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

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INTRODUCTION

The Bowen Ration Energy Balance (BREB) system is a micrometeorological method that has been widely used to assess the surface energy budget and crop evapotranspiration rates (ETa) over a variety of field conditions (Dugas et al., 1991; Ham and Heilman, 2003; Spano et al., 2000; Yunusa et al., 2004; Zhang et al., 2007). Addicionally, 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. For these reasons the implementation of BREB system in sparse crop (such as fruit trees and vineyard) is not clear yet. The problems in the application of BREB system 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 micrometeorogical systems 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 *BREB* system to estimate latent heat flux (or evaptranspiraton) over a homegeneus reference surface (*Festuca sp.*) and drip-irrigated viyard (sparse crop). To account the differences in latent heat fluxes obtained from *BREB* system, estimated values were compared with lysimeter and eddy covariance (EC) records.

BREB THEORY

The BREB system is based on vertical gradients of temperature (ΔT) and water vapor (Δq) between two levels (Heilman et al., 1989; Stannard, 1997), and derives the latent heat flux (λE) as a function of Bowen-ratio (β) and available energy measurements which corresponds to the difference between the net radiation and soil heat flux, (Rn-G). The distribution of energy between sensible (H, Wm^{-2}) and latent heat fluxes (λE, Wm^{-2}) is calculated using the Bowen-ratio (β, dimensionless) as follows: (Monteith and Unsworth, 1990; Rosenberg et al., 1983) and calculated as:

$$\beta = \frac{\mathrm{H}}{\lambda E} = \gamma \frac{\Delta T}{\Delta q}$$

where γ (kPa ° C^{-1}) is the psychrometric constant; ΔT (° C) and Δq (kPa) are the gradients of temperature and water vapor concentration between measurement heights. Using β and energy available, latent heat flux is estimated as follows:

$$\lambda E = \frac{(Rn - G)}{(1 + \beta)}$$

MATERIALS AND METHODS

Experiment 1: 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). In this plot, a reference surface (Festuca arundinacea Schreb, cv. "Asterix", 1 ha) was establish following FAO guidelines (Allen et al., 1998) with 0.12 m grass height, under optimal water supply. Also, a weighing lysimeter was installed at the middle of the experimental plot to measure grass evapotranspiration. The climate is continental with annual average temperature of 13.7 °C and 310 mm of precipitation (López-Urrea et al., 2006).

Experiment 2: 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), Albacete, 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 shoots were maintained on a vertical plane by three wires, the highest one was located 2 m above the soil surface. The maximum fractional was 30% (Campos et al., 2010).

EQUIPMENT

Lysimeter: 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.

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® - FHA646DTC1 / 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, UT). The same BREB equipment was used in both experiments.

EC system: 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).
Available energy: 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 Inc., Delft, Netherlands) in the experiment 2 set at 4.5 m height.

RESULTS AND DISCUSSION

Reference surface: The values of ETa obtained by BREB in the evaluated period 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}**	**ETa_{ave}**	**P_{ave}/LYS_{ave}**	**ETa_{Obs}=a*ETa_{LYS}+b**		**r^2**	**RMSE**	**I.A.**
	mm	mm/h	%	a	b		mm/h	
LYS	56.4	0.38	-	-	-	-	-	-
BREB	55.5	0.38	1.65%	1.05	-0.027	0.92	0.08	0.977

Oave and Pave 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).

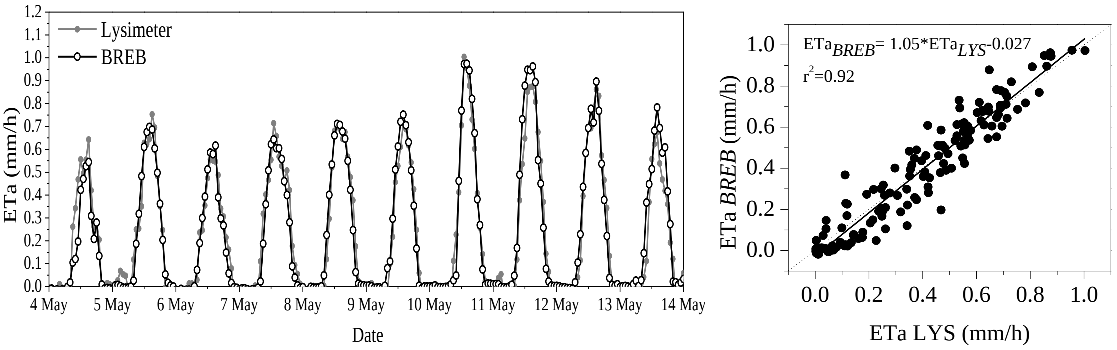

Figure 1 - Daily behavior of ETa from LYS and BREB systems and correlation

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 $\lambda E_{\mathrm{BREB}}$ was higher than λE_{EC} with 101.3 Wm^{-2} and 95.7 Wm^{-2}, respectively (Table 2)

Table 2 - Average of the fluxes lE, H and R2 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 $\lambda E_{\mathrm{BREB}}$ (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).

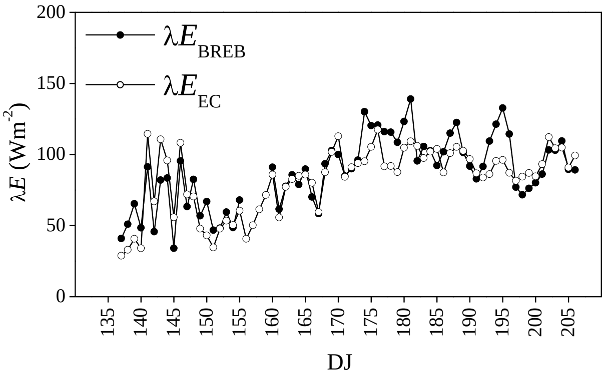

Figure 2 - Daily mean values of λE estimated with the EC and BREB systems.

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, Zhang et al., 2007), 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, Weiss and Allen (1976) and 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 where the impact of the surface heterogeneity on the development of the mixed layer was lower.

The values of crop coefficient *Kc* (ET/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 (Allen et al., 1998), 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. Howevre, 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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