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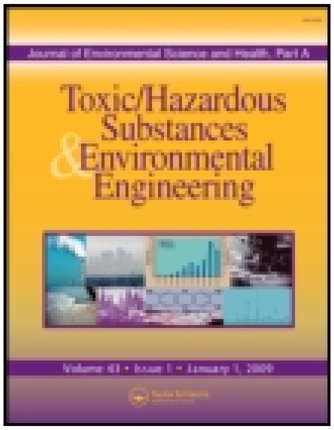

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Mirco Milani [a] & Attilio Toscano [a]

[a] Department of Agri-food and Environmental Systems Management , University of Catania , Catania , Italy

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Evapotranspiration from pilot-scale constructed wetlands planted with *Phragmites australis* in a Mediterranean environment

MIRCO MILANI and ATTILIO TOSCANO

Department of Agri-food and Environmental Systems Management, University of Catania, Catania, Italy

This article reports the results of evapotranspiration (ET) experiments carried out in Southern Italy (Sicily) in a pilot-scale constructed wetland (CW) made of a combination of vegetated (*Phragmites australis*) and unvegetated sub-surface flow beds. Domestic wastewater from a conventional wastewater treatment plant was used to fill the beds. Microclimate data was gathered from an automatic weather station close to the experimental plant. From June to November 2009 and from April to November 2010, ET values were measured as the amount of water needed to restore the initial volume in the beds after a certain period. Cumulative reference evapotranspiration (ET_0) was similar to the cumulative ET measured in the beds without vegetation (ET_{con}), while the *Phragmites* ET (ET_{phr}) was significantly higher underlining the effect of the vegetation. The plant coefficient of *P. australis* (K_p) was very high (up to 8.5 in August 2009) compared to the typical K_c for agricultural crops suggesting that the wetland environment was subjected to strong “clothesline” and “oasis” effects. According to the FAO 56 approach, K_p shows different patterns and values in relation to growth stages correlating significantly to stem density, plant height and total leaves. The mean Water Use Efficiency (WUE) value of *P. australis* was quite low, about 2.27 g L^{-1}, probably due to the unlimited water availability and the lack of the plant’s physiological adaptations to water conservation. The results provide useful and valid information for estimating ET rates in small-scale constructed wetlands since ET is a relevant issue in arid and semiarid regions. In these areas CW feasibility for wastewater treatment and reuse should also be carefully evaluated for macrophytes in relation to their WUE values.

Keywords: Constructed wetlands, crop coefficient, evapotranspiration, *Phragmites australis* (Cav.) Trin., water use efficiency, wetland hydrology.

Introduction

Evapotranspiration (ET) may be defined as the water lost to the atmosphere by evaporation from the soil and/or open water surfaces and by the transpiration of plants.[1] This factor plays a key role in constructed wetland treatment performances, particularly in the Mediterranean’s semi-arid conditions and when treated wastewater reuse is required.[2] In particular, during the spring and summer, ET significantly reduces outflow rates, causing an increase in hydraulic residence time (HRT) and concentrations of non-degradable contaminants in the effluent, such as dissolved solids and nutrients.[3] Longer HRTs mean longer times for pollutant degradation, thereby increasing treatment performance. On the other hand, higher salt concentrations in the effluent are deleterious for potential irrigation reuse, rendering the water unusable for many crops.[4,5] However, this phenomenon can have a positive effect by concentrating the pollutants dissolved in the rhizosphere and increasing reaction rates and plant uptake.[6]

Evaporative water loss is particularly evident in small-scale constructed wetlands due to “clothesline” and “oasis” effects.[7,8] High water availability coupled with the turbulent transport of sensible heat into the canopy and the removal of vapour from the canopy determine high ET rates.[9,10] These effects are the basis of zero-discharge systems, such as the Danish Willow System and the Evapotranspiration Bed.[11,12] The first is a sewage disposal solution in rural Denmark generally consisting of approximately 1.5 m deep high-density polyethylene-lined basins filled with soil and planted with willow clones (*Salix viminalis* L.).[13] The second system, used when site characteristics dictate that conventional methods of effluent disposal are inappropriate, employs a sand-bed surface planted with grasses like alfalfa, broad leaf trees and evergreens.[14] In both techniques, total flow is lost from the system by evaporation from soil and plant transpiration.

Address correspondence to Attilio Toscano, Department of Agri-food and Environmental Systems Management, University of Catania, Via S. Sofia 100, 95123 Catania, Italy; E-mail: attilio.toscano@unict.it
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Different species of trees and herbaceous plants with high transpiration, have been tested in zero-discharge systems.[15–17] Recent research by Bialowiec[18] to examine the effect of two species of willows (*Salix amygdalina* L. and *Salix viminalis* L.) and *Phragmites australis* in evapotranspirative soil-plant systems, has shown that common reed is the most suitable plant to landfill leachate evapotranspiration, because of their very high evapotranspiration rates, high biomass yield and high resistance to pollutant loads. This plant species is one of the most commonly used in constructed wetlands (CWs) for wastewater treatment.[19] However, despite its widespread use, the evapotranspiration capacity of *P. australis* in CWs, in various climatic conditions, has not been thoroughly investigated.

Some studies measuring the ET of common reed have produced results which vary from 0.2 mm d^{-1} to 57 mm d^{-1} depending on vegetation growth, climatic conditions and how ET is measured. [20,21] Fermor et al.[20] used plastic phytometers planted with common reed and sunk within a stand of reed to estimate ET, which ranged between 0.2–6.3 mm d^{-1} in a maritime climate in England. Burba et al.[22] and Peacock and Hess[23] used a Bowen ratio energy balance system (BREBS) to measure the ET of common reed at Ballards Marsh (Northcentral Nebraska, USA) and Stodmarsh NNR (Kent, UK), finding values which ranged between 0.5–6.5 and 0.5–5.0 mm d^{-1}.

Zhou and Zhou[24] used the Eddy Covariance technique to estimate the magnitude and dynamics of ET over a reed marsh in the Liaohe Delta (Northeast China) finding ET values which ranged between 0.5–5.8 mm d^{-1}. Other researchers have carried out direct ET measurements in reed bed systems of various sizes, reporting ET rates which ranged from 7.74 mm d^{-1}, at Curienne in France, to 57 mm d^{-1}, at Rabat in Morocco.[21,25]

Allen et al.[26] have shown that the cover coefficient approach produces acceptable and accurate estimates of wetland ET. It consists of estimating the crop evapotranspiration (ET_c) for a crop canopy using a reference evapotranspiration (ET_0) and a crop coefficient (K_c) integrating the effects of four characteristics (crop height, crop-soil surface albedo, canopy resistance and evaporation from the soil) which distinguishes the crop from reference grass.[1,27,28] The ET_0 can be estimated with the Penman-Monteith FAO 56 method, implemented with meteorological data, while K_c can be derived empirically based on lysimetric data and local climatic conditions.[1] K_c values are reported in the literature for most agricultural crops under several environmental conditions,[1,28,29] but there are very few studies on the crop coefficients of wetland plants.[24,30–33] Recently, Hadley et al.[34] monitored the water balance of subsurface horizontal flow CWs vegetated with *Phragmites australis* in a sub-tropical climate and found that monthly crop evapotranspiration (ratio of wetland ET to pan evaporation) ranged from 0.9 to 4.5.

The main goal of this study was to investigate evapotranspiration in a pilot-scale constructed wetland system located in Southern Italy. In particular, the 2-year study aimed at determining the ET rates, crop coefficients (K_c) and water use efficiency (WUE) index of *P. Australis*, and investigating the effects of the meteorological conditions and plant growth phase on ET and K_c.

Materials and methods

Experimental plant

The experimental plant is in San Michele di Ganzaria (latitude 37° 30′ North, longitude 14° 25′ East), a small community (5,000 inhabitants) of Eastern Sicily, at 370 m above sea level. The area has a semi-arid Mediterranean climate with medium rainfall (approximately 500 mm $year^{-1}$), mainly in the winter. The experimental pilot plant is in an open area covered with spontaneous grass (Fig. 1a) and consists of four horizontal subsurface flow CWs: two beds vegetated with *Phragmites australis* (Cav.) Trin. (common reed) and two without vegetation.[35] Each bed is 1.5 m wide, 3.0 m long and 0.8 m deep, built of concrete, partially buried, and lined with an impermeable membrane. These beds were filled to 0.6 m, with volcanic gravel (10–15 mm). A piezometer was placed at the outlet of each bed to monitor the water level (Fig. 1b). There was also an overflow hole above the gravel, connected to a graduated container, to measure any water excesses due to abundant rainfall.

In June 2004, fragments of *Phragmites australis* rhizomes were collected from a nearby river and transplanted into two beds at a density of 8 rhizomes m^{-2}. Over the two year investigation (2009 and 2010), the above-ground biomass of common reed was harvested at the beginning of May 2009 and at the end of March 2010.

The pilot-scale wetlands were filled with domestic wastewater treated by a wastewater treatment plant (WWTP), with a pre-treatment step followed by an Imhoff tank, a trickling filter and secondary settlement. No significant differences were detected in WWTP effluent quality over the two research years, with average concentration values equal to 128 (±33) mg L^{-1} for TSS, 33 (±13) mg L^{-1} for COD, and 25 (±7) mg L^{-1} for TN.

A CR510 automatic weather station (Campbell Scientific, Logan, UT) was installed close to the experimental plant to measure air temperature, wind speed and direction, rainfall, global radiation and relative humidity.

ET and K_p evaluations

Evapotranspiration data was measured from June to November 2009 and from April to November 2010. In those periods, the beds were operated as zero-discharge systems, i.e., with no outflow and topped up (with discontinuous feedings) to maintain a constant water level. Under these conditions, the amount of water lost by evapotranspiration from the vegetated (ET_{phr}) and unvegetated control (ET_{con})

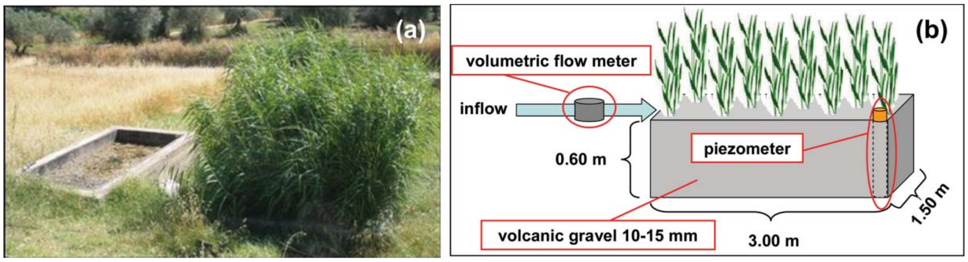

Fig. 1. Layout of experimental plant (a) and view of two beds, vegetated with *Phragmites australis* (Cav.) Trin. and without vegetation (b) (color figure available online).

beds was measured by a volumetric flow meter which provided the volume of water required to restore the initial water level in the gravel filters over a certain period. This volume was added to net rainfall being the difference between the weather station value and the overflow volume from the beds through the discharge system. ET measurements were conducted two-three times per week during the hot and dry seasons, and once a week when the temperature and water consumption were low. To obtain homogeneous and comparable data series, the ET values were cumulated and averaged over 10-day periods.

The reference ET (ET_0) was calculated by means of the standardized Penman-Monteith formula using the spreadsheet program PMday.xls,[36–38] implemented with data taken from the on-site weather station according to the method described in Borin et al.[32] The 10-day values of measured evapotranspiration (ET_{phr}) and calculated reference ET (ET_0) were used to calculate 10-day plant coefficients (K_p) by the FAO-56 crop coefficient approach, as:[1]

$$K_p = ET_{phr}/ET_0 \tag{1}$$

Bio-agronomical analyses

Bio-agronomical analyses of *P. australis* on gravel filters were carried out during the second growing season (from April to November 2010) to evaluate the main parameters such as stem diameter, total and dead leaves, plant height and stem density. So, three 0.5 m^2 sampling areas at opposite ends and in the middle of each bed were surveyed every 10 days.

P. australis samples were collected to evaluate biomass production at the end of the two growing seasons (end of November). The shoot biomass dry weight was determined by drying the plant tissue in a thermo-ventilated oven at 65°C to constant weight.

Water use efficiency (WUE)

The Water Use Efficiency (WUE) index is defined as the ratio of biomass accumulation (carbon dioxide assimilation or total crop biomass) to the water consumed (transpiration, evapotranspiration, or total water input to the system).[39] Stanhill[40] and Monteith[41] have stated that the term WUE is erroneous, as plants do lose water rather than use it as a raw material for the production of biomass. Therefore, terms such as "biomass water ratio" and "transpiration efficiency" are sometimes used instead of WUE, although this is the most well-known term.[41,42] WUE is mainly used in agriculture to compare the yield or economic return from a crop to the amount of water the crop transpires. However, if the use of biomass produced in constructed wetlands is planned, it can be a useful tool for selecting macrophytes.

Over both research years, the WUE index (g L^{-1}) was calculated as the ratio between dry biomass production (g m^{-2}) at the final harvest and the evapotranspired water (L m^{-2}).

Results

Environmental conditions

Figure 2 shows the daily values of maximum, minimum and average air temperature and mean relative humidity during the study periods 2009 and 2010. The air temperature trends over the two years were very similar with an increase from the beginning of April to the beginning of July, followed by an almost constant phase till the end of August and a tendency to decrease up to the end of November. In 2009 (April-November), the daily minimum air temperatures ranged from 1.3 to 14.8°C and the maxima from 22.1 to 44.9°C with an average seasonal value of 19.3°C. In 2010, the average seasonal daily temperature was 18.8°C, with minimum and maximum values ranging from 3.2 to 11.6°C and 24.4 to 40.6°C.

Also, the average relative humidity trends (average values of 68.8% and 67.0% during the 2009 and 2010 seasons) were similar over the two research years with the exception of April and May where the 2009 values were higher than those of 2010 due to differing rainfall. Total rainfall from April to May was 163.2 mm in 2009, yet in 2010 it was only 41.6 mm (Fig. 3). Over both years, most rainfall fell from September to November with none in July and August and similar total values (255.3 mm in 2009 and 278.4 mm in 2010).

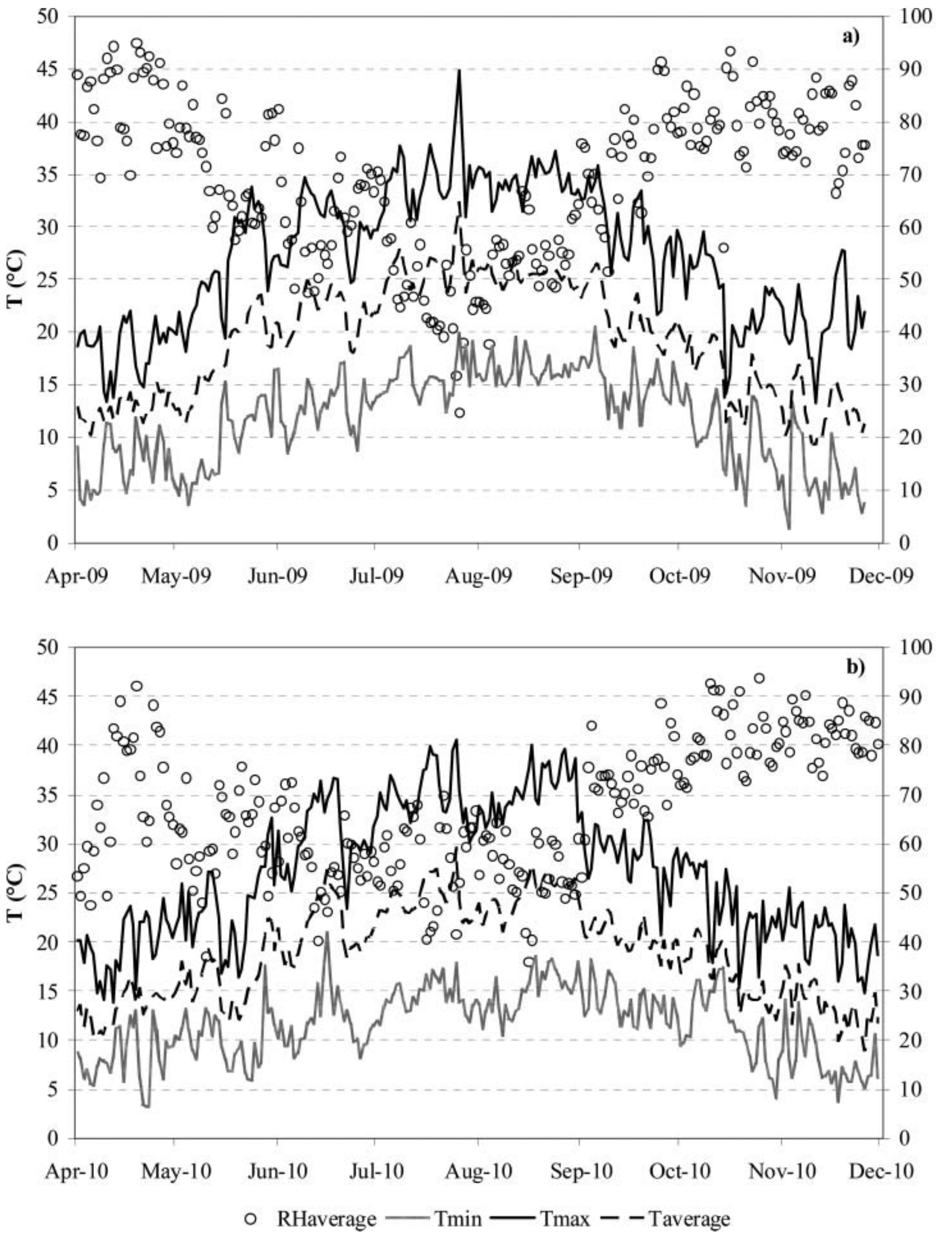

Fig. 2. Trends of daily minimum, maximum and average air temperature (T) and daily average relative humidity (RH) during 2009 (a) and 2010 (b) observation periods.

During the first observation period (2009), the seasonal average wind speed and seasonal total solar radiation were higher than those in the second (2010), with values of 1.6 ms^{-1} and 4,833 MJ m^{-2} d^{-1} and 0.8 ms^{-1} and 4,678 MJ m^{-2} d^{-1}.

Evapotranspiration rates

From April to November, daily ET$_0$ values during 2009 and 2010 were comparable from the beginning of April to mid-May and from about mid-September to the end of November; from mid-May to mid-September the daily 2009 ET$_0$ values were generally higher than in 2010 (Fig. 4). The average daily ET$_0$ was 3.9 and 3.5 mm d^{-1} in the first and second years, respectively. In 2009, the lowest daily ET$_0$ was 0.39 mm on October 16th and the highest was 7.83 mm on July 8th. In 2010, ET$_0$ values ranged from 0.12 mm d^{-1} (October 19th) to 6.13 mm d^{-1} (July 6th).

The 10-day average ET$_0$ and 10-day average ET$_{con}$ trends were very similar in both investigation periods (Fig. 5). 10-day average ET$_{con}$ values for the first growing season (June–November 2009) were slightly higher than those for the second (April - November 2010) except for June, the second 10 days of July and the third 10 days of November. During 2009, the 10-day average ET$_{con}$ trend had two peaks,

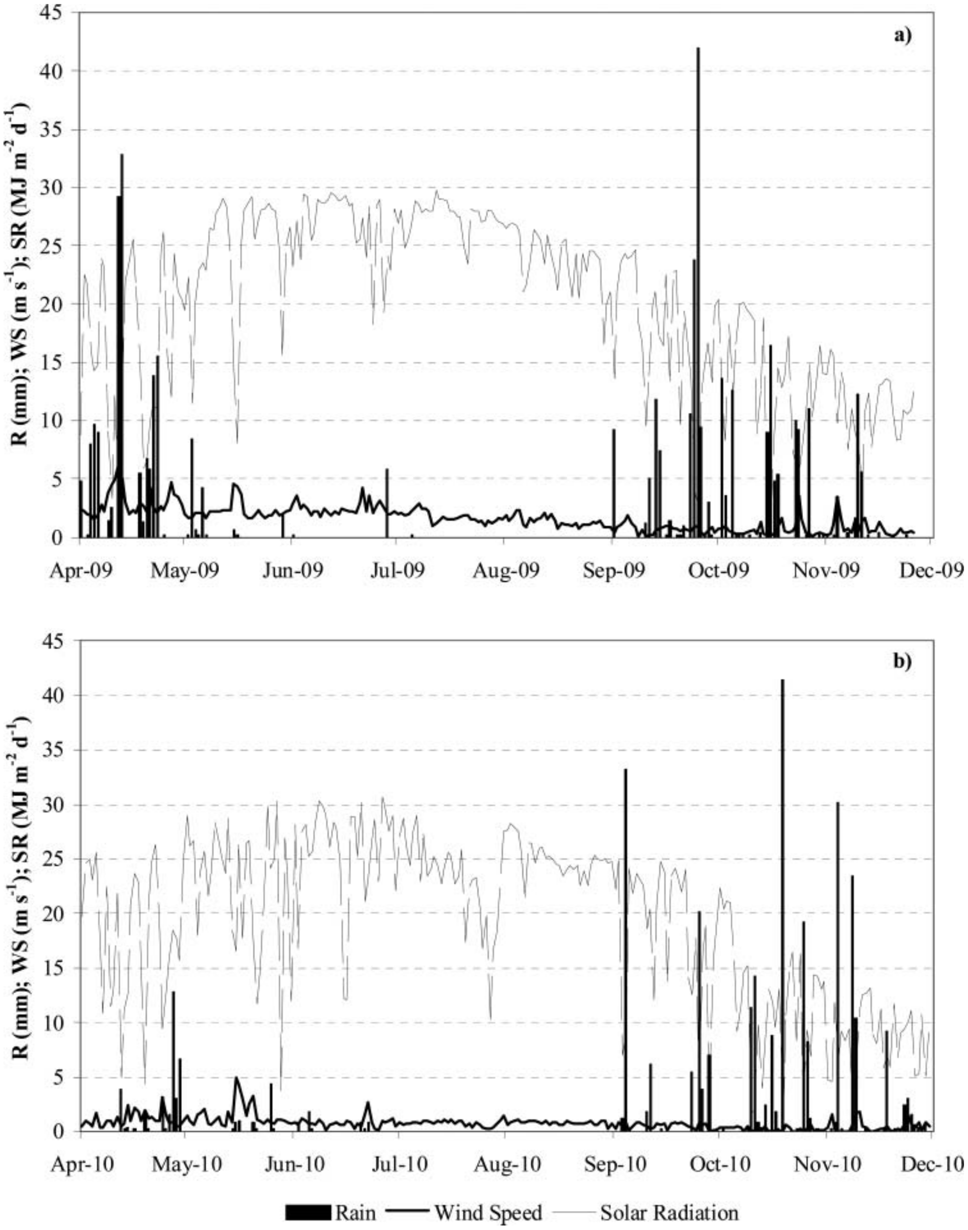

Fig. 3. Trends of daily average wind speed (WS), daily average solar radiation (SR) and daily rain (R) during 2009 (a) and 2010 (b) observation periods.

in the first 10 days of July (6.3 mm d^{-1}) and in the first 10 days of August (6.6 mm d^{-1}).

Thereafter, 10-day ET_{con} declined steadily until 0.5 mm d^{-1} in the last decade of November. In the overall 2009 period, cumulative ET_{con} was 640 mm (average daily value of 3.4 mm), which is very similar to cumulative ET_0, 750 mm (average daily value of 4.0 mm) (Fig. 6). In 2010, 10-day average ET_{con} increased from the first 10 days of April (1.8 mm d^{-1}) to the second 10 days of June (5.8 mm d^{-1}), followed by an almost constant phase till the middle of July (average value of 5.1 mm d^{-1}) and a tendency to decrease up to the end of the monitored period (minima value of 0.5 mm d^{-1} in the second decade of October and November). From April to November 2010, cumulative ET_{con} was 761 mm (average daily value of 3.1 mm) and cumulative ET_0 was 847 mm (average daily value of 3.5 mm).

Over the whole period due to the effect of vegetation, ET_{phr} showed much higher 10-day average values compared with ET_0 and ET_{con}. In both the study periods, 10-day average ET_{phr} trends increased with maximums in the first (50.4 mm d^{-1}, in 2009) and last (37.6 mm d^{-1}, in 2010) 10 days of August, followed by a decrease to the last 10 days of November when there were minimum values of 2.7 mm d^{-1} (2009) and 1.5 mm d^{-1} (2010). During the first growing season, the mean 10-day average ET_{phr} (24.7 mm d^{-1}) was higher than the second (16.7 mm d^{-1}). Overall, cumulative

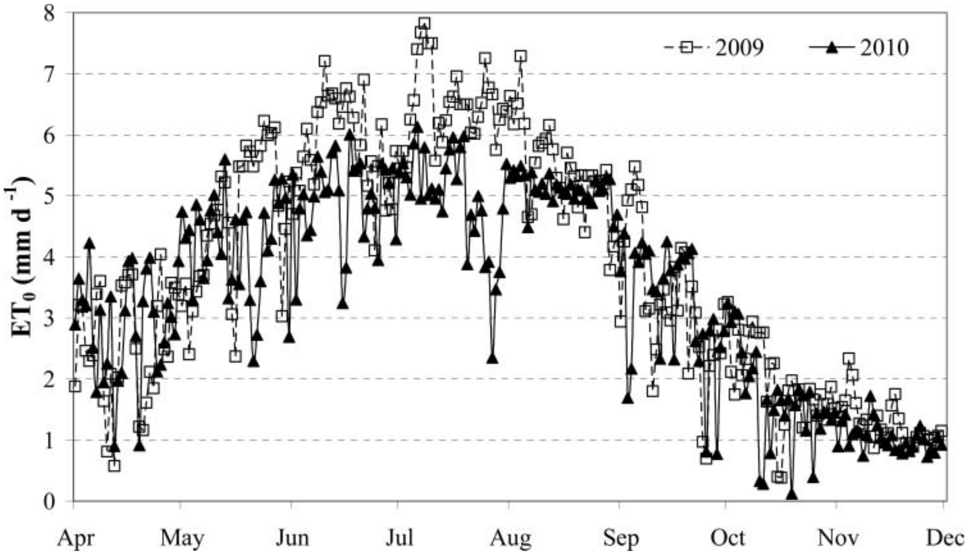

Fig. 4. ET_0 daily rates during 2009 and 2010 observation periods.

ET_{phr} in the 2009 growing season was 4,438 mm (over 6 months), while in 2010 it was 4,019 mm (over 8 months) (Fig. 6).

The 10-day average ET_{phr} versus 10-day average ET_0 showed similar trends in both years with correlation coefficients of 0.534 (2009) and 0.630 (2010) (Fig. 7). This is in agreement with Papaevangelou et al. [33] that highlighted a significant correlation (Pearson correlation coefficient = 0.74) between daily measured ET and mean daily pan evaporation for similar conditions (i.e., wetland size, vegetation, latitude, measurement method). On the contrary, the detected R^2 coefficients indicated a much greater degree of correlation compared to that observed by Headley et al.[34] (R^2 = 0.125) between mean monthly wetland ET vegetated with *P. australis* and class-A pan evaporation in a sub-tropical climate.

Plant coefficients

The plant coefficient time patterns of *P. australis* (K_p) in both research years, were similar to the classic trapezium shape of K_c for agricultural crops (Fig. 8). In particular, 10-day K_p increased continuously from 2.3 in mid-June 2009 to 8.5 at the start of August 2009 and from 0.9 at the beginning of April 2010 to 7.4 at the start of July 2010. Thereafter, in both years, the values remained almost constant until the

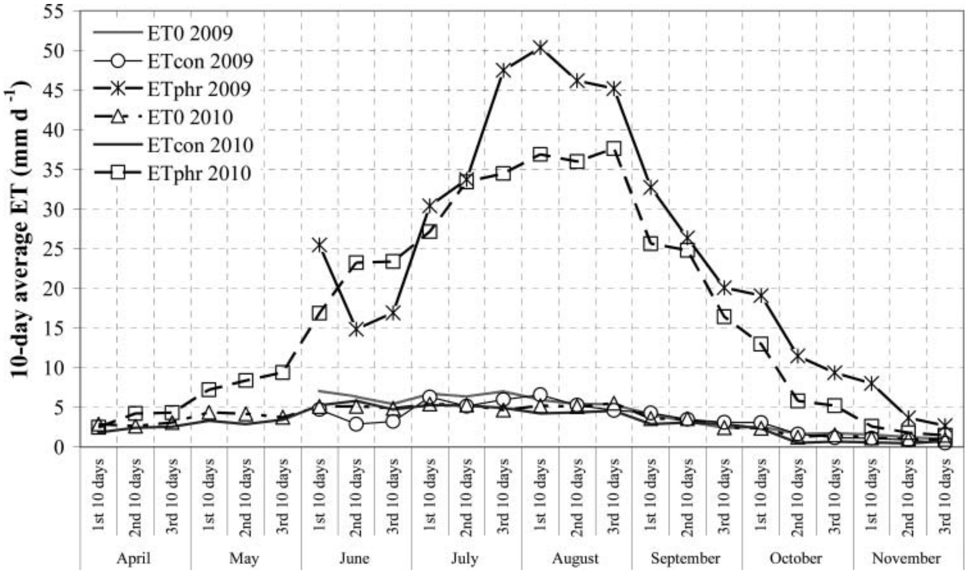

Fig. 5. 10-day average ET_0, ET_{con} and ET_{phr} during 2009 and 2010 observation periods.

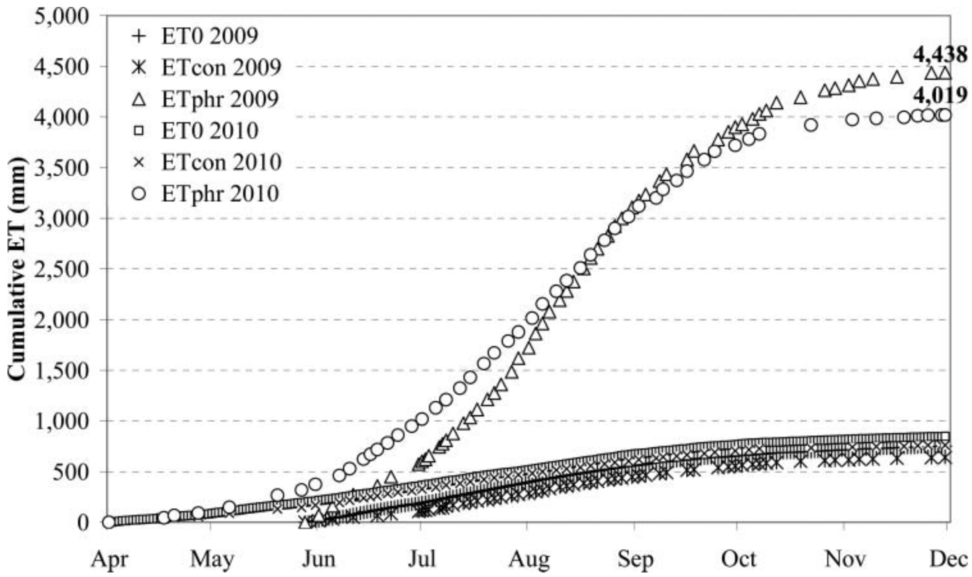

Fig. 6. Cumulative ET_0, ET_{con} and ET_{phr} during 2009 and 2010 observation periods.

third 10 days of September, then decreased to 2.6 (2009) and 1.5 (2010) at the end of November. Average seasonal K_p values for 2009 and 2010 were 5.9 and 4.3.

Regression analysis of 10-day K_p values in 2009 and 2010 indicates similar evapotranspiration during the different growing seasons (Fig. 9) with a majority of higher values in 2009.

Effect of plant growth on K_p

In 2010, the average common reed height was 0.27 m in the first 10 days of April (i.e., only 10 days after the above-ground biomass harvest), then increased to 1.90 m by mid-September and thereafter decreased to 1.78 m at the end of the observation period (Fig. 10a). The height of *P. australis* increased at an average rate of 0.017 m d^{-1} from April to June and 0.004 m d^{-1} from July to August, then remaining relatively constant until the end of the growing season. Over the same period, stem density gradually increased (Fig. 10a), remaining constant after the 2,178 stems m^{-2} peak at the end of September. The highest stem emission rate was in August with an average value of about 9 stems m^{-2} d^{-1}.

Furthermore, the base stem diameter stopped growing about a month earlier than stem height. In particular, the base stem diameter increased up to mid-August, reaching

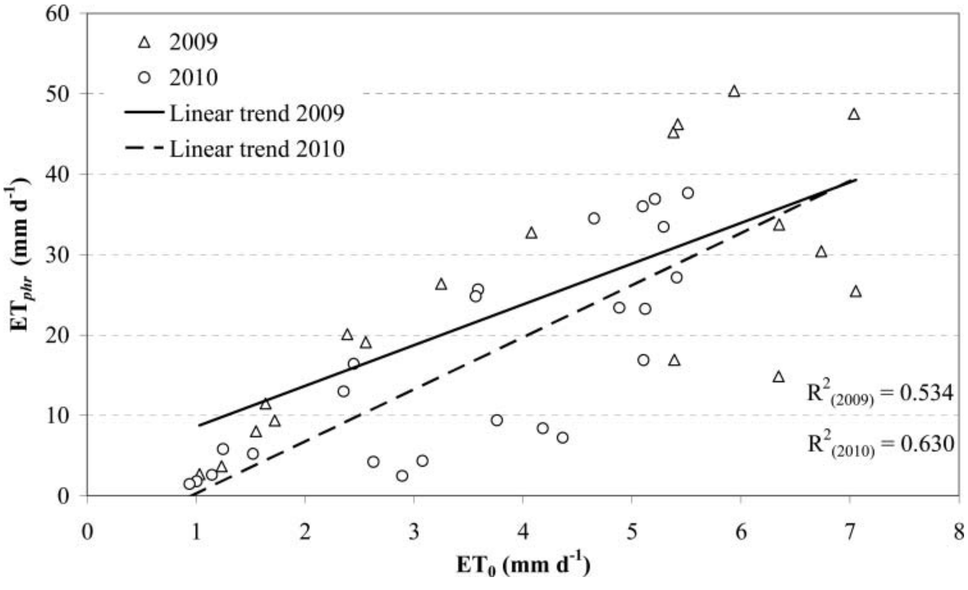

Fig. 7. Relationship between ET_{phr} and ET_0 in 2009 and 2010 observation periods.

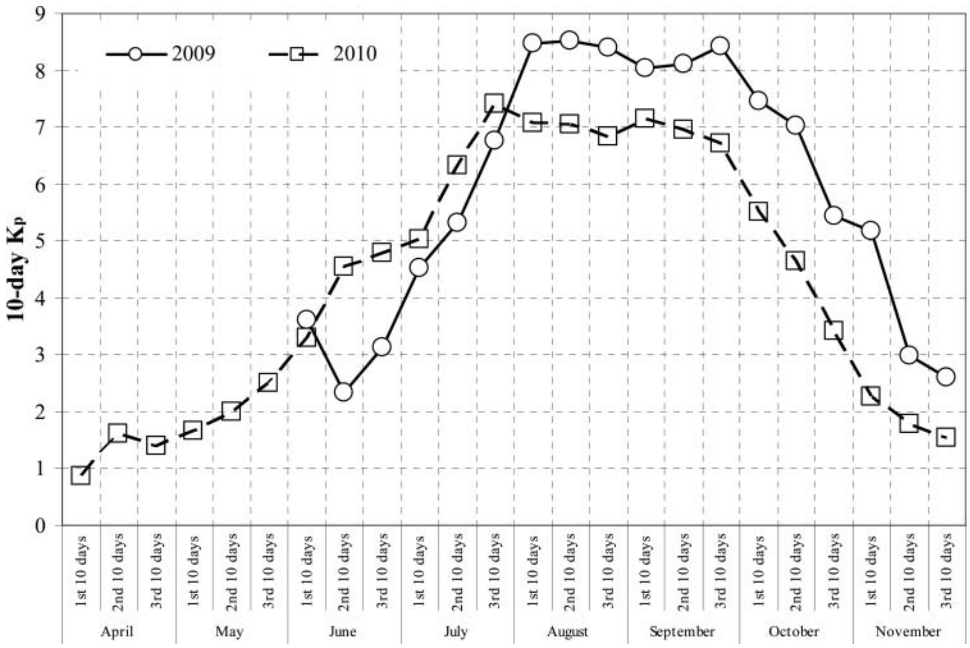

Fig. 8. 10-day K_p during 2009 and 2010 observation periods.

a maximum of 0.90 cm. From September it decreased at an average rate of 0.01 cm every 10 days (Fig. 10b).

The time pattern of the average total number of leaves per plant was comparable to that of plant height, highlighting a positive correlation between the stem height rate and the development of new leaves. From April to August 2010, the average number of leaves increased at a rate of about 3 leaves per plant per month. The senescence of leaves started in mid-June and increased at a rate of about 1 dead leaf every 10 days until the first 10 days of November, corresponding to the full senescence of the plant (Fig. 10b).

The linear trends of 10-day K_p versus stem density, plant height and total leaves, respectively, were calculated for *P. australis* from April to September 2010 (Figs. 11a, 11b, and 11c). The trend lines showed that 10-day K_p significantly correlated with all the phenological parameters with correlation factors (R^2) ranging from 0.927 (plant height) to 0.950 (total leaves).

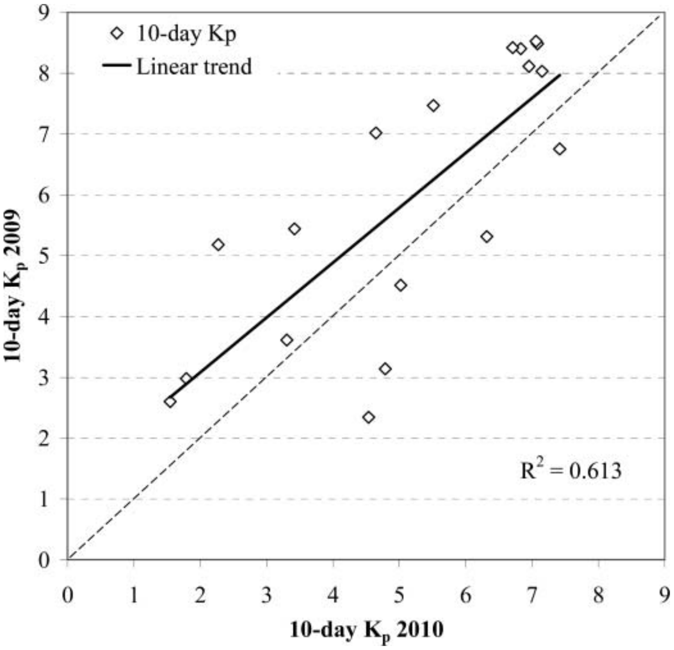

Fig. 9. Relationship between 2009 and 2010 10-day K_p.

Biomass production and water use efficiency

The total aerial dry matter produced in the first investigation period was greater than in the second (Table 1). In particular, in November 2009 5% more dry biomass (9,860 g m^{-2}) was harvested than that in November 2010 (9,340 g m^{-2}). Note that the 2009 result was obtained with a 185-day reed cycle growth whereas the 2010 result was in 244 days.

There were no significant differences between *P. australis* WUE values for the two years (Table 1), having a mean value of 2.27 g L^{-1}. As total aerial biomass increased there was an increase in water loss through evapotranspiration and viceversa.

Discussion

The results highlighted that, under semi-arid Mediterranean conditions, the ET rates for small-scale constructed wetlands are very significant (up to 8 times the reference

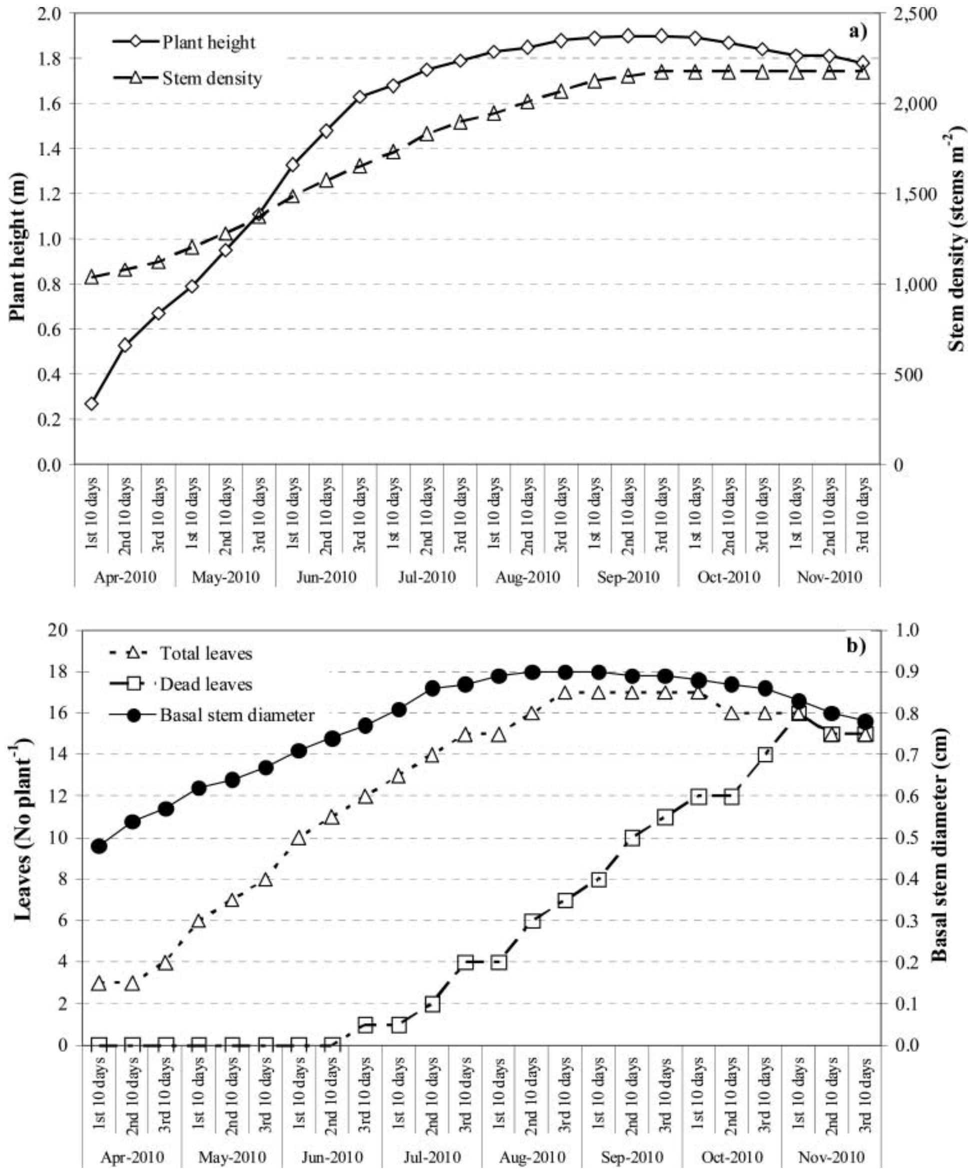

Fig. 10. Trends of plant height and stem density (a) and number of leaves (total and dead) and stem diameter (b) of *P. australis* during 2010 growing season.

ET) and could affect treated wastewater quantity and quality. This implies that the prediction models and design equations could probably be improved, given the effects of ET on wetland water balance in the warm season.[43] Although these very high ET rates and K_p values were detected only over a relatively short period (about 30–45 days, between late July and early August), the amount of water lost could be higher than what is usually considered negligible (about 10%) by the most common hydraulic and hydrological models.

The results in this article confirm that the evapotranspiration is strongly influenced by climatic conditions. The higher average evapotranspiration rates in early June to mid-August 2009 (32.8 mm d^{-1}) compared to the same period in 2010 (28.4 mm d^{-1}) was probably due to the higher wind speeds and solar radiation associated with lower relative humidities, generating the slightly different ET_0 values of 6.0 mm d^{-1} in 2009 and 5.0 mm d^{-1} in 2010.

The variation in microclimate data for these two years also produced different 10-day K_p values, which were on average higher in 2009 (5.9) than in 2010 (4.3). However, these 10-day K_p values do significantly correlate due to their similar trends over the two years. The K_p time pattern produced a very similar seasonal curve to the classical trapezium shape of K_c for agricultural crops which recognises three main different crop development and growth stages: the crop development stage, the mid-season stage and the late season stage.[1]

The data collected in the second research year confirmed a variation in the *P. australis'* morphological characteristics

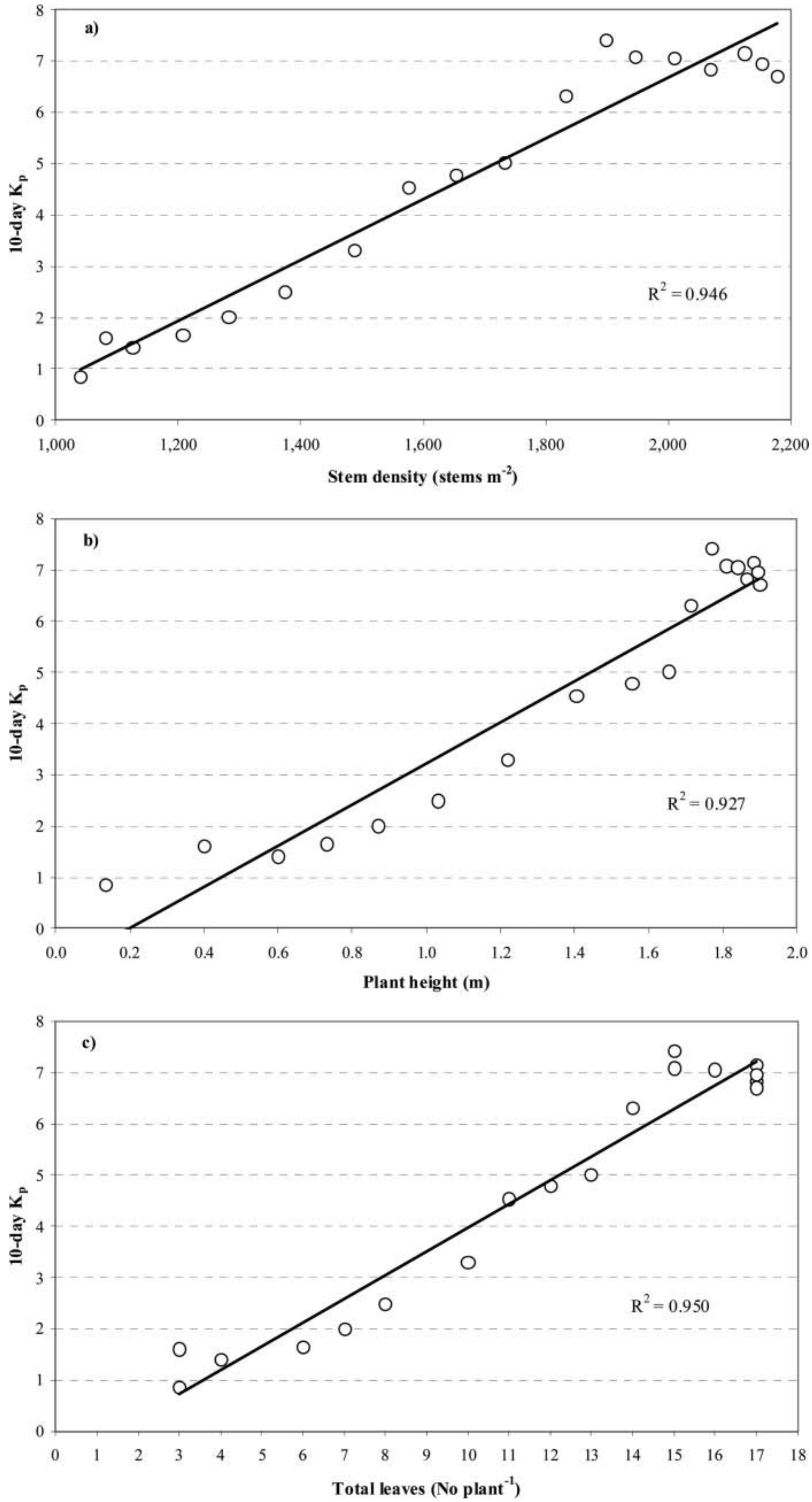

Fig. 11. Relationship between 10-day K_p and stem density (a), plant height (b) and total leaves per plant (c) of *P. australis* from April to September 2010.

Table 1. Dry biomass production and Water Use Efficiency (WUE) of *P. australis* during 2009 and 2010 observation periods.

Period	*Productivity of dry biomass (g m^{-2})*	*WUE (g L^{-1})*
June 2009–November 2009	9,860	2.22
April 2010–November 2010	9,340	2.32

at different sections of the K_c curve, as reported in the FAO-56 method. During the crop development stage (increasing K_p), between early April and mid-July, *P. australis* showed a high plant growth rate characterized by a high production of new culms and leaves and by an increase in plant height.

From mid-July to late September, i.e., in the mid-season (K_p almost constant), the growth rate of different morphological characteristics dropped until stable and the number of dead leaves increased continuously. Finally, in the late season stage (from late September to late November), the common reed showed fast senescence with plant death in just one month. Figure 10b shows the number of dead leaves equals the number of total leaves already from the beginning of November.

The strong relationship between the variation in morphological characteristics and K_p is also confirmed by high correlation coefficients ($R^2 > 0.9$). The highest correlation values were obtained between K_p, total leaves and stem density which agrees with the literature, indicating inter-dependency between the crop coefficient and LAI (significantly correlating to plant density and number of leaves).[1,33]

The higher values of 10-day K_p detected in June and July 2010 compared to the same period in 2009, are probably due to the variation in harvesting period. In 2010, the aerial biomass was harvested in late March, i.e., when the vegetation was still growing, and therefore, not fully developed. Whereas in 2009, the aerial biomass was harvested at the end of May (at the end of spring), i.e., when its morphological characteristics were already close to their maximum values. After July, the more favourable 2009 weather conditions combined with unlimited water availability, produced more biomass compared to the 2010 period, as shown in Table 1.

This greater biomass production contributed to an increase in *P. australis* evapotranspiration which, between August to November 2009, produced 10-day K_p values of about one unit higher than the same period in 2010.

These K_p values were much higher than the typical K_c for agricultural crops due to the high evapotranspiration rates. Nonetheless, these results agree with literature values for wetland systems of comparable size in areas with similar climatic characteristics,[21,32] while being higher than estimated ET rates for natural wetlands with larger areas.[20,24,44]

These differences are probably due to the clothesline effect, where vegetation height is greater than its surroundings, and due to the oasis effect, where vegetation has higher soil water availability than its surroundings. In these conditions, warm dry air can contribute to heat input and water loss well in excess of the loss driven by radiation alone. [10]

Nevertheless, the results of this study provide a useful tool with which to evaluate evapotranspiration rates in many sub-surface constructed wetlands used for the decentralized treatment of sewage from single dwellings or small communities, as they tend to be relatively small and then to present advective conditions.

The mean WUE value of *P. australis*, about 2.27 g L^{-1}, is in line with the average values of crop water use efficiency for most common agricultural crops. [45] In particular, among the crop species cultivated in the Mediterranean region, WUE values range between 0.11 g L^{-1} for wheat in Morocco and 4.20 g L^{-1} for sorghum in Italy. [46,47] This big difference is due to high environmental impact and genetic characteristics (C_3 and C_4 plants). Under optimum temperature conditions, the WUE of C_4 plants is about twice as high as for C_3 plants.[40]

The WUE value of *P. australis* was low, as expected, since it is a perennial C_3 grass that does not have physiological adaptations for water conservation, and water availability was unlimited.[48]

These factors led to extremely high water consumption and a reduction in WUE, despite high biomass production (average about 9,600 g m^{-2}). This value was higher than that reported by Mueller et al.,[49] who were using the common reed cultivated in a lysimeter, located in Germany (temperate climate) where dry biomass production was about 1,434 g m^{-2} with a WUE of 1.3 g L^{-1}. This comparison would seem to prove Mueller et al.[49] thesis: for the same species as biomass increases water use efficiency improves.

In four subsurface horizontal flow beds in a sub-tropical climate, Headley et al.[34] found levels of WUE for *P. australis* (mean annual value was 1.3 g L^{-1}) comparable with those in this study. The literature does not report any other data on the WUE for *P. australis* or for any other macrophytes used in CWs. However, familiarity with turning water and CO_2 into biomass would certainly help in choosing wetland plant species. For example, macrophytes with low WUE values and low evapotranspiration rates could be planted in CWs for wastewater reuse, whereas for dry aerial biomass utilization, plant species with high WUE values should be chosen. [50]

Conclusions

During the monitoring periods, *P. australis* showed high evapotranspiration rates and high dry biomass productions. The small experimental plant may have led to over-estimating *P. australis* evapotranspiration, due to the clothesline and oasis effects. However, the results are useful for estimating ET in subsurface flow (SSF) CWs which serve individual homes. Furthermore, it should be noted that even real scale SSF-CWs, which have an area ranging from a few dozen up to several hundred square meters, are affected by advective energy exchanges. So even if the experimental results are not indiscriminately extrapolated to full-scale systems, they represent a reliable guide for estimating the ET of *P. australis*, calculating K_p by the FAO-56 approach.

Finally, the WUE index calculated in this study could represent a useful tool for selecting the macrophytes for constructed wetlands. However, improved research on these themes is required due to the lack of data on efficient water use by wetland plants.

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