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Comparison of Evapotranspirations Measured by Lysimeter and Calculated by Various Estimating Methods

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The accuracy of methods for estimating evapotranspiration at upland in a humid area was investigated at a soybean field. First, hourly evapotranspiration were estimated using the Bowen ratio method, Brown–Rosenberg method, Batholic method and Monteith method. Second, daily evapotranspiration were estimated using the Ostromeki method, Makkink method, Stephens method, Turc method, Jensen method, van Bavel method, van Bavel–Businger method and Penman method. Correlativity between estimated and observed values was compared, and superiority of these methods was discussed. When hourly meteorological data were available, the Batholic method was accurate next to the Bowen ratio method. And when daily meteorological data were available, the Stephens method showed high accuracy next to the Penman method, though this method only use average daily temperature and daily solar radiation.

INTRODUCTION

Evapotranspiration is one of most important factors from the agricultural engineering point of view. In order to plan the proper irrigation scheduling at the upland field, to quantify the soil water consumption accurately by evapotranspiration is prerequisite. In recent years, the theory and technique on the method to measure evapotranspiration from the upland field or forest have been advancing with the help of equipments development. The measuring methods can be classified into four types such as lysimeter method, soil water balance method, meteorological method and experimental method. Lysimeter method is directly to measure the amount of decrease of soil water in a container that is filled with the soil and grown crops. Weighing lysimeter method is extremely accurate and suitable for measuring a daily change of evapotranspiration. Estimating methods such as the aerodynamics method, energy balance method and Penman–Monteith method are chosen depending on a field scale and data available. To use the aerodynamics method and energy balance method, wind speed, air temperature and vapor pressure are required. Position of instruments is also important. Sometimes consideration to atmosphere equilibrium is needed. Though the Penman– Monteith method is recommended by Richard *et al.* (1998), determining crop resistance is annoying.

In this research, accuracy of methods for estimating evapotranspiration was investigated at the soybean field in Kyushu University. The meteorological factors to estimate evapotranspiration were measured, and a weighing type lysimeter was used for checking the accuracy of estimation methods. Daily change of evapotranspiration was estimated using the Ostromeki method, Makkink method, Stephens method, Turc method, Jensen method, van Bavel method, van Bavel–Businger method and Penman method (Marvin *et al.*, 1973). And diurnal change of evapotranspiration was estimated using the Bowen ratio method, Brown–Rosenberg method (Brown and Rosenberg, 1973), Batholic method (Batholic *et al.*, 1972) and Monteith method (Monteith and Szeicz, 1962). The each correlativity between estimated and measured value was compared and superiority of these methods was discussed.

MATERIALS AND METHODS

Soybean was grown at the Kaizuka field in which furrow interval was 50 cm and crop interval was 30 cm in Kyushu University. The data to estimate evapotranspiration was measured from August 7 to November 3. Table 1 shows the list of the measurement items and used equipments. These data was recorded with a data logger at 30 minutes interval.

Figure 1 shows the schematic view of a weighing type lysimeter. Diameter of tank was 44.2 cm and area was 1534 cm^2, which is almost equal to the leaf developing area of one soybean. From the bottom of the tank to soil surface, large gravel, small gravel, sandy soil and Masa soil (sandy loam) were filled in with the thickness of 10 cm, 5 cm, 5 cm and 80 cm, respectively. One soybean plant was planted in the tank. The drainage pump was equipped to drain the water in the drainage tank. Three load cells were equipped at the bottom of the lysimeter for measuring the weight automatically.

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Table 1. Equipments of measurement

Items	Equipments	Settlements
Air temperature	Dry bulb thermometer Wet bulb thermometer	Height of 10 cm, 140 cm and 2 points inside plant community
Wind velocity	Hot wire anemometer	Height of 140 cm
Solar radiation	Irradiometer	Above plant canopy
Net radiation	Net radiometer	Above plant canopy
Soil heat flux	Heat flux plate	Under 1 cm from soil surface
Leaf temperature	Thermocouple	Five leaves at canopy top
Evapotranspiration	Weighing lysimeter	30 minuets interval

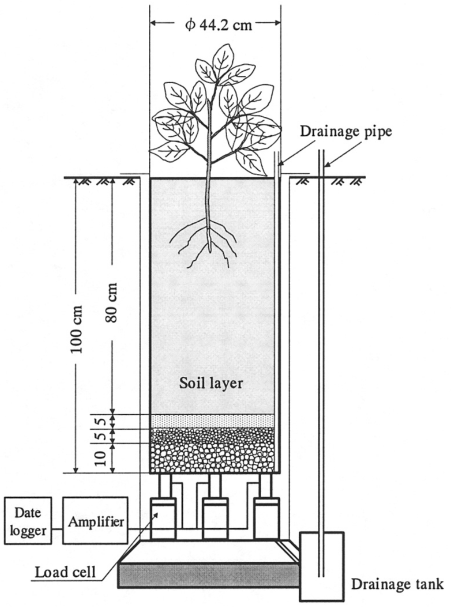

Fig. 1. Schematic view of weighing lysimeter.

Estimating method of hourly evapotranspiration

Bowen ratio method, Brown–Rosenberg method, Batholic method and Monteith method were selected for estimating the diurnal change of evapotranspiration. These methods are expressed as follows.

Bowen ratio method

$$\iota E=\frac{R_n-G}{1+\beta} \quad (1)$$

where, E is evapotranspiration rate (mm/hour), R_n is net radiation (J/cm^2/hour), G is soil heat flux (J/cm^2/hour), ι is latent heat for vaporization (J/gr). β is the Bowen ratio,

$$\beta=\gamma\frac{T_2-T_1}{e_2-e_1} \quad (2)$$

where, T_1 and e_1 are air temperature (°C) and vapor pressure (mb) at height Z_1 (cm), and T_2 and e_2 are air temperature (°C) and vapor pressure (mb) at height Z_2 (cm), and γ is psychrometer constant (0.66 mb/°C). Vapor pressure is calculated as:

$$e=e_s(T_w)-0.66(T_d-T_w) \quad (3)$$

where, T_d is dry bulb temperature (°C), T_w is wet bulb temperature (°C). $e_s(T_w)$ is saturated vapor pressure at an air temperature (mb) expressed as:

$$e_s(T_w)=6.11\exp\left(\frac{17.4T_w}{239+T_w}\right) \quad (4)$$

Brown–Rosenberg method

$$\iota E=R_n+G-\rho c_p\frac{T_l-T_a}{r_a} \quad (5)$$

where, ρ is density of air, c_p is specific heat of the air at constant pressure, T_l is leaf temperature (°C), T_a is air temperature (°C). r_a is surface resistance.

$$r_a=\frac{[\ln(Z-d)/z_0]^2}{\kappa^2 u} \quad (6)$$

where, u is wind speed at the height of 180 cm, d is zero plane displacement ($d=0.63H$:H is height of crop), z_0 is roughness length ($z_0=0.13H$), κ is von Karman's constant.

Batholic method

$$\iota E=\frac{R_n+G}{1+\gamma(T_a-T_l)/[e_s(T_a)e_s(T_l)]} \quad (7)$$

Monteith method

$$\iota E=\frac{\Delta(R_n+G)+\rho c_p[e_s(T_a)-e_a]/r_a}{\Delta+\gamma(r_a+r_s)/r_a} \quad (8)$$

where, e_a is vapor pressure (mb), Δ is $de_s(T)/dT$, r_a is crop resistance. r_s is stomata resistance expressed as:

$$r_s=\left[r_{sm}+\frac{\beta_M}{I+\beta_M/(r_c-r_{sm})}\right]/LAI \quad (9)$$

where, r_{sm} is minimum stomata resistance, I is irradiance, r_c is cuticular resistance, β_M is constant, and LAI is leaf area index.

Evapotranspiration on August 16 was calculated by these four methods using Simpson's formula.

Estimating method of daily changes of evapotranspiration

Daily changes of evapotranspiration was calculated using eight estimating methods.

Ostromeki method (humidity method)

$$E=\beta_H d_a \quad (10)$$

where, E is evapotranspiration rate (mm/day), β_H is hygrometric coefficient (0.56), d_a is average daily vapor pressure deficit (mb).

Makkink method (radiation method)

$$E=0.61\frac{\gamma}{\Delta+\gamma}\ \frac{R_s}{\iota}-0.12 \tag{11}$$

where, R_s is solar radiation (J/cm^2/day).

Stephens method (radiation method)

$$E_{tp}=(0.014T-0.37)\frac{R_s}{6270} \tag{12}$$

where, T is mean daily temperature (F).

Turc method (radiation method)

$$E=0.013\frac{T}{T+15}\left(\frac{R_s}{4.18}+50\right)\left(1+\frac{50-RH}{70}\right) \tag{13}$$

where, T is mean daily temperature (˚C), RH is relative humidity.

Jensen method (net radiation method)

$$E=K_c\Phi_1 R_n \tag{14}$$

Substituting $K_c=1.0$ into Eq. (14), and the parameter Φ_1 is defined as:

$$\Phi_1=\frac{E}{R_n}=1+\frac{G-A}{R_n} \tag{15}$$

where, A is sensible heat flux between leaves and air,

$$A=-C_p\,\rho\,\frac{T_1+T_a}{r_a} \tag{16}$$

van Bavel method (combination method)

$$E=\frac{0.167R_n+0.014u_1(T_{max}-T_{min})}{22-0.15(T_{max}-T_{min})} \tag{17}$$

where, u_1 is wind speed at the height of 100 cm (km/day), T_{max} is maximum air temperature (˚C), T_{min} is minimum air temperature (˚C).

van Bavel–Businger method (combination method)

$$E=\frac{\Delta}{\Delta+\gamma}(R_n+G)+\frac{\Delta}{\Delta+\gamma}\ \frac{0.622\,\lambda\rho k^2}{P}\ \frac{u_Z}{[In(Z-d)/z_0]^2}(e_Z{}^0-e_Z) \tag{18}$$

where, u_Z is wind speed at the height of Z cm (km/day), P is atmospheric pressure (mb), z_0 is roughness length, $e_Z{}^0$–e_Z is vapor pressure deficit (mb).

Penman method (combination method)

$$\iota E=\frac{\Delta}{\Delta+\gamma}(R_n+G)+\frac{\gamma}{\Delta+\gamma}\,15.36\,(1.0+0.0062u_2)(e_Z{}^0-e_Z) \tag{19}$$

where, u_2 is wind speed at the height of 200 cm (km/day).

RESULTS AND DISCUSSIONS

Daily evapotranspiration estimated by hourly data

Table 2 shows the average of daily evapotranspiration estimated by hourly data accumulation during the early stage of growing (August 7–August 26). Comparing four methods with the lysimeter method, the Bowen ratio method and Batholic methods showed good agreements. Though, the Bowen ratio method is known as accurate method, it needs accurate observation on temperature and humidity at two heights. The Batholic method was accurate next to the Bowen ratio method. This method only needs crop surface temperature, air temperature, net radiation and ground heat flux.

Table 2. Estimated evapotranspiration by various methods

Methods	Evapotranspiration (mm)
Bowen ratio method	3.2
Brown–Rosenberg method	2.4
Batholic method	3.1
Monteith method	2.6
Lysimeter	3.4

Relationship between observed and estimated daily evapotranspiration

Figures 2, 3 and 4 show the changes in daily evapotranspiration by the lysimeter method, solar radiation and LAI measured, respectively. Figures 5–12 show relationship between potential evapotranspiration esti-

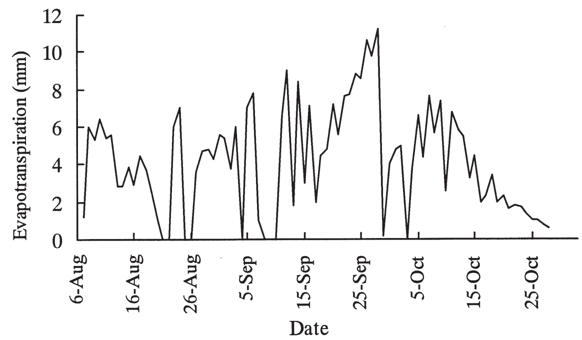

Fig. 2. Change of daily evapotranspiration measured by lysimeter method.

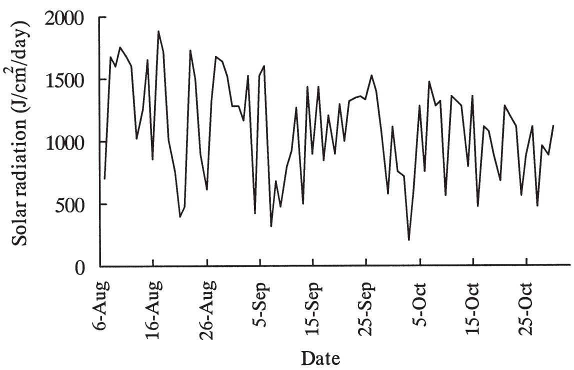

Fig. 3. Change of daily solar radiation.

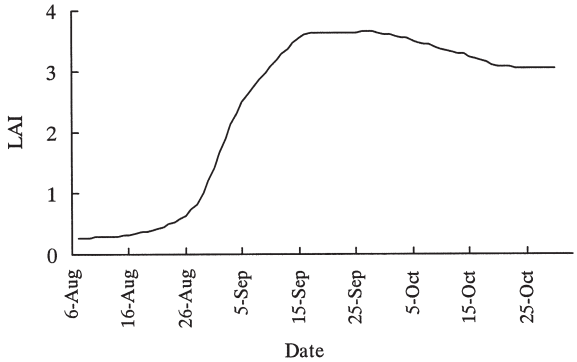

Fig. 4. Change of leaf area index.

mated by each method and actual evapotranspiration measured by the lysimeter method (August 7– October 28). Observed values by the weighing lysimeter showed rather larger values than estimation in the late growing season (September 11–October 13). This was resulted from the leaves of a soybean in the lysimeter overspread outside the lysimeter. There was a tendency that the data fit well to the regression line when the value of evapotranspiration was large. But in the rage of smaller evapotrnapiration, the deviation from the regression line became larger. Table 3 shows the correlation coefficients between observed and estimated evapotranspiration for eight methods. Penman method was more

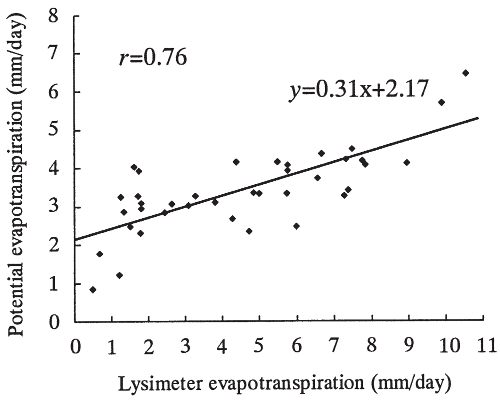

Fig. 5. Correlation between lysimeter and Ostromeki method.

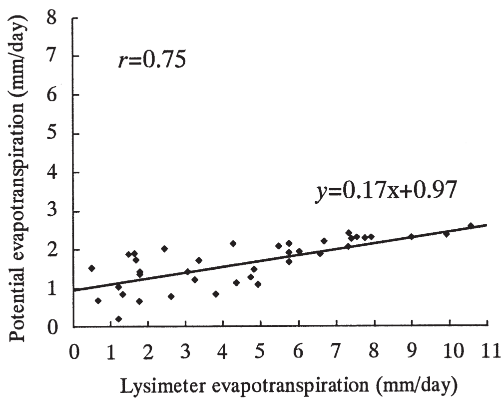

Fig. 6. Correlation between lysimeter and Makkink method.

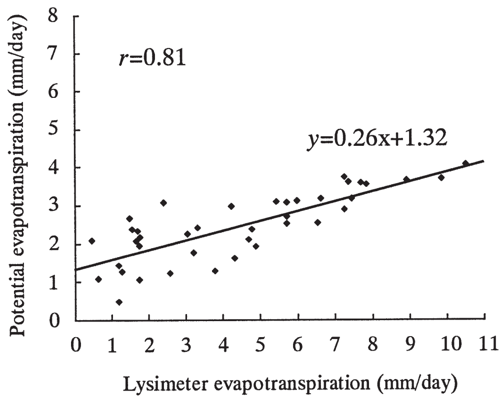

Fig. 7. Correlation between lysimeter and Stephens method.

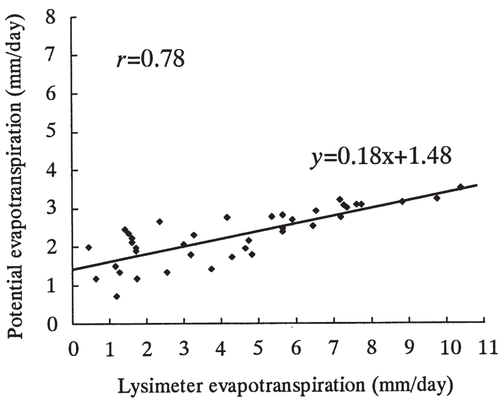

Fig. 8. Correlation between lysimeter and Turc method.

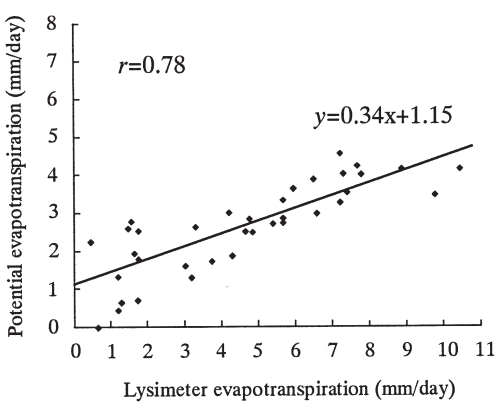

Fig. 9. Correlation between lysimeter and Jensen method.

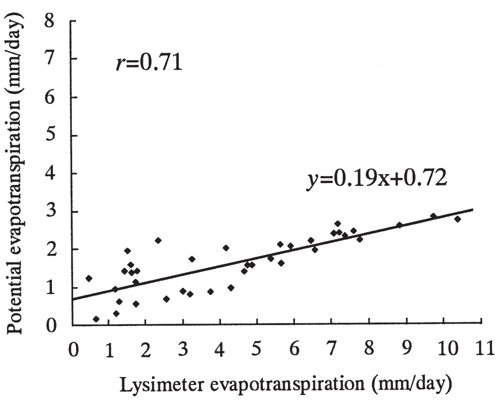

Fig. 10. Correlation between lysimeter and Van Bavel method.

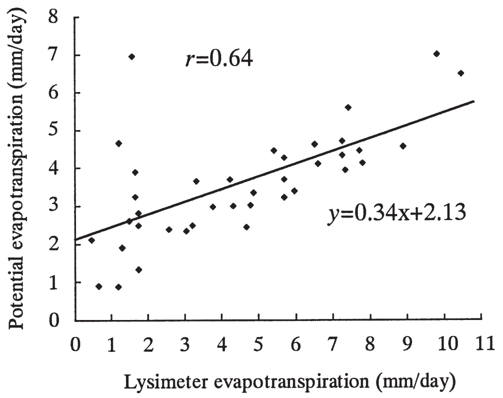

Fig. 11. Correlation between lysimeter and Van Bavel–Businger method.

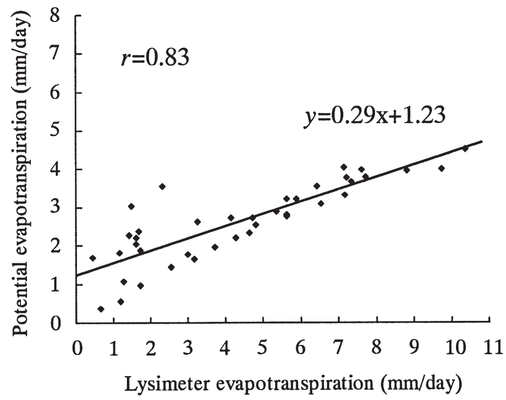

Fig. 12. Correlation between lysimeter and Penman method.

Table 3. Correlation coefficient between estimated and observed evapotranspiration

Estimating methods		Correlation coefficients
Humidity method	Ostromeki	0.76
	Makkink	0.75
Radiation method	Stephens	0.81
	Turc	0.78
Net radiation method	Jensen	0.78
	van Bavel	0.71
Combination method	van Bavel–Businger	0.64
	Penman	0.83

accurate than others. But it needs more data than simple solar radiation methods. Stephens method showed high accuracy next to the Penman method, though this method only use average daily temperature and solar radiation.

CONCLUSIONS

Evapotranspiration is a basic factor for planning irrigation scheduling at upland field. Many empirical and theoretical methods on estimating evapotranspiration have been presented and most of those methods were developed for a dry area. The applicability of those methods in a humid area has not been examined. In this research, meteorological data was measured at a crop field and evapotranspiration was measured using a weighing type lysimeter. Hourly and daily evapotranspiration were estimated by several estimating methods and compared with measured data. When the hourly meteorological data are available, the Batholic method is recommended. And when only daily data are available, the Stephens method is recommended as well as the Penman method.

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