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Full Length Research Paper

Comparison of soybean evapotranspirations measured by weighing lysimeter and Bowen ratio-energy balance methods

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Lysimeters are considered the standard for evapotranspiration (ET) measurements. However, these units are often not replicated and are few in number at any given location. The Bowen ratio-energy balance (BREB) is a micrometeorological method often used to estimate ET because of its simplicity, robustness, and cost. In this paper, ET of irrigated soybean (*Glycine max* L.) was directly measured by weighing lysimeter and estimated by BREB method over a growing season in a semi-arid climate of eastern Mediterranean region. The study was conducted in Adana-Turkey during the summer of 2009 on a 0.12 ha area with a weighing lysimeter (2.0 × 2.0 × 2.5 m) located in the center of the field completely covered by well watered soybean where the prevailing direction of the wind and the upwind fetch was about 60 m. Cumulative evapotranspiration totals from the lysimeter and BREB methods were 354 and 405 mm, respectively. The BREB method showed a good performance for daily ET estimation when compared to values measured by lysimeter. This method, with a root mean square error (RMSE) of 0.79 mmd^{-1} and a 0.96 index of agreement, over-estimates lysimetric measurements by 15%. The BREB method also performs well compared with lysimetric measurements for hourly ET, but produces overestimation of 14% with RMSE of 0.128 mmh^{-1}, and a 0.92 index of agreement.

Key words: Bowen ratio, evapotranspiration, soybean, weighing lysimeter.

INTRODUCTION

In many arid areas of the world, water is scarce and/or expensive, more over seriously endangered by over exploittation, thus, proper irrigation management has to be done by farmers. For proper irrigation scheduling and high level agricultural production, a precise knowledge of crop water use under field conditions is required. It is accepted that the measurement of evapotranspiration (ET) of agricultural crops is a basic tool to compute water balances and to estimate water availability and requirements. Thus, many techniques and models for measuring crop evapotranspiration were developed (Tanner, 1967; Doorenbos and Pruitt, 1984; Reicosky and Peters, 1977; Aboukhaled et al., 1982; Sharma 1984; Jensen et al., 1990, Burman and Pochop, 1994; Kanber and Steduto, 1999). ET determination methods vary from direct measurement techniques using lysimeters to energy balance measurements based on BREB, flux profile, and eddy correlation techniques and physiologic methods including canopy chamber and pulse methods by Sharma (1984), Hatfield (1990) and Steduto and Cetinkoku (1999). All the methods determining evapotranspiration have some limitations and superiorities. For example, weighing lysimeters are the most accurate and direct method (Jensen et al., 1990), but they are both expensive and immobile, and some time poor representation of conditions outside the area. On the other side, micrometeorological methods are mobile, but expensive and requiring large fetch. The

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Abbreviations: ET, Evapotranspiration; **BREB,** Bowen ratio-energy balance; **RMSE,** root mean square error.

methods based on soil-water balance are mobile too, but expensive, time consuming and variable in accuracy depending on soil types and conditions.

Lysimeters, both weighing and drainage types, have been used for measuring water use (which is released by plants, usually crops or trees from the mass change of an isolated soil volume and plants growing in it), determining crop coefficients, and other works on plant-soil, water and atmosphere relations and considered as basic method to calibrate evapotranspiration models (Mata et al., 1999; Todd et al., 2000; Tyagi et al., 2000; Liu et al., 2002; Yang et al., 2002; Allen and Wright, 2004; Lopez-Urrea et al., 2006; Benli et al., 2006; Lovelli et al., 2005; Zeggaf et al., 2008; Centinari et al., 2009).

Similarly, the Bowen ratio-energy balance (BREB) method has been used to quantify water use, calculate crop coefficients, investigate plant-water relations and evaluate crop water use models as being done by lysimeters (Wight et al., 1993; Malek and Bingham, 1993; Saylan, 1995; Cargnel et al., 1996; Todd et al., 2000; Alves et al., 1996; Todd et al., 1996; Steduto and Hsiao, 1998 a,b,c,d; Unlu, 2000; Unlu et al., 2001). BREB method is considered to be a fairly robust method, and has compared favorably with other methods such as weighing lysimeters (Prueger et al., 1997; Todd et al., 2000), eddy covariance (Cellier and Olioso, 1993) or water balance (Unlu et al., 2001). Most of the studies were conducted and Bowen ratios were mostly positive and sensible, heat advection absent. They showed good agreement with other methods which have been generally accepted.

The BREB method estimates latent heat flux from a surface using measurements of air temperature and humidity gradients, net radiation, and soil heat flux (Steduto, 1999). It is an indirect method, compared to methods such as eddy covariance and weighing lysimeters, which directly measure turbulent fluxes, and mass change of inside tank with growing plants, respectively. The BREB method has some advantages and disadvantages compared to other methods. They have been discussed and arranged in order by Mata et al. (1999), Tyagi et al. (2000), Todd et al. (2000), Liu et al. (2002), Yang et al. (2002), Allen and Wright (2004), Lopez-Urrea et al. (2006), Lovelli et al. (2005), and Centinari et al. (2009). Its advantages are simple measurements, not requiring information about the aerodynamic characteristics of the surface, integrating latent heat fluxes over large areas, estimating fluxes on fine time scales (less than an h), and providing continuous, unattended measurements (Todd et al., 2000). Limitations of the BREB method generally occur near sunrise and sunset, because of small gradients in T and *e* that result in β values approaching -1 or ∞. Limitations can also occur with crops of nonuniform cover and under conditions of advection, commonly found in semiarid agriculture (Prueger et al., 1997). On the other hand, its disadvantages are the sensitivity to the biases of instruments which measure gradients and energy balance terms, adequate fetch to ensure adherence to the assumptions of the method.

Comparisons between BREB and lysimeter techniques have been conducted by researchers in the different locations and differences of less than 10 percent between two methods have been reported (Prueger et al., 1997). For direct determinations of ET under different soil and water management practices, it is however necessary to develop reliable, inexpensive and portable equipment. Weighing lysimeters are considered the standard for evapotranspiration (ET) measurements; however, these units are often not replicated and are few in number at any given location. Additionally, the relative scarcity of weighing lysimeters data is mostly due to their high prices and complexity for construction and installation. The use of Bowen-Ratio Energy-Balance method (BREB) is, in turn, widely used for evapotranspiration measurements due to its relatively low cost and installation simplicity and mobilization. The main objective of the present study was to determine whether Bowen ratio system could provide accurate measurement of ET and crop coefficients of soybean in a semi arid climate having high relative humidity. At the same time, the study also seeks to compare ETc and crop coefficients measured by precision weighing lysimeter and the BREB methods to analyze the performance of the BREB under a range of conditions encountered over a growing season. Additionally, validation was done for the use of BREB for hourly ETo measurements and use of its climatic variables to be applied in the Penman-Monteith equation for hourly ETc estimations.

MATERIALS AND METHODS

Study location

The experiment was conducted at Research Fields of the Agricultural Structures and Irrigation Department, Faculty of Agriculture, University of the Cukurova (36° 59' N, 35° 18' E, and 20 m above sea level), Adana, Turkey. Evapotranspiration was directly measured by a weighing lysimeter and Bowen equipment located in the center of 0.12 ha field, completely covered by well watered soybean where the prevailing direction of the wind and the upwind fetch was about 60 m. The experiment was done in the growing season of 2009.

Arioglu soybean cultivar (*Glycine max* L.) was sown on 175 DOY with 0.70 m row distance and 8-10 cm spacing as second crop after wheat. Lysimeter has a four meter square area and were hand seeded at the same time. Throughout the season, there were few observable differences between growth in the lysimeter and in the field. The fertilizers doses were determined according to recommendations for soybean, 36 kg ha^{-1} pure nitrogen and 92 kg ha^{-1} phosphor, P_2O_5, in the region (Uncu and Arioglu, 2005) and given directly to a trickle system.

The plot together with the lysimeter has a drip irrigation system which is used for irrigation of the area. PE pipe with 16 mm diameter has in-line drippers at 0.50 m interval which supplies to each plant row. The application rate is four liter per h at 100 kPa pressure, the

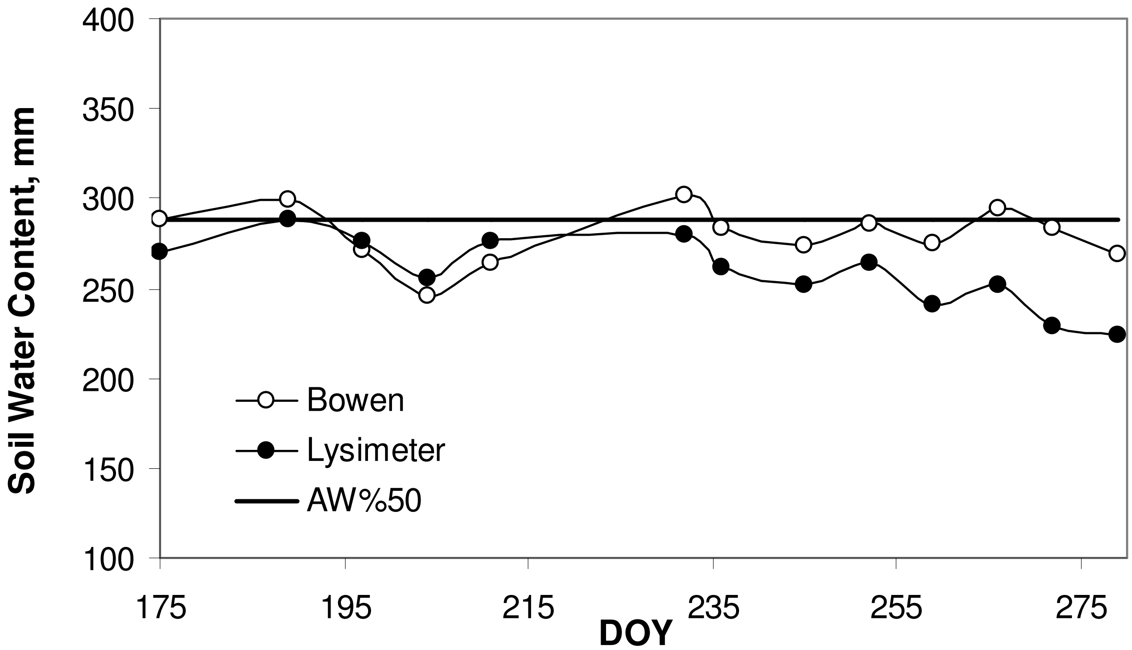

Figure 1. Change of soil water content measured by neutron scattering method before irrigation events during the growing season of soybean in the field conditions.

Christiansen uniformity coefficient is 95% (Christiansen, 1942). Irrigation applications were started on 29th July of 2009 when 50% of available soil water in the 90 cm depth was consumed. Consecutive irrigations were repeated almost every one week. Irrigation water amount was computed using free water surface evaporation and crop-pan coefficient (Equation 1).

$$IW = Epan \times Kcp \times Pw \quad (1)$$

Where, IW, irrigation water amount, mm, Epan, cumulative free water surface evaporation in irrigation intervals which is measured with screened Class A pan located at the meteorological station near the experimental field, mm, Kcp, crop and pan coefficients, taken as 0.72 for all irrigation season. Average kc value for soybean during the development season, mid season and late season is 0.9 and Kp value for experiment area conditions is 0.8 depending on moderate wind speed 100 m windward side of green crop, and high humidity (Doorenbos and Pruitt, 1984, Doorenbos and Kassam, 1979) and Pw, wetted percent of irrigated area, which is changed depending on shaded area by plant, percentage. Irrigations were ended during the crop maturity when kernels are turning yellow colour almost 15 days before harvest (Uncu and Arioglu, 2005). In this way, all kinds of water restrictions can be avoided and it is possible to maintain approximately 50 percent of the available water content before irrigations in the soil, (Figure 1) so that evapotranspiration measurements thus obtained can be considered as standard conditions-evapotranspiration of soybean (ETc) according to FAO indications (Doorenbos and Pruitt, 1984; Allen et al., 1998).

According to soil taxonomy (Soil Survey Staff, 1999), the soil in the plot where the experimental work was carried out is catalogued as Palexerollic Chromoxerert. Texture is heavy clay, as averagely, with 15.75% of sand, 19.58% of silt and 64.62% of clay, pH is slightly basic, and it is poor in organic matter (1.34 and 1.07%. for 0 - 20 and 20 - 40 cm, respectively) and total nitrogen, with a high content in active limestone and potassium. The soil is deep and has no salinity and drainage problems, and water table is more than 6 m deep (Unlu, 2000). Same soil profile was used for construction of soil profile inside of lysimeter. Some physico-chemical properties of the soil are presented in Table 1. The soil water content at field capacity (FC) and permanent wilting point (PWP) (g g^{-1}) were determined in laboratory using the pressure membranes at -33 kPa and -1.5 MPa suction pressures, respectively. The Soil bulk density (As, g cm^{-3}) was determined by the methodology given by USSL (1954). pH was measured in the soil paste using a Beckman model glass electrode pH-meter. Electrical conductivity (EC) was also measured in soil paste using standard Wheatstone resistance bridge method (USSL, 1954). The organic matter content was determined by the Walkley-Black method (Hizalan and Unal, 1966). The organic carbon content of the surface soil layers (0 - 30 and 30 - 60 cm) were 1.34 and 1.07%, respectively. Available potassium was measured by the ammonium citrate extraction given in USSL (1954). Available phosphate was determined by the Olsen method (Guzel, 1982). The available phosphorus and potash in the surface layer (0-30 cm) were 25 and 473 kg ha^{-1}, respectively. The soils had no salinity and drainage problems, and the water table was deeper than 6 m (Unlu, 2000).

A typical Mediterranean climate, with cool, rainy winters and hot, dry summers, prevails in the area with average temperatures in the coldest month (January) of 9.9°C for long time period and 7.7°C for 2009, and in the hottest month (August) of 28.1°C for long time period and 29.7°C for 2009. In the 2009 period the annual mean temperature was 19.7°C, the degree of sunshine was high with an average of 7.1 h of sunshine per year. Long-term average rainfall in the area is about 650 mm, most of which is received during the winter season when most of plants are not grown. Data are available on air, temperature and rainfall of the area over a long time period (1929 - 2009). Moreover, the data correspond to the period in which the experiment took place and were obtained from

Table 1. Some soil characteristics of the experimental field and lysimeter profiles.

Soil Layer, cm	Texture	FC* g g^{-1}	PWP* g g^{-1}	As* g cm^{-3}	pH	EC* dSm^{-1}	Organic Matter, %	Initial Mineral N, %	K_2O kg ha^{-1}	P_2O_5 kg ha^{-1}
0-30	C	34	18	1.19	7.87	0.21	1.34	0.06	473	25
30-60	C	37	18	1.16	7.61	0.12	1.07	0.06	473	29
60-90	C	38	19	1.15	7.81	0.14		0.05		
90-120	C	38	19	1.25	7.97	0.13		0.04		
120-150	C	37	19	1.24	7.64	0.18				
150-180	C	36	19	1.25	7.77	0.19				
180-210	C	36	19	1.24	7.76	0.19				

*FC: Field capacity, PWP: Permanent wilting point, C: Clay, As: Bulk density and EC: Electrical conductivity.

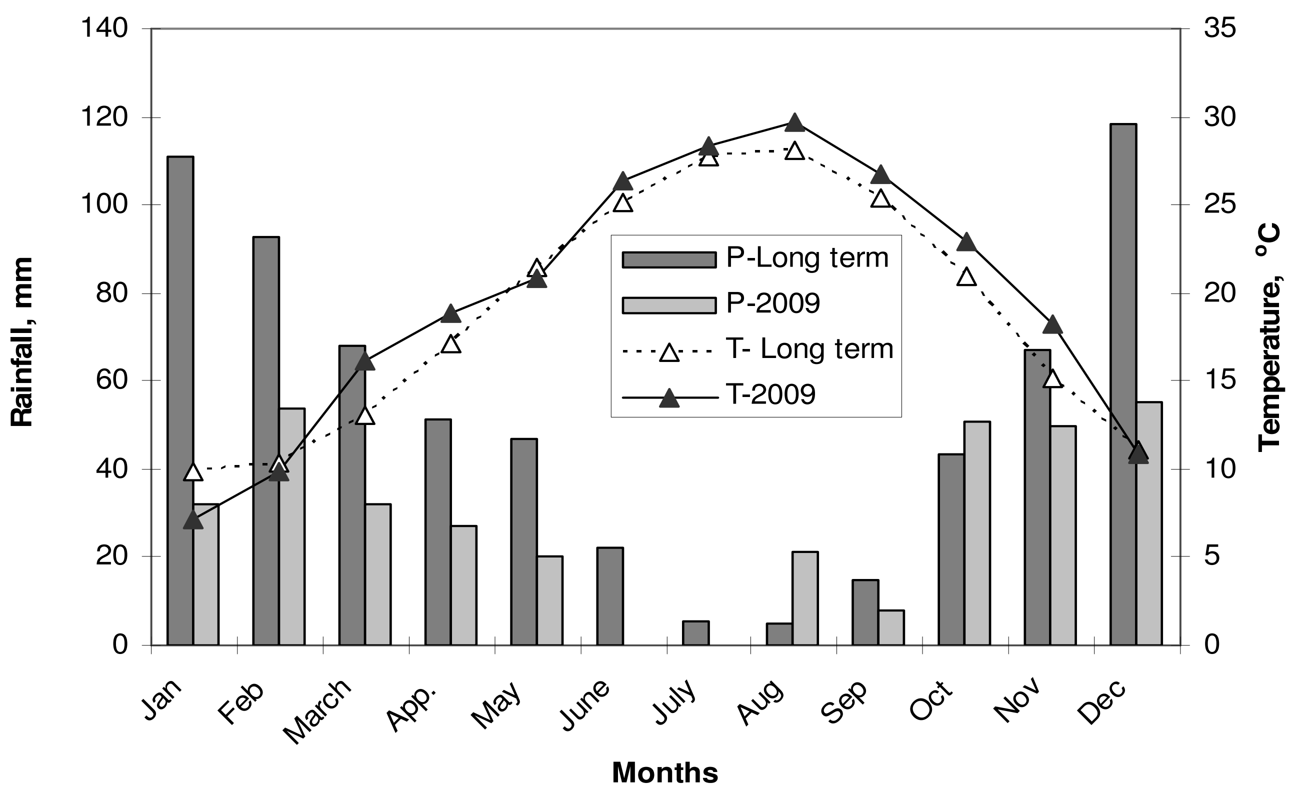

Figure 2. Environmental conditions. Period 1929 - 2009 and experimental period (2009).

automated agro climatic station. Figure 2 shows the data related to temperatures and rainfall corresponding to these periods. During the study year, total rainfall value was 349.5 mm year^{-1} which is lower than the long-term average.

Weighing lysimeter

One precision continuous weighing lysimeter, 2m × 2m × 2.5m deep, was used to directly measure soybean evapotranspiration (Figure 3). It was located at the center of more than 1.0 ha area of soybean maintained in optimum growth condition with the object of measuring potential evapotranspiration (ETc) value. Soybean crop inside the lysimeter was kept in the same condition of growth as the rest of the protection plot so that data will be as representative as possible.

The inside tank, which contains distributed soil inside, is located over a system of balances and a counterweight that offset dead weight from the soil and inside tank. In the balance system, *S type* load cell was used with a nominal capacity of 1000 kg, a 2 mV V^{-1} output range of excitation and an input of 10 V at full load. The balance system which was used in the experiment is an electro mechanic balance system. For this reason only one load cell was used in the experiment. The load cell is connected to an electronic

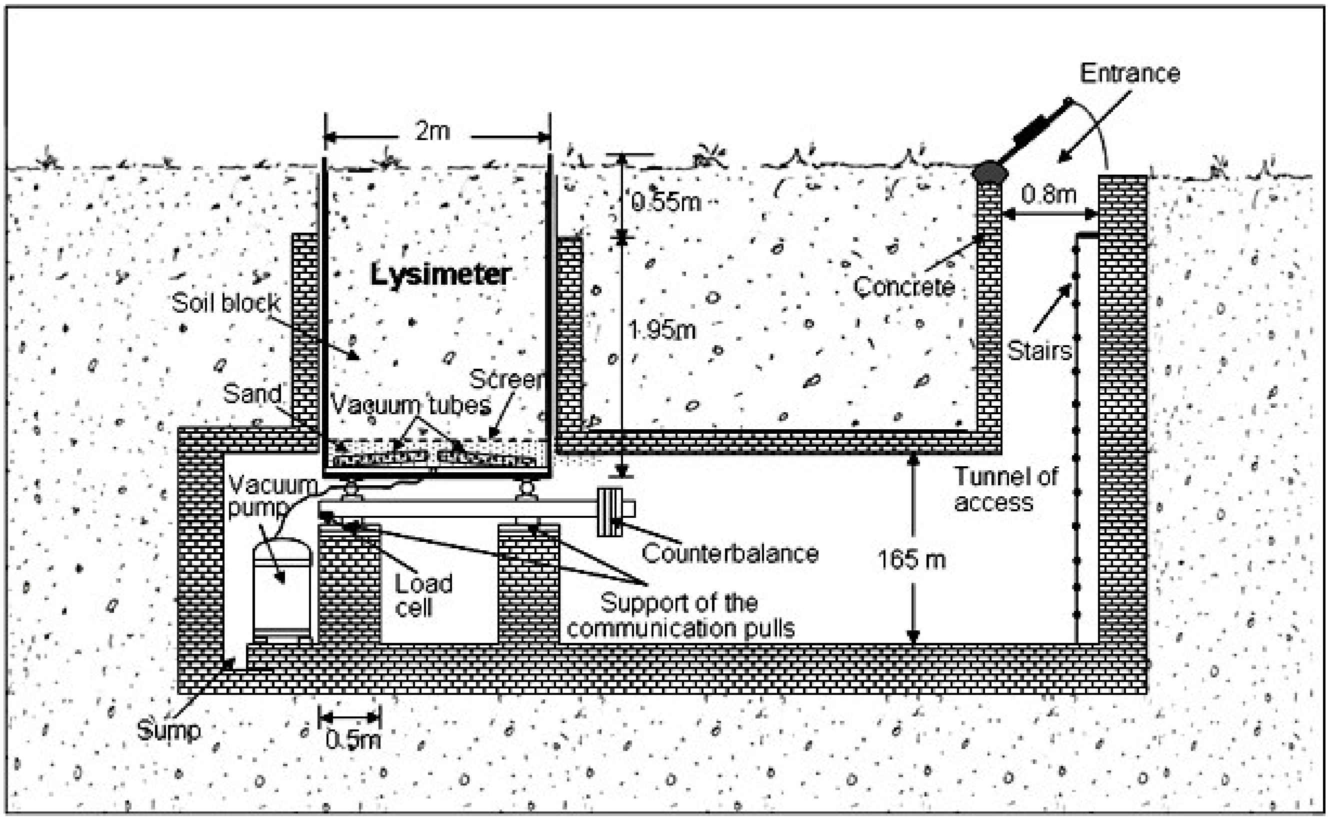

Figure 3. Continuous weighing lysimeter located at the Research Fields of the Agricultural Structure and Irrigation Department of the Cukurova University, Faculty of Agriculture, and Adana, Turkey.

visor, with a resolution of 0.100 kg, which is equivalent to 0.025 mm of water.

The lysimeter has the necessary equipment to precisely evaluate inputs (rain and irrigation) as well as outputs (evapotranspiration and deep drainage). In order to continue measurement of soil water content and uniformity throughout its profile, a neutron probe has been installed in the inside tank of lysimeter and as shown by Howell et al. (1985), a 0.27 m layer of washed pea gravel was installed in the bottom of the inside tank. A free drainage system was installed into the gravel layer, and a 0.18 m sand layer was installed above the gravel. The vacuum drainage system was installed between the sand and soil. After each irrigation, 33 kPa vacuums was applied for obtaining uniform soil water distribution inside of the lysimeter profile and to facilitate drainage of water from the bottom of the tank. The weighing system of lysimeter was tested and calibrated using methods given by Marek et al. (1988) and Howell et al. (1985, 1995). On the other hand, 2 soil heat flux plates have been installed within the soil container at the depths of 0.15 and 0.30 m from soil surface.

The soil which is used to fill the inside tank was taken from the same area where the experimental work was carried out, the properties of which are given in Table 1. Soil profile was installed using methods given by Howel et al. (1985). Soil samples were taken from the 0.3 m layer up to 2.1 m depth and kept near the system till they reached air dried weight. Although soil information indicated that no significant soil layering and other soil restrictions, replacement of the soil into the lysimeter followed exact profile removal pattern. Air dried soil was repacked in 0.10 m layers into the inside tank (soil container) to achieve the bulk density of the each layer determined from the natural soil profile.

The lysimeter measurements during the study are affected by irrigation, precipitation and moving by wind. All recordings affected by this kind of events were eliminated. During research no differences were observed between the growth of soybean inside and outside of the lysimeter. Weight data generated by the lysimeter and registered on the visor were stored in the datalogger. The equipment was programmed to take weight readings every 5 s (12 readings per min), and recordings were made every 5 min, hourly and daily. The data acquisition unit was connected to a personal computer, located in the control room of the lysimeter station, where software was installed to make communication with the datalogger possible, to program it and to obtain data files that were being generated. For measurement of the lysimeter, consecutive weight data and irrigation and drainage water amount were used.

The weighing system of the lysimeter was calibrated for its range, stability, repeatability and sensitivity (Marek et al., 1988). The test of the range was accomplished by adding and removing the known weights from 10-50 kg and recording the readings after each weight change. Figures 4a and b show the close linearities of the calibration data (R^2 = 0.999) for two cases. To test the stability of lysimeter, 1000 kg of weight was added to the lysimeter in 3 h, and then the readings were recorded every 30 min (Figure 4c). From the Figure 4c, it was concluded that it took about 3 h for the weighing system to become stabilized after adding a large weight in a short time. When a little weight (<100 kg) was added or removed, the weighing system showed no hysteresis. The sensitivity of the weighing system to detect small weight changes was determined by adding and removing very small weights such as 100, 200, 300,

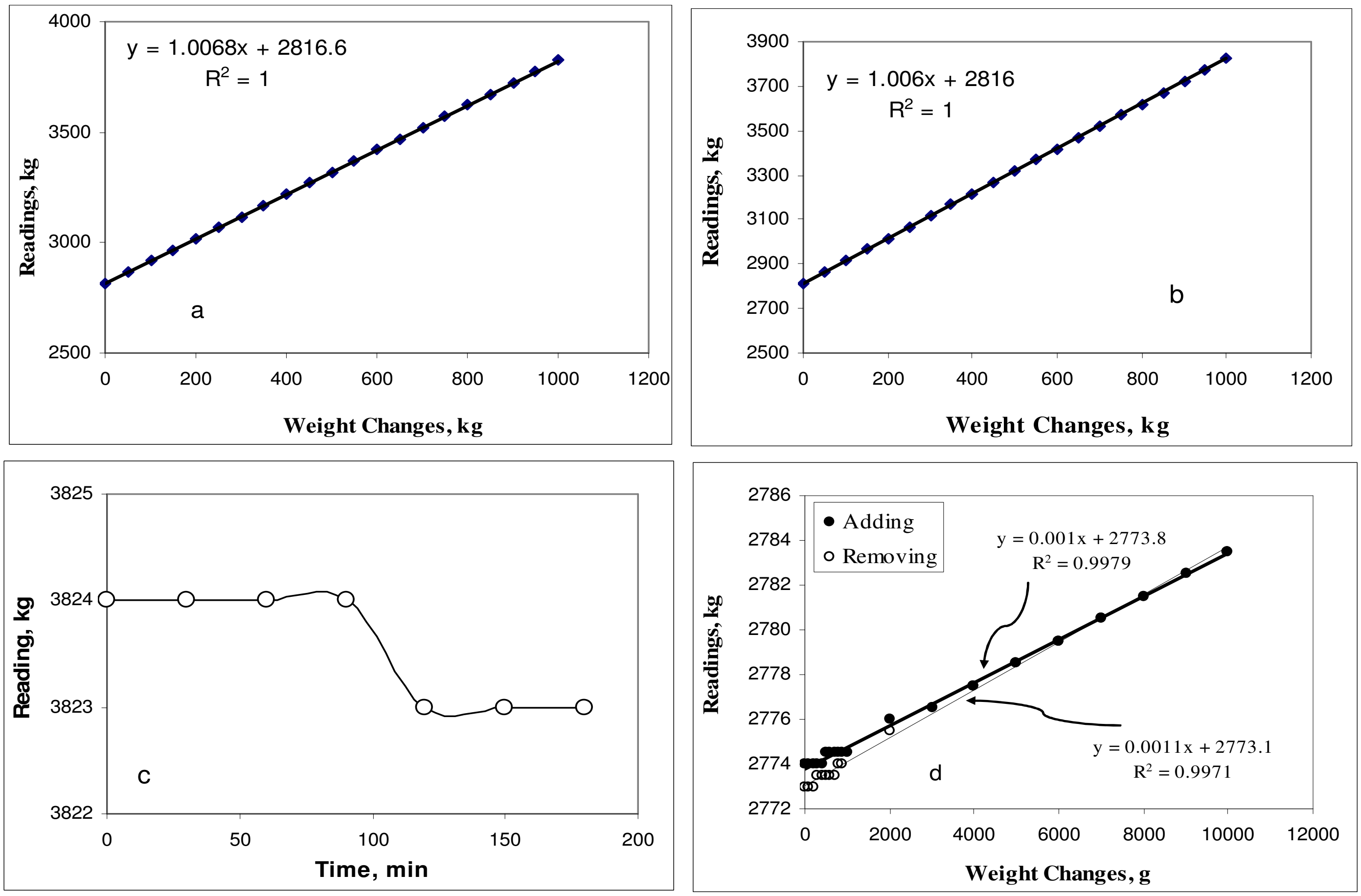

Figure 4. Results of calibration of lysimeter weighing system (an increasing mass, b decreasing mass, c stability and d sensitivity).

1000, 2000, 3000, and 10000 g of poises in succession (Figure 4d). The results indicated that the absolute resolution is 200 g of mass changes, but that the actual resolution is 100 g, equivalent to 0.025 mm of water. The higher variability of measurements was found when the mass added to the lysimeter was distributed unevenly.

The Bowen ratio-energy balance, BREB, method

A Bowen ratio-energy balance (BREB) system was initially installed near the lysimeter system on DOY 175 and used to determine the potential evapotranspiration of soybean (ETc). The Bowen ratio is defined as the ratio of sensible to latent heat (Bowen, 1926), and is expressed as

$$\beta = \frac{H}{LE} \tag{2}$$

Where β is Bowen ratio, H is the sensible heat flux ($Jm^{-2}s^{-1}$) and LE is the latent heat flux ($Jm^{-2}s^{-1}$). The measurements taken by the Bowen system were evaluated in the following order to determine the crop water consumption. The energy balance of a crop stand, neglecting minor terms, is expressed as:

$$Rn = G + LE + H \tag{3}$$

Where Rn is net radiation, LE and H are latent and sensible heat, respectively, and G is the heat flux in the soil. All fluxes are expressed in units of $Jm^{-2}s^{-1}$. In the energy balance equation, all the terms were considered positive and negative for heading to and from the surface, respectively. Taking the energy balance equation into account, the latent heat flux was rewritten according to Held et al. (1990) as:

$$LE = \frac{Rn - G}{1 + \beta} \tag{4}$$

As described before, the Bowen ratio, □, is the ratio of sensible to latent heat fluxes and is calculated by the following equation (Steduto et al., 1997):

$$\beta = \frac{\rho_a \ Cp \ Kh \ \frac{\Delta T}{\Delta z}}{\rho_a \ L \ Kw \ \frac{\Delta q}{\Delta z}} = \frac{Cp \ \Delta T}{L \ \Delta q} = \frac{Cp \ Pa \ \Delta T}{L \ \frac{Mw}{Ma} \Delta e} = \gamma \frac{\Delta T}{\Delta e} \tag{5}$$

where ρa is the dry air density (mol air^{-1}m^{-3}), Cp is the specific heat capacity of dry air at constant pressure (Jmol air^{-1}°C^{-1}), Kh and Kw are the turbulent exchange coefficients for heat transport and water vapor transfer (m^{2}s^{-1}), Δq is the difference of the water vapor concentration of two heights of the canopy (mol H_2O mol air^{-1}), L is the latent heat of vaporization (J mol H_2O^{-1}), ΔT is the differences in temperature of two heights above the canopy (°C), Δz is the differences in the measurement of heights above the canopy (m), Mw and Ma are the water and air mol weights, respectively (gmol^{-1}, Mw/Ma=0.622), γ is the psychometric constant (kPa°C^{-1}), and Δe is the differences of vapor pressure of two heights above the canopy (°C kPa^{-1}).

BREB system consisted of two integrated temperature-humidity probes (platinum temperature sensors 100- Ω thermo-element and Dew-10, General Eastern, Watertown, MA, USA) inside radiation-shielded. Two calibrated thin film platinum resistance temperature devices (PRTDs) were incorporated in each temperature–humidity probe. One PRTD measured air temperature used to calculate the air temperature gradient and the other measured the air temperature of the humidity sensor cavity of the probe, which was used to calculate the saturation vapor pressure of water. A capacitive humidity sensor measured relative humidity (Champbell, 1991). The values calculated for every height were averaged for 15 min and stored in the datalogger. The distance between the lower and upper arms of apparatus was 1.0 m. The height of sensors was periodically adjusted as soybean grew so that the bottom sensors were at least 0.3 m over the canopy. Maximum height of the top sensors during the study was 1.3 m over the canopy. Net radiation was measured with a Q-7 model radiometer installed 1.0 m over the soybean canopy as parallel to soil surface. Installation of the equipments was done according to rules by Held et al. (1990). The sensor on the radiometer was wrapped with 0.25 mm thick polyethylene cover for protecting rainfall and wind. Soil heat flux was measured with 2 sensors placed 2-3 cm soil depth (Champbell, 1991).

Fetch for the BREB system ranged from a minimum of 40 m to the north to 60 m to the south. Prevailing winds during the growing season were southerly. The maximum fetch to height ratio of the top sensors varied between 30:1 and 50:1.

Comparison of soybean evapotranspiration measurement methods

Soybean evapotranspiration was measured for daily and hourly basis throughout of the growing season. For comparison of two methods, hourly ET values were chosen for some selected days during the different growing stages of soybean. Several comparisons were obtained through the simple linear regression technique and a set of statistics proposed by Jensen et al. (1990). For comparison of ETc values measured by lysimeter and BREB methods, three criteria were used.

(i) Percentages of measured BREB-ETc over measured values of lysimeter-ETc were determined.
(ii) The root mean square error, RMSE, and the index of agreement, *d*, were calculated between values of ETc of lysimeter and BREB methods using the following equations (Lopez-Urrea et al., 2006).

$$RMSE = \left[(N)^{-1} \sum_{i=1}^{N} \left(ET_{LYS} - ET_{BREB} \right)^2 \right]^{0.5} \tag{6}$$

Where ET_{LYS} is the ETc measured by lysimeter system for daily basis, mm, ET_{BREB} is the measured ETc by BREB method, mm day^{-1}, and N is the number of observations and,

$$d = 1 - \left[\frac{\sum_{i=1}^{N} \left(ET_{LYS} - ET_{BREB} \right)^2}{\sum_{i=1}^{N} \left(\left(ET_{LYS} - ET_{LYS(ave)} \right) + \left(ET_{BREB} - ET_{BREB(ave)} \right) \right)^2} \right] \quad 0 \le d \le 1 \tag{7}$$

Perfect agreement would exist between lysimeter and BREB ET if d = 1.
(iii) A regression analysis was carried out to relate the measured ETc of lysimeter to BREB. In the regression, the values obtained from the lysimeter were independent, while the BREB-ETc values were dependent. The correlation coefficient was tested for its significance using a t-test.

RESULTS AND DISCUSSION

Daily and seasonal evapotranspiration

Cumulative lysimeter ET of soybean was nearly 354 mm from DOY 175 through DOY 279 for a daily average of 3.4 mm d^{-1}, while the Bowen ratio-energy balance (BREB) totals were 405 mm with a daily average of 3.9 mm d^{-1} (Figure 5a). The BREB and lysimeter values showed similar seasonal trends and responses to changes in daily meteorological conditions throughout the season, although significant differences between methods were observed. The lysimeter and BREB methods showed good agreement in cumulative totals until DOY 185 (Figure 5a). The BREB continued to have a higher water evaporation rate after the methods diverged. Considering the closer examination of the results, cumulative totals show that differences were attributed to a short time from DOY 185 to 198 following a rain of 13 mm. There were other periods during the latter part of the season following rain or irrigation events in which the BREB exhibited increased ET amounts. Total ET of soybean measured by BREB method was 15% higher than that in lysimeter ET.

Daily totals of ET for the lysimeter and BREB were seasonally consistent in trend, with some disagreement between methods (Figure 5b). Differences among daily ET values were initially big in the trial year. During the initial growing period, BREB estimates were consistently larger than lysimeter values until DOY 220, then lysimeter ET increased rapidly and remained so until the end of the season. These results are different from those obtained by Prueger et al., (1997). Researchers compared BREB ET of lentil against lysimeter ET in eastern Montana, Great Plains and observed that lysimeter daily ET of lentil was larger than BREB method.

Figure 6 presents the regression analysis of daily and hourly ET values calculated from lysimeter and BREB measurements. Comparing the measurements from BREB and lysimeter measurements showed that for the soybean,

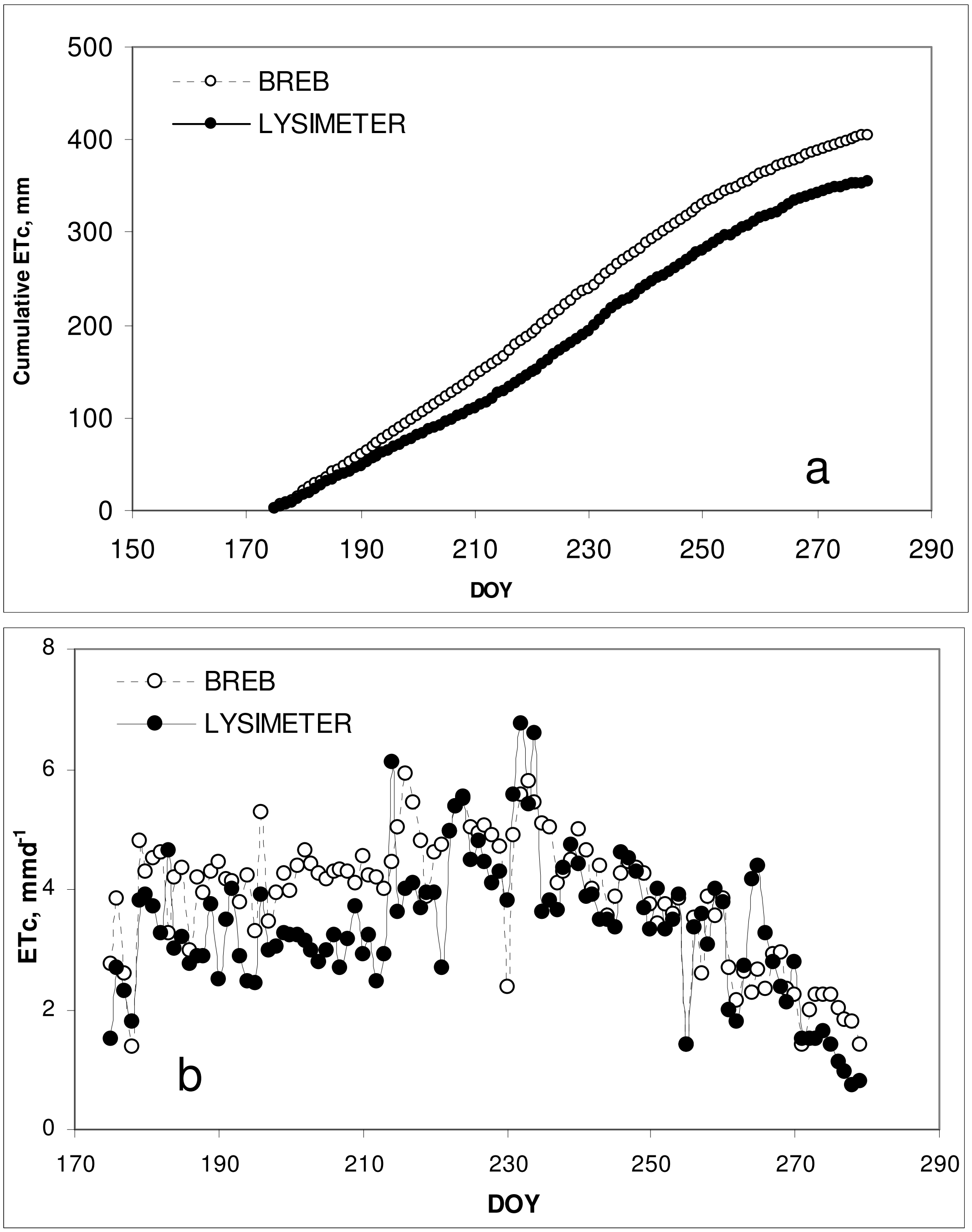

Figure 5. Cumulative (a) and daily total (b) evapotranspiration, ETc, from lysimeter method and Bowen-Ratio Energy Balance, BREB, method for soybean grown at Adana.

BREB had larger daily ET values than lys-imeter, although the fit between the two data sets was good, the BREB overestimated the lysimeter, as eviden-ced by slope of line equal to 0.6842, an intercept of 1.5505, and an R^2 of 0.555. The BREB overestimated the lysimeter by averagely 0.485mm per day and had a range of differences from 0.1 to 2.05 mm d^{-1} (Figure 6a). The reason of this overestimation was due to the fact that the water content is higher and the plant is more developed in the field than those in the lysimeter throughout growing season. Increased ET from BREB may be due to either increased soil water evaporation or plant transpiration.

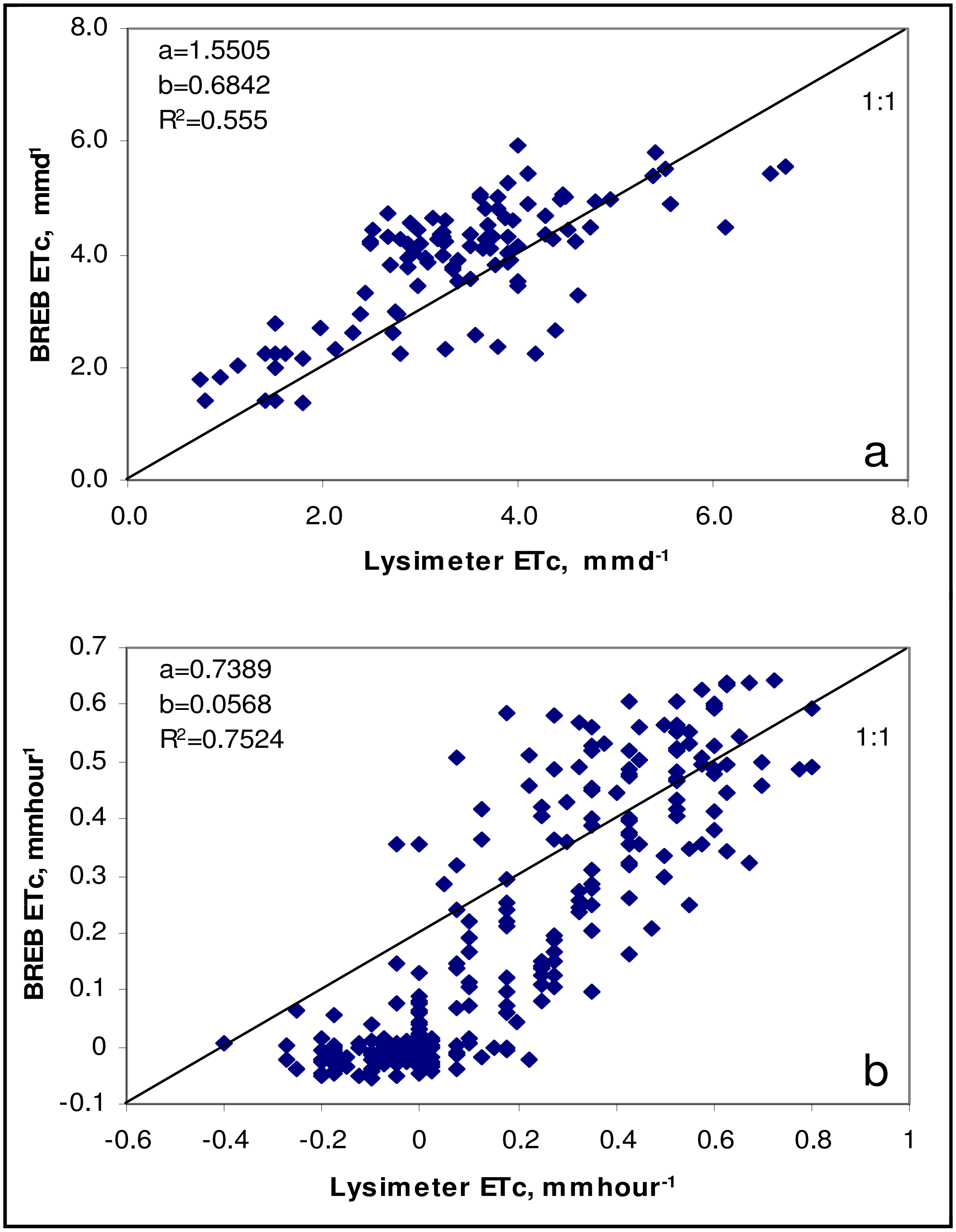

Figure 6. Comparison of BREB and lysmeter daily evapotranspiration (ETc) totals for soybean crop grown at Adana.

However, it is not possible to separate these processes with a single measurement. Nonetheless, differences between the BREB and lysimeter show that there was increased soil water availability within the field relative to the lysimeter. There were periodic soil water measurements with a neutron probe in 90 cm soil depths of lysimeter and field plot and some measurements of crop properties to confirm these observations (Figures 1 and 7).

In hourly ET, agreement between BREB and lysimeter measurements improved, although more scatter about

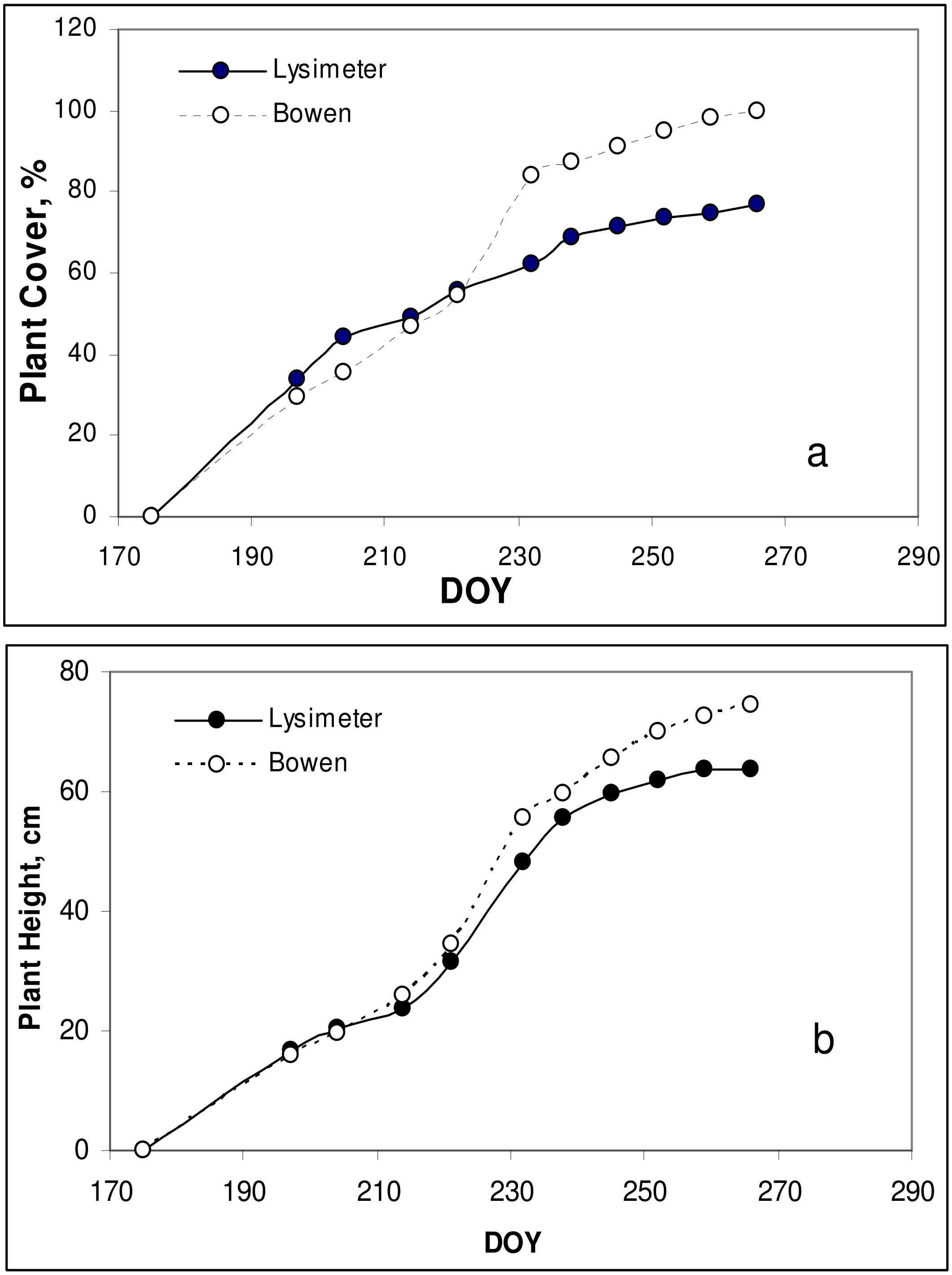

Figure 7. Change of plant height (a) and plant cover (b) during the growing period of soybean in the field and the lysimeter.

the 1:1 line was observed. The slope of the line is 0.057, with an intercept of 0.74 and R^2 of 0.75. The mean difference was 0.02 mm per h and a range of differences varied from 0.43 to -0.003mm h^{-1} (Figure 6b). The evidence that the field has access to more water than the lysimeter was revealed in the wide range of evaporation rates from the field, particularly at the higher BREB rates (Figure 6a). These results are completely different from those obtained by Prueger et al. (1997). In this study, daily ET from BREB method was evaluated and compared with a weight lysimeter. They found that there was high tendencies the BREB method underestimated the lysimeter. A similar result was obtained by Bausch and Bernard (1992). They have explained that results from a comparison of BREB measurements with lysimeter ET measurements on a day following irrigation showed that daily BREB latent heat flux underestimated daily lysimeter latent heat flux by 8%. However, during the daylight period (sunrise to sunset), BREB underestimated lysimeter by 1.4%; lysimeter was overestimated by 0.2% during the period 06:30 to 18:45 h. Zeggaf et al. (2008) have compared maize ET values measured by BREB, weighing lysimeter and sap flow methods. Results showed that, on the average, the BREB method underestimated by 6% the latent heat flux measured by weighing lysimeter data and overestimated by 14% that obtained by sap flow data resulting in a 30% underestimation of the measured latent heat flux at the soil surface. Contrarily, the results taken by Todd et al. (2000), showed that daily ET estimated by the BREB method agreed within 3% of lysimeter ET in the first year of experiment, but overestimated ET in the second year, especially when rates were greater than 6 mmd^{-1}. The BREB method also tended to overestimate half-hourly measurements of ET. In another study by Gavilan and Berengena (2007), the BREB method overestimated daily ET by an average of 5.5% and by 5.7% when only daylight hours were considered. Hourly ET rates were calculated for some selected days in the different growing stages of crop development, mid-season and late season and plotted as hourly courses (Figure 8). Growing periods of soybean in this study were determined to be 15 days from DOY 175 to DOY 189 for initial, 30 days from DOY 190 to DOY 219 for crop development, 40 days from DOY 220 to DOY 259 for mid-season and 20 days from DOY 260 to DOY 279 for late season. The selected days illustrate the middle of the growing stages which are DOY 206, DOY 237 and DOY 269. During the crop development stage, BREB ET was greater than lysimetric ET during the noon time and afternoon h, but agreed more closely day time morning. In the other days represented to other growing periods, hourly ET values from two methods showed the similar trend, except lysimetric ET during noon time h was higher than BREB ET. Hourly ET from lysimeter was consistently less than BREB ET during the night-time h. Disagreement of the BREB method with lysimeters appeared to have two components. There was a consistent disagreement during the afternoon h which was common to all growing seasons. There were also several days when the BREB method strongly disagreed with lysimetric ET. Notable examples of this were on DOYs 198, 201, 206 and 209 during the development stage when hourly Bowen ET exceeds ET from lysimeter by 21-55%, and DOYs 226, 242, and 248 during the mid-season stage, when hourly Bowen ET exceeded lysimetric ET by 9 - 52%, and DOYs 259, 265 and 273 during mid season when ET exceed ET from lysimeter by 51- 67%.

Table 2 shows the results of this comparison, through some statistical parameters such as simple regression analysis between two methods, and indicates the calculation of error and the index of agreement for daily and hourly measurements with both lysimeter and BREB methods. This comparison was conducted from 105 and 336 observations from both calculations, daily and hourly, respectively. The BREB ET for calculation was taken as dependent variables while the ET measurements made in lysimeter, as independent variable.

Values for A, B and R^2 are highly significant ($p \leq 0.01$) in all cases. The BREB method showed a good performance for daily ET estimation when compared to values measured by lysimeter. This method, with a RMSE of 0. 79 mmd^{-1} and a 0.96 index of agreement, 15% overestimates lysimetric measurements. The BREB method also performs well compared with lysimetric measurements for hourly ET, but produces overestimation of 14% with RMSE of 0. 128 mmh^{-1}, and a 0.92 index of agreement.

These results are slightly different from results taken by Prueger et al. (1997), and Zeggaf et al. (2008) while similar with studies by Todd et al. (2000), and Gavilan and Berengena (2007). In these considered studies, ET from BREB method overestimates the lysimetric ET during the different day time when latent heat fluxes were high; whereas it gives underestimation the lysimetric ET when latent heat flux is small.

Conclusion

The BREB method accurately measured ET in semiarid conditions compared with lysimeter measurements. However, BREB method overestimated daily and hourly ET lysimetric measurements by 15 and 14%, respectively. Differences in ET estimates in this study were caused by increased soil water in the field following large rain or irrigation events. Inadequate drainage overall field relative to in the lysimeter may be responsible for these observations. The BREB method overestimated ET in the afternoon h, but agreed well with lysimeter ET during morning time. Latent heat flux was overestimated by the BREB method when sensible heat flux was negative or positive, and whether or not there was sensible heat advection. In spite of these, the BREB technique can provide good estimates of ET over larger areas than is possible with lysimeters. These data provide confidence in using a simple, nonexchanging BREB method to obtain accurate estimates of ET. Throughout a growing season in a semiarid climate, the BREB system can be used to assess differences in water use among different practices in areas without lysimeter installations.

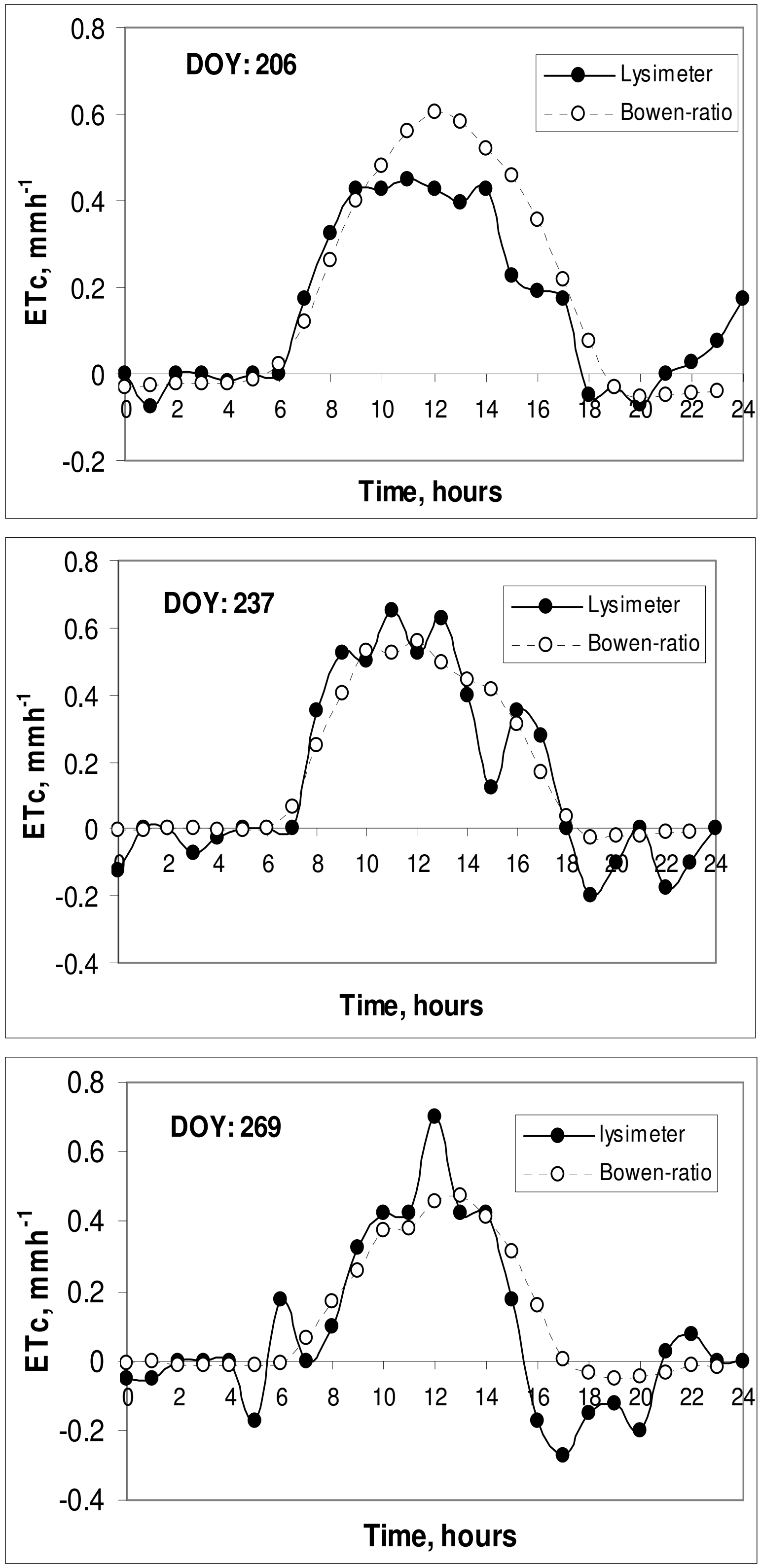

Figure 8. Relation between measured and estimated hourly ET by lysimeter and Bowen Ratio methods in some selected days during the different growing periods of soybean.

Table 2. Some statically parameters used for comparison of ET measurements taken with lysimeter and Bowen-ratio methods*.

Time step	N	ET_{LYS} mm	ET_{BREB} mm	ET_{BREB}/ET_{LYS} %	Y=A+BX			RMSE	d
					A	B	R^2		
Daily	105	3.4	3.9	115	1.55	0.68	0.55	0.79	0.96
Hourly	336	0.11	0.16	114	0.057	0.74	0.75	0.128	0.921

*N, Observation number; ET_{LYS}, average ET measured with lysimeter (daily and hourly time steps), ET_{BREB}, average ET measured with Bowen-ratio (daily and hourly time steps); A, intercept of the equation; B, regression coefficient (slope); R^2, determination coefficient; RMSE, root mean square error (mmd^{-1} and mmh^{-1}) ; d, agreement index.

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