EVALUATION OF MICROMETEOROLOGICAL BOWEN RATIO ENERGY BALANCE SYSTEM (BREB) UNDER REFERENCE (*FESTUCA SP.*) AND SPARCE CROP (VINEYARD) CONDITIONS

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ABSTRACT

The implementation of Bowen ratio energy balance system (*BREB*) in sparse crops (such as fruit trees or vineyard) is not clear yet. In this work we we check the performance of the system in a homogeneous and heterogeneous surface. The high performance of *BREB* system under homogenous surface was confirmed. However, some overestimation was register when advection appeared in coincidence to irrigation events. In a vineyard, *BREB* and *EC* systems estimated similar amounts of daily and cumulative *ETa* values. The *BREB* system slightly overestimated the *EC* system fluxes as it exhibited the highest differences over specific periods. These differences could be explained by the location of the lower arm so close to the top of the vegetation which, under certain conditions of wind direction and atmospheric stability, it may require height and placement of sensors in a different position on the cover. The analysis and comparison made in this study have enhanced the reliability of the *ETa* results obtained by *BREB* and *EC* systems and allowed to register changes of the crop coefficient (*Kc*) and define irrigation schedules during the crop season.

INTRODUCTION

The Bowen Ration Energy Balance (*BREB*) system is a micrometeorological method that has been widely used to assess the latent heat flux (λE) and crop evapotranspiration rates (*ETa*) (Ham and Heilman, 2003; Spano et al., 2000; Yunusa et al., 2004). In conjunction with meteorological data, this system allows to estimate the crop coeficiente (*Kc*), useful to define irrigation schedules. *BREB* system has a simple and economical design and requires less maintenance than other micrometereological methods. The performance of the *BREB* system depends on sensors position, fetch requirements, cover homogeneity, atmospheric conditions, etc. The implementation of *BREB* system in sparse crop (such as fruit trees and vineyard) is not clear yet. The principal problems in sparse crops are associated with the two main assumptions such as: (i) the closure of the energy balance is forced (Brotzge and Crawford, 2003) and, (ii) eddy diffusivity of vapor (k_w) is equal to eddy diffusivity of heat (k_h) (Angus and Watts, 1984). The performance of this micrometeorogical system can be evaluated using a precision weighting lysimeter (*LYS*) that provides the most robust and accurate measurements of ETa (ASCE, 1996). The objetive of this work is to evaluate a *BREB* system over a homegeneus reference surface (*Festuca sp.*) and in a sparse crop such.drip-irrigated vineyard. To account for differences, estimated *BREB* values were compared with lysimeter and eddy covariance (*EC*) records.

MATERIALS AND METHODS

The *BREB* system is based on vertical gradients of temperature (ΔT) and water vapor (Δq) between two levels and derives λE as a function of *Bowen-ratio* (β) and available energy measurements (difference between the net radiation (*Rn*) and soil heat flux (*G*). The distribution of energy is calculated using β and λE is estimated as follows:

$$\beta = \gamma \frac{\Delta T}{\Delta q} \text{ and } \lambda E = \frac{(Rn - G)}{(1+\beta)}$$

The first experiment was performed between 4th and 15th May 2007 in the experimental plot of "Las Tiesas" in Albacete, Spain (39^{o} 14'N, 2^{o} 05'W). A 1 ha reference surface (Festuca arundinacea Schreb, cv. "Asterix") with 0.12 m grass height, under optimal water supply was using. A weighing lysimeter installed at the middle of the experimental plot was used to measure grass evapotranspiration. The precision weighing lysimeter *(LYS*) (using in the experiment 1) container is 2.7 m long, 2.3 m wide and 1.7 m deep, with a total mass of approximately 14.5 t . The system registered the actual mass with a resolution of 0.25 kg, equivalent to 0.04 mm of water. Weight data are stored in a CR10X datalogger (Campbell Scientific, Logan, UT, USA). The system was programmed to take readings every second (60 reading per minute), storing the data in 15 min, hourly and daily averages. The climate is continental with annual average temperature of 13.7 °C and 310 mm of precipitation.

The second experiment was carried out in a drip-irrigated comercial vineyard located in Tarazona de La Mancha (39° 17´N, 1° 59'O, 700 m), España. Vines were planted in North–South rows, 3 m apart, with 1.5 m within-row spacing and were trained on a vertical shoot positioned system (*VSP*). The crop cover was 30% (Campos et al., 2010).

In the BREB system the gradients ΔT and Δq were measured with 1.5 m long arms at heights of 0.2 and 1.2 m above the vineyard canopy. Data was measured every second, and the means were calculated and store at a 20-min time interval. To avoid systematic errors the vapor pressure was register with unique dewpoint sensor (ALMEMO, Ahlborn Mess-und R.) and air flow was interchanged from each arm every 3 min using a solenoid valve system. The air temperature (*Ta*) was measured using fine wire thermocouples (ASPTC + 107 T. P./ Campbell Sc., Logan, USA). The same *BREB* equipment was used in both experiments.

In the vineyard the *EC* tower was located in the center of the experimental plot very close to the *BREB* station. The 3-axis sonic anemometer (CSAT3) and IRGA (LI-7500), separated by 0.14 cm were set at 1 m and 3 m height in experiments 1 and 2, respectively. The sensors were oriented to the prevailing daytime wind direction. The sample frequency in the EC system was 10 Hz. In the datalogger were implemented corrections for air density fluctuations (Webb et al., 1980) and the difference between buoyancy flux and sensible heat flux

(Schotanus et al., 1983). An additional offline correction for spectral loss due to averaging over sensor path and spatial sensors separation was performed following (Massman, 2000).
The soil heat fluxes (*G*) was estimated using the combination approach propoused by Payero et al., (2005) that includes the use of heat flux plates and thermocouples to quantify the heat stored in the layer above the transducers. The soil heat flux density (*G*) was estimated using soil heat flux plates, buried at 50 mm depth. For superficial storage component, parallel thermocouple probes were set above the plates at 40 and 20 mm soil depth. In the experiment 2 (vineyard) the plate, termocouples and soil humidity sensors were distributed in a representative patron of covers (Balbontín et al., 2011). The net radiation (*Rn*) was measure with a net radiometer (NR-Lite / Kipp&Zonen Delft, Holland) mounted at 2 m. height in experiment 1 and with a four-way net radiometer (CNR1, Kipp&Zonen, Delft, Netherlands) in the experiment 2 set at 4.5 m height.

RESULTS AND DISCUSSION

In the reference surface (*Festuca* plot) the values of *ETa* obtained by *BREB* were slightly higher than *LYS* and *EC* values. Table 1 and Figure 1 show the daily behavior of ETa from *LYS*, *BREB* and *EC* system.

Table 1 - Comparison of hourly ETa values from *BREB*, *EC* against *LYS* measurements (LYS was taken as independent variable).

ETa method	ETa_{total} mm	ETa_{ave} mm/h	P_{ave}/LYS_{ave} %	ETa_{Obs}=a*ETa_{LYS}+b a	B	r^2	RMSE mm/h	I.A.
LYS	56.4	0.38	-	-	-	-	-	-
BREB	55.5	0.38	1.65%	1.05	-0.027	0.92	0.08	0.977

O_{ave} and P_{ave} means average of hourly observed (method) and predicted (LYS) values; (a) slope, (b) intercept and (r2) coefficient in the regression fit; RMSE root mean square error, I.A. index of agreement (Willmott, 1982).

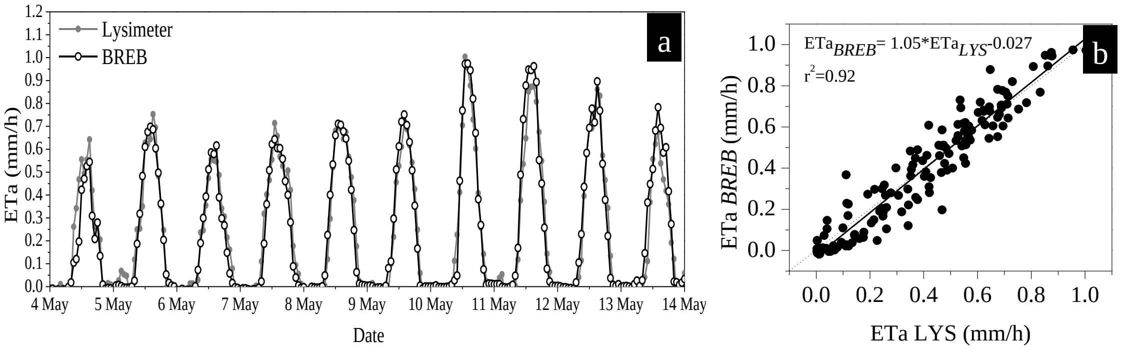

Figure 1 – a) Daily behavior of *ETa* from *LYS* and *BREB* systems and b) correlation

The ETa values from *BREB* were close to the *LYS* outputs during the whole period of analysis. The method showed a high correlation (r^2=0.92), a slope close to unity (1.05) and low RMSE (Table 1). The similarity between both methods was most expressed during the first part of the experimental period, in which neither irrigation or rain happened. In the second half of period with higher vapor pressure deficit (*VPD*) and some advection, *BREB* showed some overestimation as compared to LYS in 7%. Both BREB and LYS systems had a similar response to increase of *VPD* and showed higher rates of ETa. The *BREB* system is sensitive to the availability of energy because transport is assumed to be one-dimensional, with no horizontal gradients (Rosenberg et al., 1983). When the irrigated surface becomes cooler than the air, latent heat flux may be diverted from vertical to horizontal and the assumption of constant flux with height may be invalid (Todd et al., 2000).

Sparse surface (vineyard)

The correlation between latent heat fluxes obtained using *BREB* and *EC* systems showed high levels of adjustment (r^2 =0.94), but greater differences in their slopes. The latent heat λE_{BREB} was higher than λE_{EC} with 101.3 Wm^{-2} and 95.7 Wm^{-2}, respectively (Table 2)

Table 2 - Average of the fluxes λE, H and R^2 statistics†, a, b, RMSE and I.A.

Flux	*BREB*	*EC*	RMSE	IA	R^2	B	A
λE (Wm^{-2})	101.3	95.7	33.4	0.974	0.94	0.83	12.2

v † $Y_{EC} = b_{BREB} + a$; BREB independent variable, and EC dependent variable; IA index of agreement (Willmott, 1982); R^2: correlation coefficient; a: intersection; b: slope.

The bigger differences between both systems were represented by flux peaks of λE_{BREB} (Figure 2). The λE peaks were accompanied by decreases of the sensible heat flux (*H*). Gavilán and Berengena (2007) point out that under stable atmospheric conditions, prevailing wind direction and architecture of crops, *BREB* systems can produce overestimates of the λE fluxes, and therefore underestimates of H. In the entire experimental period the sum of ET_{BREB} was 202 mm and ET_{EC} 192 mm. The difference between both systems accounted for 5%, considered an adequate level of daily adjustment. (Table 3).

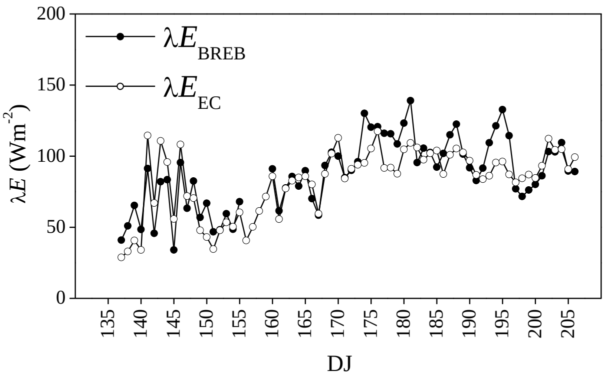

Figure 2 - Daily mean values of λE estimated with the *EC* and *BREB* systems.

Table 3. ET estimated values with the EC and BREB systems

Method	ETa_{total} mm	ETa_{ave} mm/h
BREB	201.8	3.12
EC	191.7	2.96

Most of the comparisons between these systems have shown slight overestimations of the *BREB* system in relation to *EC* (Brotzge and Crawford, 2003), and in vineyard Li et al., (2008)) report differences of 6 % in favor of *BREB*. The coincidence between the two periods of λE_{BREB} with maximum values and therefore greater differences with EC and a prevailing wind direction (south and for rows) suggest that the internal heterogeneity of the crop had a greater influence to locate the mixing zone, and that in the *BREB* system the position of the

arms above the plant cover is critical. In this regard, Heilman et al. (1994) found that over a trellis vineyard the profile of wind speed and temperature changed depending on the wind direction and sampling location (over or between the rows of plants). These authors suggest that there is further development of turbulence (mixture) in the upper canopy where the wind is perpendicular to the rows. Also in vineyards, Hicks (1973) indicate variations in intensity of the turbulence and the coefficient of dragging in the upper canopy depending on the wind direction. This situation was not observed in the *EC* system as the sensor was twice or more of the vegetation height, a height level defined for the mixed sublayer (Cellier and Brunet, 1992) and the impact of the heterogeneity on the development of the mixed layer was lower.
The values of crop coefficient *Kc* (*ETa/ETo*) were similar in both systems and captured the maximum products from the soil rainwater evaporation at the beginning of the experiment or when the subsequent irrigation applications were conducted. The two systems predicted similar *Kc* values and the differences were represented by λE peaks estimated with *BREB*. The *EC* system recorded the *Kc* behavior with greater stability and higher sensitivity over the actual availability of soil moisture and internal controls of plant fluxes. It is important to note that both systems estimated *Kc* values lower than those reported for *Vitis vinifera* in FAO56 but the estimates are consistent with the local values assessed with lysimeter in vineyard with irrigation (Montoro et al., 2008).

CONCLUSIONS

The high performance of *BREB* system under homogenous surface was confirmed in the experiment 1. However, some overestimation was register when advection appeared in coincidence to irrigation. In the vineyard *BREB* and *EC* systems estimated similar amounts of daily and cumulative *ETa* values and allowed to predict a change of the crop coefficient during the season. The *BREB* system slightly overestimated the *EC* system fluxes as it exhibited the highest differences over specific periods. These differences could be explained by the location of the lower arm so close to the top of the vegetation in the *BREB* system which, under certain conditions of wind direction and atmospheric stability, it may require height and placement of sensors in a different position on the cover. The analysis and comparison made in this study have enhanced the reliability of the *ETa* results obtained by BREB and EC systems and enabled to calculate the vineyard crop coefficient.

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