Spatial Variation in Evapotranspiration from a Lowland Field as Estimated on a 1km Grid Size in Kyushu

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Abstract

Spatial variation of evapotranspiration (ET) from a lowland field was estimated using the plant growth model coupled to a land surface model based on the climatic data on a 1km grid size in Kyushu Island. ET was compared with precipitation (P) on each grid to study the regional water balance. Seasonal variations of ET on several rice-cropping seasons were also estimated based on normal meteorological data in Miyazaki to understand the effect of change in a rice-cropping season. The Double Source Model was used as a land surface model on both estimations to calculate the evaporation (E) and transpiration (T) separately.

Total values of ET from transplanting to harvest time on a lowland field in Kyushu under normal weather conditions showed a large regional variation from 180mm to 540mm. Regional variation in monthly total values of $P-ET$ in August showed a specific feature: there was a very small $P-ET$ of less than 50mm (poor water resources) on the northern part of Kyushu. Total values of ET on different cropping seasons showed a variation from 635mm to 533mm. The maximum value of ET was found when transplanting at May 1st so that both the earlier and later cropping seasons had smaller total ET values. In addition, Total E showed a larger value when the total T was small, and a contrary E showed a smaller value when the total T was large.

Key words: Double source model, Evapotranspiration, Lowland field, Precipitation

1. Introduction

Lowland rice is a unique crop which lives in shallow water during most of the growing season; therefore, large amounts of water are required for irrigation on a lowland field. Large areas of the plains in Asia are covered with the lowland fields and lowland rice can be cultivated throughout most of the year, so the evapotranspiration (ET) from lowland fields is a dominant factor that affects the regional water balance. Therefore, it is useful to understand the seasonal and spatial variations in ET from a lowland field and the effect of change in the rice-cropping season on them for making effective decisions on proper regional water management.

On early hydrological studies to evaluate the regional water balance, ET from a reference ground surface (Potential ET) was commonly used as an index instead of an actual ET (e.g. Thornswaite, 1948; Priestley and Taylor, 1972). With the advance of theories to describe the physiological processes of water exchange in the Soil-Plant-Atmosphere system, many land surface models considering the physio-

logical processes of the plant were developed that can evaluate the seasonal and spatial variation of ET from vegetation (e.g. Martin *et al.*, 1999). However, it is also necessary to consider the plant growth process for understanding the effect of change in the rice-cropping season, because plant growth would be also affected by climatic fluctuation.

In this study, spatial variation of ET from a lowland field was estimated using the plant growth model coupled to a land surface model based on the climatic data on a 1km grid size in Kyushu Island and ET was compared with precipitation (P) on each grid to study the regional water balance. Seasonal variations of ET on several cropping seasons of rice were also estimated to understand the effect of change in the rice-cropping season on seasonal water balance.

2. Materials and Methods

2.1 Spatial variation of ET

Spatial variation of ET on a lowland field from transplanting to harvest of rice under normal weather

conditions was estimated based on climatic data on a 1km grid size in Kyushu Island. Transplanting and harvest dates on each grid were obtained using the data of usual cropping times on each farming area published by the Food Agency (1998). The climatic data, *i.e.* monthly mean value in solar radiation (S^1), precipitation (P), maximum, minimum and average air temperature (T_{amax} , T_{amin} and T_a , respectively) were provided by the Japan Meteorological Agency. The estimation of ET on each grid was based on the following five calculations.

1) Monthly mean values in water vapor pressure (e_a) were calculated using the empirical equation proposed by Sakuratani (1989) based on the monthly mean value in T_{amax} , T_{amin} and T_a .

2) Daily mean values in T_a , e_a , S^1 and P were calculated with harmonic analysis based on monthly mean value of them.

3) Daily mean values in long wave radiation (L^1) were calculated using the semi-empirical equation proposed by Kondo (1991) based on the value in T_a , e_a and S^1 . Daily mean values in wind speed at 2m heights (U) were assumed at 2.5m/s based on statistical data of the Kyushu region.

4) Leaf Area Index (LAI) of lowland rice was calculated using the plant growth model adapted to rice proposed by Horie (1987), and using the fitted parameter for the Kyushu region, which was determined by Maruyama *et al.* (1998). Canopy height h (m) of the rice was also calculated using the following empirical relationship that was determined based on our previous observation.

$$h = 0.46 \times LAI^{0.375}$$

5) Daily mean values in ET of lowland field were calculated using the land surface model based on the daily mean climatic data (T_a , e_a , S^1 , L^1 and U) and ecological data (LAI and h of lowland rice). The Double Source Model proposed by Kondo and Watanabe (1992) was used as land surface model. Several modifications by Watanabe (1993) and following empirical relationship between daily mean bulk stomatal conductance g_s (mm/s) and solar radiation absorbed by unit leaf area S_{ab} (W/m^2), which was determined based on author's previous observation on lowland field, were applied on the model.

$$g_s = 0.107 \times S_{ab}^{0.92}$$

2.2 Effect of change in the rice-cropping season

Seasonal variations of ET were estimated on five different rice-cropping seasons (transplanting at 1st

of March, April, May, June and July) based on normal meteorological data (1971-2000) from the Miyazaki local observatory. Evaporation from water surface (E) and transpiration from the canopy (T) were calculated separately using the Double Source Model based on the daily mean values of T_a , e_a , S^1 and U , which were provided by Japan Meteorological Agency. Other methods of calculation were the same as section in 2.1.

3. Results and Discussion

Figure 1 shows the spatial variations in total values of ET from transplanting to harvest time in lowland fields under normal weather conditions calculated on 1km grid sizes. There is large regional variation in ET from 180mm to 540mm. A general trend in regional variations is that ET from lowland fields in a plain area (e.g. Chikugo, Kumamoto and Miyazaki) are larger than those of mountainous areas (e.g. Aso and Kuju). To evaluate the water resources on a lowland field area, the net amount of precipitation after deduction of evapotranspiration ($P-ET$) was estimated on each grid. Figure 2 shows the spatial variation in monthly total values of $P-ET$ in June, July, August and September under normal weather

Fig. 1. Spatial variations in total evapotranspiration from transplanting to harvest on lowland fields under normal weather conditions in Kyushu.

conditions calculated on a 1km grid size. Comparing the $P-ET$ value among months, the overall values of $P-ET$ are smaller in August and September and larger in June and July. Especially in August, there is a very small $P-ET$ of less than 50mm on the northern part of Kyushu Island (e.g. Iki, Fukuoka, Kunisaki, Chikugo and Kumamoto). This suggests that these lowland areas have poor water resources, and risk of water shortage is higher than in other areas if there is no input. Comparing the trend of regional variation of $P-ET$ in August with that of ET , small $P-ET$ areas do not necessarily correspond to the large ET areas because of the difference in P ; e.g. Iki, Fukuoka and Kunisaki showed small $P-ET$ however ET is not so large; On the other hand, Miyazaki showed a large ET however $P-ET$ is not so small. In addition, regional variations of total $P-ET$ in September showed the specific feature that an area of small $P-ET$ was found in Kumamoto.

Figure 3 shows the seasonal variations of E and T on five different cropping seasons of rice calculated based on normal meteorological data in Miyazaki. As a common pattern of seasonal variation of all cropping seasons, E accounts for a large percentage of ET just after transplanting, and moderately decreases in percentage with the canopy developing, and finally T accounts for a large percentage of ET until harvest. However, there is large difference of the timing of the T increase in each cropping season. A general trend is that the timing of the E increase is late in earlier cropping seasons and is early on later cropping seasons. This could be because of the difference in canopy developments affected by climate differences of each cropping season. To understand the effect of change in cropping season on total ET , differences of total values of E and T on each cropping season are shown in Fig. 4. Total ET shows a variation from 635mm to 533mm. The maximum value of ET was found when transplanting at May 1st so that both the earlier and later cropping seasons had smaller total ET values. Iwakiri (1964) obtained the result that the total ET from a lowland field during an early cropping season and a usual cropping season showed almost same value. However, our result suggests that it was the occasional result of comparing the earlier and later cropping seasons, and not the just middle season that shows maximum total ET . Differences of total T on each cropping season showed a similar trend as ET , and that of total E showed an opposite trend, so E showed a large value when T was small, and E showed a small value when T was large. Since it is

Fig. 2. Spatial variation in monthly net amount of precipitation after deduction of evapotranspiration under normal weather conditions in Kyushu.

Fig. 3. Seasonal variations of evaporation E and transpiration T on different transplanting times under normal weather conditions in Miyazaki.

Fig. 4. Total evaporation E and transpiration T on different transplanting times of rice under normal weather conditions in Miyazaki.

supposed that the total T is proportional to the amount of production by photosynthesis, this result suggests that the water use efficiency of lowland rice during earlier and later cropping seasons are lower than that of usual cropping season.

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