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Evaluation of *Phragmites australis* (Cav.) Trin. evapotranspiration in Northern and Southern Italy

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ABSTRACT

The design, operation, pollutant removal as well as hydraulic modeling of wetland systems for wastewater treatment can be improved by better understanding and simulating the evapotranspiration process. To this purpose, two experiments were carried out in Northern (Veneto region) and Southern (Sicily region) Italy to measure evapotranspiration (ET) and determine the crop coefficient of *Phragmites australis* (Cav.) Trin. using the FAO 56 approach. The experimental set-up consisted of a combination of vegetated and unvegetated plastic tanks (Veneto) or pilot sub-surface flow beds (Sicily). The ET values were obtained by measuring the amount of water needed to restore the initial volume in the tanks and in the beds after a certain period. All the needed climatic variables were measured and taken into account in the ET measurements. In the two experimental sites cumulative reference evapotranspiration (ET_0) was similar to the cumulative ET measured in the control tanks and beds (without vegetation, ET_{con}), while ET measured for *P. australis* (ET_{phr}) was significantly higher, underlining the strong effect of vegetation. From June 2009 to September 2009 the cumulative ET_0, ET_{con} and ET_{phr} in Veneto were 455, 424 and 3048 mm, in Sicily 653, 556 and 3899 mm, respectively. The plant coefficient trend of *P. australis* (K_p) estimated in Veneto was similar to that in Sicily, suggesting that the role of the plant in dispersing water is similar under different environmental conditions. Additional measurements made in the Veneto plant showed that K_p assumes different patterns and values in relation to plant age and growth stage. These results highlight the importance of the plants in regulating water losses from a wetland system, above all from small-scale constructed wetlands where the effect of the advection in ET rates is evident.

1. Introduction

Phragmites australis (Cav.) Trin. is one of the most widespread wetland plant species on earth (Brix et al., 2001) and is the main species used in constructed wetlands (CWs), a semi-natural technology with low costs and maintenance needs for treating various types of wastewater. Hydrological regimes are key factors in controlling the ecological, physical and chemical characteristics of wetlands (Mitsch and Gosselink, 2000). In sub-surface flow wetlands, both with horizontal and vertical flow, water balance is simplified compared to natural or surface flow wetlands, because they are hydraulically isolated and interactions with groundwater are missing. As a consequence, the key components of the hydrologic cycle in these systems are rainfall and evapotranspiration (ET), the process by which water moves from wetlands into the atmosphere through plants and medium. In CWs these variables may influence pollutant removal efficiency since precipitation dilutes the pollutant concentration and increases through-flow (IWA, 2000), shortening the contact time between waterborne substances and the wetland ecosystem. By contrast, ET decreases wastewater volume reducing outflow and concentrating the pollutants, but it does increase retention time which allows longer interaction with the wetland ecosystem (Kadlec and Wallace, 2009).

In mild temperate climates annual rainfall slightly exceeds annual ET and there is little effect of atmospheric gains and losses over the course of a year. But most climatic regions have a dry season and a wet season, which vary depending upon geographical setting. As a consequence ET losses may have a seasonally variable impact (Kadlec and Wallace, 2009). Unfortunately, the specific effects of ET on constructed wetland performance have not been thoroughly investigated because good ET estimates are hard to obtain (USEPA, 2000), even if better evaluation of ET can improve CW design and produce better predictions of simulation models. Many techniques have been developed to measure ET rates: lysimeter techniques, Bowen ratio energy balance (BREB) or

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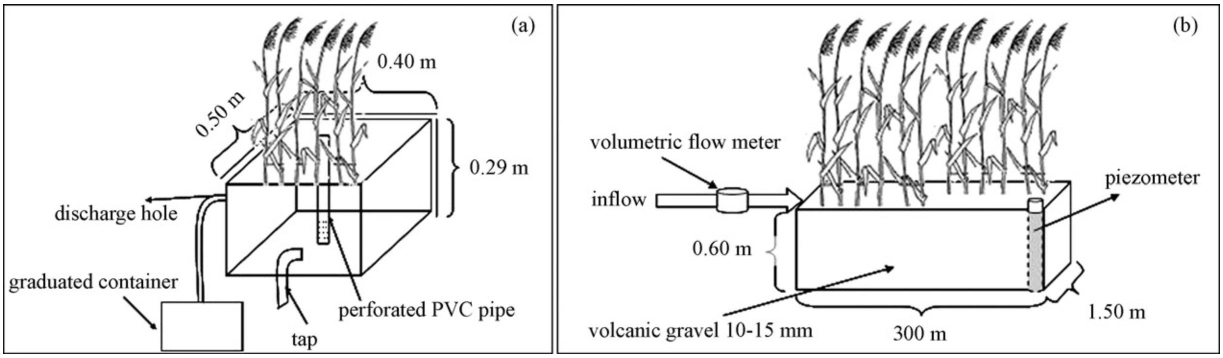

Fig. 1. Experimental facilities in Veneto (a) and in Sicily (b).

Eddy Covariance method. Lysimeters are the most reliable tool to measure the ET rates directly (by water balance measurements), but they are time consuming and laborious to manage (Hassan et al., 2008). BREB-based ET rates can be obtained independently of weather conditions. However, whatever the inaccuracy of one instrument, it will directly influence all the measured fluxes. Furthermore, the method does not work when the sensible and latent heat fluxes have approximately equal magnitude but opposite direction. This can happen around dawn or dusk, when the available energy is low and the temporal rate of change in net radiation is large (Unland et al., 1996). In the Eddy Covariance method, instruments do not work properly when rain or dew is formed on the instruments during daybreak (Twine et al., 2000; Burba and Anderson, 2007).

On the other hand, ET rates can also be estimated using meteorological variables measured in situ. The most common methods used for this purpose are: Penman–Monteith, Turc–Radiation, Priestley–Taylor, FAO–Radiation, FAO–Blaney–Criddle and FAO 56 methods (Zhao et al., 2005). The FAO 56 approach (Allen et al., 1998) has been widely used for ET calculation in agricultural ecosystems, and has lots of successful applications (Smith, 2000; Kang et al., 2003; Paco et al., 2006; Singh et al., 2007). Usually, it performs well in ET estimates of monotypic or low-diversity vegetation (Allen et al., 1998; Drexler et al., 2004). In this approach, the ET of a crop is given by the product of the reference ET (ET_0), easily computable using the Penman–Monteith equation, by the crop coefficient (K_c). Values of K_c varied widely due to the different characteristics of vegetation, seasons and sites (Garatuza-Payan et al., 1998; Fermor et al., 2001; Peacock and Hess, 2004; Drexler et al., 2008).

Applying the FAO 56 approach (Allen et al., 1998) to wetland ecosystems has been limited in particular because of the shortage of reliable K_c values associated with the macrophyte species used in constructed wetlands (Fermor et al., 2001; Drexler et al., 2008). Some works underline that different macrophytes have different aptitudes for absorbing and dispersing water (Borin et al., 2001; Salvato and Borin, in press) and so the K_c of each species must be determined. Moreover, for the same species, the common reed in particular, daily ET rates differ significantly for different meteorological conditions and latitudes, ranging from 0.5–6.5 mm d^{-1} in Nebraska (Burba et al., 1999) to 57 mm d^{-1} in Morocco (Hamouri et al., 2007).

In this paper the results of two experiments carried out in Northern (Veneto region) and Southern (Sicily region) Italy on the ET of *P. australis* (Cav.) Trin. (common reed) are presented. The main objectives of this study were to (1) measure the ET of *P. australis*, (2) estimate the crop coefficient (K_c) of *P. australis*, (3) compare the values obtained under different climatic conditions and (4) investigate the role of plant age and growth phase on ET and K_c.

Table 1
Average quality characteristics of water used during the experiments in Veneto and Sicily.

Parameters (mean values)	Units	Veneto	Sicily
pH	–	6.9	8.2
EC	$\mu S\,cm^{-1}$	2830	1388
TSS	$mg\,L^{-1}$	n.d.	138
COD	$mg\,L^{-1}$	n.d.	34.5
BOD_5	$mg\,L^{-1}$	n.d.	18.4
NH_4-N	$mg\,L^{-1}$	206	14.4
NO_3-N	$mg\,L^{-1}$	200	n.d.
TN	$mg\,L^{-1}$	n.d.	24.5
TP	$mg\,L^{-1}$	50	6.5

2. Materials and methods

ET was measured at both experimental sites from June 2009 to September 2009. Additional measurements were carried out in Veneto from June 2008 to September 2008 and February 2009 to May 2009.

2.1. Description of the experimental plants

2.1.1. Veneto

The experimental activity was carried out in Tavo di Vigodarzere (Eastern Veneto – latitude 45°49′North, longitude 11°85′East, altitude 15 m a.s.l.). The climate of the site is sub-humid, with a mean annual rainfall of about 850 mm fairly uniformly distributed throughout the year. The temperature increases from January (average minimum value: −1.5 °C) to July (average maximum value: 27.2 °C). The experimental set-up consisted of a combination of four vegetated and four non-vegetated plastic tanks (Fig. 1a) filled with gravel grain size of 0.1–10 mm (d_{10} = 3.9 mm; d_{60} = 5.2 mm) with 25% porosity. The tanks were 50 cm × 40 cm × 29 cm in length, width, height. The tanks were planted in October 2006 with *P. australis*, at a density of 30 rhizomes m^{-2}. The aerial part was harvested in February 2007 and December 2008; in spring 2009, the tank surfaces were completely covered with vegetation. Twice a month, the tanks were filled with reconstructed wastewater with a concentration of NO_3-N and NH_4-N of about 200 ppm for each form of nitrogen and about 50 ppm of TP (Table 1). At the beginning of the cycle, 60 L m^{-2} of wastewater were added to each tank and left inside for two weeks.

2.1.2. Sicily

The experimental pilot plant is located in San Michele di Ganzaria (Eastern Sicily – latitude 37°30′North, longitude 14°25′East, altitude 370 m a.s.l.). The area has a dry climate (around