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Water consumption by *Asteraceae* weeds under field conditions

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Knowledge of weedy species' moisture demands is the basis for determining the relationships in relation to competition for water within agronomic plant communities, but it is also essential for assessing water balance in stands of cultivated plants. The aims of this work were to determine the flow of water in selected weed species from the *Asteraceae* family under field conditions and to verify the dependence of water flow on selected meteorological phenomena. Between 2006 and 2010, the water flow in *Artemisia vulgaris*, *Conyza canadensis*, and *Lactuca serriola* was studied under field conditions at a central European (Czech Republic) site. The sap flow rates (Q; kg per day) were measured by a sap flow meter. The growth stage, plant weight, and plant length at the end of the Q measurement periods were recorded. Adding the missing values of Q (kg h^{-1}) was carried out by calculating Q_{calc} (kg h^{-1}, calculated values), while Q_{fill} (kg h^{-1}, replaced values) was used for the final evaluation. In *A. vulgaris*, the average daily value of Q_{fill} (kg per day) in individual years ranged from 0.020 to 0.148 (BBCH 67–75), while it ranged from 0.006 to 0.657 (BBCH 55–89) in *C. canadensis*, and from 0.002 to 0.327 (BBCH 59–85) in *L. serriola*. The experiments have demonstrated *Q's* dependence on global solar radiation and a vapor pressure deficit.

Keywords: *Artemisia vulgaris*, *Conyza canadensis*, global radiation, *Lactuca serriola*, sap flow, weeds.

Plants' water consumption comprises a significant part of the countryside's water balance. An important factor influencing the water balance of plant stands on agricultural land, and thereby in the countryside, is the species composition of the plant community. Within their communities, cultivated plants and weeds share in the water balance (Pivec & Brant 2009). Knowledge of the water consumption of the cultivated plants and weeds is also important for determining the level of competition for water and the influence of weeds on yield reduction due to their ability to decrease the amount of water that is available in the soil for cultivated plants. Competition between plants to capture the resources that are essential to plant growth (i.e. light, water, and nutrients) is one of the key processes that determines the performance of natural, seminatural, and agricultural ecosystems (Kropff & van Laar 1993).

Sap flow measurements (the heat balance method) may be used to determine the water demand at an individual level. The current knowledge of plant species' moisture requirements has been acquired predominantly from studying forest communities and transpiration values are known in tree species (e.g. Čermák *et al.* 1995). 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. Table 1 summarizes the values of the water flow through several crop plant species under laboratory or field conditions. Kjelgaard *et al.* (1997) and Jara *et al.* (1998) reported that sap flow measurements in the same plant were practicable for ≤1 week, depending on the weather conditions and stem thickening. Data on weeds' water consumption represent a basic parameter for determining the ecological and economic functions of agriculture.

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Table 1. Sap flow rates (*Q*) for crop plants

Species	Variety/cultivar	*Q* (g h^{-1})	Condition	Source
Winter rape	Quantum	≤39	Greenhouse	Angadi *et al.* (2003)
	Arrow	0–27	Field	
Cotton	Deltapine 77	0–95	Field	Dugas *et al.* (1994)
Maize	–	0–175	Greenhouse	Gavloski *et al.* (1992)
	–	0–150	Greenhouse	Kjelgaard *et al.* (1997)
Potato	Atlantic	0–55	Greenhouse	Gordon *et al.* (1997)
	Monona	0–25		
	–	0–35	Greenhouse	Kjelgaard *et al.* (1997)
Soyabean	–	0–95	Plastic chamber	Cohen *et al.* (1993)
Sunflower	–	0–200	Greenhouse	Kjelgaard *et al.* (1997)
Wheat	–	0–5	Field	Senock *et al.* (1996)

Some representatives of the *Asteraceae* family, such as *Artemisia vulgaris*, *Conyza canadensis*, and *Lactuca serriola*, are important weed species, especially when their wide distribution throughout the world is considered. Most of these species are difficult to control by using herbicides, usually because of their strong resistance to these chemical agents.

Artemisia vulgaris L. is a perennial weed species with persistent rhizomes. It is native to Eurasia and has been naturalized in North America (Weston *et al.* 2005). Severe infestations have been identified recently in a number of new settings in Virginia in the USA (Bradley & Hagood 2002). The occurrence of *A. vulgaris* in oilseed rape (*Brassica napus*) crops in England was described by Froud-Williams and Chancellor (1987) and in maize fields in Germany by Mehrtens *et al.* (2005).

Conyza canadensis (L.) Cronq. often is classified as a winter or summer annual weed that has adapted to being able to germinate under various environmental conditions (Basu *et al.* 2004; Shields *et al.* 2006). *Conyza canadensis* occurs in North America (Weaver 2001), Western Europe (Thebaud & Abbott 1995), the Mediterranean old fields (Thebaud *et al.* 1996), and throughout Australia (Owen *et al.* 2009). This species is found commonly in field and non-crop settings where tillage has been reduced or eliminated (Weaver 2001; Shields *et al.* 2006).

Lactuca serriola L. is an annual weed that germinates in both the fall and the spring. It occurs in Europe, Asia, Africa, North America, and Australia (Lebeda *et al.* 2004). The plant typically has a single stem, but large plants in non-crop areas and plants that have been damaged by the winter wheat (*Triticum aestivum*) harvest occasionally develop multiple stems (Weaver *et al.* 2006). The plant is considered to be drought-tolerant and a potential competitor to crops for water because of its deep taproot system (Werk & Ehleringer 1986). *Lactuca serriola* also occurs as a weed in the state of Washington in the USA (Yenish & Eaton 2002), in Canada (Weaver *et al.* 2006), and in Germany (Mehrtens *et al.* 2005). Froud-Williams and Chancellor (1987) presented *L. serriola* as a weed of oilseed rape in central southern England. This weed emerges in the fall or spring in the wheat-producing region of North America's Pacific North-West (Weaver & Downs 2003).

The aims of this work were to determine the flow of water in the plant species that were selected from the *Asteraceae* family under field conditions and to verify the dependency of the water flow on selected meteorological elements that were used for calculating the water flow values for the plants.

MATERIALS AND METHODS

Site, soil, and meteorological factors

The experiments were conducted in 2006, 2007, 2009, and 2010 at an experimental area in Prague–Suchdol, Czech Republic (geographic coordinates [WGS-84]: 50°7′35.845″N, 14°22′32.72″E). The site is situated at 284 m a.s.l. The main soil unit is Haplic Luvisols. The following yearly meteorological characteristics were measured at the experimental site: air temperature (*t*; °*C*) with a sensor (50 Y; Vaisala, Helsinki, Finland), volumetric water content (*VWC*; %) for a soil depth down to 0.3 m with a sensor (CS 615; Campbell Scientific, Logan, UT, USA), and precipitation (*P*; mm) with a rain gauge (ARG 100; Campbell Scientific), in combination with a data-logger (CR10X-2M; Campbell Scientific). These values were taken from the meteorological station at a nearby phenological garden (geographic coordinates [WGS-84]: 50°7′40.811″N, 14°22′19.258″E; recording interval of 15 min). Global solar radiation values (Rg; kJ m^{-2} 10 min^{-1}) were taken from a meteorological station of the Czech University of Life Sciences in Prague (recording interval of 10 min; http://meteostanice.agrobiologie.cz). In order to assess the claims of moisture habitat, the potential evapotranspiration rate (ET_o; mm) was calculated for April to May by using Turc's (1961) algorithm. Figure 1 shows the differences in *VWC* within the years observed at the research site and the moisture conditions of the location by establishing the difference between ET_o and P.

Plant material and growth conditions

The actual values of the water flow were measured in selected species of *Asteraceae* weeds under field conditions in consecutive years. These were *A. vulgaris*, *C. canadensis*, and *L. serriola*. The evaluated weed species, number of plants (or stems), measuring times, and the Biologische Bundesanstalt, Bundessortenamt, and Chemical Industry (BBCH) phases are presented in Table 2. Observations of the BBCH phases were made from BBCH 55 (the first visible individual flowers) to BBCH 89 (fully ripe). The BBCH stages were determined according to Hess *et al.* (1997). The measured plants were represented by naturally growing, solitary individuals on spontaneous fallow – unsown soil (*C. canadensis* in 2006, 2007, and 2010 and *L. serriola* in 2006) or newly established stands of white clover (*Trifolium repens*) that had poorly emerged and provided incomplete cover (*A. vulgaris* in 2006 and 2007 and *L. serriola* in 2007 and 2009). The different dates of the sap flow measurements, evaluated in different years, were caused by differences in the plants' development, depending on the weather conditions and the possibilities of sensor instalments on the individual plants. In particular, it was associated with the achievement of a suitable diameter of the stems and defoliation of the plants at the sensor location. The plants that emerged at the location and evolved naturally were assessed. The number of measured plants was given by a number of individuals of that species that were found on the site and had been rated as suitable for the use of the sap flow method (stem diameter a minimum of 6 mm). The stem diameters ranged from 6.1 mm to 18.3 mm (Table 3). The weight of the dried plants or stems and the length (mm) of the plants or stems were evaluated at the end of the measurement period. The length of the plants was measured from where the plants were cut off close to the soil surface up to the highest part of the inflorescence. The biomass of the plants was dried for 24 h at 105°C. The stem diameter (mm) at the plants' base also was measured in 2006, 2007, and 2010. In the case of *A. vulgaris*, in which the individual plant simultaneously creates more than one stem, the biometric characteristics were determined for the stems in which the sap flow was measured. In the case of *C. canadensis* and *L. serriola*, the biometric characteristics were determined for the whole plant because these species produce one stem only.

Table 2. Weed species that were evaluated in 2006, 2007, 2009, and 2010

Species	Date of measurement	BBCH	N†
Artemisia vulgaris	2.8.2006–27.8.2006	67–73	7
	21.7.2007–16.8.2007	67–75	7
Conyza canadensis	2.8.2006–27.8.2006	69–89	5
	21.7.2007–16.8.2007	67–85	9
	24.7.2010–9.8.2010	55–67	5
Lactuca serriola	2.8.2006–27.8.2006	67–81	7
	21.7.2007–16.8.2007	63–85	7
	2.7.2009–28.7.2009	59–79	11

† Number of measured plants (or individual stems for those in the first two rows). Always seven plants of *A. vulgaris* were evaluated, one stem on each plant. BBCH, Biologische Bundesanstalt, Bundessortenamt, and Chemical Industry.

Sap flow measurements and calculations

The so-called "heat balance method" is based on the relationship between the amount of heat input and the increase in temperature within a defined space (Kučera *et al.* 1977; Tatarinov *et al.* 2005). The sap flow rates (Q; kg h^{-1}) were measured by using a 12-channel T4.2 flow meter that was designed for stems of 6–20 mm in diameter (EMS Brno, Brno, Czech Republic). The measured values were recorded at 10 min intervals during the entire period of individual measurements. The measurement points always were located at the base of the plant or stem (selected stems of the *A. vulgaris* plant were measured).

The calculated values of Q_{calc} (kg h^{-1}) were used for the completion of the missing values of Q (kg h^{-1}). An approximation of the sap flow measurement (Q_{calc}) was made using special Mini32 software (v. 4.2.31.0; EMS Brno), based on the following algorithm (Kučera J., 2000, personal communication; Pivec *et al.* 2011):

$$Q_{calc} = par1 \frac{Rg}{(Rg + par2)} \frac{VPD}{(VPD + par3)}, \quad (1)$$

where Rg is global solar radiation (W m^{-2}) and VPD is the vapor pressure deficit (hPa). Parameters (*par*) 1–3

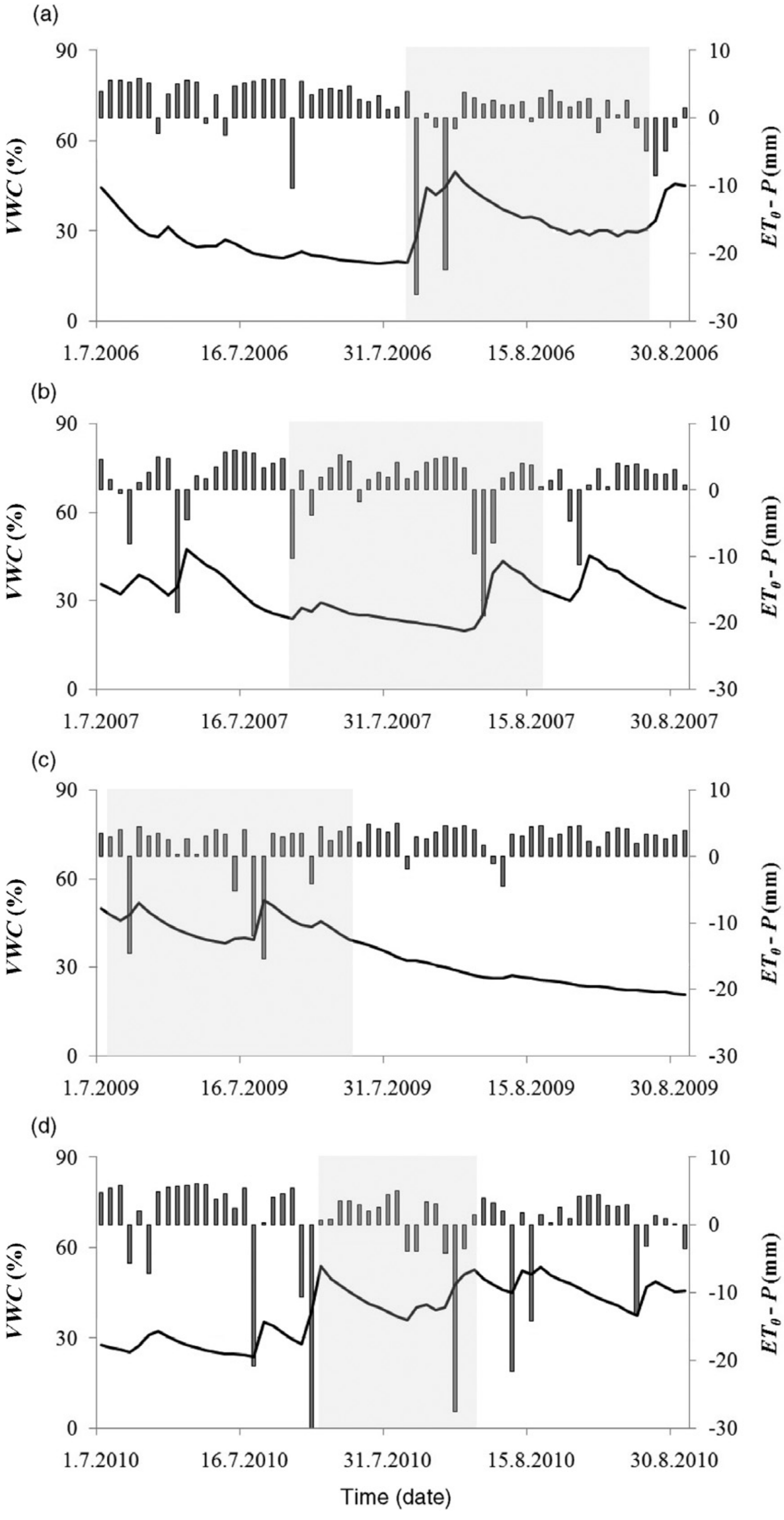

Fig. 1. Dynamics of volumetric water content (*VWC*; daily averages, solid line) and daily differences between the evapotranspiration (ET_0) and precipitation (*P*; mm, column), measured from July to August at the experimental site within the years (a) 2006, (b) 2007, (c) 2009, and (d) 2010. The gray shading indicates the periods of measuring the water flow in the plants.

Table 3. Average weight of the plants, average diameter of the plants or stems at their base, and average length of the plants in 2006, 2007, 2009, and 2010

Species	Year	Weight of plants (g)			Base diameter (mm)			Length of plants (mm)		
		Average	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum
Artemisia vulgaris										
	2006	68.6	32.4	133.0	10.5	7.9	14.3	1584	1167	2019
	2007	70.5	40.5	101.3	12.1	9.6	15.1	1324	1225	1440
Conyza canadensis										
	2006	15.3	12.4	23.5	8.2	7.4	10.4	1142	1026	1234
	2007	27.4	11.5	54.5	9.5	6.1	12.7	1120	895	1310
	2010	31.0	9.3	68.9	8.8	6.1	12.7	1158	945	1365
Lactuca serriola										
	2006	46.9	22.1	87.3	12.3	9.7	18.3	1518	1352	1725
	2007	21.9	10.9	31.4	9.7	7.8	11.3	1177	1030	1310
	2009	148.3	80.3	248.2	–	–	–	1949	1755	2082

for the Q_{calc} calculation were estimated for the entire measurement period. The algorithm of Tetens (1930) for the saturation vapor pressure calculation was used. The Q_{calc} values were calculated from the set of data that was measured at 10 min intervals for the entire measured period within the year. The values of Q_{fill} (kg h^{-1}) were determined by substituting the missing values of Q (kg h^{-1}) by Q_{calc} (kg h^{-1}). The completion of the Q values was carried out for individual plants by using the average values, determined for each 10 min (kg h^{-1}) interval. The average daily value for Q_{fill} (kg per day) was determined for each species by using the arithmetic average of the daily sums of Q_{fill} for individual plants of the same species. For each species, the daily maximum value, Q_{max} (g h^{-1}), also was determined, calculated as an arithmetic average of the daily maxima for the species. The missing values of Q (kg h^{-1}; 10 min interval) were replaced by Q_{calc} values (kg h^{-1}; 10 min interval). On average, from the total number of Q values within the measured period (3749 values per measured period for individual plants in 2006), 12.5% of the missing Q values were replaced in the *A. vulgaris* species, 21.2% in the *C. canadensis* species, and 9.3% in the *L. serriola* species. In 2007, from the total number of Q values of 3888, 6.8% were replaced in the *A. vulgaris* species, 1.4% in the *C. canadensis* species, and 10.2% in the *L. serriola* species. In 2009, from the total number of Q values of 3264, 0.9% of the values was replaced in the *L. serriola* species; in 2010, from the total number of Q values of 3981, 5.2% of the values were replaced in the *C. canadensis* species. The replacement of the missing values was related mainly to the early-morning and late-evening periods. The higher number of Q values that were replaced in 2006 was caused by the failure of battery voltage. The problem was eliminated by using a battery that was charged by solar energy during the following years. The data were processed with the Mini32 program, STATGRAPHICS Plus (v. 4.0; STATGRAPHICS, Warrenton, VA, USA), and CANOCO 4.5 (Microcomputer Power Attention, Ithaca, NY, USA). For the estimation of the relative influence of the evaluated variables, a variation partitioning by redundancy analysis (RDA) was used (Lepš & Šmilauer 2003). In this study, the aim of the regression was only a basic comparison of the influence of the Rg, VPD, t, VWC, and year conditions (independent variables) on Q_{fill} (the dependent variable). The process of variation partitioning in RDA includes a possibility to eliminate the year effect as covariate, which is considerable in this case. These results clearly demonstrate the importance of each independent variable on Q_{fill} within the species after separation of the year effect.

RESULTS

Moisture conditions at the site

The total rainfall from January to August was 450.6 mm in 2006, 380.8 mm in 2007, 377.0 mm in 2009, and 533.5 mm in 2010. The highest annual amount of precipitation was recorded in 2010 (732.5 mm). The habitat's water balance can be illustrated by the difference between the daily totals of ET_0 and P ($ET_0 - P$; Fig. 1). In accordance with the aforementioned facts, the moisture conditions at the site are illustrated by the *VWC* values in Figure 1. The graph shows that the lowest *VWC* values were observed within the period when Q was being measured on the plants in 2006 and 2007.

Morphological characteristics of the plants

It is evident from the biometric measurements of the assessed plants that the wild plants that were assessed in each year presented a very heterogeneous group in terms of the height and weight of the plants (or stems) and also in terms of the stem diameter. The variability of the plants is evident from Table 3, not only within a genus in a given year but also among the evaluated years. The regression analysis demonstrated a positive correlation between the average daily value of Q (kg per day) and the evaluated biometric plant characteristics (Table 4). Statistically significant relationships between Q and the weight of the plants, average diameter of the plant base, and the length of the plants were estimated for the species, *L. serriola* and *C. canadensis*.

Approximation of the sap flow values

Table 5 documents the intervals of the correlation coefficients, which reflect the degree of dependence between Q (kg h^{-1}; dependent variable) and Q_{calc} (kg h^{-1}; independent variable). The degree of dependence was observed for each plant on the basis of the measurements that were

Table 4. Correlation coefficients expressing the degree of dependence between the daily average sap flow rates (Q†) and the weight of the plants, plant or stem base diameter, and the length of the plants or stems‡

Year	Species	Dependence of Q (kg per day) on the weight of the plant (g)	Dependence of Q (kg per day) on the base diameter (mm)	Dependence of Q (kg per day) on the length of the plant (mm)
2006	*Artemisia vulgaris*	0.65	0.67	0.33
	Conyza canadensis	0.66	0.73	0.93*
	Lactuca serriola	0.93**	0.93**	0.97**
2007	*A. vulgaris*	0.47	0.44	0.51
	C. canadensis	0.72*	0.41	0.26
	L. serriola	0.56	0.46	0.28
2009	*L. serriola*	0.50	–	0.76**
2010	*C. canadensis*	0.99**	0.92*	0.39

† Arithmetic average of the last 7 days of measurement and the dependent variable; ‡ a linear model was used and each measured plant (eventually stem) of the species in the year was included in the analysis (see Table 2). * Significant at the 95% and ** 99% confidence levels.

Table 5. Intervals of the correlation coefficient values expressing the degree of dependence between the sap flow rates (Q; kg h^{-1}; dependent variable) and the Q_{calc} (kg h^{-1}; independent variable)†

Species	Year			
	2006	2007	2009	2010
Artemisia vulgaris	0.710–0.883	0.661–0.928	–	–
Conyza canadensis	0.675–0.815	0.697–0.928	–	0.646–0.957
Lactuca serriola	0.792–0.937	0.471–0.748	0.767–0.951	–

† Estimated measurements for individual plants were made at 10 min intervals during the observation period in the evaluated years. A linear model was used.

taken every 10 min. The lowest degree of dependence between Q and Q_{calc} was determined in 2007 for the *L. serriola* plants (Table 5). In other years, the values of the correlation indices for the evaluated species ranged from 0.65 to 0.96.

Sap flow values

The average daily values of Q_{fill} (kg per day) for the *A. vulgaris* species in individual years ranged between 0.036 to 0.141 in 2006 and between 0.020 and 0.148 in 2007. In the case of *C. canadensis,* the ranges were between 0.006 and 0.109 in 2006, between 0.013 and 0.174 in 2007, and between 0.008 and 0.657 in 2010. For *L. serriola*, the ranges of Q_{fill} values were from 0.011 to 0.139 in 2006, from 0.002 to 0.097 in 2007, and from 0.018 to 0.327 in 2009. Figures 2–5 present the daily average Q_{fill} values (kg per day) for the observed species in the different years. In 2006, the highest average daily values were recorded for the stems of *A. vulgaris* and the lowest were recorded for *C. canadensis* (Fig. 2). In 2007, by contrast, the lowest Q_{fill} values were determined for *L. serriola*. The graphic representation of the daily Q_{fill} values for *L. serriola* demonstrates that the moisture requirements of this species were lower in 2007 than in 2006 and 2009 (Figs 2–4). In 2010, the average daily Q_{fill} value for *C. canadensis* (Fig. 5) indicated that the measured sap flow greatly exceeded the moisture demands of this species during 2006 and 2007 (Figs 2,3). Also very apparent from these graphs is the dependence of the water flow in the plants on *Rg*. Table 6 documents how the daily maximum values of Q (g h^{-1}) depended on the intensity of *Rg*. Graphic representation as to the homogeneity of the set of variables that was used (depicting standard deviations and the curves of the average daily Q_{fill} values) points to significant differences in the individual consumptive water use by the evaluated plants within a species (Figs 2–5). Table 7 documents the influence of selected meteorological phenomena (*Rg, t, VPD*, and *VWC*) on the values of Q_{fill}, as estimated by RDA. The RDA analysis is a linear ordination method that is based on principal component analysis. The substantial influence of *Rg* and *VPD* on Q_{fill} was confirmed in all the evaluated species.

DISCUSSION

Sap flow values and their approximation

The results show that the Q_{fill} values that were recorded for each species differed significantly between individual years (Figs 2–5). In particular, there are notable differences in the values of Q_{fill} (kg per day) for *C. canadensis* and *L. serriola*. A significant difference is apparent in the values of Q_{fill} in *C. canadensis*, where in 2010 the average daily value of Q_{fill} was 0.254 kg per day, but in 2006 it was only 0.052 kg per day and in 2007, it was 0.080 kg per day. The higher average daily Q_{fill} for *C. canadensis* can be explained by the better moisture conditions during the observed period in 2010. Another reason might be that the Q_{fill} values for *C. canadensis* were measured in earlier BBCH growth stages, compared with 2006 and 2007 (Table 2). The Q values that were measured at a later stage of plant growth might reflect plant senescence that is associated with the consecutive termination of the plants' vegetation period and reduction in moisture requirements. For example, the influence of the senescence process changes the water flow in the plants of winter oilseed rape, as described by Pivec *et al.* (2011). The different moisture conditions during the vegetation period are likely to have caused the difference in Q_{fill} values for *L. serriola* in 2009, compared with 2006 and 2007. The effect of water stress in decreasing the Q values, in comparison with optimally wetted plants, has been described previously (e.g. Gordon *et al.* 1999). Pivec *et al.* (2011) reported that the average daily value of Q in the second half of winter oilseed rape's vegetation period ranged from 0.002 to 0.201 kg per day under field conditions, which corresponds well with the Q_{fill} values that were found for *L. serriola* in this study. This also corresponds with previously reported claims (Pivec & Brant 2009) that the presence of one *L. serriola* plant in a given unit area has the same effect on the water consumption of vegetation as does a one-plant increase in *B. napus* plants for the given unit area. The daily Q_{fill} values that are reported here for *A. vulgaris* represent water consumption for just one stem, but the plant may have multiple stems (Jursík *et al.* 2008) and thus higher moisture requirements. The considerable range in the average daily Q_{fill} values for individual plants (indicated by the standard deviations in Figs 2–5) was associated with the great heterogeneity that was observed between the plants that were developing under natural conditions (Table 2). Based on a comparison of the maximum daily values of Q (g h^{-1}; Table 6), which also display the daily interval scale values of Q (because the night values of Q are equal to 0), with the values that have been reported in the literature (Table 1), the results of this study show that the estimated values of Q (g h^{-1}) for the reviewed weed species reach similar values as do those of the cultural types. It is necessary to keep in mind, however, that the reported values in this study were obtained under field conditions. Therefore, it can be assumed that, under optimal conditions (especially of moisture and temperature), higher values should be expected. Based on the degree of dependence between Q and Q_{calc} (Table 5), the

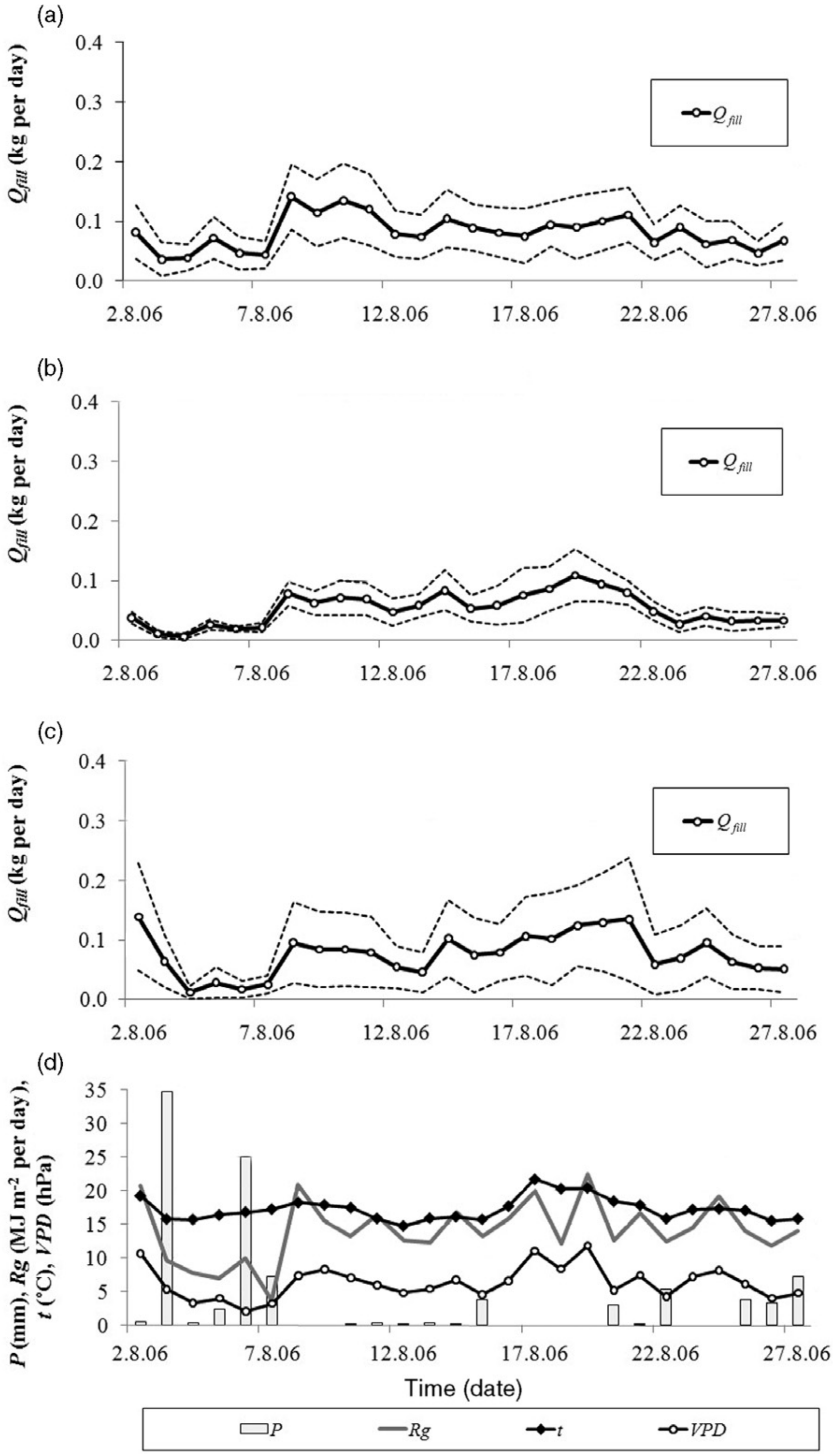

Fig. 2. Average daily sap flow rates (Q_{fill}; kg per day) for (a) *Artemisia vulgaris* (average of seven stems), (b) *Conyza canadensis* (average of five plants), and (c) *Lactuca serriola* (average of seven plants) for 2–28 August 2006, as well as (d) the daily course of global solar radiation (*Rg*; MJ m^{-2} per day), average daily air temperature (*t*; °C), average daily vapor pressure deficit (*VPD*; hPa), and daily precipitation totals (*P*; mm) for the same period. The dashed lines illustrate the standard deviation for the *Q* values.

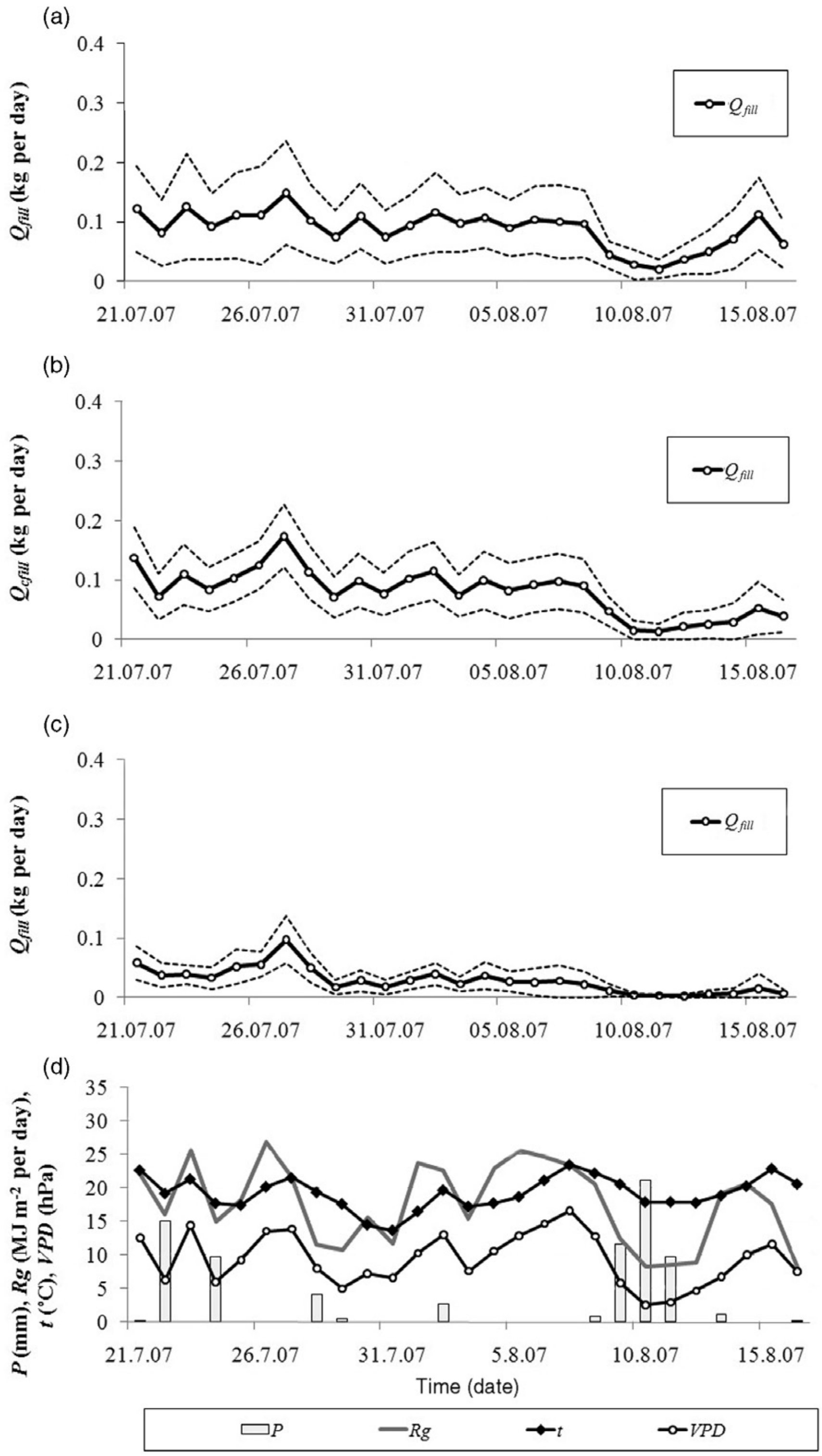

Fig. 3. Average daily sap flow rates (Q_{fill}; kg per day) for (a) *Artemisia vulgaris* (average of seven stems), (b) *Conyza canadensis* (average of nine plants), and (c) *Lactuca serriola* (average of seven plants) from 21 July to 16 August 2007, as well as (d) the daily course of global solar radiation (*Rg*; MJ m^{-2} per day), average daily air temperature (*t*; °C), average daily vapor pressure deficit (*VPD*; hPa), and daily precipitation totals (*P*; mm) for the same period. The dashed lines illustrate the standard deviation for the *Q* values.

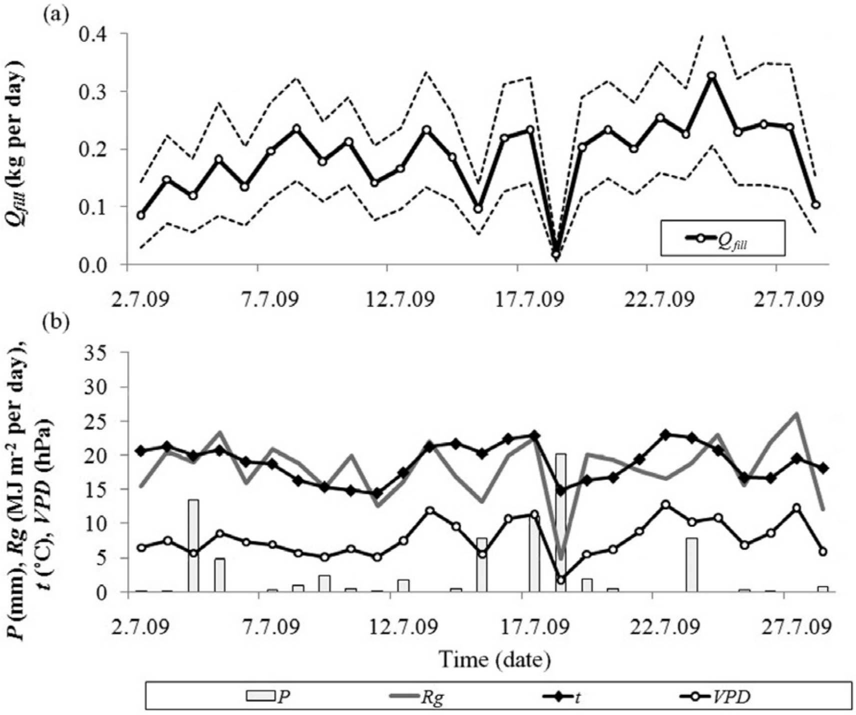

Fig. 4. (a) Average daily sap flow rates (Q_{fill}; kg per day) for *Lactuca serriola* (average of 11 plants) for 2–28 July 2009, as well as (b) the daily course of global solar radiation (*Rg*; MJ m^{-2} per day), average daily air temperature (*t*; °C), average daily vapor pressure deficit (*VPD*; hPa), and daily precipitation totals (*P*; mm) for the same period. The dashed lines illustrate the standard deviation for the *Q* values.

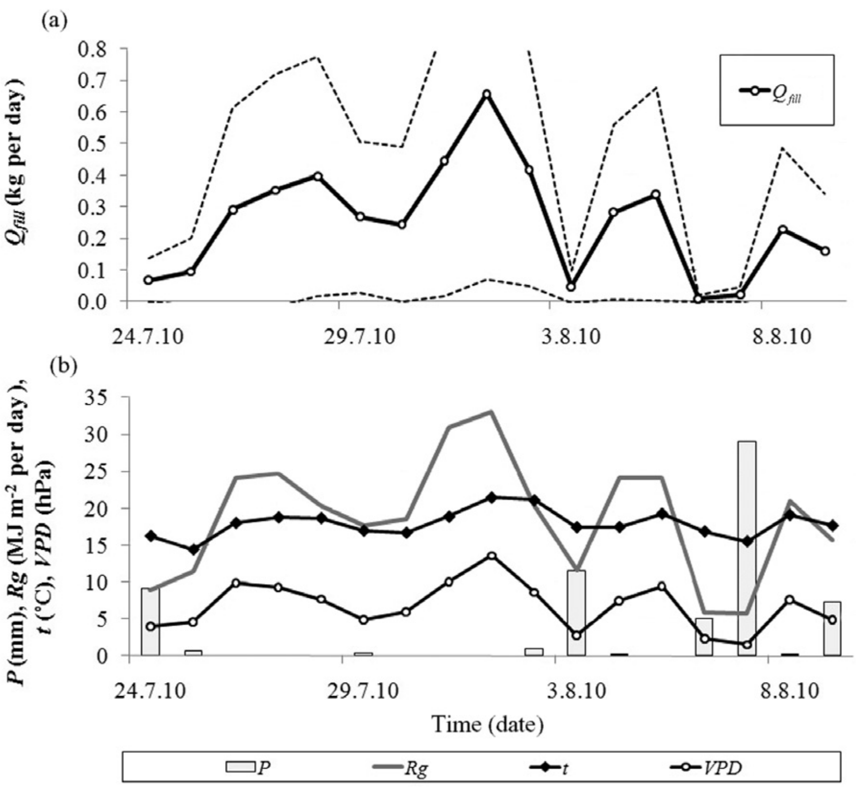

Fig. 5. (a) Average daily sap flow rates (Q_{fill}; kg per day) for *Conyza canadensis* (average of five plants) from 24 July to 9 August 2010, as well as (b) the daily course of global solar radiation (*Rg*; MJ m^{-2} per day), average daily air temperature (*t*; °C), average daily vapor pressure deficit (*VPD*; hPa), and daily precipitation totals (*P*; mm) for the same period. The dashed lines illustrate the standard deviation for the *Q* values.

Table 6. Average daily maximum sap flow rates (Q_{max}; g h^{-1}), estimated for the evaluated species, depending on the daily sum of global solar radiation (*Rg*†; MJ m^{-2}·per day) within the observed years

Species	Year											
	2006			2007			2009			2010		
	*Rg*1 5‡	*Rg*2 17‡	*Rg*3 4‡	*Rg*1 4‡	*Rg*2 11‡	*Rg*3 12‡	*Rg*1 1‡	*Rg*2 17‡	*Rg*3 9‡	*Rg*1 3‡	*Rg*2 5‡	*Rg*3 9‡
Artemisia vulgaris	18.5	32.6	26.8	18.2	32.4	30.9	–	–	–	–	–	–
Conyza canadensis	7.1	19.4	21.9	12.3	22.2	25.5	–	–	–	21.7	85.3	141.2
Lactuca serriola	15.6	39.3	41.5	3.8	13.9	17.1	14.8	51.8	58.2	–	–	–

† *Rg*1 represents values of *Rg* ≤ 10 MJ m^{-2} per day, *Rg*2 represents values within the interval of 10 < *Rg* ≤ 20 MJ m^{-2} per day, and *Rg*3 represents values of *Rg* > 20 MJ m^{-2} per day; ‡ number of days within individual groups *Rg*1–*Rg*3.

Table 7. Redundancy analysis of the effect of global solar radiation (*Rg*; MJ m^{-2} per day), air temperature (*t*; °C, daily average), vapor pressure deficit (*VPD*; hPa, daily average), volumetric water content (*VWC*; %, daily average), and year conditions on sap flow (Q_{fill}; kg per day, yearly average per species) in the three evaluated weed species (explanatory variables of all canonical axes, Monte Carlo permutation test, 499 permutations)

Species	Factor	Covariable	% of explained variability	*F*-test	*P*-value
Artemisia vulgaris (*n* = 53)† (2 years)	All	–	48.8	9.0	0.002
	Rg	Year	39.5	33.3	0.002
	t	Year	8.6	4.8	0.042
	VPD	Year	41.8	36.7	0.002
	VWC	Year	4.4	2.3	0.164
Conyza canadensis (*n* = 70) (3 years)	All	–	74.6	30.9	0.002
	Rg	Year	28.1	70.7	0.002
	t	Year	10.3	15.4	0.002
	VPD	Year	21.0	41.4	0.002
	VWC	Year	5.9	8.1	0.006
Lactuca serriola (*n* = 80) (3 years)	All	–	81.6	54.0	0.002
	Rg	Year	10.5	41.1	0.002
	t	Year	2.6	7.1	0.006
	VPD	Year	9.9	37.6	0.002
	VWC	Year	3.3	9.5	0.006

† *n* = number of measurements.

possibility was confirmed by the model's estimation of water consumption by the evaluated weed species. The dependence of the *Q* values on the input of solar radiation and *VPD* (Table 7) is consistent with the data in the literature (e.g. Gordon *et al.* 1999; Pivec *et al.* 2011).

Relationship between the sap flow and the plant parameters

The determination of a positive correlation between Q_{fill} and the evaluated plant parameters (plant weight, stem-base diameter, and length of the plant; Table 4) points to the fact that the moisture requirements of the observed plants can rise with increasing values of those plant parameters. Cohen and Li (1996) reported a positive correlation between the flow of water in the plant and the leaf area. Kjelgaard *et al.* (1997) and Jara *et al.* (1998) described the relationship between sap flow and stem thickening. This evaluation identified statistically significant relationships between Q_{fill} and the evaluated parameters only in eight cases (Table 4). The reason for this might lie in an inhibition of water flow through the plants that is related to a lack of water. Another factor is that the growth phases of individual plants within a species for a given year were different. Not the least importantly, significant heterogeneity of the evaluated plants, from the viewpoint of their reaction to the environmental conditions, can be presumed. In relation to Q and the biometric parameters, dependency would be appropriate in order to determine the relationship between Q and the leaf area. In the case of the continuous measurement of Q, the determination of the leaf area of plants is difficult. Most of the available studies have been devoted to determining the dependency between Q and stem thickening (Kjelgaard *et al.* 1997; Jara *et al.* 1998).

Knowledge of the moisture demands of weed species currently is very limited. This article presents data on the claims regarding the water consumption of globally important weed species in the *Asteraceae* family, as determined under field conditions. It also describes the dependence of water flow on abiotic factors and points out the relationships between plants' water consumption and selected biometric characteristics. In terms of the evaluated characteristics that were measured under field conditions and on naturally developed plants, this work cannot determine particular dependencies between the water requirements of the observed weeds and the abiotic factors of the environment. The aims of the study were to determine the correct values of the flow of water in plants, depending on the soil and climatic conditions, and to verify the suitability of the chosen method for the sap flow measurements of the water flow in the weeds over a longer period of time.

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