Separate estimation of transpiration and evaporation from a maize field

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1. Introduction

The impact of climate change on crop productivity will be predicted by using SWAP model. Understanding present water use condition is essential to utilize SWAP model adequately. Maize field was selected to investigate in this study during two growth seasons in 2003 and 2004. The intensive field observation was conducted at maize field near Adana from 14 to 28 August 2003 and from 6 to 16 August 2004. The objectives of our study are as follows,

1) Check the present farm irrigation method and the efficiency
2) Evapotranspiration with the Bowen ratio method as a standard approach for long period is improved by introducing the energy balance flux ratio method.
3) Separation of evapotranspiration into transpiration and soil evaporation with the sap flow measurements. Direct transpiration rate is available for considering crop productivity and stress response analysis.
4) Obtain the crop and miclo-meteorological parameter for SWAP model to predict the future change of the water balance and crop productivity following climate change.

Practical furrow irrigation has been applied every 13-15days. During our observation period, one cycle irrigation period was obtained. Root depth and profile was surveyed for evaluating application efficiency and consumptive use efficiency. Observed results and analysis of water use on maize field were reported for our intensive observation period in August 2003 and temporal data are also reported for August 2004 in this manuscript

2. Field observation

2.1 Site in 2003

The observation was conducted at commercial field (Sorakuri, ÖZEKİCİ farm), located 40km south from Adana and 100 km from the Mediterranean Sea. The size of the field size was about 10 ha and surrounded by another huge maize fields. Ground water table near this field was about 1.0m and soil was clay loam soil.

Maize (*Pioneer G-98*) were grown on furrows and distances between plants are about 20cm. The furrow has 40 cm width and the distance between two furrows was 70-75cm. Crop heights were 3-3.5m. The sowing date was 19 June 2003 and harvest date was 8 November 2003. Irrigated water was applied by furrow surface irrigation on 10 and 23 August. During the observation period, no rain was accounted.

2.2 Site in 2004

The observation was conducted at the research field for agricultural structures and irrigation department of Cukurova university in Adana. The soil of this site is classified as clay Mutlu soil series. Maize was grown almost same condition as we saw in 2003. Crop heights were changed from 1.6m to 2.7m within 12days. Irrigated water was applied by furrow surface irrigation on 11 and 12 August for 102mm.

2.3 Measurements

1) Transpiration

As an application for the estimation of transpiration in field conditions, the hourly variations of transpiration was estimated satisfactorily by using both methods at the same time without using predetermined calibration coefficient for the heat pulse method. (Takeuchi et al.1995) In this study, the heat pulse method and the stem balance method was applied on same stems.

Six sample plants (1.9-2.2cm in diameter, 309-347cm height) for monitoring sap flow were selected form 100 plants with measuring the diameter of each stem. Heat pulse probes were inserted at No.3 nods (23-31cm height) while the stem heat balance gauges were installed at No.4 nods (37-44cm height) for 2003 observation.

2) Evaporation

The microlysimeter technique allowed researchers make gravimetric measurements of daily evaporation under a crop canopy without drastically modifying the field and soil environment. Three microlysimeters, 0.2m long and 0.105m in diameter were installed midway between the rows, 2 rows apart from the sap flow measuring plot.

3) Evapotranspiration

Evapotranspiration was measured by Bowen ratio method and the energy balance flux ratio method (the EBFR method). In the EBFR method, the latent heat flux (evapotranspiration rate; F kg $s^{-1}m^{-2}$) is calculated by complementing the flux ratio equation (1) and energy balance equation (2).

$$LF=LH_s(\rho_{w1}/\rho_1-\rho_{w2}/\rho_2)/C_p(T_{d1}-T_{d2}) \qquad (1)$$

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 (kg/m^3) the dry air density, ρ_w(kg/m^3) the water vapor density, C_p(JK^{-1}kg^{-1}) the specific heat for constant pressure and ρ_w/ρ the mixing ratio and T_{d1} and T_{d2} temperatures at two heights z_1 and z_2, respectively.

$$LF=p\cdot Rn-q\cdot G-H \qquad (2)$$

where Rn (W/m^2) is net radiation, G(W/m^2) the soil heat flux, and p, q are coefficients related to in-balance in energy balance equation.

The sonic anemometer was applied to measure the sensible heat flux and its sampling time was 10Hz, and the averaging time was 30 minutes. The dry and wet bulb temperature was measured at three heights, 3.375m(z_1), 3.7m, and 4.14m(z_2).

4) Additional measurements

Soil moisture was measured by ADR soil moisture sensor and SENTEK soil profile sensor. Root profile was surveyed and determined by root analyzer.

3. Results

3.1 Observations 2003

An example of obtained data is shown in Fig.1.

It was clear sky day on 16 August, air temperature on the canopy showed constant value from 11:00 to 17:00. In the afternoon, prevailing wind blew from the south seacoast constantly.

Sap flow rate measured by the stem heat balance method were shown higher than 100g h^{-1} at mid-noon, so combined approach with the heat pulse and the heat balance methods was applied to compute accurate sap flow rate. Daily sap flow rate was 741, 679, 784, 903, 770, 919g d^{-1} among 6 plants, while average value was 800g d^{-1}. These values are corresponding to 85 to 115% of average value.

Soil evaporation rate was reduced from 1.3 to 1.0 mm d^{-1} during first 3 days after irrigation, and then indicated 0.9 to 1.0 mm d^{-1} constantly. The ratio between transpiration and evaporation was changed from 16.6% to 23%.

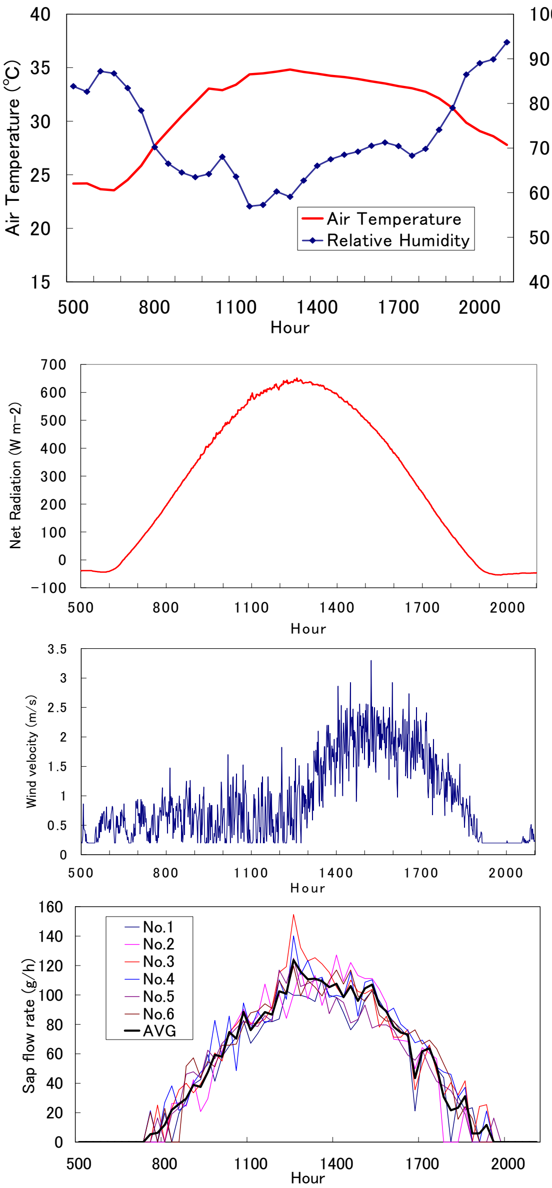

Fig. 1. Diurnal course of sap flow rate on 16 August with air temperature, relative humidity, net radiation and wind speed data. (Clear day)

In Fig.2, evapotranspiration rate (ET) estimated by Bowen ratio method and EBFR method was compared with transpiration rate for two days as examples. In EBFR method, the flux is calculated in case that wind direction is agreed with allowable measuring direction for sonic anemometer in this system. On 19 August, similar curves were obtained between the Bowen ratio method and the EBFR method. On the contrary, the Bowen ratio method

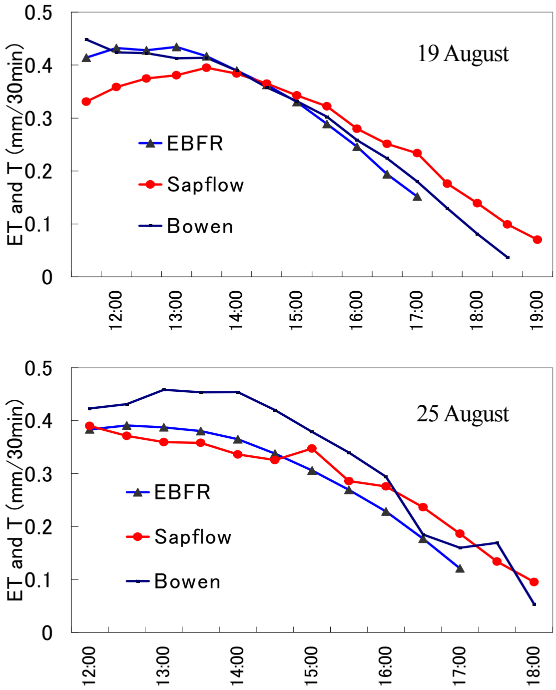

Fig. 2. Diurnal course of evapotranspiration :ET and sap flow rate :T on 19 and 25August

indicated greater that the EBFR method on 25 August. In this day, the sensible heat was estimated negative value in Bowen ratio method, while EBFR method with eddy correlation showed positive value. This discrepancy may come from the small difference between two wet and dry bulb temperature sensors. So, water use on maize field was analyzed below with transpiration by sap flow measurement and soil water evaporation by miclolysimeter in this study. In Fig.2, transpiration rate (sap flow:T) was also compared with EBFR method. Evaporation (E) was not considered in these figures, so E+T is greater than ET. This subject was investigated in 2004 whether vertical one dimension measurement is enough to capture all ET components.

The time lags between ET and T were also found on several days as shown in Fig.2. In Fig.3, the verification experiments for these time lags were conducted in August 2004. An enclosure with black screen (1.1 × 1.55 × 2.0m) was applied to make shadow effect for potted maize plants. This is the consideration of inside of maize canopy. Sap flow was measured with the stem heat balance method and transpiration was measured by mass loss method. A significant time lag between two curves was not obtained. So it is concluded that the time lag shown in Fig.3 was not related to water flow inside of plants as we saw on tree species. This will be come from complicated structure with tall maize canopies.

54 % of plant root was concentrated from 10 to 20

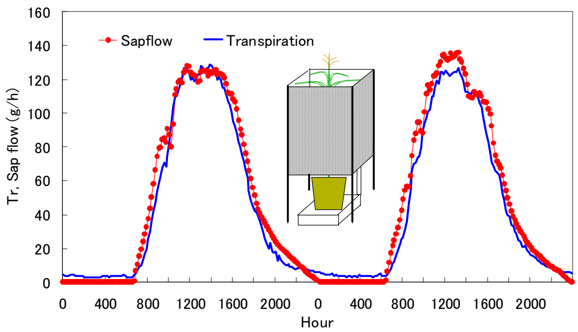

Fig. 3. Verification experiment for the time lag between transpiration and sap flow with potted maize (Pioneer 31 G-98)

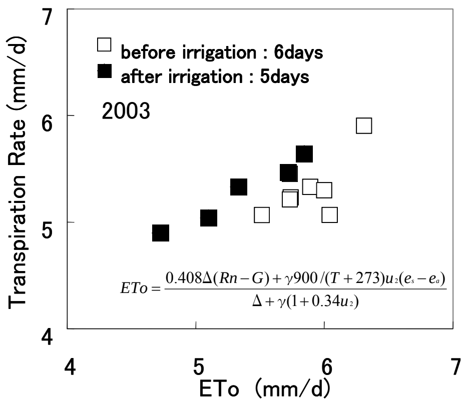

Fig. 4. Relationship between T and ETo,2003

cm from soil surface within 40cm furrow. Between furrow, root was not find significantly. The changes of soil moisture content near plant stem indicated significant stepped reduction in daytime within 20 cm soil layers from surface. It is also clarified that irrigated water penetrated immediately with passing cracks formed before irrigations.

The relationship between transpiration and reference evapotranpiration (ET_0) is indicated in Fig.5. Moderate water stress was shown within six days after the previous irrigation. After the irrigation on 23 August, transpiration was recovered and indicated liner relationship between T and ET_0. Before and after irrigation, the value of T/ET_0 was 0.906 and 0.978, respectively. The Kcb_{mid} for sweet corn is 1.10 and for field corn is 1.15. Our value was smaller than Kcb_{mid} although our plants were larger than normal plants.

Total water use amount between irrigation intervals was estimated 13.6 liter/plant, which is corresponded with 91mm/irrigation. On the contrary, irrigation water was applied with the depth of 100-200mm by soil sampling data. This is possible to conclude that maize were not suffered water stress condition and water saving will be achieved on farm basis and irrigation system bases.

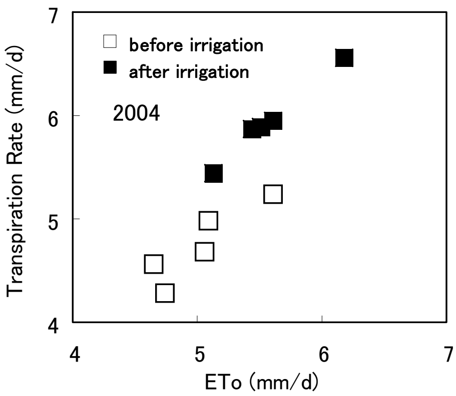

Fig. 5. Relationship between T and ETo,2004

3.2 Observations 2004

The relationship between transpiration and reference evapotranpiration (ET_0) is also indicated in Fig.5. Irrigation was conducted at 11:00 am on 12 August for observed area by furrow irrigation. Transpiration rate was dramatically increasing after irrigation. Before and after irrigation, the value of T/ET_0 was 0.944 and 1.066, respectively. Plants size and leaf area in Fig.4 were larger than in Fig.5. Plants height was changed from 205cm to 273cm within 7 days. The growth rate of plants in this period was higher than 10cm/day and increased after the irrigation significantly. The tendency of ET value during 2004 observation period was also higher than that in 2003. This may come from the structure of maize canopy that can absorb more energy and climatic condition.

In previous report and in Fig.4 and Fig.5, plant occupied ground area was employed as 75cm×20cm with considering seedling distances. However, actual condition of maize germination was not uniform and regular intervals. So, another plant occupied ground area was employed as 75cm×22.5cm. In this case, transpiration rate was decreased 87% of the value in previous ICCAP report. Soil water evaporation was measured by miclo-lysimeter. One lysimeter was installed between the rows and another one was installed between the maize stems on the furrow in 2004. Evaporation rate was calculated with considering shape of the furrow simply.

A diurnal course of transpiration, evaporation and evapotranspiration from Aug.7 to Aug.18 is shown in Fig.6. Furrow irrigation was executed on 13 August at observation site. Across the irrigation day, evapotranspiration rate was exceeded its potential value. This may be caused by stimulation of plant growth with the irrigated soil moisture. They grew 68cm within 8 days. Most of leaves were upward direction and it is well known that this shape is advantageous for collecting solar radiation.

It has rain in the morning on 12.Angust, soil water evaporation by miclo-lysimeter underestimated real evaporation rate. On the next day, the irrigation day on 13.Aug., ET+T was 2mm higher than ET. This is caused by the structure of the lysimeter. The bottom of lysimeter obstructed soil water flow to downward and this extra soil moisture caused additional evaporation as contrasted with natural soil condition.

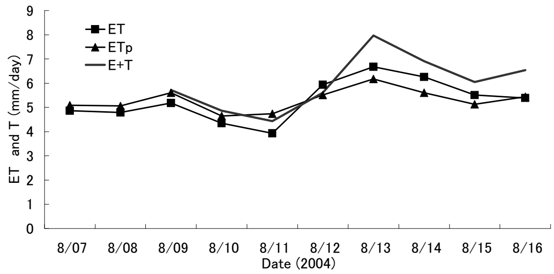

Fig. 6. Diurnal course of transpiration, evaporation and evapotranspiration (Re-analysis)

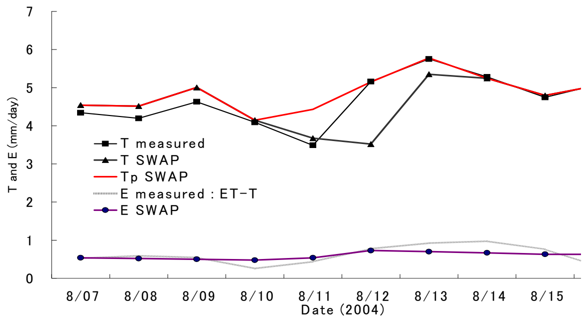

Fig.7. Estimated T and E by SWAP model

4. Estimated T and E by SWAP model

Transpiration rate and soil evaporation rate in Fig.1 was compared with both computed values by SWAP model. To obtain correct value of ET, meteorological data measured in the maize field was used. In case of meteorological data used in Adana weather station, computed evapotranspiration rate was smaller than the one with measured data in the field. Potential transpiration and soil evaporation computed by SWAP model were quite well agreed with measured value, while actual transpiration before irrigation were not good estimated. For investigating hydraulic property of the soil, computed results closed to the measured values.

5. Reference

S.Takeuchi, T.Yamada, K.Momii, T.Yano, 1995 : Measurement on sap flow rate for estimating transpiration, Proceeding of Soil Moisture Control in Arid to Semi-Arid Regions for Agro-forestly.