# Evapotranspiration of Maize Crop in Adana Region, Turkey

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## 1. Introduction

The impact of climate change on crop productivity will be predicted with the SWAP model. Before the prediction, the applicability of the SWAP model needs to be examined under present crop, soil and micrometeorological conditions. Evapotranspiration (latent heat flux) is one of the basic input data in this model. It is important, therefore, to determine reliable evapotranspiration in the rapid grow season of crop. An examined crop is maize.

Daily evapotranspiration and mean latent heat fluxes for 30 min. of maize crop have been calculated for 50 days of July 29 to Sept. 16, 2004. Both calculated values were determined by using three methods of the energy balance flux ratio method (the EBFR method), the energy balance Bowen ratio method (the EBBR method) and the Penman-Monteith method (the PM method). These results are reported in this manuscript.

## 2. Calculation of the latent heat flux

### 2.1 The EBFR method

The EBFR method is used as the basic method to determine the latent heat flux. In this method, the latent heat flux is calculated as follows (Odani *et al*., 2001):

①The latent heat flux (the water vapor flux; $F_{H_2O,f}$ , kg s$^{-1}$ m$^{-2}$) is calculated by the flux ratio method,

$$LF_{H_2O,f} = LH_s \frac{\rho_{w1}/\rho_1 - \rho_{w2}/\rho_2}{C_p(T_{d1} - T_{d2})}, \qquad (1)$$

where $L$(J/kg) is the latent heat of vaporization, $H_s$(W/m$^2$) the sensible heat flux measured by the eddy correlation method, $\rho_w$(kg/m$^3$) the water vapor density, $\rho$(kg/m$^3$) the dry air density, $C_p$(J K$^{-1}$ kg$^{-1}$) the specific heat for constant pressure and $\rho_w/\rho$ the mixing ratio. $T_{d1}$ and $T_{d2}$ temperatures at two heights $z_1$ and $z_2$, respectively. In the EBFR method, it is assumed that measured values of $H_s$ are reliable.

In the flux ratio method, however, unreliable values of $F_{H_2O,f}$ are sometimes estimated for very small values of $|T_{d1}-T_{d2}|$.

②Values of $Rn$-$G$ don't usually agree with those of $H_s+LF_{H_2O,f}$ , where $Rn$(W/m$^2$) is net radiation and $G$(W/m$^2$) the soil heat flux.

③ Therefore, coefficients of $p$ and $q$ are introduced so that the energy balance equation hold good, and values of coefficients are determined by the method of least squares. Then the following a) and b) are assumed:

a)In the condition of relatively larger $|T_{d1}-T_{d2}|$ or $|H_s|$, latent heat fluxes, $LF_{H_2O,f}$, are estimated satisfactorily, and

b)$Rn$ and $G$ are overestimated or under-estimated by $p$ and $q$ times, respectively.

④New estimated values of the latent heat flux, $LF_{H_2O,ef}$, are calculated from the following equation instead of $LF_{H_2O,f}$ for all data,

$$LF_{H_2O,ef} = p \cdot Rn - q \cdot G - H_s \qquad (2)$$

### 2.2 The EBBR method

$H_s$ was not measured during July 29 to Aug. 5 and Aug. 17 to Sept. 16. In addition, reliable values can be measured only in the restricted range of wind direction in the case of the instrument employed here to measure $H_s$. In the above period and the other range of wind direction, therefore, the latent heat flux, $LF_{H_2O,b}$, and the sensible heat flux, $H_b$, are calculated by the EBBR method with the next equations.

$$LF_{H_2O,b} = \frac{p \cdot Rn - q \cdot G}{(1+\beta)}, \qquad (3)$$

$$H_b = \beta LF_{H_2O,b}, \qquad (4)$$

$$\beta = \lambda \frac{T_{d1} - T_{d2}}{e_1 - e_2}, \qquad (5)$$

where $\beta$ is the Bowen ratio, $\lambda$ the psychrometric constant and $e$(hPa) water vapor pressure.

### 2.3 The PM method

In the EBBR method, reliable values of $LF_{H_2O,b}$ and $H_b$ can't be obtained in the range of $-1.5< \beta<-0.5$, and it is often found out that the plus and minus signs of $LF_{H_2O,b}$ or $H_b$ are inconsistent with those of $e_1$-$e_2$ or $T_{d1}$-$T_{d2}$. Such data can't be also adopted as the right value of the latent heat flux. In such cases, potential evapotranspiration calculated from the FAO Penman-Monteith equation is used (Allen *et al.*, 1998).

The potential evapotranspiration ($ET_p$) of Penman-Monteith is calculated from the next equation.

$$LET_p = \frac{\Delta(p\cdot Rn - q\cdot G) + \rho_a C_p \dfrac{(e_s - e_a)}{r_a}}{(\Delta+\lambda)} \quad (6)$$

where ($e_s$-$e_a$) represents the vapor pressure deficit of the air, $\rho_a$ is the mean air density, $\Delta$ represents the slope of the saturation vapor pressure temperature relationship and $r_a$ is the aerodynamic resistance. The value of $r_a$ is calculated from the next equation.

$$r_a = \frac{\ln\left[\dfrac{z_m - d}{z_{0m}}\right]\ln\left[\dfrac{z_h - d}{z_{0h}}\right]}{k^2 u_z}, \quad (7)$$

where $z_m$ is the height of wind measurements, $z_h$ the height of humidity measurements, $d$ the zero plane displacement height, $z_{0m}$ the roughness length governing momentum transfer, $z_{0h}$ the roughness length governing transfer of heat and vapor, $k$ the von Karman's constant (0.41) and $u_z$ wind speed at height $z$.

The value of $r_a$ is given for a grass reference surface with a constant crop height of $h_g$=0.12m. Therefore, $d$, $z_{0m}$ and $z_{0h}$ are calculated from equations of $2/3h_g$, $0.123h_g$ and $0.1z_{0m}$, respectively. It is assumed that a grass is located at the height of $2/3h_m+0.123h_m$, where $h_m$ is the crop height of maize. Therefore, $z_m$ and $z_h$ are reduced by $2/3h_m+0.123h_m$.

The actual latent heat flux is calculated from the relationship between $ET_p$ and adopted $LF_{H_2O,b}$ or $LF_{H_2O,ef}$.

## 3. Measurements

### 3.1 Observation site

The observation was conducted at the research field of the Cukurova university in Adana. Maize was planted on June 28, 2004. Crop heights changed from 1.43m on July 29 to 3.25m on Sept. 4, and were almost constant after that. Irrigated water of 160mm, 102mm and 138mm was applied on July 28-29, Aug. 11-12 and Sept. 14-15, respectively.

### 3.2 The EBBR measurement system

Temperatures and the relative humidity at 2-3 heights were measured from July 29 to Oct. 24. During the same period, net radiation, the soil heat fluxes and the wind speed were measured with a net radiometer, heat flow meters at two locations in soil and a cup anemometer, respectively.

### 3.3 The EBFR measurement system

The sensible heat flux ($H_s$) was measured by the eddy correlation method with a sonic anemometer during Aug. 6-16. The sampling time was 10 Hz, and the averaging time was 30 minutes. During the same period, the dry and wet bulb temperatures were measured by the self-made psychrometers with platinum resistance thermometers at three heights.

## 4. Results

### 4.1 Relationship between $p\cdot Rn$-$q\cdot G$ and $H_s+LF_{H_2O,f}$ in the EBFR method

The relation of $p\cdot Rn$-$q\cdot G$ to $H_s+LF_{H2O,f}$ was obtained from data of $17<H_s<65$W/m$^2$, as shown in **Fig.1**. The values of $T_{d1}$-$T_{d2}$ in these data were in the range of 0.110 to 0.365℃.

The values of $p$ and $q$ were 0.905 and 1.28, respectively. As seen from **Fig.1**, $p\cdot Rn$-$q\cdot G$ was satisfactorily proportional to $H_s+LF_{H_2O,f}$. The value of correlation coefficient was 0.98.

### 4.2 Disagreement between $H_b$ and $H_s$

The values of $H_b$ in the EBBR method didn't agree with the values of $H_s$ in the EBFR method. Similar results were also obtained between $LF_{H2O,b}$ and $LF_{H2O,ef}$ . **Fig.2** shows the relationship between $H_b$ and $H_s$ in the case of $H_b$ >0.0W/m$^2$. The value of $H_b$, therefore, was corrected with the equation shown in **Fig.2**, and

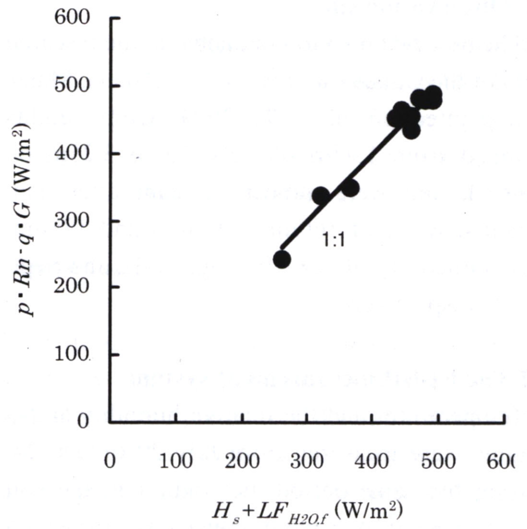


**Fig.1** Relationship between $H_s+LF_{H2O,f}$ and $p\cdot Rn+q\cdot G$.

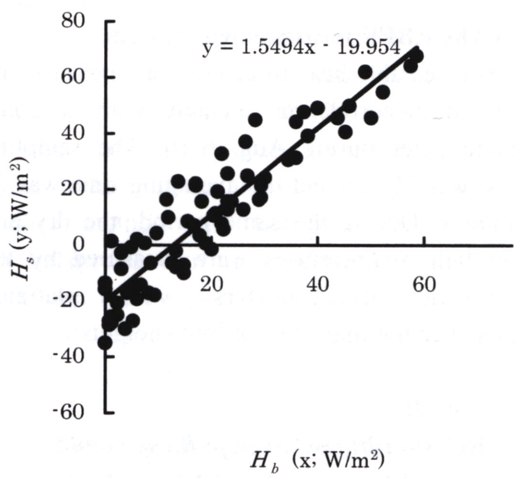


**Fig.2** Relationship between $H_b$ and $H_s$.

the latent heat fluxes were calculated from the energy balance equation with corrected values of $H_b$.

In the case of $H_b$ <0.0W/m², calculated values of $|H_b|$ were very small compared with the absolute values of $H_s$. The value of $H_b$ , therefore, was also corrected from the similar relationship between $H_b$ and $H_s$.

The latent heat fluxes calculated with corrected values of $H_b$ agreed satisfactorily with the values of $LF_{H2O,ef}$.

### 4.3 Results of $p\cdot Rn$, $q\cdot G$, $H$ and $LF_{H2O}$

**Fig.3** and **Fig.4** show fluctuations with time of $p\cdot Rn$, $q\cdot Q$, $H$ and $LF_{H2O}$ measured on

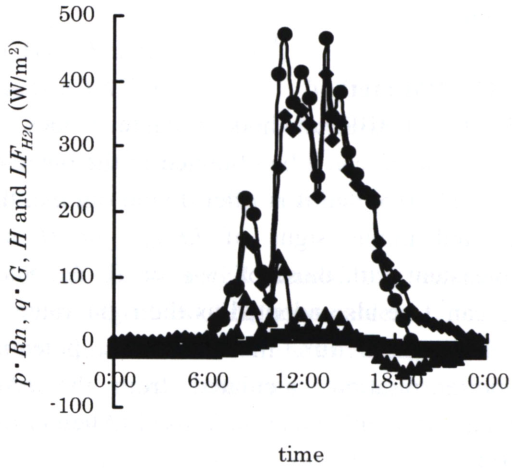


**Fig.3** Fluctuations with time of $p\cdot Rn$ (●), $q\cdot G$(■), $H$ (▲) and $LF_{H2O}$ (◆) measured on Aug. 11, 2004.

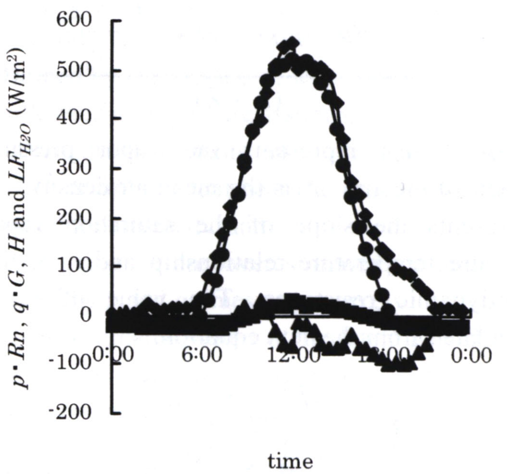


**Fig. 4** Fluctuations with time of $p\cdot Rn$ (●), $q\cdot G$(■), $H$ (▲), $LF_{H2O}$(◆) measured on Aug. 13, 2004.

Aug.11 and on Aug.13, respectively. $H$ and $LF_{H2O}$ are the sensible heat flux and the latent heat flux calculated with any of three methods. **Fig.3** and **Fig.4** show results obtained immediately before and after irrigation, respectively.

As seen from both figures, most or almost energy of $Rn$ was distributed to the latent heat flux. $H$ was negative during 16:00-24:00 on Aug. 11, and during 11:00-24:00 on Aug. 13. This sensible heat was used mostly or almost as the heat for vaporization. Such characteristics of the energy balance were seen on all days of July 29 to Oct. 16.

**Table 1** Calculated results of daily evapotranspiration (*ET*) and daily potential evapotranspiration ($ET_p$).

| Date | *ET* | $ET_p$ | Date | *ET* | $ET_p$ | Date | *ET* | $ET_p$ | Date | *ET* | $ET_p$ | Date | *ET* | $ET_p$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7/29 | 5.03 | 5.76 | 8/08 | 4.79 | 5.06 | 8/18 | 6.21 | 6.14 | 8/28 | 5.21 | 5.16 | 9/07 | 5.85 | 5.79 |
| 7/30 | 6.05 | 6.53 | 8/09 | 5.18 | 5.61 | 8/19 | 6.14 | 5.92 | 8/29 | 4.62 | 4.81 | 9/08 | 5.52 | 5.33 |
| 7/31 | 5.88 | 6.38 | 8/10 | 4.35 | 4.65 | 8/20 | 6.17 | 5.86 | 8/30 | 5.05 | 5.21 | 9/09 | 4.58 | 5.32 |
| 8/01 | 4.90 | 5.37 | 8/11 | 3.93 | 4.74 | 8/21 | 5.78 | 5.56 | 8/31 | 5.06 | 5.24 | 9/10 | 4.32 | 4.58 |
| 8/02 | 6.21 | 7.34 | 8/12 | 5.94 | 5.51 | 8/22 | 5.50 | 5.49 | 9/01 | 4.89 | 5.03 | 9/11 | 5.27 | 6.12 |
| 8/03 | 5.55 | 6.30 | 8/13 | 6.68 | 6.18 | 8/23 | 4.72 | 4.61 | 9/02 | 4.81 | 4.94 | 9/12 | 6.33 | 8.21 |
| 8/04 | 5.81 | 6.22 | 8/14 | 6.26 | 5.61 | 8/24 | 5.37 | 5.36 | 9/03 | 5.17 | 5.12 | 9/13 | 5.37 | 5.87 |
| 8/05 | 5.69 | 6.45 | 8/15 | 5.51 | 5.13 | 8/25 | 5.57 | 5.84 | 9/04 | 5.10 | 5.08 | 9/14 | 4.58 | 5.00 |
| 8/06 | 5.15 | 5.64 | 8/16 | 5.39 | 5.44 | 8/26 | 5.54 | 5.91 | 9/05 | 5.21 | 5.27 | 9/15 | 4.89 | 5.15 |
| 8/07 | 4.87 | 5.09 | 8/17 | 5.17 | 5.10 | 8/27 | 5.49 | 5.55 | 9/06 | 6.10 | 6.56 | 9/16 | 4.63 | 4.84 |

### 4.4 Calculated results of daily evapotranspiration

**Table 1** shows calculated results of daily evpotranspiration (*ET*) and daily potential evapotranspiration ($ET_p$). Larger values of *ET* were obtained, when soil was wet and $ET_p$ was large. Examples of the former were obtained on July 30 and Aug. 13, and examples of the latter were obtained on Aug. 2, Aug.13 and Sept. 12.

### 4.5 Comparison with transpiration obtained from the sap flow measurement

Transpiration from the maize field was obtained from the sap flow measurement during Aug. 7-16. **Fig.5** shows the relationship between daily evapo transpiration (*ET*, mm/day) and daily transpiration (*T*, mm/day). As seen from **Fig.5**, agreement between *ET* and *T* was very good. Evapotranspiration, however, is the sum of transpiration and evaporation from soil surface. Evaporation was measured with the microlysimeter during Aug. 9-16. The obtained value was in the range of 0.45-2.25mm per day. *ET*, therefore, may be underestimated by evaporation from soil surface. However, there is possibility that most or almost evaporation from soil surface was transferred laterally due to advection in the space of furrow underneath maize canopy. *ET* and *T*, therefore, might be estimated satisfactorily.

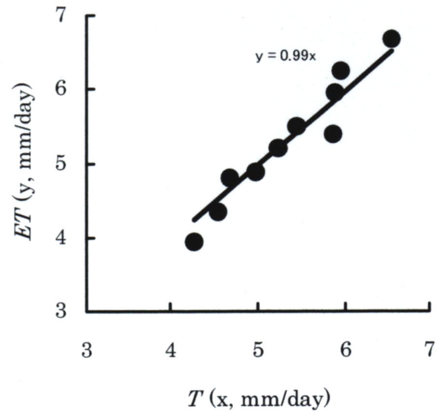


**Fig.5** Relationship between daily evapotranspiration (*ET*,mm/day) and daily transpiration (*T*, mm/day).

### 5. Conclusion

Daily evapotranspiration and mean latent heat fluxes for 30 min. of maize crop, which are one of the basic data of the SWAP model, were determined for 50 days of July 29 to Sept. 16, 2004. Mean daily evapotranspiration for 50 days was 5.35mm/day, and mean potential evapotranspiration of Penman- Monteith was 5.58mm/day.

The reliability of these data would be confirmed through the calculation of water balance in the SWAP model.

### 6. Reference

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