Rev. Bras. Agrometeorologia, v. 14, n.3, p.336-346, 2006
Recebido para publicação em 28/06/06. Aprovado em 07/12/06.

ISSN 0104-1347

The ratio of water hyacinth evapotranspiration to open-water evaporation as influenced by weather conditions, leaf area and aerodynamic effects

Relação entre a evapotranspiração do aguapé e a evaporação da superfície de água livre influenciada pelas condições meteorológicas, área foliar e efeitos aerodinâmicos

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Abstract: Water hyacinth is a well known aquatic plant which causes several problems when in massive infestations, like the increase of water loss due its high evapotranspiration rate. Aiming to understand how water hyacinth evapotranspiration is influenced by weather conditions, leaf area, and aerodynamic effects, its relationship with open-water evaporation from a class A pan was studied at Piracicaba, State of São Paulo, Brazil (22°42'S; 47°30'W; 576 m a.m.s.l.), from October 1999 to October 2000. Water hyacinth evapotranspiration was measured from three class A pans populated with plants enough to cover all pan surface. Leaf area index was obtained by the relation between leaf area and pan area. Weather variables were measured with an automatic station installed close to the pans. Our results showed that monthly average ratio of water hyacinth evapotranspiration (ETw) to open-water evaporation (E) ranged from 1.89 ± 0.55 to 4.05 ± 1.02 along the year, which was significantly correlated with leaf area (r = 0.84). ETw was most influenced by net radiation (r = 0.50), air temperature (r = 0.60) and leaf area (r = 0.51). In average, water hyacinth increased the water loss by 150%, showing the importance of an effective control program when it infests reservoirs. These results are similar to those obtained in other climatic conditions around the world. However, the influence of aerodynamic effects as advection of energy ("oasis" effect) and periphery overexposure of the plants ("clothesline" and "bouquet" effects) on ETw/E were observed, which recommends caution about the adoption of ETw/E values for operational purposes and shows that more studies are required for Brazilian conditions.

Key words: *Eichhornia crassipes*; water loss; "oasis effect"; "clothesline effect"; "bouquet effect"

Resumo: O aguapé é uma planta aquática muito conhecida pelos vários problemas que ela causa quando em infestações massivas, como o aumento da perda de água de reservatórios devido à sua alta taxa de evapotranspiração. Com o objetivo de entender como a evapotranspiração do aguapé é influenciada pelas condições climáticas, pela sua área foliar e pelos efeitos aerodinâmicos, a sua relação com a evaporação do tanque classe A foi estudada em Piracicaba, SP, Brasil (22°42'S; 47°30'W; 576 m), de outubro de 1999 a outubro de 2000. A evapotranspiração do aguapé foi medida em três tanques classe A povoados com plantas suficientes para cobrir toda a área superficial dos tanques. A área foliar do aguapé foi determinada semanalmente e o índice de área foliar foi obtido pela relação entre a área foliar e a área do tanque. As variáveis meteorológicas foram medidas por uma estação automática instalada ao lado dos tanques. Os resultados mostraram que a relação média mensal entre a evapotranspiração do aguapé (ETw) e a evaporação do tanque classe A (E) variou de 1,89 ± 0,55 a 4,05 ± 1,02 ao longo do ano, o que esteve significativamente correlacionado com a área foliar (r = 0,84). As variáveis que mais influenciaram a ETw foram o saldo de radiação (r = 0,50), a temperatura do ar (r = 0,60) e a área foliar (r = 0,51). Em média, a presença do aguapé aumentou em 150% a perda de água para a atmosfera, mostrando a importância de programas efetivos de controle dessa invasora em reservatórios infestados por ela. Os resultados deste estudo são similares aos obtidos em outras condições climáticas. Entretanto, foi observado que efeitos aerodinâmicos, tais como a advecção de energia (efeito "oásis") e a superexposição periférica (efeitos "varal" e "bouquet") tiveram influência sobre ETw/E. Isso recomenda atenção com relação à adoção dos valores de ETw/E para fins operacionais e indica que mais estudos são necessários para as condições brasileiras.

Palavras-chave: *Eichhornia crassipes*; perda de água; efeito "oásis"; efeito "varal"; efeito "bouquet"

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Rev. Bras. Agrometeorologia, v. 14, n.3, p.336-346, 2006

Introduction

The water hyacinth (*Eichhornia crassipes* (Mart.) Solms) is a floating aquatic weed from tropical and subtropical regions (DEBUSK et al., 1983). This species has spread from tropical South America to more than fifty countries around the world (WOLVERTON & MCDONALD, 1979). Today, the water hyacinth is a real nuisance in countries such as Argentina, Australia, Bangladesh, Brazil, China, Egypt, India, Indonesia, New Zealand, Nicaragua, Pakistan, Philippines, Puerto Rico, South Africa, Sudan, Surinam, Thailand, United States of America, and Zaire (WEERT & KARMELING, 1974; BENTON et al., 1978; WOLVERTON & MCDONALD, 1979, DEBUSK et al., 1983; SNYDER & BOYD, 1987; SINGH & GILL, 1996).

Water hyacinth is well known by its high propagation capacity which is faster than other aquatic plants. Under favorable conditions, especially in polluted water, 10 plants can multiply to 600,000 in eight months (WOLVERTON & MCDONALD, 1979). BATANOUNY & EL-FIKY (1975), in Egypt, observed that 450 cm^2 of water hyacinth increased to 1,082 m^2 after fifty days and after two hundred days the water hyacinth plants covered an area of almost fifteen hectares.

Massive infestations can cause the following problems: restriction to boat traffic and to commercial fishing, reduction of yield of rice paddies, and obstruction of drainage canals. Another serious problem is the capacity of the water hyacinth to increase water loss due its high evapotranspiration rate. According to BENTON et al. (1978), transpiration per surface unit area from mature water hyacinth substantially exceeds open-water evaporation. This is due to the stomatal density of its leaves (about 120 per mm^2) and the size of the open stomatal aperture which is over four times the area of most other plants, which allows this aquatic plant to have an exceptional rapid diffusion of gases (BENTON, 1979). The increase in water loss promoted by water hyacinth can have drastic consequences to food production, especially in arid and semi-arid regions where irrigation is needed to obtain high yield levels, and to hydroelectric power production.

Several authors (PENFOUND & EARLE, 1948; TIMMER & WELDON, 1967; ROGERS & DAVIS, 1972; DUNIGAN, 1973; BREZNY et al., 1973; WEERT & KARMELING, 1974; BENTON et al., 1978; DEBUSK et al., 1983; SNYDER & BOYD, 1987; RAO, 1988; SINGH & GILL, 1996; HERBST & KAPPEN, 1998; PAULIUKONIS & SNYDER, 2001) have shown that most aquatic plants have higher water consumption when compared to open-water evaporation. Table 1 presents a summary of the main results of the water hyacinth evapotranspiration and open-water evaporation relationship (ETw/E) around the world, with values ranging from 0.87 to 12.

Values of ETw/E have been obtained from different area/volume containers what could influence the evapotranspiration process, as well as weather conditions and leaf area, as observed by ANDERSON & IDSO (1987) and discussed by ALLEN et al. (1997). However, other studies showed similar ETw/E values obtained with containers of different sizes, as reported by DEBUSK et al. (1983) and SNYDER & BOYD (1987) (Table 1), which could be related to other factors like water hyacinth leaf area.

Other questions arose from the studies about water hyacinth evapotranspiration and open-water evaporation ratio are: the place where the container is installed and the plant height. The first is related to the "oasis effect", term used to describe the advection of energy due to horizontal differences in surface humidity across an area, and the second is related to the "clothesline effect", term used to describe the advection of energy due changes in the geometry of an evaporating surface, and to the "bouquet effect", which is related to the growth of the leaves over the container's limits. These effects could result in ETw/E ratios very high (ANDERSEN & IDSO, 1987; ALLEN et al., 1997), not representing a real condition of a lake or reservoir.

For the Brazilian tropical climatic conditions, water hyacinth evapotranspiration and its relationship with open-water evaporation are unknown, despite its adverse impact on several economic activities. Therefore, the present study was conducted to evaluate the seasonal values of ETw/E and the effect of weather conditions and water hyacinth leaf area on ETw in a tropical climate of the State of São Paulo, Brazil. The influence of "clothesline", "oasis" and "bouquet" effects on ETw and on ETw/E were also investigated.

Table 1. Ratios of reported water hyacinth evapotranspiration to open-water evaporation (ETw/E). Adapted from ALLEN et al. (1997).

Reference	ETw/E	Container Size(area or volume)	Location/Country
Penfound and Earle (1948)	3.20	0.20 m^2	Louisiana, USA
Timmer and Weldon (1967)	3.70	2.50 m^2	Florida, USA
Rogers and Davis (1972)	5.30	2 L	Alabama, USA
Dunigan (1973)	2.60	4 L	Louisiana, USA
Brezny et al. (1973)	1.26	0.36 m^2	Rajasthan, India
Weert and Karmeling (1974)	1.48	1.17 m^2	Paramaribo, Surinam
Weert and Karmeling (1974)	1.44 – 1.79	3.14 m^2	Paramaribo, Surinam
Benton et al. (1978)	3.20	*	Texas, USA
DeBusk et al. (1983)	1.70	0.50 m^2	Florida, USA
Snyder and Boyd (1987)	1.75	5.76 m^2	Alabama, USA
Anderson and Idso (1987)	12.00	0.12 m^2	Arizona, USA
Anderson and Idso (1987)	0.87	4.15 m^2	Arizona, USA
Lallana et al. (1987)	2.67	100 L	Entre Rios, Argentina
Rao (1988)	1.44	1.00 m^2	Kottamparamba, India
Singh and Gill (1996)	1.42 – 2.66	2.00 m^2	Ludhiana, India

* Estimates for lakes and rivers in Texas, USA.

Materials and Methods

The experimental site

This study was conducted in Piracicaba, São Paulo State, Brazil (22°42'S; 47°30'W; 576 m a.s.l.). The climate is classified as tropical, with monthly mean temperature ranging from 17 to 25°C, and 1,257 mm of rainfall per year, being 977 mm from October to March.

Open-water evaporation (E) and water hyacinth evapotranspiration (ETw) measurements

The experiment was carried out at the experimental area of the Department of Exact Sciences, close to an automatic weather station, where six class A pans (1.15 m^2 surface area) were installed over mowed turfgrass - three to measure E and three to measure ETw. All pans had an evaporation gauge (Novalynx Systems 255-100) for automatic measurements of the water level. Water levels in the pans were maintained so that they were always between 5 and 10 cm below the edge walls.

The water hyacinth (*Eichhornia crassipes* (Mart) Solms) plants were placed in three class A pans at the beginning of October 1999, covering all surface area of each pan. Nutrients (NPK and micronutrients) were applied to each pan every fifteen days when the water was replaced.

Daily E and ETw were measured from October 1999 to October 2000. Adjustments were made for days with rainfall, when the amount of rain was deducted. Water used for plant growth was not considered since ETw was measured in a daily time-scale. E and ETw data were not considered in days of intense rainfall, leaf area measurement or cleaning and replacement of water in the pans.

Weather data

Weather data: air temperature (T); relative humidity (RH); wind speed (*u*); rainfall (RF); incoming solar radiation (SR); and net radiation (Rn) were measured with an automatic weather station (Campbell Sci.), installed close to the pans. T and RH were measured using a HMP35C-U probe

(Vaisala), *u* with a 014A cup anemometer (Met One), RF with a TE525 tipping bucket raingage (Texas Electronics), SR with a LI200 pyranometer (LiCor) and Rn with a Q*7.1 net radiometer (REBS). All sensors were connected to a datalogger (model CR10, Campbell Sci.) programmed to make measurements every second and to store averages/totals every 15 minutes.

Plant measurements

In order to evaluate the effect of plant size on the ETw and on its relationship with E, leaf area and plant height were measured every week. The area of a single leaf (Al, in cm^2) was found to be related to its width (w), as expressed by eq. 1:

$$Al = 0.5769w^{1.9879} \quad (R^2 = 0.97) \qquad (1)$$

The total leaf area (LA) of each pan was obtained by the sum of the area of each leaf after measuring width of all leaves. Leaf area index (LAI) was determined dividing the total leaf area by 1.15 m^2 (pan surface area). The average leaf diffusive resistance (rs) was calculated from measurements of single leaves (five per pan) at different positions in the canopy with a steady-state diffusion null-balance porometer (LI-1600, LiCor) during daytime for six days.

Data Analysis

Mean daily ETw/E was determined and used to calculate monthly, seasonal and annual averages and standard deviations. Statistical correlation analysis was used to determine the relationship between ETw (mm day^{-1}) and the following weather variables: average air temperature (T); deficit of vapor pressure (D); average wind speed at 2m (*u*); net radiation (Rn); and class A evaporation (E). This analysis was also conducted to determine the relationship between ETw and leaf area.

To evaluate the influence of advection of energy ("oasis" effect) and periphery overexposure of the plants ("clothesline" and "bouquet" effects) on ETw and ETw/E, ETw per leaf area unit (ETw', mm m^{-2} day^{-1}) was determined and compared to Rn converted to mm (Rn'= Rn / 2.45 MJ kg^{-1}). Reference evapotranspiration in mm day^{-1} (ETo) and in mm m^{-2} day^{-1} (ETo') were also determined by Penman-Monteith method (ALLEN et al., 1998) and correlated with ETw' and Rn'. ETw' and ETo' were determined considering the leaf area of water hyacinth and reference crop, respectively. Such analysis was done considering two periods: one preceded by rainfall during the previous five days to nullify the "oasis" effect, and other preceded by at least five days without rainfall, during dry season, to emphasize this effect.

Results and Discussion

Weather conditions during the experiment

The weather conditions (Table 2) in Piracicaba during the experiment were very close to the normal. The average incoming solar radiation ranged from 12.4 $MJm^{-2}day^{-1}$ in June to 22.1 MJ m^{-2} day^{-1} in December, with daily values reaching up to 30 MJ m^{-2} day^{-1} during the summer days. The average air temperature ranged from 16.0°C in July to 23.7°C in December, while average daily relative humidity remained between 73% and 88%. Total rainfall during the experimental period was 1,196 mm, distributed in 135 days, being 64% from December to March, characterizing two distinct periods: one wet during four months and another very dry during nine months (Figure 1). The wind speed was very low, varying from 1.1 to 2.3 m s^{-1} in average. These weather conditions resulted in a reference evapotranspiration ranging from 82 mm $month^{-1}$ in July to 139 mm $month^{-1}$ in December, corresponding to 2.7 and 4.6 mm day^{-1}, respectively.

Evaporation (E) and evapotranspiration (ETw) rates

The evaporation (E) and water hyacinth evapotranspiration (ETw) values are presented in the Figure 2. There was an overall significant difference in daily E and ETw values over the course of the study. The open-water evaporation for the corresponding period ranged from 0.8 to 9.0mm day^{-1} while ETw varied between 0.9 and 31.0 mm day^{-1}. ETw rates exhibited considerable variability not only among seasons but also among days of the same season, which could be related to the variability of the weather conditions (Table 2).

ETw was positively correlated ($P<0.01$) with net radiation, average air temperature, class A open-water evaporation and leaf area index (Table 3). The correlation between ETw and deficit of vapor pressure was less significant ($P<0.05$) and ETw was

Table 2. Monthly mean weather conditions in Piracicaba, São Paulo State, Brazil, from October 1999 to October 2000.

	Oct/99	Nov	Dec	Jan/00	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
SR	19.8	21.6	22.1	20.5	19.9	17.8	18.4	13.7	12.4	12.7	13.9	16.4
Tav	21.0	21.6	23.7	23.4	23.5	22.8	21.5	18.4	18.5	16.0	18.7	20.3
Tmx	28.0	28.6	30.2	29.7	29.6	29.1	28.8	26.0	26.7	24.1	26.2	26.8
Tmn	15.3	15.4	18.8	18.9	19.4	18.6	15.1	11.9	11.3	9.1	12.2	15.1
URav	75	73	80	86	88	88	79	79	76	77	76	82
URmx	97	97	99	100	100	100	100	100	98	99	99	99
URmn	45	43	49	57	61	60	44	45	40	43	45	55
u	2.3	2.0	1.7	1.4	1.4	1.5	1.1	1.3	1.2	1.3	1.4	1.8
RF	28	52	261	224	117	166	1	5	5	61	78	89
DR	6	10	18	18	15	15	2	6	6	9	10	11
ETo	134	137	139	121	105	107	109	89	83	82	92	99

SR = incoming solar radiation (MJ m^{-2} day^{-1}); Tav = average air temperature (°C); Tmx = maximum air temperature (°C); Tmn = minimum air temperature (°C); URav = average relative humidity (%); URmx = maximum relative humidity (%); URmn = minimum relative humidity (%); u = average wind speed at 2m above the surface (m s^{-1}); RF = total rainfall (mm $month^{-1}$); DR = days with rain; ETo = Penman-Monteith reference evapotranspiration (mm $month^{-1}$).

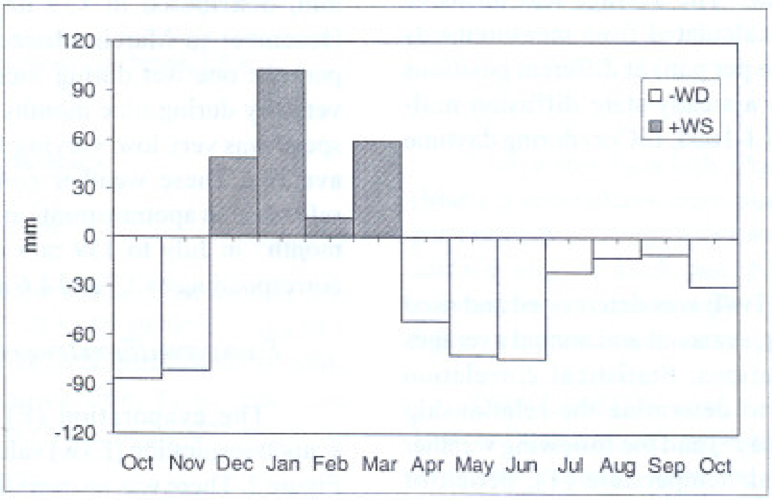

Figure 1. Climatic soil water balance (field capacity = 100 mm) from October 1999 to October 2000, in Piracicaba, São Paulo State, Brazil. Positive values correspond to water surplus (+WS), indicating the wet season, and negative values to water deficit (-WD), indicating the dry season.

not significantly correlated with average wind speed, which is a consequence of the small variation of this parameter over the year (Table 2). An expressive increase in ETw during the summer months was observed, which was related to the high dependence of evapotranspiration on weather conditions and leaf area, also influenced by these environmental parameters.

ETw and E relationship

Daily ratios of evapotranspiration to evaporation (ETw/E) are presented in Figure 3 and Table 4 shows ETw/E values for monthly, seasonal and annual time periods. Monthly ETw/E averages ranged from 1.89 ± 0.55 in October 2000 to 4.05 ± 1.02 in April 1999, having an expressive correlation

Table 3. Correlation coefficients (r) between ETw and weather parameters and leaf area index.

Variable	r	Variable	r
Net radiation	0,50**	Deficit of vapor pressure	0,26*
Average temperature	0,60**	Class A evaporation	0,46**
Average wind speed	0,11^{ns}	Leaf area index	0,51**

Number of observations is 215 for each correlation; * Significant at P<0.05 level; ** Significant at P<0.01 level; ^{ns} = not significant.

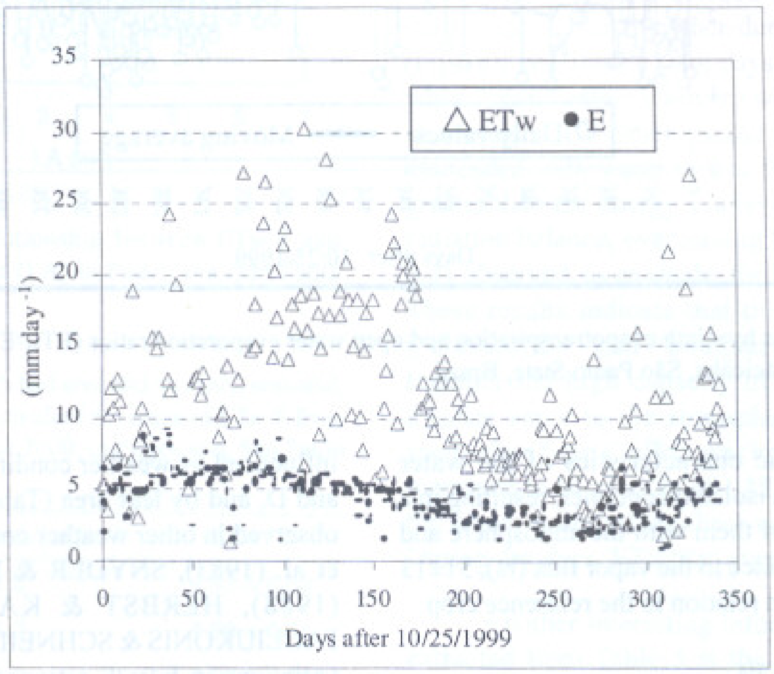

Figure 2. Daily open water evaporation (E) and water hyacinth evapotranspiration (ETw) from October 1999 to October 2000, in Piracicaba, São Paulo State, Brazil.

with leaf area, with r = 0.84 (Figure 4 and Table 4). Daily ETw/E values during this period ranged from 0.9 to 5.4, showing its high variability. On the other hand, little variability was observed for average seasonal values.

"Oasis", "Clothesline" and "Bouquet" effects

The days selected to evaluate the influence of advection of energy and periphery overexposure of the plants inside the pans ("oasis", "clothesline" and "bouquet" effects) were divided in two groups and are presented in Table 5. ETw' ranged during these days from 1.6 to 5.6 mm m^{-2} day^{-1} and the ratio ETw'/Rn' varied between 0.53 and 1.84. During days without "oasis" effect, when five previous days were wet, almost 67% of the days presented ETw'/Rn' ratio above 1.0 (from 1.06 to 1.84), which is an evidence of the influence of other effects as "clothesline" and "bouquet", associated with periphery overexposure of the plants. During the dry season, ETw'/Rn' ratios were greater than 1.0 (from 1.26 to 1.76) in more than 80% of the days, what is related especially to the additional contribution of "oasis" effect to the other two effects mentioned previously.

ETw'/ETo', which means the ratio between water hyacinth and reference crop evapotranspiration per leaf area unit, ranged from 1.9 to 6.8. This is evidence that water hyacinth has an efficient design for transpiration, around 2 to 7 times more than the hypothetical reference crop. This behavior is related

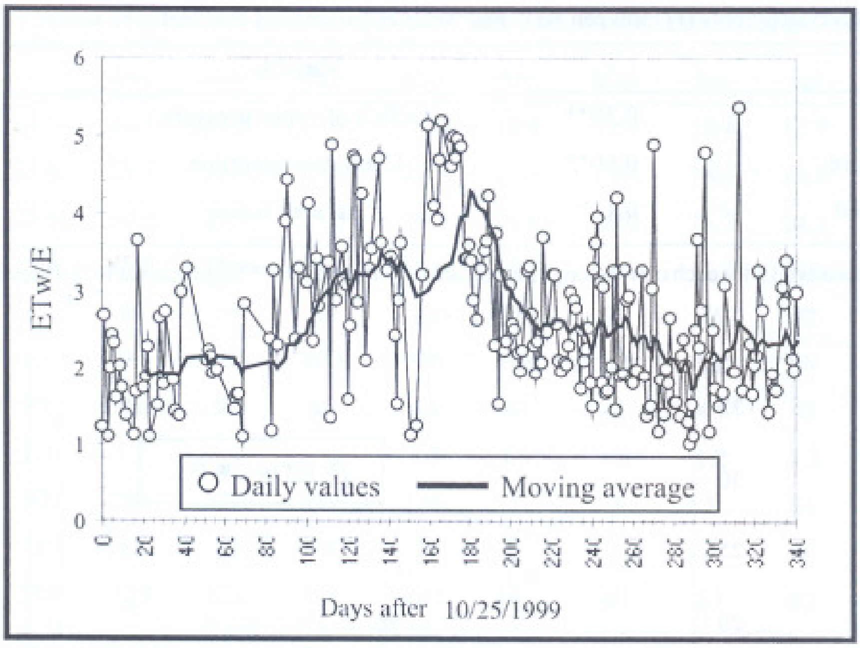

Figure 3. Daily water hyacinth evapotranspiration and open water evaporation ratios (ETw/E), from October 1999 to October 2000, in Piracicaba, São Paulo State, Brazil.

to the aerodynamic characteristics of the water hyacinth plants in a isolated container, resulting in a strong interaction of them with the atmosphere and its lower leaf resistance to the vapor flux (rs), 51±13 sm^{-1}, around 73% in relation to the reference crop.

General analysis

The results obtained in this study confirm that water hyacinth is an aquatic plant with high capacity to transfer water to the atmosphere, which is influenced by its morphological and physiological characteristics, as observed by PAULIUKONIS & SCHNEIDER (2001) when studying different wetland plant species along the southern shoreline of Oneida Lake, NY, USA. According to PENFOUND & EARLE (1978) and BENTON (1979), water hyacinth leaves have an usual stomatal density but the size of the open stomatal aperture is over four times the area of most other plants, making this aquatic plant exceptionally well equipped for the rapid diffusion of gases. ETw and ETw/E values obtained in this study support these statements. ETw ranged from 0.9 to 31 mm day^{-1} while E varied between 0.8 and 9.0 mm day^{-1} (Figure 2), resulting in daily ETw/E ratios between 0.9 and 5.4 (Figure 3), which agree with the results obtained by several authors (Table 1). The variation in ETw rates was influenced by weather conditions, mainly by Rn, T and D, and by leaf area (Table 3), which was also observed in other weather conditions by DEBUSK et al. (1983), SNYDER & BOYD (1987), RAO (1988), HERBST & KAPPEN (1999) and PAULIUKONIS & SCHNEIDER (2001), while the variations in ETw/E ratios was mainly correlated with leaf area (Figure 3).

For monthly periods, ETw/E rates varied between 1.89 ± 0.55 and 4.05 ± 1.02, being the annual average 2.59 ± 1.01. These rates were not only influenced by leaf area and weather conditions, as described above, but also by "oasis", "clothesline" and "bouquet" effects, which are related to advection of energy and periphery overexposure of the plants inside the pan, as also observed by ANDERSEN & IDSO (1987) and ALLEN et al. (1997). According to these authors, measurements in small containers, where the vegetation had a much greater exposed periphery surface area than the water, result in an ETw and ETw/E overestimation because the differences between open-water and water hyacinth aerodynamic characteristics. According to our calculations, based on the analysis of the data presented in the literature (Table 1), the relationship between ETw/E and containers size or area was very small (r = 0.35). So, the effects cited above are more

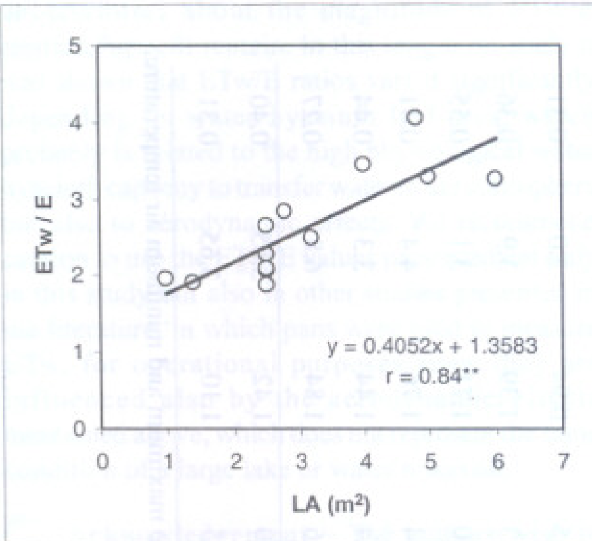

Figure 4. Monthly relationship between ETw/E and water hyacinth leaf area (LA) in Piracicaba, São Paulo State, Brazil.

Table 4. Water hyancinth leaf area and monthly, seasonal, and annual average and standard deviation of ETw/E from October 1999 to October 2000, in Piracicaba, São Paulo State, Brazil.

Month	Leaf area (m^2)	ETw / E
Oct/99	1.0	1.95 ± 0.60
Nov	1.2	1.90 ± 0.64
Dec	1.9	2.07 ± 0.58
Jan/00	5.5	3.26 ± 1.55
Feb	6.0	3.27 ± 1.00
Mar	3.5	3.44 ± 1.65
Apr	4.8	4.05 ± 1.02
May	3.0	2.65 ± 0.67
Jun	3.3	2.49 ± 0.65
Jul	2.5	2.27 ± 0.90
Aug	2.1	2.09 ± 0.86
Sep	3.0	2.82 ± 1.61
Oct	3.2	1.89 ± 0.55
Sp-Su[a]	-	2.54 ± 0.64
Au-Wi[b]	-	2.72 ± 0.59
Annual	-	2.59 ± 1.01

[a] Average for Spring and Summer seasons;

[b] Average for Autumn and Winter seasons.

related to the plant size (height and leaf area) and current weather conditions. This is proved by analyzing data from Figure 4, where the high correlation between ETw/E and leaf area for monthly periods is shown. It helps to explain why ETw is extremely influenced by the "oasis", "clothesline" and "bouquet" effects. The identification of the interaction of these effects and leaf area was possible by the analysis of several days during the experimental period, divided in two spells, one during the wet and another during the dry season (Figure 1 and Table 5). For days during wet season, when "oasis" effect was very weak, ETw'/Rn' was in average 1.10, which means that the latent heat associated with water lost to the atmosphere was greater than the energy available from the vertical radiation balance, overcoming largely the value of 0.31 observed, as example, for ETo'/Rn' (Table 5). These results indicate that the other two effects ("clothesline" and "bouquet") were occurring together the high capacity of water hyacinth to transfer vapor to the atmosphere. During the dry spell, when "oasis" effect was intensified, ETw'/Rn' increased to an average of 1.42, in consequence of the whole action of the three aerodynamic effects. During dry days, ETo'/Rn' averaged 0.4.

Another interesting information that can be extracted from Table 5 is the ETw'/ETo', which indicates the ratio between water hyacinth and reference evapotranspiration per leaf area unit, taking into account 2.88 m^2 as reference crop leaf area. ETw'/ETo' ranged from 1.9 to 6.8, showing that water hyacinth exhibit an efficient design for transpiration, in average about 3.7 times more than the hypothetical reference crop, as also observed by PENFOUND & EARLE (1948) and BENTON (1979). In average, ETw'/ETo' did not show difference between dry and wet days.

Conclusions

The high water consumption by water hyacinth showed to be influenced by weather conditions, leaf area, advection of energy ("oasis" effect), and overexposure of the plants inside the pan to weather conditions ("clothesline" and "bouquet" effects). Analyzing data from the literature, the ratio ETw/E showed not to be related to the size of the container. The results of this study agree with those presented in the literature, but some

Table 5. Weather conditions, water hyacinth leaf area (LA) and evapotranspiration (ETw), and reference evapotranspiration (ETo) for selected days of the experimental period, in Piracicaba, São Paulo State, Brazil.

Day	RF_{-5d} mm	Rn MJ m^{-2} day^{-1}	T* °C	URmin %	*U* m s^{-1}	D kPa	Eto mm day^{-1}	ETw mm day^{-1}	LA m^2	ETw' mm m^{-2} day^{-1}	ETw'/ Rn'	ETw'/ ETo'	ETo'/Rn'
12/11	105	5.52	25/19	77	2.3	0.41	1.9	5.0	1.8	2.8	1.23	4.2	0.29
01/05	70	5.59	26/21	77	1.3	0.39	1.8	9.9	4.1	2.4	1.06	3.9	0.27
01/15	32	10.27	31/21	61	1.1	0.86	3.4	14.7	6.6	2.2	0.53	1.9	0.28
02/02	25	14.34	21/20	49	1.2	1.14	4.8	22.1	6.3	3.5	0.60	2.1	0.28
03/29	95	4.80	29/16	56	2.2	0.96	2.5	10.8	4.1	2.6	1.34	3.0	0.44
04/02	0	10.93	28/17	61	2.9	0.72	3.8	24.2	4.3	5.6	1.26	4.2	0.30
04/30	0	9.07	30/13	36	0.9	1.40	3.3	13.6	3.9	3.5	0.94	3.0	0.31
05/16	0	7.57	29/13	41	1.6	1.17	3.2	11.6	2.7	4.3	1.39	3.9	0.36
06/29	0	5.77	29/13	27	2.0	1.68	3.7	11.7	2.9	4.0	1.71	3.1	0.55
07/12	0	3.35	21/11	57	1.8	0.55	1.6	5.8	2.4	2.4	1.76	4.4	0.41
08/09	0	7.53	32/13	18	1.5	1.94	3.9	9.8	2.2	4.4	1.44	3.3	0.44
09/03	40	2.20	17/13	86	1.7	0.13	0.7	4.8	2.9	1.6	1.84	6.8	0.27
Dry days	0	7.37	28/13	40	1.8	1.24	3.3	12,8	3.1	4.0	1.42	3,65	0.40
Wet days	367	7.12	25/18	68	1.6	0.65	2.5	11.2	4.3	2.5	1.10	3.65	0.31

RF_{-5d} = rainfall during the five previous days; ETw' = ETw / LA; ETo' = ETo / 2.88; * correspond to the maximum and minimum air temperature, respectively; Rn' = Rn/2.45.

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uncertainties about the magnitude of ETw/E relationship still remain. In this long-term study it was shown that ETw/E ratios varied significantly depending on water hyacinth leaf area, which probably is related to the high physiological water hyacinth capacity to transfer water to the atmosphere but also to aerodynamic effects. We recommend caution to use the ETw/E values presented not only in this study but also in other studies presented in the literature, in which pans were used to measure ETw, for operational purposes since they are influenced also by the aerodynamic effects mentioned above, which does not represent the same condition of a large lake or water reservoir.

Acknowledgement – The authors wish to thank Fundação de Amparo à Pesquisa no Estado de São Paulo (FAPESP) for supporting this study partially and CNPq for the fellowship to the first and third authors.

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