1.0
		ET_0										4.7	4.7	3.1	4.0	4.7	3.1	3.6	3.3	2.6	1.5
		ET_c										4.8	4.8	3.4	4.2	3.4	3.0	3.5	3.0	2.2	1.6
	<i>Medicago sativa</i> 3	β														1.1	0.9	0.6	0.8	1.1	1.2
		ET_0														4.9	3.3	3.9	3.4	2.7	1.5
		ET_c														3.7	2.5	3.8	3.2	1.9	1.4
2009	<i>Medicago sativa</i> 4	β	0.8	1.1	0.8	0.7	1.0	1.0	0.7	0.7	0.6	0.7	0.6	0.5	0.8	1.2	1.1	1.7	2.3	1.3	1.5
		ET_0	1.4	3.3	3.6	4.1	3.4	3.3	3.5	3.3	3.9	2.7	4.0	3.5	4.2	4.5	4.2	4.2	3.4	2.7	2.7
		ET_c	1.8	3.1	3.9	4.2	3.2	2.9	3.5	3.6	4.3	2.5	3.8	3.6	4.0	2.8	2.7	2.0	1.6	2.0	1.6
	<i>Zea mays</i> 5	β				1.7	1.6	1.1	1.0	1.6	1.1	0.8	0.5	1.5	1.6	1.7	1.5	1.8			
		ET_0				4.7	3.6	3.6	3.5	3.1	3.8	2.8	4.0	3.5	4.0	4.5	4.1	4.1			
		ET_c				4.9	2.8	3.2	3.1	2.5	2.9	2.3	3.3	2.0	2.3	2.5	2.4	2.1			
2010	<i>Triticum aestivum</i> 6	β	0.7	1.2	1.0	0.7	0.8	0.9	0.8	1.2	1.0	0.9	1.4	1.5	1.7	1.7	1.7				
		ET_0	2.4	2.9	3.3	4.1	3.6	3.2	3.4	2.7	3.4	2.3	2.3	2.2	2.4	2.5	2.1				
		ET_c	1.5	3.3	3.5	4.1	3.4	3.3	3.4	3.3	4.0	2.7	4.2	3.7	4.3	4.4	4.1				
	<i>Zea mays</i> 7	β								1.0	1.3	1.3	0.9	0.6	0.5	0.6	0.5	0.6			
		ET_0								3.3	3.8	4.7	5.2	4.9	3.5	3.1	3.0	3.5			
		ET_c								2.5	2.3	2.8	3.6	3.9	3.1	2.6	2.6	3.0			
2010	<i>Sorghum bicolor</i> 8	β									1.0	1.5	1.0	0.6	0.7	0.8	1.1	1.2			
		ET_0									3.8	4.4	4.9	4.8	3.5	3.0	2.7	3.4			
		ET_c									2.7	2.2	3.0	3.7	2.7	2.1	1.7	2.2			
	<i>Triticum aestivum</i> 9	β	1.0	1.1	0.9	0.9	0.8	0.7	0.8	0.7	0.8	0.9	1.0	1.4	1.3	0.9	0.9	1.0			
		ET_0	2.3	2.3	2.5	3.8	1.9	1.8	2.5	3.1	3.5	4.6	4.8	4.9	3.4	3.0	3.1	3.4			
		ET_c	2.5	1.9	2.7	3.7	2.0	2.0	2.6	3.0	3.1	3.6	3.2	2.6	2.1	2.0	2.1	1.9			

Table 1. Average daily values of the Bowen ratio (β), reference evapotranspiration (ET_0 , mm period⁻¹) and actual evapotranspiration (ET_c , mm period⁻¹) for selected periods at selected stands in the years of 2007 to 2010. For the determination of the ET_c values the BREB method was used. DOY means day of the year. 1 – Spring barley, harvest 194 DOY, 2 – harvest 291 DOY, 3 - cutting 218 DOY, 4 - cutting 134, 171 and 208 DOY, 5 - harvest 243 DOY, 247 DOY stubble ploughing, 6 - Winter wheat, harvest 205 DOY, 7 - harvest 245 DOY, 8 - harvest 245 DOY, 9 - Winter wheat, harvest 226 DOY, 231 DOY stubble ploughing.

Year	Crop		Period of DOY															
			81-90	91-100	101-110	111-120	121-130	131-140	141-150	151-160	161-170	171-180	181-190	191-200	201-210	211-220	221-230	231-240
2007	<i>Hordeum</i>	BBCH	23 33 43 61 71 76 85 89 92															
	<i>vulgare</i>	K _c	0.90 1.03 0.97 0.66 0.69 0.43 0.52 0.53 0.48															
2009	<i>Medicago</i>	a)	cutting I. cutting II. cutting III.															
	<i>sativa</i>	K _c	1.27	0.96	1.09	1.02	0.94	0.86	1.03	1.11	1.12	0.93	0.96	1.03	0.95	0.63	0.65	0.49
	<i>Zea</i>	BBCH	13 14 16 30 31 33 35 39 57 65 73 79 83															
	<i>mays</i>	K _c	1.04 0.78 0.88 0.89 0.81 0.75 0.85 0.84 0.58 0.57 0.56 0.58 0.51															
	<i>Triticum</i>	BBCH	22	23	25	28	31	33	55	61	69	73	83	87	91			
	<i>aestivum</i>	K _c	0.64	1.10	1.07	1.01	0.95	1.00	0.98	1.22	1.17	1.17	1.80	1.67	1.84			
2010	<i>Zea</i>	BBCH	16 31 32 34 39 59 67 75 81															
	<i>mays</i>	K _c	0.75 0.61 0.58 0.70 0.80 0.86 0.85 0.86 0.86															
	<i>Sorghum</i>	b)	2 3 5 6															
	<i>bicolor</i>	K _c	0.71 0.49 0.61 0.77 0.76 0.68 0.64 0.64															
	<i>Triticum</i>	BBCH	20	21	23	25	31	32	45	51	61	71	83	85	92	93		
	<i>aestivum</i>	K _c	1.06	0.83	1.10	0.96	1.08	1.09	1.07	0.96	0.90	0.79	0.67	0.54	0.61	0.67		

a) for *M. sativa* the cutting dates are introduced
b) for *S. bicolor* the following growth stages were estimated: 2 – five leaf stage, 3 – growing point differentiation, 5 – boot stage and 6 – half bloom
 K_c values were determined on the basis of the relationship $ET_c = ET_0 \times K_c$.

Table 2. Average daily values of K_c for the period and growth stage BBCH (BBCH principal stage in a given period) for selected crops in the years of 2007, 2009 and 2010. K_c values were determined on the basis of the relationship $ET_c = ET_0 \times K_c$. ET_0 is the average daily reference evapotranspiration (mm period⁻¹) and ET_c the average daily actual evapotranspiration (mm period⁻¹). DOY means day of the year. BBCH stages were estimated by Meier (2001).

ET_0 is the average daily reference evapotranspiration (mm period⁻¹) and ET_c the average daily actual evapotranspiration (mm period⁻¹). Table 2 documents the K_c values for selected field crops in central Europe in relation to crop growth stages. The table clearly shows a decrease in the K_c values in case of cereal crops just at the onset of the grain maturation stage. The stands of *M. sativa* illustrated the value of K_c around 1 throughout the whole vegetation period. Cutting reduces water demands and hence the decrease of K_c values. Stands with *Z. mays* and *S. bicolor* have a typical lower K_c values provided in the main crop growth compared with cereals.

4. Transpiration of field crops

The current knowledge of the plant species moisture requirements has been obtained predominantly within the framework of the study of forest communities while the transpiration values are known in wood species (e.g. Čermák et al. 1992 and 1995; Schulze et al. 1985). Information on the moisture requirements of the herbal species by using the sap flow method, particularly their determination under natural conditions, are relatively, on the basis of literature survey, not so abundant. Much more frequent are data of moisture demands on field crops set out in laboratory conditions (e.g. Dugas 1990; Angadi et al. 2003).

4.1 Transpiration of crop-plants

Moisture requirements of crops in relation to different abiotic and biotic factors are intensively investigated. Table 3 summarizes the values of water flow through several crop plant species under laboratory or field conditions. Longer-term measurements allow the determination of moisture needs based on daily values of Q , particularly in relation to the growth phase. Table 3 shows the average daily values of Q for selected cultivated plants established under the field conditions around the world, while Table 4 includes the values measured by authors.

Species	Variety/Cultivar	Q	Conditions	Source
<i>Brassica napus</i>	Quantum	to 39	greenhouse	Angadi et al. 2003
	Arrow	0 – 27	field	
<i>Glycine soja</i>		0 – 95	plastic chamber	Cohen et al. 1993
<i>Gossypium</i> sp.		0 – 75	greenhouse	Dugas 1990
	Deltapine 77	0 – 95	field	Dugas et. al. 1994
<i>Helianthus annuus</i>		0 – 200	greenhouse	Kjelgaard et al. 1997
<i>Solanum tuberosum</i>	Atlantic	0 – 55	greenhouse	Gordon et al. 1997
	Monona	0 – 25		
		0 – 35	greenhouse	Kjelgaard et al. 1997
<i>Triticum</i> sp.		0 – 5	field	Senock et al. 1996
<i>Zea mays</i>		0 –175	greenhouse	Gavloski et al. 1992
		0 – 150	greenhouse	Kjelgaard et al. 1997

Table 3. Large range of sap flow rates (Q , g h⁻¹) by crop-plants.

4.2 Transpiration of weeds

Weedy plants are a permanent part of the plant-based agricultural soil communities. In terms of water demands determination of agrophytocoenosis is also important to determine the transpiration of wild plants. Knowledge of weed transpiration plays an important role in assessing the competition of weeds against cultivated plants. Table 5 demonstrates the values of transpiration flow of select weeds using sap flow method (Pivec & Brant 2009). Based on these results, it is possible to make a detailed comparison of water demands of weeds and cultivated plants. If, for example, we compare the transpiration requirements of

Plant species	Date of measurement	BBCH stage	<i>n</i>	<i>Q</i>	<i>Q</i> _{max}
<i>Brassica napus</i>	9.6. – 22.7.2005	71 – 88	6	0.044	0.121
	5.6. – 25.7.2006	75 – 97	6	0.092	0.187
	26.4. – 29.6.2007	64 – 86	24	0.030	0.079
	29.5. – 14.7.2008	71 – 87	17	0.085	0.203
<i>Helianthus annuus</i>	7.7. – 22.7.2009	53 - 59	3	0.337	0.731
<i>Sorghum bicolor</i>	14.8. – 31.8.2010	-	12	0.177	0.816
<i>Zea mays</i>	15.7. – 3.9.2008	63 - 75	11	0.080	0.201
	12.8. – 30.8.2009	75 - 83	11	0.081	0.244
	24.7. – 31.8.2010	63 - 81	10	0.178	0.885

Table 4. Averages of daily values of transpiration flow (*Q*, kg day⁻¹), their maxima (*Q*_{max}, kg day⁻¹) and BBCH stages for the evaluated plant species for the period under observation. *n* - number of measured plants.

the plants of *B. napus* and those of *Lactuca serriola*, which can become a weed in the stands of *B. napus*, we will find out that they are similar. We can then express an assumption that the occurrence of one plant of *L. serriola* per unit of area of the *B. napus* stand has the same effect on the transpiration requirements of the stand and competition relations for water, as the increase in the numbers of individuals of *B. napus* per given area unit by one plant. A more distinct effect on the transpiration requirements of the growth stand will be found if we evaluate the influence of the occurrence of *Artemisia vulgaris* plants in the stands of *B. napus*. If the daily average value of the transpiration flow in *A. vulgaris* reached 0.077 to 0.084 kg H₂O per single stalk, then with the average number of stalks, which can range from 3 to 7 in *B. napus*, the moisture requirements of this weed are considerably higher in comparison with a single plant of *B. napus* (Pivec & Brant 2009).

Plant species	Date of measurement	<i>n</i>	<i>Q</i>	<i>Q</i> _{max}	<i>Rg</i>	<i>P</i>	Notes
<i>Amaranthus retroflexus</i>	2.8. – 27.8.2006	2	0.018	0.080	14.1	99.0	1
<i>Artemisia vulgaris</i>	2.8. – 27.8.2006	7*	0.077	0.150	14.1	99.0	1
	19.7. – 17.8.2007	7*	0.084	0.157	17.8	79.0	
<i>Cirsium arvense</i>	2.8. – 8.8.2005	1*	0.016	0.025	14.8	20.6	2
<i>Conyza canadensis</i>	2.8. – 27.8.2006	6	0.046	0.116	14.1	99.0	1
	19.7. – 17.8.2007	9	0.078	0.174	17.8	79.0	
<i>Lactuca serriola</i>	2.8. – 27.8.2006	9	0.068	0.153	14.1	99.0	1
	19.7. – 17.8.2007	8	0.025	0.093	17.8	79.0	

Table 5. Averages of daily values of transpiration flow (*Q*, kg day⁻¹), their maxima (*Q*_{max}, kg day⁻¹) for the evaluated weed species and the average daily sums of global solar radiation (*Rg*, MJ m⁻² day⁻¹) and daily totals of precipitation (*P*, mm) for the period under observation (modified by Pivec & Brant 2009). *n* - number of measured plants or stalks*, 1 - measured in solitary plants, 2 - measured in the stand of *Z. mays*.

4.3 Transpiration modelling

One way or determining the influence of different factors on the plant water consumption is the model estimation of the calculated value of sap flow (Q_{calc}). An actual value of Q depends strongly on the input of the solar radiation and vapour pressure deficit (e.g. Gordon et al. 1999; Pivec et al. 2009; Pivec et al. 2010). One of the possibilities of Q_{calc} determination is to use the algorithm (3) as shown below (Kučera, EMS Brno, pers. comm.; Pivec et al. 2010):

$$Q_{calc} = par1 \frac{Rg}{(Rg + par2)} \frac{VPD}{(VPD + par3)}$$

(3)

where Rg is global solar radiation ($W\ m^{-2}$) and VPD is vapour pressure deficit (hPa). The parameters (par) 1-3 for the Q_{calc} calculation were estimated for the entire measurement period.

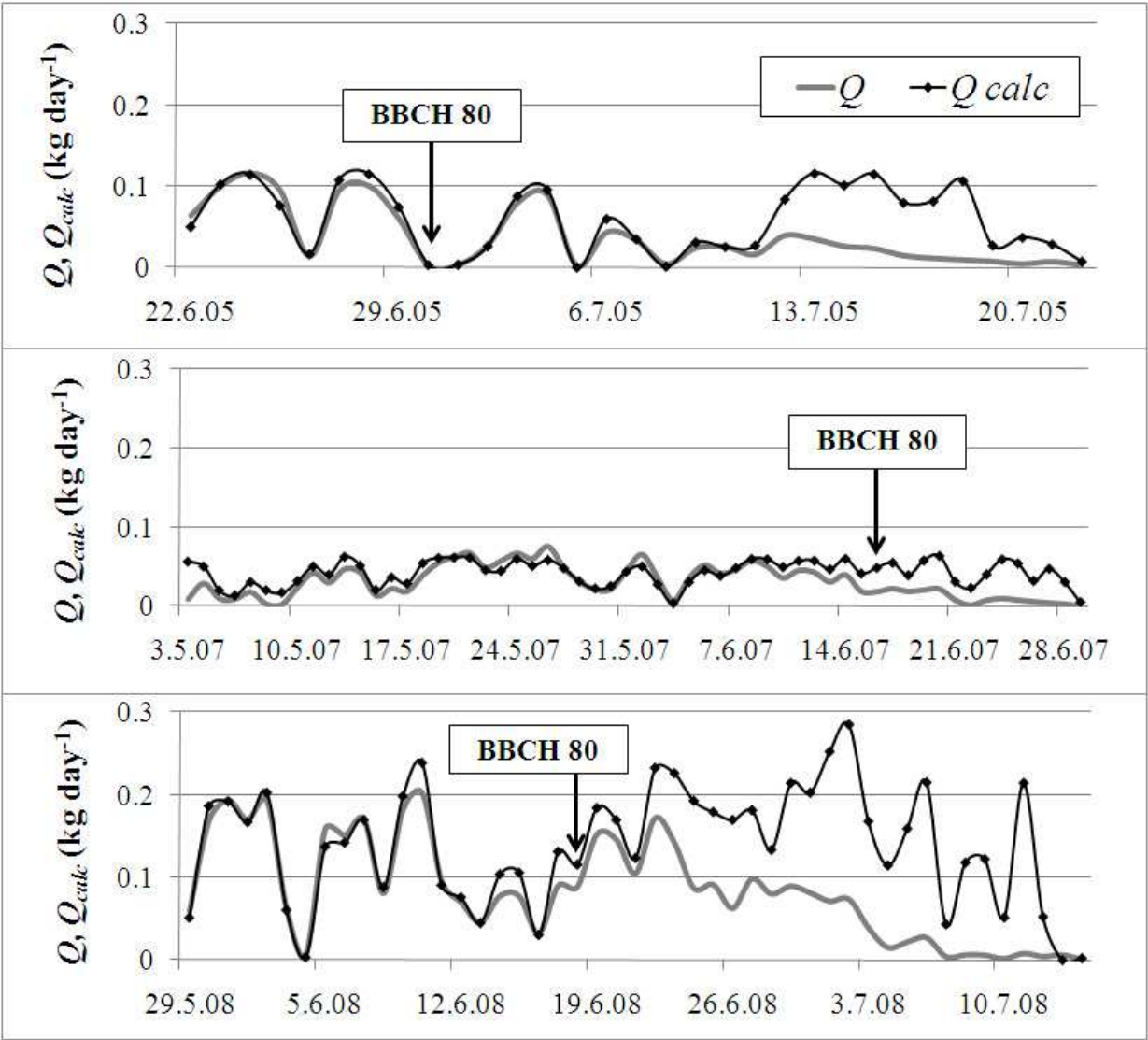


Fig. 3. Daily values of Q and Q_{calc} ($kg\ day^{-1}$) in the *B. napus* plant during the observed period in the years 2005, 2007 and 2008 (Pivec et al. 2010).

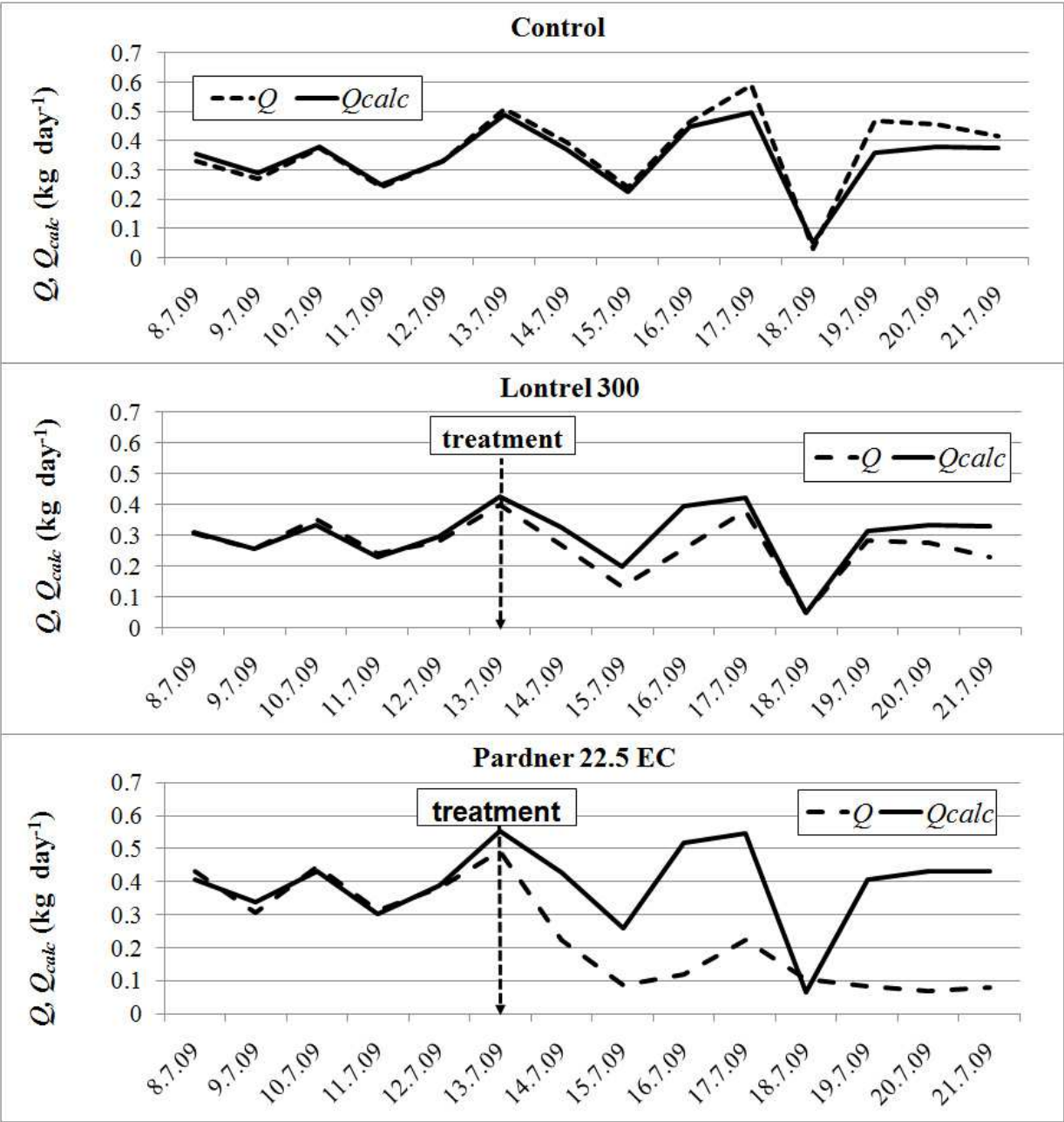


Fig. 4. Influence of herbicide treatment on average daily values of Q and Q_{calc} (kg day^{-1}) in the *Helianthus annuus* plant. Influence of herbicide treatment on water flow decline was proved by computing correlation coefficients comparing transpiration average daily values (Q) – in the period from 8.7. to 13.7.2009 with the calculated values of (Q_{calc}). Modified by Brant et al. (2010).

An example is the usage of Q_{calc} calculation for determining the moisture changes in plants, depending on the growth stage. It is obvious from the different course of daily averages of Q and Q_{calc} values (kg day^{-1}) during the years under observation (Fig. 3) that sap flow decreases from the beginning of the maturation stage of *B. napus* plants. Values of the parameters (par) 1–3, used for the Q_{calc} computation were, in 2005, 0.257554/5205.436/22.10980 (corresponding period for the pars' estimation 22–29 June 2005), in 2007, 0.019516/992.2398/4.741211 (corresponding period 29 May – 11 June 2007),

and in 2008, 0.101538/778.5762/17.45747 (corresponding period 29 May–10 June 2008). In terms of regression analysis a closer dependence between Q_{calc} and Q was confirmed from the start of the measurements up to the BBCH 83 stage in 2005, and up to the BBCH 81 stage in 2007 and 2008 (Pivec et al. 2010).

Another possibility for using the calculation of Q_{calc} is, for example, assessment of the effect of herbicides on the change of water demands of the plant. Effect of herbicides was tested on the plants of *Helianthus annuus* (the modelled plant). Herbicide treatment was carried out on 13.7. 2009. Three plants were untreated, three plants were treated with the herbicide Pardner 22.5 EC (225 g a.i. *bromoxynil* l⁻¹, active ingredient inhibiting PSII) at 1.5 l ha⁻¹ while the three remaining plants were treated with Lontrel 300 (300 g a.i. *clopyralid* l⁻¹, synthetic auxin) at 0.4 l ha⁻¹. The growth stage of *H. annuus* was BBCH 56 at the beginning of the experiment. Mean values of Q in untreated plants exceeded the values of Q_{calc} (Fig. 4). This can be explained by an unlimited growth of the control plants. Average daily Q values in the plants treated with herbicide Lontrel 300 was lower on sunny days (14.7–21.7.) than Q_{cal} before the herbicide treatment. This illustrates that plants transpired less than before the herbicide treatment and their growth was reduced, perhaps even stopped. Strong herbicide effect on Q decrease was evident following an application of Pardner 22.5 EC (Fig. 4).

5. Relationship between transpiration and evapotranspiration

In terms of actual evapotranspiration it is necessary to remember the contribution of its components, transpiration and evaporation, to its total value. Under annual field crops, the soil surface remains bare during fallow, preparatory tillage, planting, germination, and seedling stages. Most water is lost during these periods by direct evaporation from soil (Jalota & Prihar 1998). During the growing season, characterized by the highest evapotranspirational demands of crops, however, a proportion of evaporation to the total value of evapotranspiration is fundamental. Lösch (2001) states that on the land covered by vegetation the share of water delivered from the soil into the atmosphere via plants represents 2/3 up to 3/4 of the total evapotranspiration. An important role in terms of the proportion of evaporation to total evapotranspiration is played by tillage, crop architecture (row crops or densely sown crops), mulching technologies etc. During a normal growing season, evaporation from the soil surface may reach up to 50% of evapotranspiration (Peters 1960). Russell & Peters (1959) and Pivec & Brant (2009) points out the high proportion of evaporation to evapotranspiration, approximately 50% in crops such as *Z. mays*. Crop residues, applied to the soil surface (mulching), prevent water loss by evaporation (Brussiere & Cellier 1994; Gill & Jalota 1996).

Figure 5 illustrates the daily totals of Q /ETC measured by the sap flow/BREB technique in *B. napus* and *Z. mays* plants. Q values of *Z. mays* achieved 35% of ETC values. The amount of water passing through the *Z. mays* plant stems on 1 m² of crop as measured by the sap flow, when compared with the evapotranspiration values measured by BREB technique, denotes a higher evaporation than we had expected. This suggests that the heat balance method of the sap flow rate measurement can be disputed in respect to *Z. mays* plants, which are monocotyledonous and in which, therefore, the water flow runs across the whole cross-section of the vascular bundles in the stem. On the other hand, *Z. mays* is a representative of C4 plants with a smaller water consumption and a higher water use efficiency than revealed by C3 plants. In any case, the study of *Z. mays* will require a much greater effort and more detailed observation since there are few literature references on this

subject. From Figure 5 is it clear that *B. napus* transpiration rates decline with the advancing maturation stage (BBCH phase 84) according to the results of Pivec & Brant (2009). After the maturation stage, the crop transpiration still drops and the values of evapotranspiration are probably influenced by evaporation.

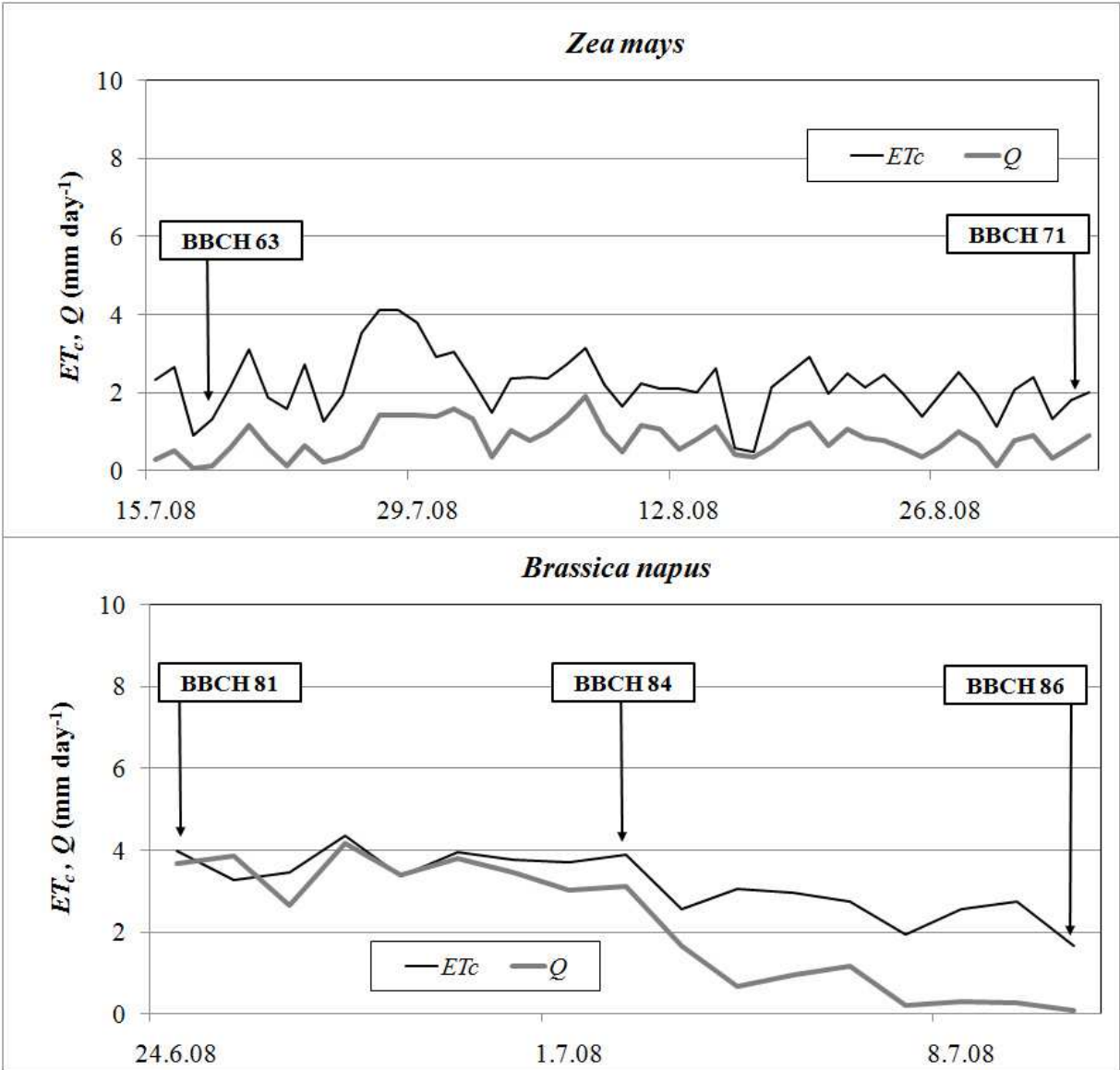


Fig. 5. Daily values of evapotranspiration (ET_c , mm) and sap flow (Q , mm) of *Zea mays* and *Brassica napus* plants. The average number of individuals in *Z. mays* was 96 000 ha^{-1} and in *B. napus* 42 individuals m^{-2} (Pivec & Brant 2009). Growth stages of plants are expressed by the BBCH growth scale.

6. Conclusions

This study presents the values of evapotranspiration and transpiration of field crops under the temperate climate conditions set out in the field. In practical terms, the usage of published results is important to determine the ratio between the actual and potential evapotranspiration of evaluated crops. The material can also be considered for determining

the value of transpiration for selected field crops and weeds, which makes it possible to specify partially competitive relationships between plant species within agrophytocoenosis. The most crucial conclusion of this work is a comparison of actual evapotranspiration values measured by both the BREB method and the sap flow. Simultaneous use of these methods provides also the verification of the results obtained.

7. Acknowledgments

This contribution originated from work supported by the Research Project MSM 6046070901 of the Ministry of Education, Youth and Sports of the Czech Republic and the Project QH 82191 of the National Agency for Agriculture Research under the Ministry of Agriculture of the Czech Republic.

8. References

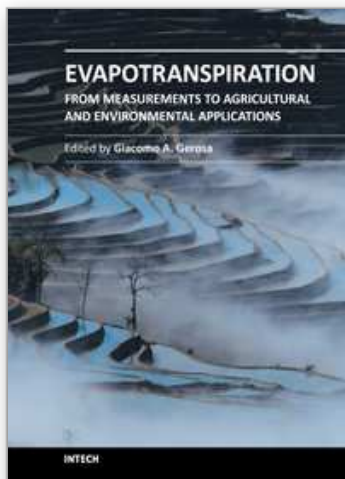
- Allen, R.G.; Pereira, L.S., Raies, D. & Smith, M. (1998). *Crop evapotranspiration: guidelines for computing crop water requirements*. FAO Irrigation and Drainage Paper 56, ISBN 92-5-104219-5 United Nations, Rome, Italy
- Angadi, S.V.; Cutforth, H.W. & Mcconkey, B.G. (2003). Determination of the water use and water use response of canola to solar radiation and temperature by using heat balance stem flow gauges. *Canadian Journal of Plant Science*, Vol. 83, No. 1, pp. 31-38, ISSN 1918-1833
- Asseng, S. & Hsiao, T.C. (2000). Canopy CO₂ assimilation, energy balance, and water use efficiency of an alfalfa crop before and after cutting. *Field Crops Research*, Vol. 67, No. 3, pp. 191-206, ISSN 0378-4290
- Brant, V.; Pivec, J., Hamouzová, K. & Satrapová, J. (2010). Herbicide efficacy evaluation using sap flow method. *15th EWRS Symposium 2010*, pp. 294, ISBN 978-963-9821-24-8, Kaposvár, Hungary, July 12-15, 2010
- Brotzge, J.A. & Crawford, K.C. (2003). Examination of the surface energy budget: A comparison of eddy correlation and Bowen ratio measurement systems. *Journal of Hydrometeorology*, Vol. 4, No. 2, pp. 160-178, ISSN 1525-755X
- Brussiere, F. & Cellier, P. (1994). Modification of the soil temperature and water content regimes by a crop residue mulch: experiment and modelling. *Agricultural and Forest Meteorology*, Vol. 68, No. 1-2, (March 1994), pp. 1-28, ISSN 0168-1923
- Čermák, J.; Cienciala, E., Kučera, J. & Hällgren, J.E. (1992). Radial velocity profiles of water flow in trunks of Norway spruce and oak and the response of spruce to severing. *Tree Physiology*, Vol. 10, No. 4, (June 1992), pp. 376 – 380, ISSN 0829-318X
- Čermák, J.; Cienciala, E., Kučera, J., Lindroth, A. & Bednářová, E. (1995). Individual variation of sap-flow rate in large pine and spruce trees and stand transpiration: a pilot study at the central NOPEX site. *Journal of Hydrology*, Vol. 168, No. 1, (June 1995), pp. 17-27, ISSN 0022-1694
- Čermák J.; Kučera, J. & Nadezhdina, N. (2004). Sap flow measurements with some thermodynamic methods, flow integration within trees and scaling up from sample trees to entire forest stands. *Trees*, Vol. 18, No. 5, pp. 529-546, ISSN 0931-1890
- Cohen, Y.; Takeuchi, S., Nozaka, J. & Yano, T. (1993). Accuracy of sap flow measurement using heat balance and heat pulse methods. *Agronomy Journal*, Vol. 85, No. 5, pp. 1080-1086, ISSN 0002-1962

- Connor, D.J.; Theiveyanathan, S. & Rimmington, G.M. (1992). Development, growth, water-use and yield of a spring and a winter wheat in response to time of sowing. *Australian Journal of Agricultural Research*, Vol. 43, No. 3, pp. 493–516, ISSN 0004-9409
- Corbeels, M.; Hofman, G. & Van Cleemput, O. (1998). Analysis of water use by wheat grown on a cracking clay soil in a semi-arid Mediterranean environment: weather and nitrogen effects. *Agricultural Water Management*, Vol. 38, No. 2, (December 1998), pp. 147–167, ISSN 0378-3774
- Dugas, W.A. (1990). Comparative measurement of stem flow and transpiration in Cotton. *Theoretical and Applied Climatology*, Vol. 42, No. 4, pp. 215 – 221, ISSN 0177-798X
- Dugas, W.A.; Heuer, M.L., Hunsaker, D., Kimball, B.A., Lewin, K.F., Nagy, J. & Johnson, M. (1994). Sap flow measurements of transpiration from cotton grown under ambient and enriched CO₂ concentrations. *Agricultural and Forest Meteorology*, Vol. 70, No. 1-4, pp. 231-245, ISSN 0168-1923
- Eastham, J. & Gregory, P.J. (2000). The influence of crop management on the water balance of lupin and wheat crops on a layered soil in a Mediterranean climate. *Plant and Soil*, Vol. 221, No. 2, pp. 239–251, ISSN: 0032-079X
- Gavloski, J.E.; Whitfield, G.H. & Ellis, C.R. (1992). Effect of restricted watering on sap flow and growth in corn (*Zea mays* L.). *Canadian Journal of Plant Science*, Vol. 72, No. 2, pp. 361-368, ISSN: 0008-4220
- Gill, B.S. & Jalota, S.K. (1996). Evaporation from soil in relation to residue rate, mixing depth, soil texture and evaporativity. *Soil Technology*, Vol. 8, No. 4, (March 1996), pp. 293-301, ISSN: 0933-3630
- Gordon, R.; Brown, D.M., Madani, A. & Dixon, M.A. (1999). An assessment of potato sap flow as affected by soil water status, solar radiation and vapour pressure deficit. *Canadian Journal of Soil Science*, Vol. 79, No. 2, pp. 245–253, ISSN 1918-1841
- Gordon, R.; Dixon, M.A. & Brown, D.M. (1997). Verification of sap flow by heat balance method on three potato cultivars. *Potato Research*, Vol. 40, No. 3, pp. 267-276, ISSN 0014-3065
- Hanson, B.R. & May, D.M. (2006). Crop coefficients for drip-irrigated processing tomato. *Agricultural Water Management*, Vol. 81, No. 3, (March 2006), pp. 381–399, ISSN 0378-3774
- Hunsaker, D.J.; Pinter, P.J., Barnes, E.M. & Kimball, B.A. (2003). Estimating cotton evapotranspiration crop coefficients with a multispectral vegetation index. *Irrigation Science*, Vol. 22, No. 2, pp. 95–104, ISSN: 0342-7188
- Inman-Bamber, N.G. & McGlinchey, M.G. (2003). Crop coefficients and water-use estimates for sugarcane based on long-term Bowen ratio energy balance measurements. *Field Crops Research*, Vol. 83, No. 2, pp. 125–138, ISSN: 0378-4290
- Jalota, S.K. & Prihar, S.S. (1998). *Reducing soil water evaporation with tillage and straw mulching*. ISBN 0813828570, Iowa State University Press, Ames, Iowa, USA
- Jara, J.; Stockle, C.O. & Kjølgaard, J. (1998). Measurement of evapo-transpiration and its components in a corn (*Zea mays* L.) field. *Agricultural and Forest Meteorology*, Vol. 92, No. 2, (July 1998), pp. 131–145, ISSN 0168-1923
- Jensen, M.E.; Burman, R.D. & Allen, R.G. (1990). *Evapotranspiration and irrigation water requirements*. ASCE – *Manuals and Report on Engineering Practice*, no. 70. ISBN 0872627632, American Society of Civil Engineers, New York, USA

- Kato, T. & Kamichika, M. (2006). Determination of a crop coefficient for evapotranspiration in a sparse sorghum field. *Irrigation and Drainage*, Vol. 55, No. 2, (April 2006), pp. 165–175, ISSN 1531-0353
- Kjelgaard, J.F.; Stockle, C.O., Black, R.A. & Campbell, G.S. (1997). Measuring sap flow with the heat balance approach using constant and variable heat inputs. *Agricultural and Forest Meteorology*, Vol. 85, No. 3-4, pp. 239-250, ISSN 0168-1923
- Köstner, B.; Biron, R., Siegwolf, R. & Granier, A. (1996). Estimates of water vapour flux and canopy conductance of Scots Pine at the tree level utilizing different xylem sap flow methods. *Theoretical and Applied Climatology*, Vol. 53, No. 1-3, pp. 105-113, ISSN 0177-798X
- Kropff, M.J. & Van Laar, H.H. (1993). *Modelling crop-weed interactions*. ISBN 0851987451, CAB International, Wallingford, UK
- Kučera, J.; Čermák, J. & Penka, M. (1977). Improved thermal method of continual recording the transpiration flow rate dynamics. *Biologia Plantarum (Praha)*, Vol. 19, No. 6, pp. 413–420, ISSN 0006-3134
- Liu, H.P. & Foken, T. (2001). A modified Bowen ratio method to determine sensible and latent heat fluxes. *Meteorologische Zeitschrift*, Vol. 10, No. 1, pp. 71-80, ISSN 0941-2948
- Lösch, R. (2001). *Wasserhaushalt der Pflanzen*. Quelle und Meyer, Wiebelsheim, Germany, ISBN 3-494-02238-0
- Meier U. (ed.) (2001). Growth stages of mono-and dicotyledonous plants. BBCH Monograph, 2. Edition, Federal Biological Research Centre for Agriculture and Forestry. (<http://syntechresearch.hu/sites/default/files/>)
- Merta M.; Sambale, C., Seidler, C. & Peschke G. (2001). Suitability of plant physiological methods to estimate the transpiration of agricultural crops. *Journal of Plant Nutrition and Soil Science*, Vol. 164, No. 1, pp. 43–48, ISSN 1522-2624
- Perez, P.J.; Castellvi, F., Ibanez, M. & Rosell, J.I. (1999). Assessment of reliability of Bowen ratio method for partitioning fluxes. *Agricultural and Forest Meteorology*, Vol. 97, No. 3, pp. 141-150, ISSN 0168-1923
- Peters, D.B. & Russell, M.B. (1959). Relative water losses by evaporation and transpiration in field corn. *Proceedings - Soil Science Society of America*, Vol. 23, No. 2, pp. 170-173, ISSN 0038-0776
- Peters, D.B. (1960). Relative magnitude of evaporation and transpiration. *Agronomy Journal*, Vol. 52, No. 9, pp. 536-538, ISSN 0002-1962
- Pivec, J.; Brant, V. & Moravec, D. (2006). Analysis of the potential evapotranspiration demands in the Czech Republic between 1961 – 1990. *Biologia*, Vol. 61, (Suppl.19), pp. 294–299, ISSN 0006-3088
- Pivec, J. & Brant, V. (2009). The actual consumption of water by selected cultivated and weed species of plants and the actual values of evapotranspiration of the stands as determined under field conditions. *Soil and Water Research*, Vol. 4, (Special Issue 2), pp. 39–48, ISSN 1801-5395
- Pivec, J.; Brant, V. & Bečka, D. (2009). The influence of weather conditions on the sap flow of *Brassica napus* L. during the fructification and maturation stages. *Ekológia (Bratislava)*, Vol. 28, No. 1, pp. 43–51, ISSN 1335-342X

- Pivec, J.; Brant, V., Bečka, D. & Cihlár, P. (2010). Consumptive use of water in *Brassica napus* L. from flowering to ripening stage under the rainless region conditions. *Irrigation and Drainage*, DOI: 10.1002/ird.598publikaciok/bbch.pdf
- Ripl, W. (1995). Management of water cycle and energy flow for ecosystem control – The Energy-Transport-Reaction (ETR) Model. *Ecological Modelling*, Vol. 78, No. 1-2, pp. 61–76, ISSN 0304-3800
- San José, J.J.; Bracho, R., Montes, R. & Nikonova, N. (2003). Comparative energy exchange from cowpeas (*Vigna unguiculata* (L.) Walp cvs. TC-9-6 and M-28-6-6) with differences in canopy architectures and growth durations at the Orinoco llanos. *Agricultural and Forest Meteorology*, Vol. 116, No. 3, pp. 197–219, ISSN 0168-1923
- Schulze, E.D.; Čermák, J., Matyssek, R., Penka, M., Zimmernann, R. & Vašíček, F. (1985). Canopy transpiration and water fluxes in the xylem of the trunk of *Larix* and *Picea* trees – a comparison of xylem flow, porometer and cuvette measurements. *Oecologia*, Vol. 66, No. 4, pp. 475–483, ISSN 0029-8549
- Senock, R.S.; Ham, J.M., Loughin, T.M., Kimball, B.A., Hunsaker, D.J., Pinter, P.J., Wall, G.W., Garcia, R.L. & LaMorte, R.L. (1996). Sap flow in wheat under free-air CO₂ enrichment. *Plant, Cell and Environment*, Vol. 19, No. 2, pp. 147–158, ISSN 0140-7791
- Shepherd, K.D.; Cooper, P.J.M., Allan, A.Y., Drennan, D.S.H. & Keatinge, J.D.H. (1987). Growth, water use and yield of barley in Mediterranean-type environments. *Journal of Agricultural Science*, Vol. 108, No. 2, pp. 365–378, ISSN 0021-8596
- Tatarinov, F.A.; Kučera, J. & Cienciala, E. (2005). The analysis of physical background of tree sap flow measurement based on thermal methods. *Measurement Science and Technology*, Vol. 16, No. 5, pp. 1157–1169, ISSN 0957-0233
- Woodward, F.I. & Sheehy, J.E. (1983). *Principles and Measurements in Environmental Biology*. ISBN 0-408-10637-9, Butterworth & Co., Ltd., London, UK
- Zeggaf, A.T.; Takeuchi, S., Dehghanisanij, H., Anyoji, H. & Yano, T. (2008). A Bowen ratio technique for partitioning energy fluxes between maize transpiration and soil surface evaporation. *Agronomy Journal*, Vol. 100, No. 4, pp. 988–996, ISSN 0002-1962

IntechOpen



Evapotranspiration - From Measurements to Agricultural and Environmental Applications

Edited by Dr. Giacomo Gerosa

ISBN 978-953-307-512-9

Hard cover, 410 pages

Publisher InTech

Published online 09, November, 2011

Published in print edition November, 2011

This book represents an overview of the direct measurement techniques of evapotranspiration with related applications to the water use optimization in the agricultural practice and to the ecosystems study. Different measuring techniques at leaf level (porometry), plant-level (sap-flow, lysimetry) and agro-ecosystem level (Surface Renewal, Eddy Covariance, Multi layer BREB), are presented with detailed explanations and examples. For the optimization of the water use in agriculture, detailed measurements on transpiration demands of crops and different cultivars, as well as results of different irrigation schemes and techniques (i.e. subsurface drip) in semi-arid areas for open-field, greenhouse and potted grown plants are presented. Aspects on ET of crops in saline environments, effects of ET on groundwater quality in xeric environments as well as the application of ET to climatic classification are also depicted. The book provides an excellent overview for both, researchers and student,s who intend to address these issues.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

J. Pivec, V. Brant and K. Hamouzová (2011). Evapotranspiration and Transpiration Measurements in Crops and Weed Species by the Bowen Ratio and Sapflow Methods Under the Rainless Region Conditions, Evapotranspiration - From Measurements to Agricultural and Environmental Applications, Dr. Giacomo Gerosa (Ed.), ISBN: 978-953-307-512-9, InTech, Available from:

<http://www.intechopen.com/books/evapotranspiration-from-measurements-to-agricultural-and-environmental-applications/evapotranspiration-and-transpiration-measurements-in-crops-and-weed-species-by-the-bowen-ratio-and-s>

INTECH
open science | open minds

InTech Europe

University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China

Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821

© 2011 The Author(s). Licensee IntechOpen. This is an open access article distributed under the terms of the [Creative Commons Attribution 3.0 License](https://creativecommons.org/licenses/by/3.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

IntechOpen

IntechOpen