COMPARATIVE ANALYSIS OF THE PYSEBAL MODEL AND LYSIMETER FOR ESTIMATING ACTUAL EVAPOTRANSPIRATION OF SOYBEAN CROP IN ADANA, TURKEY

Alidou Sawadogo [1]*, Hessels Tim [2], Kemal Sulhi Gündoğdu[1], Ali Osman Demir [1], Mustafa Ünlü [3], Sander Jaap. Zwart [4]

[1] Uludag University, Faculty of Agriculture, Biosystems Engineering Department, Bursa-Turkey.
(sawadogoalidou@yahoo.fr; kemalg@uludag.edu.tr; aodemir@uludag.edu.tr); **ORCID 0000-0002-7437-8415, ORCID 0000-0002-5591-4788, ORCID 0000-0003-3409-6680**
[2] UNESCO-IHE Institute for Water Education, Delft, The Netherland. (timhessels@hotmail.com);
ORCID 0000-0002-7264-7220
[3] University of Çukurova, Faculty of Agriculture, Department of Agricultural Structures and Irrigation, Adana - Turkey.
(munlu@cu.edu.tr); **ORCID 0000-0002-1889-516X**
[4] University of Twente, Faculty of Geo-Information Science and Earth Observation, Department of Natural Resources.
(s.zwart@cgiar.org); **ORCID 0000-0002-5091-1801**

ABSTRACT: Accurate estimation of evapotranspiration (ET) is an important factor in water management, especially in irrigated agriculture. Accurate irrigation scheduling requires accurate estimation of ET. The objective of this study was to estimate the actual evapotranspiration (ET_a) by the pySEBAL model and to compare it with the actual evapotranspiration measured by the lysimeter method of soybean crop in Adana, Turkey. Five Landsat 5 Thematic Mapper (TM) images and weather data were used for this study to estimate actual evapotranspiration by the pySEBAL model. The results showed a good relationship between ET_a estimated by the pySEBAL model and ET_a measured by the lysimeter method, with an R^2 of 0.73, an RMSE of 0.51 mm.day^{-1}, an MBE of 0.04 mm.day^{-1} and a Willmott's index of agreement (*d*) of 0.90. Based on this study, there is a good relationship between the actual evapotranspiration estimated by the pySEBAL model and the actual evapotranspiration measured by the lysimeter method. Consequently, ET_a of soybean crop can be estimated with high accuracy by the pySEBAL model in Adana, Turkey.

Keywords: Actual Evapotranspiration, Lysimeter, PySEBAL Model, Remote Sensing.

1. INTRODUCTION

Freshwater resources are becoming increasingly scarce in many parts of the world (Anonymous, 2007) and agriculture is the largest water user worldwide (FAO, 2011). Water use in agriculture is one of the main causes of the water scarcity, and according to the FAO (2009), the world's population is predicted to increase to 9.1 billion people by 2050. Face to this reality, there is a need to increase agricultural water productivity in a sustainability way to meet rising demands for water and food. Water productivity can be improved by increasing yield using less water. This could be done by proper irrigation management practices. In this process, more water could be save to meet the rising demand for water. To improve water productivity by proper irrigation management, a precise knowledge of evapotranspiration is required. ET can be estimated by many methods such as direct measurements using the lysimeters (Allen et al., 1998) and indirect measurements using remote sensing-based methods (Bastiaanssen, 1995).

The remote sensing model, such as the Surface Energy Balance Algorithm for Land (SEBAL) model developed by Bastiaanssen et al. (1998), is used to estimate the ET_a (Bastiaanssen et al., 2005). Other energy balance models such as the Surface Energy Balance System (SEBS) developped by Su (2002), the Simplified Surface Energy Balance Index (S-SEBI) developed by Roerink *et al.* (2000) and most recently, the Mapping Evapotranspiration at high Resolution with Internalized Calibration (METRIC) algorithm developed Allen et al. (2007) to estimate the crop water consumption. SEBAL has been validated in many countries under a wide variety of conditions (Bastiaanssen et al., 2005) and has been identified as the most promising approach currently available to estimate evapotranspiration. The Python module for Surface Energy Balance Algorithm for Land (pySEBAL) model was developed by the IHE-Delft Institute for Water Education. Lysimeters, both weighing and drainage types, are considered as basic method to calibrate evapotranspiration models (Mata et al., 1999; Centinari et al., 2009). Weighing lysimeters are considered as standard for ET measurements. However, due to their high prices, these units are few in number at any given location.

To estimate crop water use for irrigation management, remote sensing-based methods may be more appropriate than lysimeters. One of the main advantages of remote sensing-based methods is their ability to provide the spatial variability of the ET under a different range of scales. There is a general consensus that the SEBAL model provide reliable measure of ET_a. However, the model need to be validated for a given area. The accuracy of the evapotranspiration determined from SEBAL model can be assessed from lysimeters data. In this study, the pySEBAL model was applied to estimate actual evapotranspiration of soybean crop in Adana, Turkey. The estimated ET_a from the pySEBAL model was compared with the ET_a measured by the lysimeter method and the accuracy of the pySEBAL model to estimate ET_a of soybean crop in Adana, Turkey was discussed.

2. MATERIALS AND METHODS

2.1. Lysimeter Data Collection

In this study, secondary data of actual evapotranspiration measured by lysimeter is used (Table.1). Actual evapotranspiration was directly measured by a weighing lysimeter in the center of 0.12 ha field at Research Fields of the Agricultural Structures and Irrigation Department, Faculty of Agriculture, University of the Cukurova (37° 1' N, 35° 21' E, and 20 m above sea level) Adana, Turkey. Turkey is between the 36° and 42° north latitudes and 26° and 45° south meridians (Iscan and Ilgaz, 2017; Ernst et al 2019). Lysimeter was used to measure well-watered soybean (*Glycine max* L.) evapotranspiration growing in 2009 season. Arioglu soybean cultivar was used in this study. Soybean crop have been sown on 175 Day of year (DOY) and inter and intra row distances of 0.70 m and 0.10 m, respectively, were applied. Irrigation was applied using a drip irrigation system (Table.1) and crop growth inside and outside of the lysimeter was homogenous. The fertilization doses of 36 kg.ha^{-1} pure nitrogen and 92 kg.ha^{-1} phosphor, P_2O_5, recommended in the region for soybean were applied (Uncu and Arioglu, 2005). The soil texture in the experiment plot 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. The climate of study area is typical Mediterranean climate, with cool rainy winters, and hot dry summers. Temperature varies from 9.9 °C in January to 28.1 in August.

Table.1. Irrigation intervals (day of year), depth of irrigation water (mm) and ET_a (mm)

Day of Year	Irrigation Water (mm)	lysimeter ET_a (mm)
177	64.0	2.7
197	na[1]	2.9
210	43.4	3.7
213	na	2.5
223	32.3	5.0
229	na	4.1
231	23.6	3.8
239	24.0	4.4
245	na	3.5
247	26.4	4.6
253	16.0	3.3
261	16.5	3.8
277	na	1.1

[1] na: not applicable

2.2. Meteorological Data

Hourly air temperature, wind speed, relative humidity, and solar radiation, were used in the pySEBAL model (Table 2). Weather data were obtained from the Adana meteorology station and from http://www.soda-pro.com for solar radiation.

Table.2. Meteorological data

Day of Year	Wind speed (m.s⁻¹)	Air temperature (° C)	Relative humidity (%)	Solar radiation (W.m⁻²)
197	1.1	27.5	77.7	238
213	1.2	29.2	76.3	278
229	1.2	29.0	83.3	298
245	1.2	28.9	78.7	221
277	1.3	23.3	60.8	200

Table.3. Landsat scenes information

Number	Day of Year	Landsat Scene	Acquisition day	Overpass Time(AM)
1	197	LT51750342009197MOR00	2009-07-16	10:04:32 AM
2	213	LT51750342009213MOR00	2009-08-01	10:04:47 AM
3	229	LT51750342009229MOR00	2009-08-17	10:05:01 AM
4	245	LT51750342009245MOR00	2009-09-02	10:05:16 AM
5	277	LT51750342009277MOR00	2009-10-04	10:05:40 AM

2.3. Landsat Images

Due to the lack of Landsat free cloud images in the period of interest, five Landsat 5 TM clear-sky images were used in this study. Landsat images were downloaded from the Earth Explorer (https://earthexplorer.usgs.gov/) website. Table 3 shows the scene information used in this study.

2.4. Surface Energy Balance Algorithm for Land (SEBAL)

The SEBAL model is based on modelling the surface energy balance using remote sensing data. The pySEBAL model was developed by IHE-Delft Institute for Water Education in Python programming language (https://pypi.org/project/SEBAL/). A brief summary of the main algorithms of the pySEBAL model is given below. The model calculates the latent heat flux (λE, W.m⁻²) as the residual of surface energy equation:

$$\lambda E = R_n - G - H \tag{1}$$

where R_n is the net radiation (W.m⁻²), G is the soil heat flux (W.m⁻²) and H is the sensible heat flux (Wm⁻²).

Net radiation (R_n): R_n is computed using the following equation:

$$R_n = (1 - \alpha) \, Rs \downarrow + RL \downarrow - RL \uparrow - (1 - \varepsilon_0) \, RL \downarrow \tag{2}$$

where α is the surface albedo, $Rs\downarrow$ is the incoming shortwave radiation (W.m⁻²), $RL\downarrow$ is the incoming longwave radiation (W.m⁻²), $RL\uparrow$ is outgoing longwave radiation (W.m⁻²), and ε_0 is surface emissivity.

Soil heat flux (G): The following equation is used to calculate G.

$$G = R_n(T_s \, (0.0038 + 0.0074 \, \alpha)(1 - 0.978 \times NDVI^4)) \tag{3}$$

where T_s is the surface temperature (K) and NDVI is the normalized difference vegetation index.

Sensible heat flux (H): H is estimated using the heat transfer equation:

$$H = \frac{\rho \times c\rho \times dT}{rah} \tag{4}$$

where ρ is the air density (kg.m⁻³) $c\rho$ is the specific heat of air at constant pressure (J.kg⁻¹. K⁻¹), dT is the vertical near surface temperature difference (K) and *rah* is the aerodynamic resistance to heat transport (s.m⁻¹). H is calculated in an iterative way due to the relationship between the aerodynamic resistance and sensible heat flux. Within the first iteration, a neutral air condition without convection is assumed. This first iteration will result in a sensible heat flux, and therefore, the air will become unstable, which will change the aerodynamic resistance. This will provide the input for the next iteration step. This iteration is performed multiple times to find the final sensible heat flux.

Evaporative Fraction (EF): The instantaneous EF is calculated using the following equation:

$$EF_{inst} = \frac{\lambda E}{\lambda E + H} \tag{5}$$

The instantaneous evaporative fraction can be used to calculate the daily ET. The daily evaporation is calculated using the following equation:

$$ET_{24} = EF_{inst} \times AF \times \frac{R_{n24}}{\lambda \times \rho_w} \times 86400000 \tag{6}$$

where AF is the advection factor, λ is the latent heat of vaporization (J.kg⁻¹) and ρw is the density of water (kg.m⁻³). The advection factor is used to account for any effects

of regional advection and is calculated by the following equation:

$$AF = 1 + 0.985(\exp((e_{sat\_24} - e_{act\_24}) \times 0.08) - 1) \, EF_{inst} \qquad (7)$$

where e_{sat_24} is the 24-hour averaged saturated vapor pressure (kPa) and e_{act_24} is the 24-hour averaged actual vapor pressure (kPa).

2.5. Statistical Analysis

Statistical comparison between actual evapotranspiration obtained by the pySEBAL model and by the lysimeter method was done using a simple linear regression. Others statistical evaluations, such as the root mean square error (RMSE), the coefficient of determination (R^2), the Willmott's index of agreement (*d*) and the mean bias error (MBE) were used to determine the relationships between ET_a obtained from the pySEBAL model and from the lysimeter method.

3. RESULTS AND DISCUSSIONS

3.1. PySEBAL Model Based ET_a Maps

Fig. 1 and Fig. 2 shows maps of daily actual evapotranspiration around the area of interest. The white small square in Fig. 1 and Fig. 2 shows the pixel selected for ET_a data collection. The selected pixel shows the lysimeter field. The Day of Year (DOY) 197 and the DOY 245 of the Fig. 1 and Fig. 2, respectively, shows the variation of ET_a by the pySEBAL model throughout the 2009 growing season. The ET_a was 2.3 mm.day^{-1} and 3.1 mm.day^{-1} for the DOY 197 and the DOY 245, respectively. The increased values of ET_a from the DOY 197 to the DOY 245 are attributed to the crop growth and meteorological conditions.
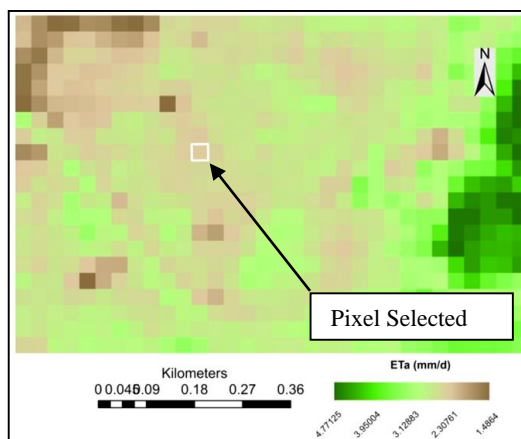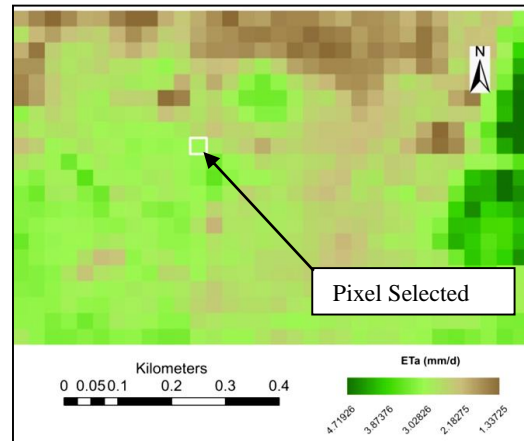

Fig.1. ETa map of the DOY 197

Fig.2. ETa map of the DOY 245

3.2. Comparison of ET_a by the PySEBAL Model with ET_a by Lysimeter Method

A simple linear relationship between ET_a from the pySEBAL and ET_a from the lysimeter method is shown in Fig. 3. The Statistical comparison between ET_a from the pySEBAL model and ET_a from the lysimeter method is shown in Table 4. The results revealed that the RMSE was 0.51 mm.day^{-1}, the R^2 was 0.73, the MBE was 0.04 and, the *d* was 0.9. The results of the simple linear regression showed a good relationship between ET_a by the pySEBAL model and ET_a by the lysimeter method and have been confirmed by many researchers. Similar results in R^2 (0.76) was reported by Ruhoff et al. (2012) by comparing ET_a estimated by the SEBAL model with ET_a measured by the eddy-covariance method for sugarcane croplands. Zamansani et al. (2018) also found a good coefficient of determination of 0.77 by comparing actual ET from the SEBAL model with actual ET from the lysimeter method for wheat crops. Based on the R^2 in this study, ET_a by the pySEBAL model and ET_a by the lysimeter method showed a good accuracy between the two data sets. For the RMSE found in this study, Bala et al. (2015) reported similar results in RMSE of 0.51 mm.d^{-1} by comparing ET_a estimated by the SEBAL model and ET_a measured by the lysimeter method. In addition, Hassanpour et al. (2011) by comparing ET_a estimated by the SEBAL model and ET_a measured by the lysimeter method found an RMSE of 0.29 mm.day^{-1}. Bhattarai et al. (2011) by comparing ET_a estimated by the SEBAL model and ET_a measured by the eddy covariance method on grass crop, reported a MBE of 0.05 mm.day^{-1}, and then confirm the MBE of 0.04 mm.day^{-1} found in this study. The Willmott's index of agreement of 0.9 and the lower values of RMSE and MBE indicates better performance of the pySEBAL model to estimate the ET_a.
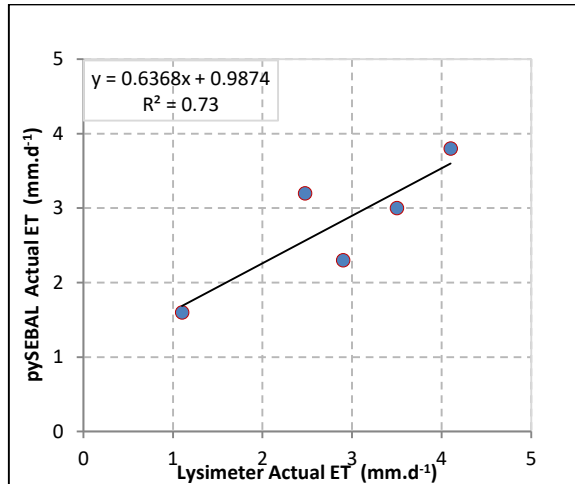
Fig. 3. The relationship between ETa from lysimeter and ETafrom pySEBAL.

Table.4. Statistic results of ET_a from pySEBAL and ET_a from lysimeter

Statistic parameters	Actual evapotranspiration
RMSE (mm.day^{-1})	0.51
MBE (mm.day^{-1})	0.04
R^2	0.73
d	0.90

RMSE	=	Root Mean Square Error
MBE	=	Mean Bias Error
R^2	=	Coefficient of determination
d	=	Willmott index of agreement

The capability of the SEBAL model to estimate actual ET with R^2 close to one is shown by many researchers. Bala et al. (2015) found an R^2 of 0.91 by comparing ET_a estimated by the SEBAL model and ET_a measured by the lysimeter method. The estimation of ET_a by the SEBAL model as a residual energy of energy balance equation should therefore be as accurate as possible in R_n, H and G estimation. Therefore, the accuracy of SEBAL model can be affected by many errors related in R_n, H and G estimation. Bastiaanseen et al. (2005) shown that the typical accuracy of SEBAL is 85 % at field scale on a daily basis. One of the important source of error at field scale in ET_a estimation by the SEBAL model is the advection effect. Mkhwanazi and Chávez (2013) by comparing the SEBAL model under advective and non-advective conditions found and error ranged between 5 and 46%. Singh et al. (2008) observed an error of 28% for the SEBAL model due to advection effect. At regional scale, pySEBAL model include an advection factor to account for any effects of regional advection (Eq. [7]). Unfortunately, the minimum scale at which advection will have to be considered remain a research challenge. In this study, the small experimental area of 0.12 ha could be prone to decrease the accuracy of the pySEBAL model due to advection effect. The validation of remote sensing data with ground truth observation is the dissimilarity between the spatial scales of field and satellite data (Orhan et al.,

2019). With an R^2 of 0.73, an RMSE of 0.51 mm.day^{-1}, an MBE of 0.04 mm.day^{-1}, and an *d* of 0.90, indicates a good accuracy of the pySEBAL model in daily ET_a estimation of soybean crop in Adana, Turkey.

4. CONCLUSION

We have evaluated the pySEBAL model in Adana, Turkey by comparing ET_a estimated by the pySEBAL model with ET_a measued by lysimeter method. In this study, Landsat 5 Thematic Mapper images were used to estimate the ET_a by pySEBAL model. The results showed a good relationship between ET_a estimated by the pySEBAL model and ET_a measured by the lysimeter method, with an R^2 of 0.73, an RMSE of 0.51 mm.day^{-1}, an MBE of 0.04 mm.day^{-1} and a Willmott's index of agreement (*d*) of 0.90. Based on the results of this study, ET_a of soybean crops can be estimated with high accuracy by pySEBAL model in Adana, Turkey. Success of pySEBAL model ET_a estimation depends on the availability of Landsat cloud-free images. In this study, the availability of Landsat cloud-free images was limited. Thus, the application of pySEBAL model with more satellite images is recommended.

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