Estimation of Evapotranspiration from a Maize Field with the Energy Balance Flux Ratio Method

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1. Introduction

The impacts of climate change on crop productivity will be predicted with the SWAP model. Evapotranspiration (latent heat flux or water vapor flux) is one of the basic input data in this model. One of targets in our investigations is to determine evapotranspiration accurately in the whole growing season of maize.

We have proposed the energy balance flux ratio method (the EBFR method) as one of reliable micrometeorological methods to estimate evapotranspiration, and have shown that there is much possibility that evapotarnspiration is estimated accurately using the EBFR method in a paddy field (Odani *et al.*, 2001).

Evapotranspiration from a maize field was measured using the EBFR method in Adana, Turkey during August 15-27, 2003. Measured results of evapotranspiration are shown, and are compared with transpiration obtained from the sap flow measurement.

2. Calculation of the latent heat flux by the EBFR method

In the EBFR method, the latent heat flux is calculated as follows:

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

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

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 $|T_{d1}-T_{d2}|$.

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.

③Therefore, 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 underestimated 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,

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

3. Measurement

The sensible heat flux, the dry bulb and wet bulb temperature profiles, net radiation and the soil heat flux were measured over a maize field in Adana, Turkey. The height of maize crop was in the range of 3.0-3.5m.

Measurements were carried out during 10:00-17:00 on Aug. 15, during 10:00-17:00 on Aug. 16, during 9:30-17:30 on Aug. 18, during 9:30-17:30 on Aug. 19, during 10:00-17:30 on Aug. 20, during 10:30-17:30 on Aug. 21, during 10:30-18:00 on Aug. 24, during 10:30-17:30 on Aug. 25, during 10:00-11:00 and 12:00-16:00 on Aug. 26 and during 9:30-16:00 on Aug. 27, 2003.

In the case of the probe employed here of a three dimensional sonic anemometer thermometer (Kaijo, DA-600-3TV), reliable wind velocities can be measured only in the restricted range of wind direction. Therefore, only such as data were adopted in this analysis.

The time zones of adopted data were 15:30-17:00 on Aug. 15, 12:30-17:00 on Aug. 16, 12:00-17:30 on Aug. 18, 11:30-17:30 on Aug. 19, 12:00-17:30 on Aug. 20, 11:30-12:30 and 14:30-17:30 on Aug. 21, 11:30-12:00 and 13:00-18:00 on Aug. 24, 12:00-17:30 on Aug. 25, 10:00-11:00 and 12:00-16:00 on Aug. 26, and 9:30-10:00 and 10:30-16:00 on Aug. 27.

The sensible heat flux was measured by the eddy correlation method with the sonic anemometer. The sampling time was 10 Hz, and the averaging time was 30 minutes.

The dry and wet bulb temperatures were measured by the self-made psychrometers with platinum resistance thermometers (Eko, MT/010/Z) at three heights of z=3.375m=z_1, 3.7m and 4.14m=z_2. To satisfy the requirement of similarity in the temperature and humidity profiles, the following equations were fitted to these adopted profiles (Odani *et al.*, 1996),

$$T_d = A + B\ln(z - d_0)\,, \quad (3)$$

$$T_w = A' + B'\ln(z - d_0)\,, \quad (4)$$

where T_w is wet bulb temperature, and A, B, A', B' and d_0 are experimental coefficients.

Net radiation was measured with a net radiometer (Prede, REBS Q*7.1), and soil heat fluxes were measured at three locations in soil with heat flow meters (Eko, MF-81).

4. Results and considerations

4.1 Measured dry and wet bulb temperature profiles

The dry and wet bulb temperature profiles were measured on Aug. 15, 16, 18, 19 and 20.

Fig.1 shows an example of measured dry and wet bulb temperature profiles. In **Fig.1**, the plus sign of T_{d1}-T_{d2}=0.067 ℃ were consistent with it of H_s=45.51W/m^2. The value of temperature difference, however, was very small.

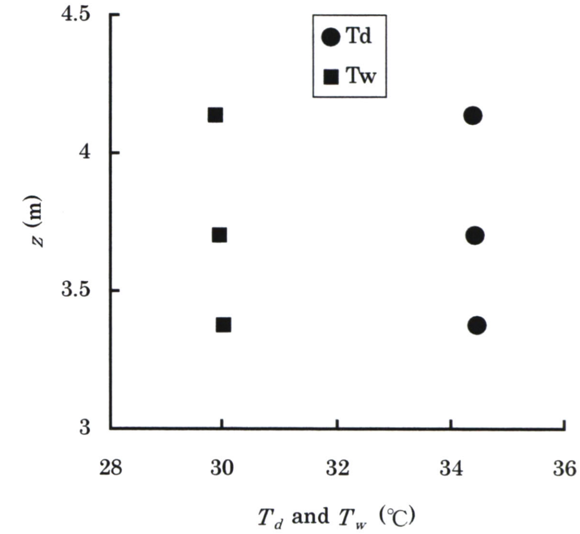

Fig.1 An example of dry and wet bulb temperature profiles (● and ■) measured at 14:30-15:00 on Aug. 20, 2003.

4.2 Relationship between $p\cdot Rn\text{-}q\cdot G$ and $H_s+LF_{H2O,f}$

As shown in **4.1**, since the temperature difference between two heights is small, it is not clear if the assumption a) in ③ of **2** is satisfied. Nevertheless, the relation of $p\cdot Rn\text{-}q\cdot G$ to $H_s+LF_{H2O,f}$ was obtained from data of $|H_s|$>45.5W/m^2, as shown in **Fig.2**. The values of $|T_{d1}$-$T_{d2}|$ in these data were in the range of 0.067 to 0.147℃.

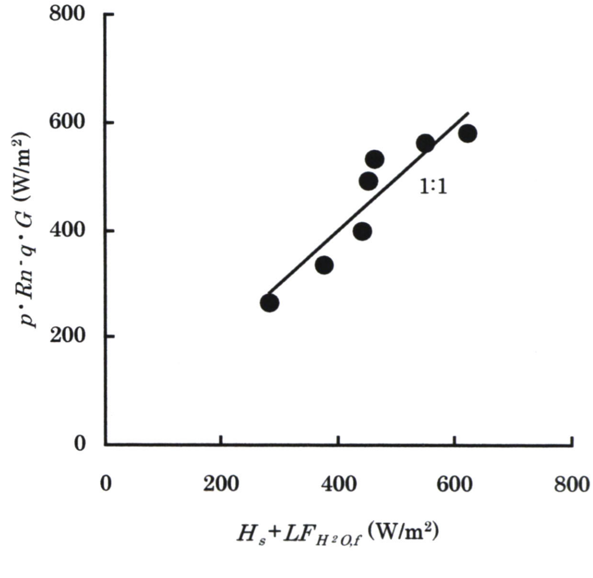

Fig.2 Relationship between $H_s+LF_{H2O,f}$ and $p\cdot Rn\text{-}q\cdot G$.

The values of p and q were 0.994 and 1.25, respectively. As seen from **Fig.2**, $p \cdot Rn - q \cdot G$ was satisfactorily proportional to $H_s + LF_{H_2O,f}$. The value of correlation coefficient was 0.93.

4.3 Results of $p \cdot Rn$, $q \cdot G$, H_s and $LF_{H_2O,ef}$

The values of $LF_{H_2O,ef}$ were calculated from the equation (2) for all adopted data.

Fig.3 and **Fig.4** show fluctuations with time of $p \cdot Rn$, $q \cdot Q$, H_s and $LF_{H_2O,ef}$ measured during 11:30-17:30 on Aug. 19 and during 12:00-17:30 on Aug. 25, respectively.

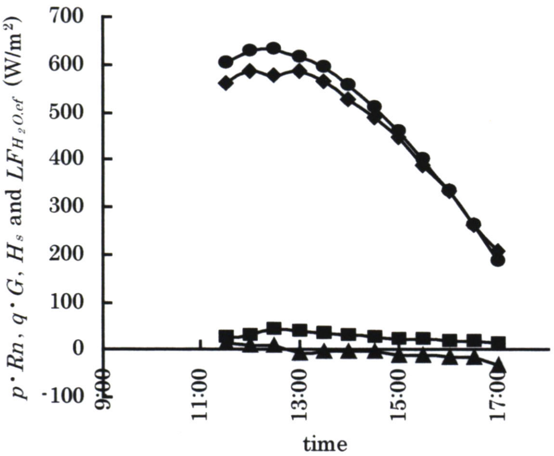

Fig.3 Fluctuations with time of $p \cdot Rn$ (●), $q \cdot G$(■), H_s (▲) and $LF_{H_2O,ef}$(◆) measured during 11:30-17:30 on Aug. 19, 2003.

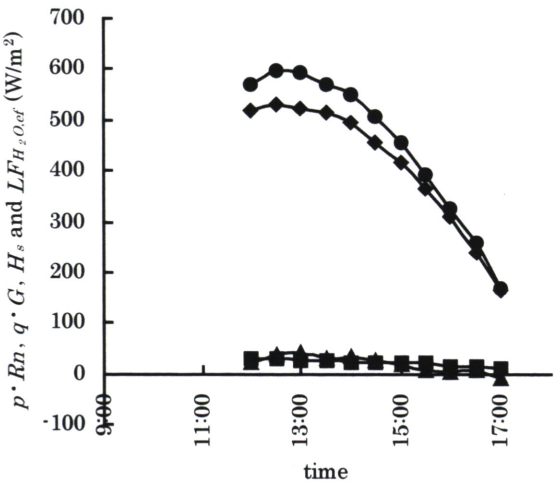

Fig. 4 Fluctuations with time of $p \cdot Rn$ (●), $q \cdot G$(■), H_s (▲), $LF_{H_2O,ef}$(◆) measured during 12:00-17:30 on Aug. 25, 2003.

As seen from both figures, energy greater than 85% of Rn was distributed to the latent heat flux, $LF_{H_2O,ef}$. On Aug. 19, H_s was negative during 13:00-17:30, and was used as the heat for vaporization. Smaller negative values of H_s were also observed during 15:30-17:00 on Aug. 15. These values were -60.4, -74.9 and -79.6W/m^2.

4.4 Comparison with transpiration obtained from the sap flow measurement

Transpiration from the maize field was obtained from the sap flow measurement. Evapotranspiration estimated by the EBFR method was compared with the transpiration.

Fig.5 shows the relationship between cumulative evapotranspiration (ET, mm) and cumulative transpiration (T, mm). ET is the sum of ET_{30} in each measurement day, where ET_{30} (mm) is evapotranspiration for 30 minutes calculated from $F_{H_2O,ef}$ (kg s^{-1} m^{-2}) of adopted data. T is the sum of T_{30}, and T_{30} (mm) is transpiration for 30 minutes calculated for the same time zones with ET_{30}.

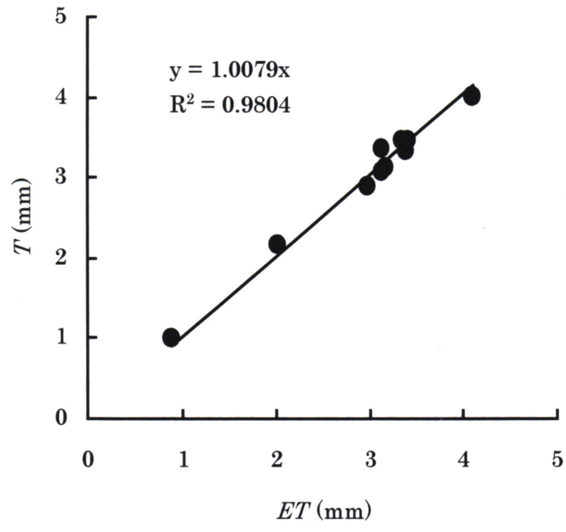

Fig.5 Relationship between cumulative evapotranspiration (ET, mm) and cumulative transpiration (T, mm).

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. The obtained value was about 1mm per day; therefore, T per day may be greater than ET per day by about 1mm.

Although good agreement was obtained between *ET* and *T*, the difference was seen between ET_{30} and T_{30}. **Fig.6** and **Fig.7** show fluctuations with time of T_{30} and ET_{30} measured during 11:30-17:30 on Aug. 19 and during 12:00-17:30 on Aug. 25, respectively. From these figures, were seen the tendencies that ET_{30} was greater than T_{30} in the time zones of 11:30-14:00, and that T_{30} was greater than ET_{30} in the time zones of 14:00-17:30.

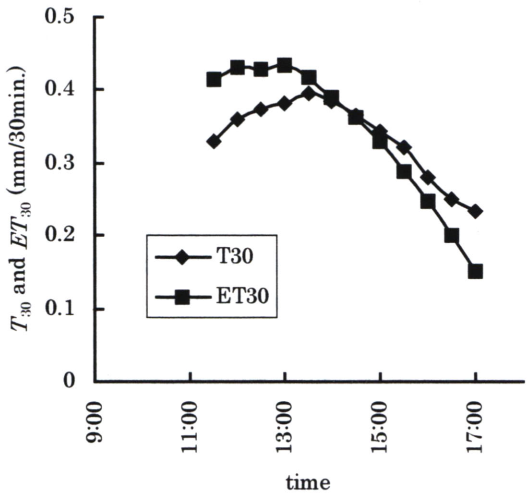

Fig.6 Fluctuations with time of T_{30} and ET_{30} measured during 11:30-17:30 on Aug. 19, 2003.

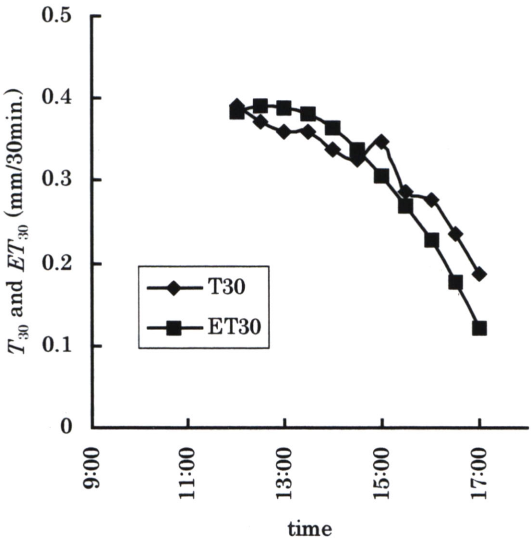

Fig.7 Fluctuations with time of T_{30} and ET_{30} measured during 12:00-17:30 on Aug. 25, 2003.

As evaporation from soil surface is not included in T_{30}, it is considered that the tendency in the time zones of 11:30-14:00 is reasonable. Next, T_{30} in the time zones of 14:00-17:30 is considered. For example, *Rn* was 403.6W/m^2, and H_s was −9.8W/m^2 at 15:30-16:00 on Aug. 19. If all energy of 413.4W/m^2(=403.3+9.8) were distributed to evapotranspiration, the value of 0.306mm for 30 minites would be obtained. This value is greater than ET_{30}=0.289mm/30min., but smaller than T_{30}=0.322mm/30min. From considerations like this, it is considered that T_{30} in the time zones of 14:00-17:30 may be too great. T_{30}, however, was obtained from the sap flow measurement at the location of the stem near the ground surface, and *Rn* was measured over the canopy of maize. Therefore, there might be the time lag in measurement of T_{30} and *Rn*.

5. Conclusion

From the above results and considerations, it is considered that estimated values of evapotranspiration by the energy balance flux ratio method are reasonable.

Next year, we intend to determine evapotranspiration from a maize field in the whole growing season.

6. Acknowledgments

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7. Reference

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