7

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

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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 ± 20 W m^{-2} higher than H (EC) and λE (BREB) is about 180 ± 40 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):

$$\beta = \frac{H}{\lambda ET} = \gamma \frac{dt}{de} \tag{1}$$

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):

$$P = Q \cdot dT \cdot c_w + dT \cdot z \tag{2}$$

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.

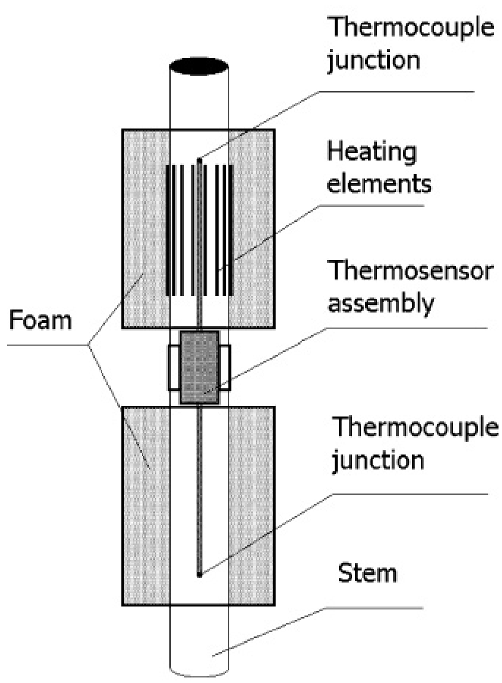

Fig. 2. Diagram of the EMS "baby sensor" for shoots or small stems (adapted from Čermák et al. 2004).

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 (J kg^{-1}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 Kc 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	*Hordeum vulgare* 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	*Beta vulgaris* var. *altissima* 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
	Medicago sativa 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	*Medicago sativa* 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
	Zea mays 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			
	Triticum aestivum 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				
2010	*Zea mays* 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			
	Sorghum bicolor 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			
	Triticum aestivum 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	*Hordeum*	BBCH				23	33	43	61	71	76	85	89	92				
	vulgare	K_c				0.90	1.03	0.97	0.66	0.69	0.43	0.52	0.53	0.48				
2009	*Medicago*	a)					cutting I.				cutting II.			cutting III.				
	sativa	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
	Zea	BBCH				13	14	16	30	31	33	35	39	57	65	73	79	83
	mays	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
	Triticum	BBCH	22	23	25	28	31	33	55	61	69	73	83	87	91			
	aestivum	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	*Zea*	BBCH								16	31	32	34	39	59	67	75	81
	mays	K_c								0.75	0.61	0.58	0.70	0.80	0.86	0.85	0.86	0.86
	Sorghum	b)									2		3		5		6	
	bicolor	K_c									0.71	0.49	0.61	0.77	0.76	0.68	0.64	0.64
	Triticum	BBCH	20	21	23	25	31	32	45	51	61	71	83	85	92	93		
	aestivum	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
Brassica napus	Quantum	to 39	greenhouse	Angadi et al. 2003
	Arrow	0 – 27	field	
Glycine soja		0 – 95	plastic chamber	Cohen et al. 1993
Gossypium sp.		0 – 75	greenhouse	Dugas 1990
	Deltapine 77	0 – 95	field	Dugas et. al. 1994
Helianthus annuus		0 – 200	greenhouse	Kjelgaard et al. 1997
Solanum tuberosum	Atlantic	0 – 55	greenhouse	Gordon et al. 1997
	Monona	0 – 25		
		0 – 35	greenhouse	Kjelgaard et al. 1997
Triticum sp.		0 – 5	field	Senock et al. 1996
Zea mays		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	n	Q	Q_{max}
Brassica napus	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
Helianthus annuus	7.7. – 22.7.2009	53 - 59	3	0.337	0.731
Sorghum bicolor	14.8. – 31.8.2010	-	12	0.177	0.816
Zea mays	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 H_2O 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	n	Q	Q_{max}	Rg	P	Notes
Amaranthus retroflexus	2.8. – 27.8.2006	2	0.018	0.080	14.1	99.0	*1*
Artemisia vulgaris	2.8. – 27.8.2006 19.7. – 17.8.2007	7* 7*	0.077 0.084	0.150 0.157	14.1 17.8	99.0 79.0	*1*
Cirsium arvense	2.8. – 8.8.2005	1*	0.016	0.025	14.8	20.6	2
Conyza canadensis	2.8. – 27.8.2006 19.7. – 17.8.2007	6 9	0.046 0.078	0.116 0.174	14.1 17.8	99.0 79.0	*1*
Lactuca serriola	2.8. – 27.8.2006 19.7. – 17.8.2007	9 8	0.068 0.025	0.153 0.093	14.1 17.8	99.0 79.0	*1*

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):

$$Q_{calc} = par1 \frac{Rg}{(Rg + par2)} \frac{VPD}{(VPD + par3)} \tag{3}$$

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.

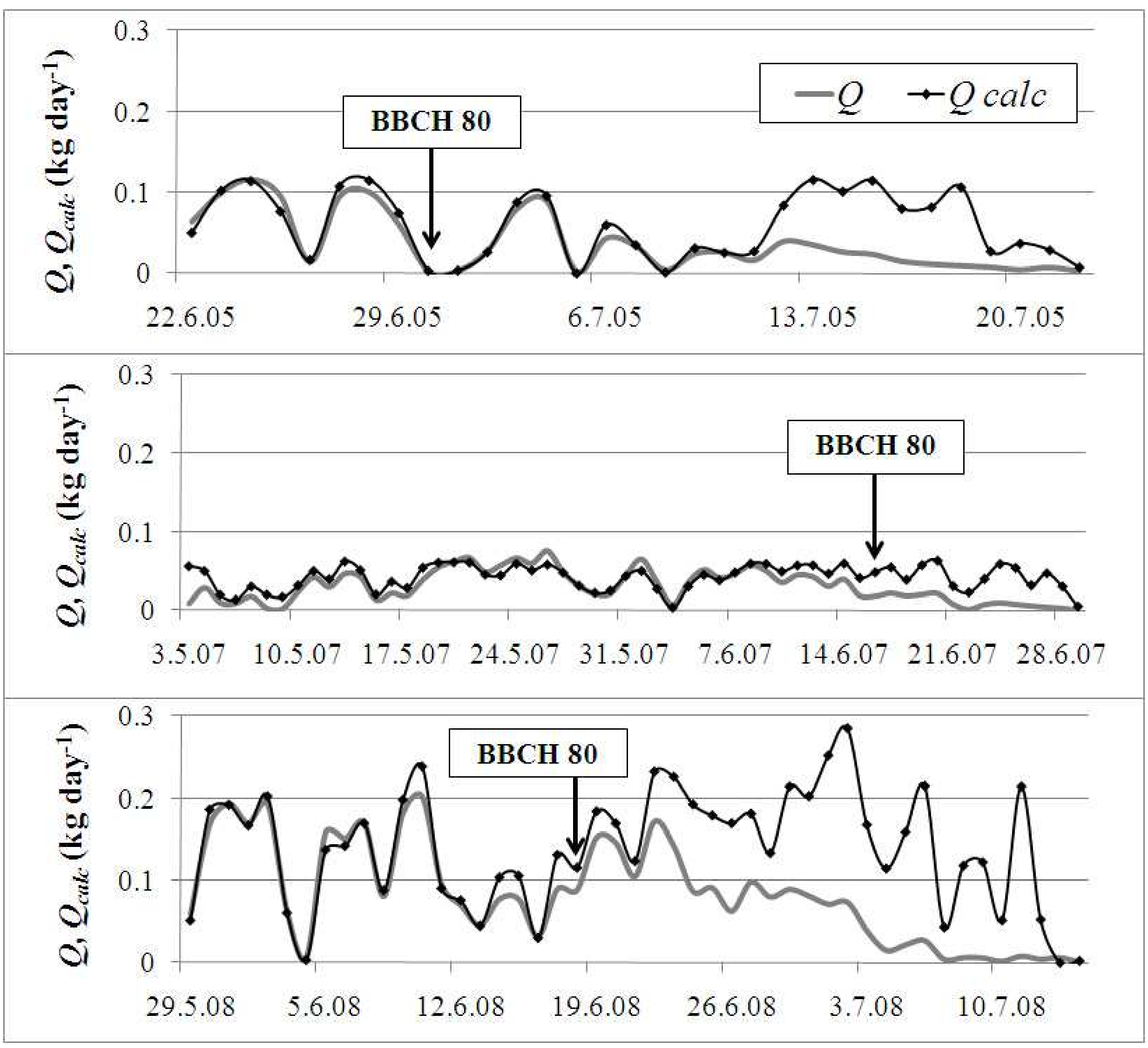

Fig. 3. Daily values of Q and Q_{calc} (kg day^{-1}) in the *B. napus* plant during the observed period in the years 2005, 2007 and 2008 (Pivec et al. 2010).

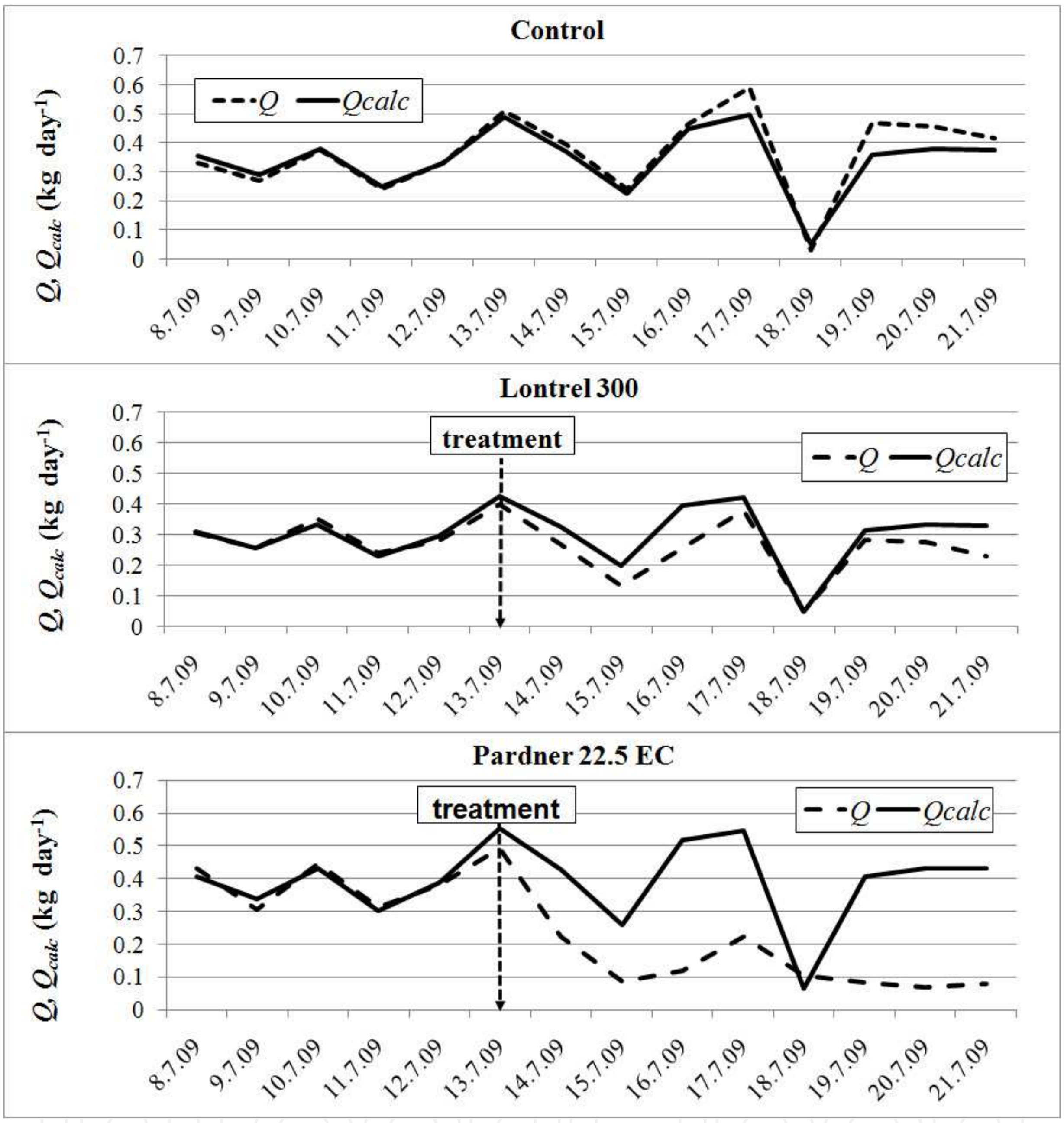

Fig. 4. Influence of herbicide treatment on average daily values of *Q* and Q_{calc} (kg day^{-1}) in the *Helianthus annuus* plant. Influence of herbicide treatment on water flow decline was proved by computing correlation coefficients comparing transpiration average daily values (*Q*) – in the period 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 *Qcalc* 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 m^2 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.

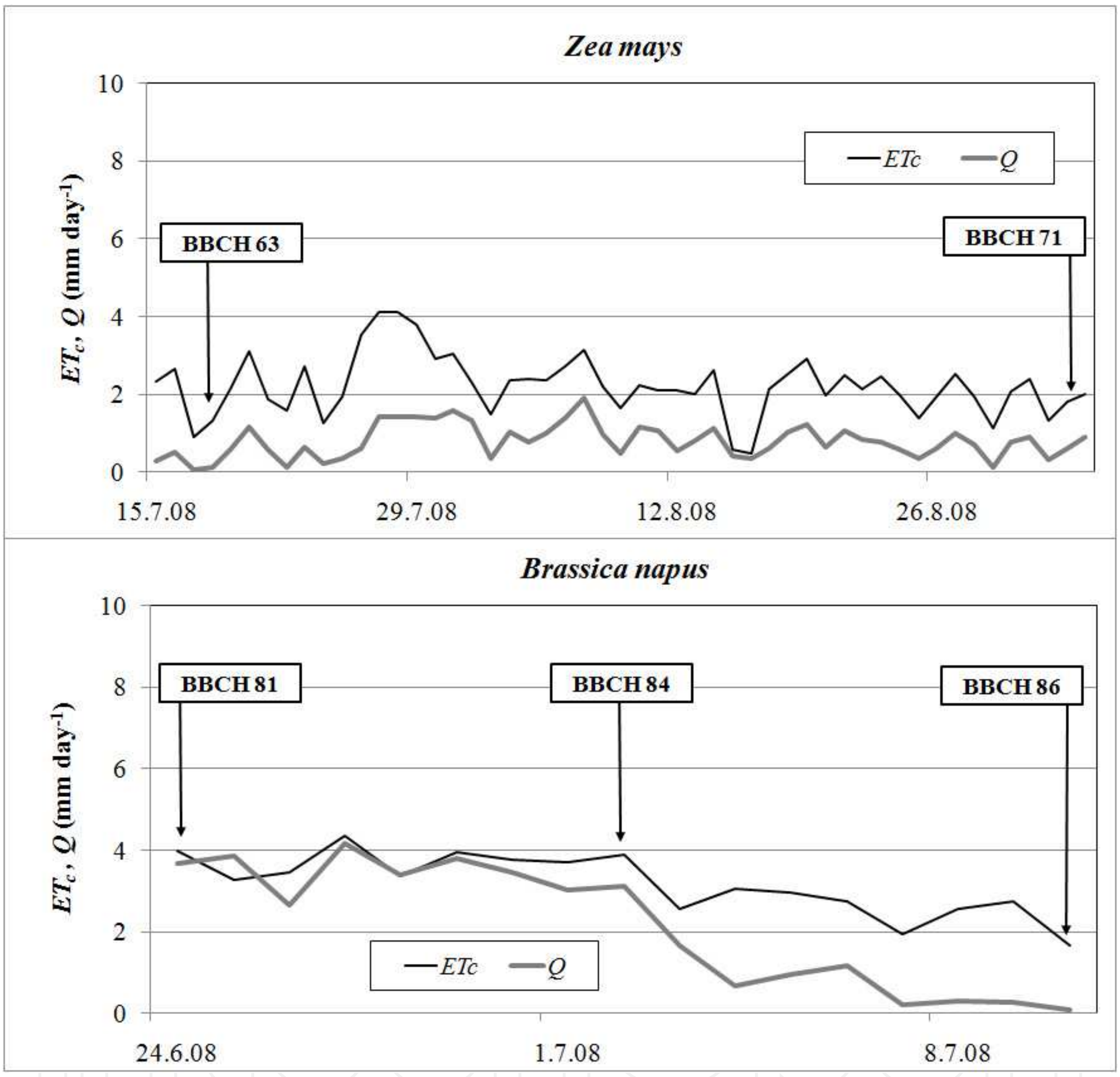

Fig. 5. Daily values of evapotranspiration (ET_c, mm) and sap flow (Q, mm) of *Zea mays* and *Brassica napus* plants. The average number of individuals in *Z. mays* was 96 000 ha^{-1} and in *B. napus* 42 individuals m^{-2} (Pivec & Brant 2009). Growth stages of plants are expressed by the BBCH growth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

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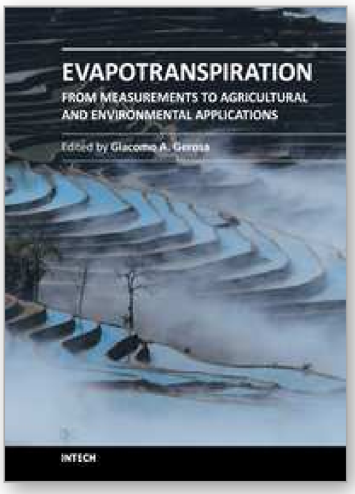

Evapotranspiration - From Measurements to Agricultural and Environmental Applications
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This book represents an overview of the direct measurement techniques of evapotranspiration with related applications to the water use optimization in the agricultural 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.