Actual Evapotranspiration and Potential Evapotranspiration of Maize Crop in Adana Region, Turkey

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1. Introduction

Actual evapotranspiration (ET, mm/day) and potential evapotranspiration (ET_p, mm/day) of maize crop under present crop, soil and micro- meteorological conditions have been determined as basic data to predict the impact of climate change on crop productivity. Both values have been calculated by using three micrometeorological 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) for 88 days of July 29 to Oct. 24, 2004 (Odani *et al.*, 2005).

Transpiration (T, mm/day) of maize was obtained from the sap flow measurement during Aug. 7-16, 2004. Evaporation (E, mm/day) from soil surface was measured with the microlysimeter during Aug. 9-16, 2004 (Odani *et al.*, 2005). The quantity of latent heat (E_A, mm/day) transferred laterally due to advection in the space of furrow under maize canopy was measured during Aug. 8-15, 2004 (Odani *et al.*, 2006). Relationships between ET and $E+T$, and between $ET+E_A$ and $E+T$ have been examined.

2. Calculation of the latent heat flux

First, the mean latent heat flux for 30 min. is calculated to obtain ET and ET_p.

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):

① The 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, ρ_w(kg/m^3) the water vapor density, ρ(kg/m^3) the dry air density, C_p(J K^{-1} kg^{-1}) the specific heat for constant pressure and ρ_w/ρ 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 $|T_{d1}-T_{d2}|$.

② Values 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 Oct. 24. 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 β is the Bowen ratio, λ 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 to obtain ET and ET_p (Allen *et al.*, 1998).

The potential evapotranspiration (LEt_p, W/m^2) of Penman-Monteith is calculated from the next equation.

$$LEt_p = \frac{\Delta(p \cdot Rn - q \cdot G) + \rho_a C_p \frac{(e_s - e_a)}{r_a}}{(\Delta + \lambda)}, \qquad (6)$$

where (e_s-e_a) represents the vapor pressure deficit of the air, ρ_a is the mean air density, Δ 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.

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

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 LEt_p and adopted $LF_{H_2O,b}$ or $LF_{H_2O,ef}$.

2.4 Calculation of latent and sensible heat trans- ferred laterally due to advection

The area of vertical cross section through which advection passed was supposed to be 0.6 × 0.7m^2. The quantities of latent or sensible heat transferred laterally due to advection in evaporation or sensible heat from soil surface were calculated from the difference of latent or sensible heat carried horizontally through the vertical cross section at two locations. The averaging time was 30 minutes. These values were divided by 0.7×14m^2, and corrected to values per unite area of soil surface. The quantities of latent and sensible heat transferred due to advection are represented in notations of F_{EA} and F_{HA} in W/m^2, respectively. The daily value in mm/day of F_{EA} is represented with E_A.

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.

Table 1 Calculated results of actual and potential evapotranspiration (ET and ET_p, mm/day).

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	8/16	5.39	5.44	9/03	5.17	5.12	9/21	4.41	4.49	10/09	2.81	3.57
7/30	6.05	6.53	8/17	5.17	5.10	9/04	5.10	5.08	9/22	4.35	4.45	10/10	3.02	3.45
7/31	5.88	6.38	8/18	6.21	6.14	9/05	5.21	5.27	9/23	3.78	4.16	10/11	3.22	3.49
8/01	4.90	5.37	8/19	6.14	5.92	9/06	6.10	6.56	9/24	4.33	4.30	10/12	3.17	3.59
8/02	6.21	7.34	8/20	6.17	5.86	9/07	5.85	5.79	9/25	3.94	4.29	10/13	2.73	3.34
8/03	5.55	6.30	8/21	5.78	5.56	9/08	5.52	5.33	9/26	3.90	4.19	10/14	2.73	3.10
8/04	5.81	6.22	8/22	5.50	5.49	9/09	4.58	5.32	9/27	3.71	3.99	10/15	2.89	3.28
8/05	5.69	6.45	8/23	4.72	4.61	9/10	4.32	4.58	9/28	3.79	4.20	10/16	2.75	2.99
8/06	5.15	5.64	8/24	5.37	5.36	9/11	5.27	6.12	9/29	3.90	4.23	10/17	2.92	3.45
8/07	4.87	5.09	8/25	5.57	5.84	9/12	6.33	8.21	9/30	3.54	3.85	10/18	2.83	3.30
8/08	4.79	5.06	8/26	5.54	5.91	9/13	5.37	5.87	10/01	3.76	3.89	10/19	2.61	3.28
8/09	5.18	5.61	8/27	5.49	5.55	9/14	4.58	5.00	10/02	3.54	4.18	10/20	2.25	2.93
8/10	4.35	4.65	8/28	5.21	5.16	9/15	4.89	5.15	10/03	3.19	3.31	10/21	2.49	3.66
8/11	3.93	4.74	8/29	4.62	4.81	9/16	4.63	4.84	10/04	3.88	4.47	10/22	2.65	3.01
8/12	5.94	5.51	8/30	5.05	5.21	9/17	4.52	4.53	10/05	4.30	5.39	10/23	2.67	3.49
8/13	6.68	6.18	8/31	5.06	5.24	9/18	5.07	5.12	10/06	2.76	3.43	10/24	2.72	3.28
8/14	6.26	5.61	9/01	4.89	5.03	9/19	4.98	4.87	10/07	2.49	2.83			
8/15	5.51	5.13	9/02	4.81	4.94	9/20	4.84	4.71	10/08	3.00	3.78			

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.

3.4 Measurements of wind speed, temperature and humidity in a furrow under maize canopy

Horizontal wind speed was measured with a hot-wire anemometer at the center of a furrow under maize canopy and the height of 0.3m over soil surface during Aug. 8-15. During the same period, the dry and wet
bulb temperatures were measured by the self-made psychrometers with platinum resistance thermometers at two locations of the furrow and the same height as the hot-wire anemometer. The horizontal distance between two psychrometers was 14m. The anemometer was located in the middle of two psychrometers. The width of the furrow was 0.7m.

4. Results

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

Fig.1 shows fluctuations with time of $p \cdot Rn$, $q \cdot Q$, H and LF_{H2O} measured on Aug.13. Values of p and q were 0.905 and 1.28, respectively. H and LF_{H2O} are the sensible heat flux and the latent heat flux calculated with any of three methods.

As seen from this figure, most or almost energy of Rn was distributed to the latent heat flux. H was negative during 11:00-24:00. 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. 24.

4.2 Calculated results of actual and potential evapotranspiration

Table 1 shows calculated results of actual evpotranspiration (ET) and

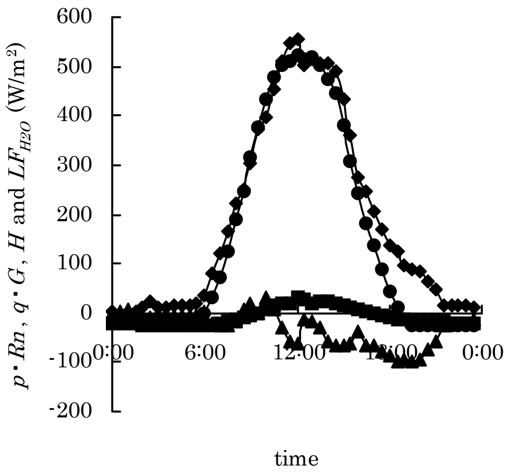

Fig. 1. Fluctuations with time of $p\cdot Rn$ (●), $q\cdot G$(■), H (▲), LF_{H2O}(◆) measured on Aug. 13, 2004.

potential evapo- transpiration (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.

4.3 Relationship between ET and $E+T$

Fig.2 shows the relationship between ET and $E+T$. As seen from **Fig.2**, values of $E+T$ were larger than values of ET by 12%.

From the result of **Fig.2**, the next hypotheses will be made : ①Values of $E+T$ were overestimated, ②Values of ET were underestimated, and ③Part of evaporation from soil surface was transferred laterally due to advection in the space of furrow under maize canopy. Here, the hypothesis of ③ was examined.

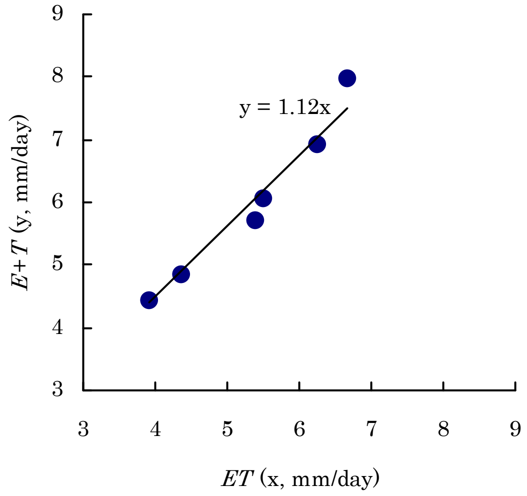

Fig.2. Relationship between *ET* and *E+T*.

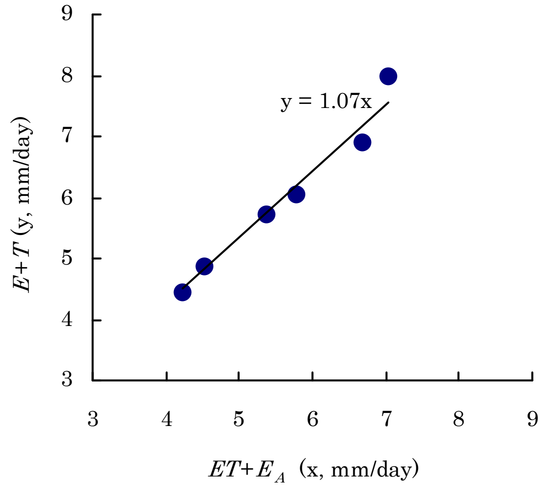

Fig. 3. Relationship between $ET+E_A$ and *E+T*.

4.4 Results of F_{EA},and F_{HA}

On all measurement days, F_{HA} was negligibly small. F_{EA} was as large as *G* during the daytime, and was negligibly small during the nighttime.

4.5 Relationship between $ET+E_A$ and *E+T*

Fig.3 shows the relationship between $ET+E_A$ and *E+T*. As seen from **Fig.3**, values of *E+T* were larger than values of $ET+E_A$ by 7％.

5. Conclusion

Actual and potential evapotranspiration of maize crop were determined for 88 days of July 29 to Oct. 24, 2004. Mean actual evapotranspiration for 88 days was 4.52mm/day, and mean potential evapo-transpiration of Penman- Monteith was 4.83mm/day.

Actual evapotranspiration (*ET*, mm/day) was compared with the sum of transpiration (*T*, mm/day) obtained from the sap flow measurement and evaporation (*E*, mm/day) from soil surface measured with the microlysimeter. Values of *E+T* were larger than values of *ET* by 12％.

The quantity of water vapor (E_A, mm/day) transferred laterally due to advection in the space of furrow under maize canopy was estimated. *E+T* was larger than $ET+E_A$ by 7％.

6. Reference

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