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Annual Trends in Evapotranspiration from Major Vegetations of Thailand

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Abstract: Evapotranspiration (ET) is an essential factor to estimate crop water use. It is also one of the major elements in soil water storage and water resource in a region. This study was accomplished to compare the yearly trends of ET among three main vegetations in Thailand, a rain-fed paddy rice field, cassava plantation and teak plantation. Bowen Ratio Energy Balance (BREB) technique was applied in this study to measure the ET and heat flux between ground surface and atmosphere. Penman-Monteith (PM) equation, recommended by FAO, was used to calculate reference crop evapotranspiration (ET_0). Measurements were carried out during 1999-2003 in the both paddy rice field and teak plantation and during 2002-2003 in the cassava plantation. The results indicated that the amount of daytime ET during the rainy season in the paddy rice field and cassava plantation varied between 1 and 7 mm and in the teak plantation between 2 and 6 mm. The averages amounts of daytime ET in the rainy season were about 4 mm in all sites, although, the variations of ET were different. In the dry season, day time ET of the cassava plantation was around 2.7 mm, slightly lower than those of other sites. During the growing season, ET/ET_0 varied in the paddy rice field between 0.4 and 1.2 and in the cassava between 0.3 and 1.2. In the rainy season, LE/R_n ratios of the cassava plantation and paddy rice field were around 70%, while LE/R_n ratio in the teak plantation was found to be around 73%. Long-terms trends of ET and ET/ET_0 were observed in the main vegetations of Thailand characterized by tropical monsoon climate. Meteorological data were limited to only routine meteorological measurements in this region.

Key words: Evapotranspiration, cassava plantation, paddy rice field, teak plantation

INTRODUCTION

The Northeast Thailand and Chao Phraya river basin is characterized by tropical monsoon climate where the dry season begins in November and ends in April (Attarod *et al*., 2006). The yearly mean air temperature is 27°C and the rough annual precipitation is 1300 mm, almost all of which falls during the rainy season (April-October). Dry spells also occur from time to time during the rainy season.

Rain-fed paddy rice field, cassava and teak plantations are the most important crops that cover large portions of land use in Northeast region and the Chao Phraya River basin of Thailand (Attarod *et al*., 2006).

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Measurement of evapotranspiration (ET) from surfaces is important for multiple purposes such as regional water studies, field irrigation practice, description of atmospheric boundary layer and weather forecasting (Amarakoon *et al*., 2000). In artificial and natural ecosystems including agricultural lands, it is essential to evaluate ET for developing more efficient and sustainable water management techniques. To better predict actual or potential crop production, it is quite necessary to evaluate ET and hence, vegetative productivity is closely related to ET (Watanabe *et al*., 2004).

ET/ET_0 is the ratio of ET to the reference evapotranspiration (ET_0) calculated by the FAO Penman-Monteith method (Allen *et al*., 1998). ET/ET_0 which represents the effect of canopy characteristics that distinguish the crop from reference surface (Peacock and Hess, 2004) is a wide range in different climatic regions and crop fields. Therefore, its measuring can be useful for assessment of ET in tropical monsoon Asian Region where researches on ET and on ET/ET_0 values are relatively rare (Attarod *et al*., 2005) and meteorological data are limited to the routine meteorological measurement. Using a ET/ET_0 removes the need for a separate evapotrasnpiration equation or measurement for each crop type and season. Once ET/ET_0 have been developed they can be used to estimate ET (Peacock and Hess, 2004).

Regarding the importance of ET and ET/ET_0 values, e.g., for agricultural applications, the objective of the present research was to find out the yearly trends of ET and ET/ET_0 as well as their absolute values observed in three major and widely extended crop covers in Thailand including a rain-fed paddy rice field, a cassava plantation and a teak plantation in Thailand.

The rain-fed paddy rice fields of Thailand play a critical role in National food production. Cassava is an important starchy root crop in the Northeast Thailand that its starchy root is a food source for people. Teak is also one of the most renowned timbers which its plantations have been broadly established near Chao Phraya river basin (Attarod *et al*., 2006).

MATERIALS AND METHODS

Study Sites

The measurements were carried out in three measurement sites in Thailand that were a rain-fed paddy rice field in Sukhothai province (17° 03' N, 99° 42' E, elevation 50 m a.s.l.), a cassava plantation near Konburi town, about 50 Km in the Southeast of Nakhonratchasima (14° 47' N, 102° 38' E, elevation 311 m a.s.l.) and a teak plantation in Lampang province (18 40' N, 99° 47' E, elevation 380 m a.s.l.) (Fig.1). The rain-fed paddy rice field and the teak plantation are located near Chao-Phraya River basin while the cassava plantation is in the Northeast Thailand (Attarod *et al*., 2006).

Measurements were performed during 1999-2003 in the both paddy rice field and teak plantation and during 2002-2003 in the cassava plantation. Measurement sites of the paddy rice field and cassava plantation were selected in farmer lands. Rice seeds are sown every year by a farmer usually after starting the rainfall period in the late July and harvested in the end of November. Cassava is generally planted every year at the beginning of the dry season in March or April and harvested in dry season and grown without irrigation.

Teak, a 38-year deciduous plantation, starts leafing mostly in May and shedding in January. Teak is one of the most important and renowned timber production trees that its plantations have been extensively established by Forest Industry Organization (FIO) in Northern regions of Thailand due to their market values (Yoshifuji *et al*., 2006). At each field, micrometeorological measurements have been carried out for over 10 years in the paddy rice field and teak plantation and for over 5 years in the cassava plantation using Automatic Weather Station (AWS) systems (Attarod *et al*., 2006).

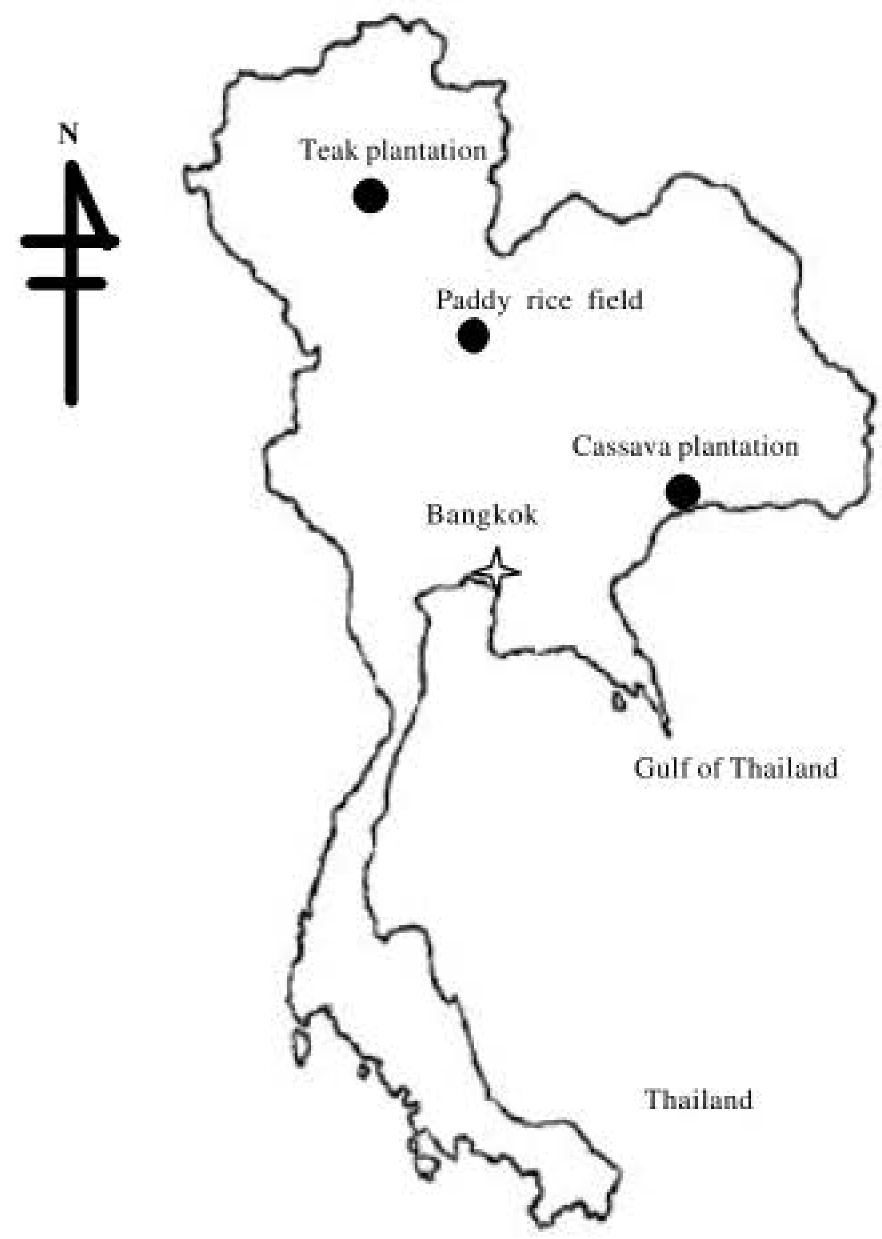

Fig. 1: Location of the measurements sites in Thailand

Evapotranspiration (ET) Measurements

ET from each site was obtained using Bowen Ratio Energy Balance (BREB) system based on the heat balance at the surface described by the following equation:

$$LE = (R_n - G - G_w)/(1+\beta) \quad (1)$$

where, R_n (MJ m^{-2} day^{-1}) is net heat gain from radiation, G (MJ m^{-2} day^{-1}) is ground heat loss, G_w (MJ m^{-2} day^{-1}) is heat flux into water layer (in the paddy rice field only) and β is the Bowen ratio obtained from the ratio of sensible heat flux, H (MJ m^{-2} day^{-1}) , to latent heat flux, LE (MJ m^{-2} day^{-1}).

A net radiometer (MF-11 EKO Seiki Ltd.) was installed at 4.5, 4 and 20 m above the soil surface in the paddy, cassava and teak, respectively, to measure the net radiation flux density (R_n). Two or three heat flux plates (P-MF-81, EKO Seiko Ltd) were placed at 1 cm beneath the soil surface to measure soil heat flux density (G).

Heat flux into the water layer in the paddy rice field (G_w) was calculated by Eq. 2:

$$G_w = c_w \rho_w W_L \frac{dT_w}{dt} \quad (2)$$

where, c_w is the specific heat of water (MJ kg^{-1} $°C^{-1}$), ρ_w is water density (kg m^{-3}), W_L is water depth (m) measured by a hydraulic water level sensor (WL-400, EIKO Co.,) and T_w is water temperature (°C) measured at 1 cm below the water surface.

β was calculated from the dry and wet bulb temperature measured at two different levels above the canopy coverage (paddy, cassava: 1-3 and 10 m; teak: 12 and 24 m) using a hand made (self-produced) 10 paired copper-constant an thermocouple thermometer (shielded and ventilated). All instruments were installed on a 10 m tower in the paddy rice field and cassava and on a 24 m tower in the teak plantation.

The fetches were around 500 m in the paddy rice field, 2 km in the cassava and 400 m in the teak plantation.

Their instantaneous data of every one minute were collected by a data logger to obtain 10 min average and all data were lastly averaged into the daytime mean when R_n was positive. The daytime LE then converted into the daily ET in mm per daytime (mm day^{-1}) as ET=LE/λ in which λ is latent heat of vaporization of water (MJ kg^{-1}).

Two or three tensiometers (pF meter) were installed at 15 cm underneath the soil surface to measure soil water tension.

The average contribution of the latent heat flux to net radiation (LE/R_n) was calculated to understand the energy allocated to the evapotranspiration process (Attarod *et al*., 2005).

Reference Evapotranspiration (ET_0) and ET/ET_0

Daily reference crop evapotranspiration (ET_0) was calculated using the form of Penman-Monteith equation recommended by the FAO (Allen *et al*., 1998) for a hypothetical grass crop with an assumed height of 0.12 m, a fixed surface resistance (70 m sec^{-1}) and an albedo (0.23) as Eq. 3:

$$ET_0 = \frac{0.408\,\Delta(R_n - G) + \gamma(900/(T+273))\,u_2\,(e_s - e_a)}{\Delta + \gamma(1 + 0.34\,u_2)} \tag{3}$$

where, R_n is the net radiation at the cop surface (MJ m^{-2} day^{-1}), T is the daily mean air temperature (°C), u_2 is the wind speed at the height of 2 (m sec^{-1}), e_s is the saturation vapor pressure (kPa)of the air, e_a is the actual vapor pressure (kPa) of the air, Δ is the slope of the vapor pressure curve (kPa °C^{-1}) at the daily mean air temperature and γ is the psychrometric constant (kPa °C^{-1}) calculated as:

$$\gamma = PC_p/\lambda\epsilon \tag{4}$$

where, P is the air pressure (kPa) estimated as a function of altitude, C_p is the specific heat of air at constant pressure (1.013×10^{-3} MJ Kg^{-1} °C^{-1}), λ is the latent heat of vaporization of water (MJ kg^{-1}) expected as a function of air temperature at the lower level of installed AWS and ϵ is the ratio of molecular weights of water vapor and air (0.622).

R_n was estimated through the recommended equations after Allen *et al.* (1998), FAO 56 method for estimating the net radiation (Maruyama *et al*., 2004; Goyal, 2004). To calculate the wind speed at 2 m above the surface, a logarithmic wind speed equation recommended by FAO including the observed wind speed u_z at height z was applied (Allen *et al*., 1998).

Soil heat flux (G) was ignored beneath the hypothetical crop surface for daytime scale (Maruyama *et al*., 2004; Attarod *et al*., 2009) since soil heat flux at the magnitude of the day below the grass reference surface is relatively small.

In the present study, tends of ET/ET_0 values for the paddy rice field, cassava and teak plantations were observed.

RESULTS AND DISCUSSION

Trends of ET

Figure 2 shows annual trends of daily ET expressed in a year for the paddy rice field taken from June 1999 to December 2003, for the cassava plantation from May 2002 to December 2003 and for the teak plantation from May 1999 to December 2003. ET in January was the lowest in three sites (Average; paddy: 2.7 mm, cassava: 1.7 mm, teak: 2.9 mm). ET started to increase around May (Average: 3.2 mm in all sites) when the growing season started and reached its peak (Average; paddy and cassava: 4.5 mm, teak: 4.1 mm) during the mid growing season in September and October.

Increase in net radiation and LE/R_n ratio in May and April might increase the evaporation from the submerged water in paddy rice field before starting the growing season (Attarod *et al*., 2006). Increase in ET from the cassava in May and April can be explained by presence of the plants before starting the rainy season. The peak of ET in three sites synchronized with the peak of net radiation and the peak of LE/R_n ratio.

During the rainy season, ET of the paddy rice field and cassava ranged between 1 and 7 mm. The range of ET for teak plantation was between 2 and 6 mm.

Data were classified to four groups based on the soil moisture condition. Group 1 (closed circles), group 2 (open circles) and group 3 (crosses) correspond to the data obtained from days when the pF values at 15 cm were less than 2.3, between 2.3 and 2.6 and higher than 2.6, respectively. Group 4 (triangles) represents the days with missing pF values.

Table 1 shows the averages of LE/R_n, ET and ET_0 in the measurement sites during the dry and rainy seasons. In the rainy season, average amounts of ET were about 4 mm in all sites, although the variations of ET were different (paddy rice field: $\sigma = 1.28$ mm, cassava: $\sigma = 1.42$ mm and teak: $\sigma = 0.88$ mm). This variation partly relates to the variation of R_n.

In the dry season, ET of the teak plantation showed less variation in comparison with those of the paddy rice field and cassava (paddy rice field: $\sigma = 0.99$ mm, cassava: $\sigma = 1.25$ mm, teak: $\sigma = 0.80$ mm).

In the dry season, average amounts of daily ET in the paddy rice field and teak plantation were nearly the same, around 3 mm and in the cassava slightly lower than those of other sites, approximately 2.7 mm. The results showed different values of LE/R_n mostly depended on the variation of R_n (paddy: 60, cassava: 54 and teak: 67%) in the dry season. LE/R_n was about 70% during the rainy season in the paddy rice field, whereas teak and cassava plantations indicated somewhat higher values of LE/R_n.

Trends of ET/ET_0

Figure 3 shows the seasonal changes of ET/ET_0 for the paddy rice field, cassava and teak plantations. Absolute maximum of ET/ET_0 in the paddy rice field, cassava and teak plantations observed in September and October were approximately 1.2, 1.2 and 1.3, respectively. The monthly average of ET/ET_0 began to increase in May in the paddy rice field

Table 1: Daily averages of the evapotranspiration (ET), LE/R_n ratio and reference evapotranspiration (ET_0) in the three measurement sites

	ET (mm day^{-1})		LE/R_n(%)		ET_0 (mm day^{-1})	
Measurment site	DS	RS	DS	RS	DS	RS
Paddy rice field	3.0	4.1	60	70	4.9	4.4
Cassava plantation	2.7	3.9	54	72	4.5	5.1
Teak plantation	3.0	3.8	67	73	4.1	4.6

DS: Dry season, RS: Rainy season

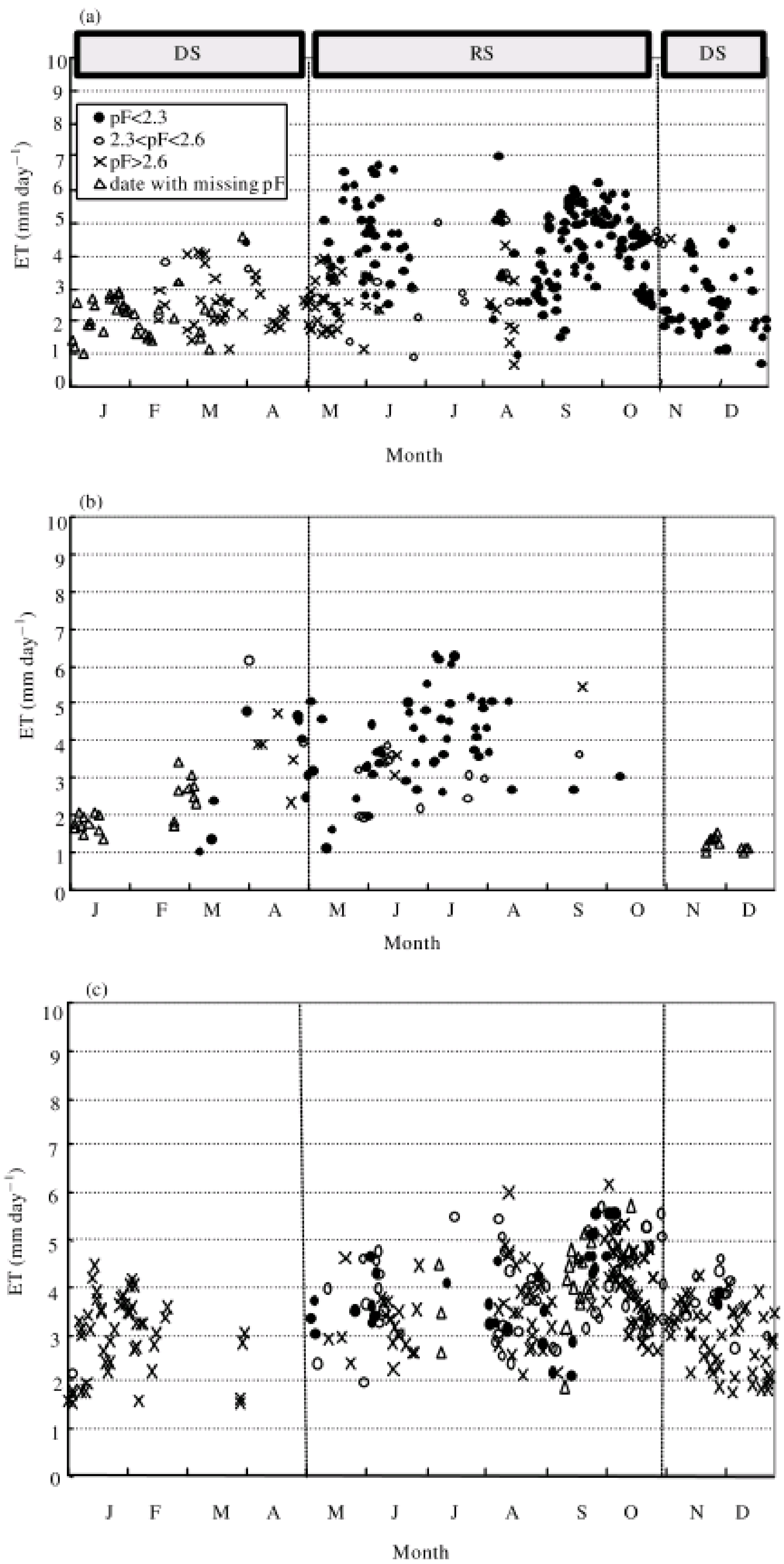

Fig. 2: Seasonal changes in the daily evapotranspiration (ET) for the (a) paddy rice field, (b) cassava and (c) teak plantations. Data were classified based on the soil moisture tension (pF) values. DS: Dry season, RS: Rainy season

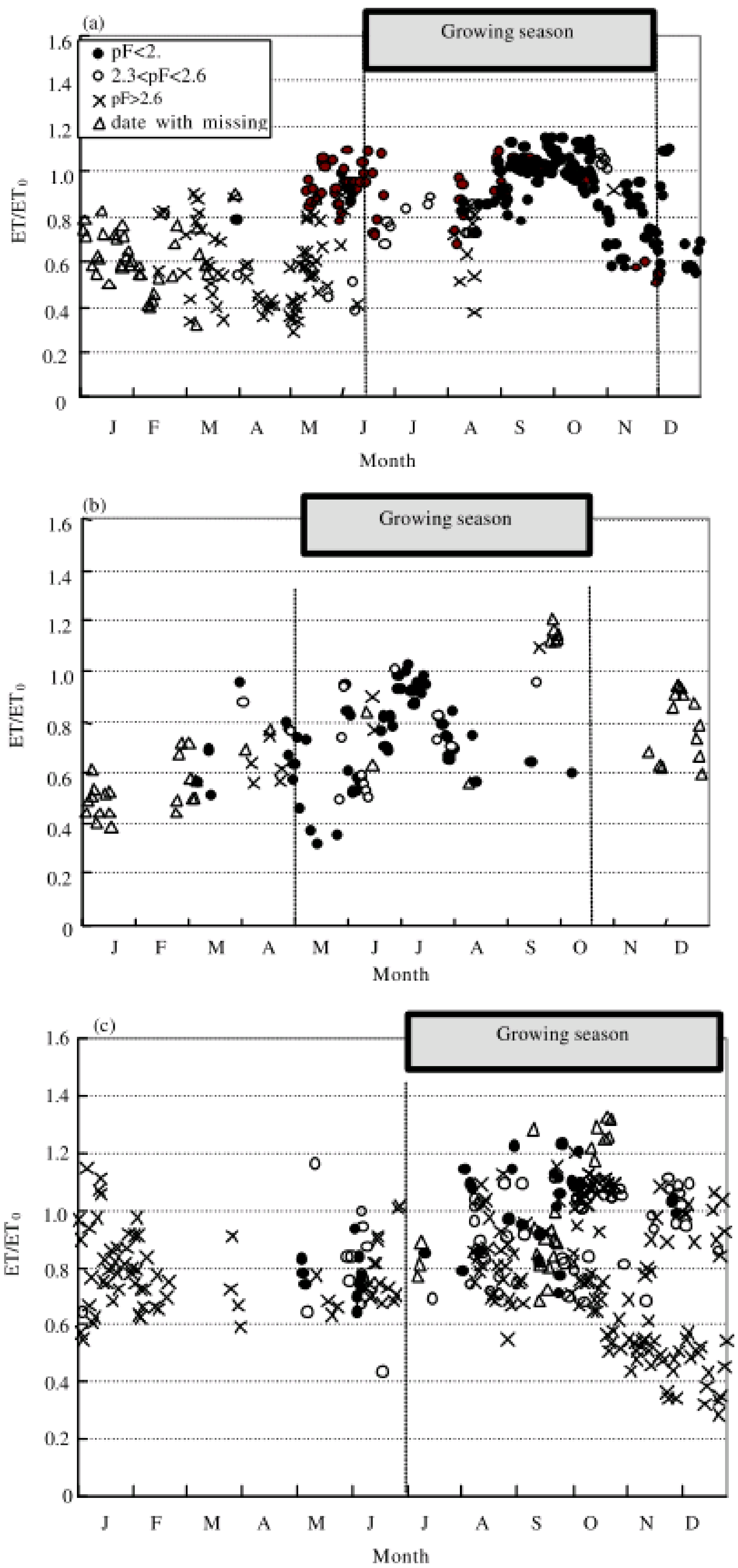

Fig. 3: Seasonal changes in the ratio of ET to ET_0 (ET/ET_0) in the (a) paddy rice field, (b) cassava and (c) teak plantations. Data were categorized based on the values of the soil moisture tension (pF)

and the cassava plantation. It reached the peak around October in the cassava and teak plantations. It decreased gradually thereafter in all sites and reached its minimum in January and February. The average values of the paddy rice field, cassava and teak plantations were found to be 0.7, 0.5 and 0.8, respectively.

During the growing season, ET/ ET_0 varied in the paddy rice field between 0.4 and 1.2 and in the cassava between 0.3 and 1.2. Variation of ET/ET_0 in the teak plantation was between 0.3 and 1.3. The ET/ET_0 value in a cassava plantation planted in November in Khon Kaen, Northeast Thailand was reported around 1.2 happened in June (Watanabe *et al*., 2004). The difference of peak incidence times may be attributed to the difference of planting months of the cassava fields.

Data were divided into four groups as the same way previously done. No sensitivity of ET/ET_0 to the soil moisture was detected in the cassava and teak plantations while in the paddy rice field ET/ET_0 was affected by soil moisture. This fact implies that cassava plants and teak trees were capable of utilizing water from deeper soil layers because of their deeper root zones and also confirming that the cassava and teak plantations were tolerable to drought (Attarod *et al*., 2005).

CONCLUSION

During the rainy season, the range of daily ET in the paddy rice field and cassava plantation was between 1 and 7 and in teak plantation between 2 and 6 mm. The average amount of ET in rainy season was nearly equal in the three sites. ET initiated to increase when the growing season started in May and reached its peak in October or September in all sites. During the dry season, daily ET of the cassava plantation was around 2.7 mm, slightly lower than those of other sites. In the dry season, average ET of the teak plantation showed no significant trend. During the rainy season, LE/R_n ratios in the paddy rice field and cassava plantation were somewhat less than that of the teak plantation. The results showed that maximum ET/ET_0 in the paddy rice field, cassava and teak plantations observed in September and October.

ET/ET_0 in the paddy rice field was more affected by soil moisture than those of cassava and teak plantations suggesting that cassava plants and teak trees tolerate the water shortage during the dry season.

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