Kasetsart J. (Nat. Sci.) 43 : 642 - 649 (2009)

Estimation of Solar Radiation Use Efficiency in Paddy and Cassava Fields

Siriphan Leepipatpaiboon[1], Samakkee Boonyawat[1]* and Ed Sarobol[2]

ABSTRACT

The estimation of solar radiation use efficiency in rice and cassava fields was studied in Sukhothai and Nakhon Ratchasima provinces, during November 2004 to January 2006. Crop growth was divided into three periods of cultivation: early vegetative, actively growing and before harvesting. The objectives of the study were to: 1) compare the radiation use efficiency (RUE) between rice and cassava; and 2) study the relationship between biomass and absorbed photosynthetically active radiation (PARa). The results of the experiment may be used as basic data for studying the energy balance of other watershed areas with different land uses.

The comparison of photosynthetically active radiation (PAR) between cassava and rice revealed that PARa in cassava was higher than in rice. In a cassava crop, the greatest value (10.99 MJm^{-2}) of daily PARa was obtained during the actively growing period, with an average PARa of 8.98 MJ m^{-2} and a radiation use efficiency (RUE) of 1.09–4.42 g MJ^{-1}. Similarly, in a rice crop, the greatest value (9.53 MJ m^{-2}) of daily PARa was observed during the actively growing period, with an average PARa of 6.41 MJ m^{-2} and an RUE of 0.58–0.66 g MJ^{-1}. PARa in the cassava crop, however, was higher than in the paddy field. The relationships between total biomass and PARa in the paddy and cassava crops were linear with R^2 values of 0.97 and 0.89, respectively.

Key words: radiation use efficiency (RUE), photosynthetically active radiation (PAR), cassava, rice

INTRODUCTION

Solar radiation is the ultimate power source in the world and it plays an important role in terrestrial ecological systems and living organisms. The radiation received by an organism consists of direct beam, diffuse sky and reflected radiation from terrestrial objects (Campbell and Norman, 1998). The resultant net radiation is used for such natural processes as evapotranspiration, sensible heat, soil heat flux and biological processes. Different land uses may affect the absorption and reflection of solar radiation causing different values for the radiation use efficiency (RUE) of crops.

RUE is a useful parameter in studying crop productivity (Curt *et al.*, 1998) and has been used in many crop growth models to estimate total or above-ground biomass and crop yields (Apakupakul, 1995). RUE varies with crop coefficients of radiation extinction, biochemical exchange and carbon dioxide (Monteith, 1977). RUE is different among crop plants; therefore, they have different growth rates and yields. Several

[1] Department of Conservation, Faculty of Forestry, Kasetsart University, Bangkok 10900, Thailand.
[2] Department of Agronomy, Faculty of Agriculture, Kasetsart University, Bangkok 10900, Thailand.
* Corresponding author, e-mail: fforskb@ku.ac.th

Received date : 27/03/09 Accepted date : 29/05/09

studies have reported on different RUE values for crops, including sweet sorghum (Curt *et al*., 1998), peanuts (Kiniry *et al*., 2005); wheat, field peas and mustard (O'Connell *et al*., 2004), and cassava (Oka *et al*., 1987). In Thailand, RUE of wet-sown and transplanted rice for Suphanburi 90 was 2.77 and 3.20 gMJ^{-1}, respectively, and for Chieng was 2.13 and 2.67 gMJ^{-1}, respectively, (Apakupakul, 1995). Nevertheless, study on crop RUE in Thailand is quite rare. Information on RUE can be applicable to a breeding program aimed at improving crop yield through changes in crop architecture. The objectives of this experiment were to: 1) estimate and compare radiation use efficiency (RUE) between paddy rice and cassava; and 2) study the relationship of biomass, leaf area index (LAI) and absorbed photosynthetically active radiation (PARa) in rice and cassava crops.

MATERIALS AND METHODS

Site selection

The two experimental sites were a cassava crop in Kornburi district, Nakhon Ratchasima province and a rice crop in Muang district, Sukhothai province. Both sites were equipped with automatic weather stations as part of the GEWEX Asian Monsoon Experiment Tropics (GAME-T) and Coordination Enhanced Observation Period (CEOP) projects.

The cassava crop site had an area of 20 km^2 in Kornburi district, Nakhon Ratchasima province and was located at 14° 29' 50" N latitude and 102° 23' 28" E longitude, 280 m above mean sea level (amsl) (Table 1).

The rice crop in Muang district, Sukhothai Province was located at 17° 04' 16" N latitude 99° 42' 18" E longitude, with an altitude of 50 m amsl and an area of 20 km^2. The paddy fields were rain-fed, with no supplemental irrigation during the growing season. Rice was sown in mid-July 2006 at the seed rate of 94 kg ha^{-1} and harvested during November and December 2006. After harvest, the rice stubble and crop debris were burnt for the next irrigated rice crop (Table 1).

Data collection

The experiment was carried out from July 2004 to January 2006 and data were collected during three periods of crop growth: early vegetative (crop establishment / root bulking); actively growing; and before harvest (Table 2).

Plant samples were collected from three areas. Each area for rice and cassava was 0.5 × 0.5 m^2 and 0.8×0.8 m^2, respectively. The experimental area of rice had 1-2 tillering (1 tillering = 3-4 plants) and cassava had 3-4 plants. The experiment

Table 1 Activities/schedule and crop growth period of rice in Muang district, Sukhothai province and cassava in Kornburi district, Nakhon Ratchasima province during the period 2004-2006.

Land uses	Activities	Time periods
Rice		
	Broadcasting	July-August
	Active, fully-grown period	September-October
	Harvest period	November – December
Cassava		
	Fallow	March-April
	Beginning cultivation	May
	Crop establishment/Root bulking	June-August
	Active, fully-grown period	September-December
	Harvest period	January

collected one sample per area.

The plant samples were separated into two parts, above-ground and underground. The above-ground components were the leaves, stems and grains (rice) and the underground component was the roots. Plant samples were weighed and oven-dried at 80°C for 72 h after which they were weighed for dry weight.

Leaf area index (LAI) was determined using a plant canopy analyzer model, LAI-2000.

Calculation

PARa was calculated using methods described by Gosse *et al*. (1986) and Varlet-Grancher *et al*. (1989), as cited by Apakupakul 1995 (Equations 1 and 2).

$$PARa = \varepsilon i PARi \quad (1)$$

Where PARa = absorbed photosynthetically active radiation (MJ m^{-2} day^{-1})

εi = radiation absorption efficiency of PAR above crop canopy.

Table 2 Comparisons of PARa, biomass and leaf area index (LAI) between rice and cassava crops during 2004-2006.

Land uses	Growth period/Month	PARa (MJ m^{-2})	PARa efficiency (εi)	Total biomass (kg rai^{-1})	LAI
Rice crop	Early vegetative period				
	August	1.72	0.15	229.33	0.28
	Actively growing period				
	September	6.76	-	-	-
	October	9.53	0.75	464.00	2.56
	Before harvest period				
	November	7.65	0.64	789.33	1.89
	Grand mean	6.41	0.51	494.22	1.58
Cassava crop	Early vegetative period				
	July	6.37	0.46	484.05	1.09
	August	8.76	0.62	1,686.40	1.75
	Average	7.56	0.54	1,085.23	1.42
	Actively growing period				
	September	11.50	0.89	1,988.80	4.50
	October	13.00	0.82	3,876.48	3.28
	November	8.45	0.62	8,656.00	1.79
	Average	10.99	0.78	4,840.43	3.19
	Before harvest period				
	December	7.16	0.51	11,899.52	1.30
	January	7.64	0.56	11,384.96	1.49
	Average	7.40	0.54	11,642.24	1.40
	Grand mean	8.98	0.64	5,710.89	2.17

PARi = photosynthetically active radiation above crop canopy (MJ m^{-2} day^{-1})

$$\varepsilon i = 0.95\ (1- EXP\ (-KL)) \quad (2)$$

Where K = extinction coefficient (K values for cassava and rice = 0.6 in this study)

L = leaf area index (LAI)

Radiation use efficiency (RUE) was derived from the slope of the linear regression line of the above-ground biomass and accumulative absorbed PAR (PARa). It was compared between different land uses.

Regression analysis was also carried out to determine the relationship between total biomass and PARa for rice and cassava.

RESULTS AND DISCUSSION

Absorbed photosynthetically active radiation (PARa)

PARa varied ontogenetically. During the early vegetative period (July to August), PARa was low because during this period plant size was too small to absorb large amounts of light energy. This was confirmed by an LAI crop value of 0.28 for paddy rice. In the actively growing period for cassava (October), PARa was greater than in other periods because plant size was large enough (LAI=2.56) to absorb large amount of PAR for crop growth. At a later stage, before the harvest period (November), PARa decreased because plants encountered the dry period and leaves dropped (Table 2). Therefore, ontogenetic drift affected PARa.

Table 2 shows that the average daily efficiency of PARa in the cassava crop (0.64) was higher than for the rice crop (0.51). The result can be attributed to different plant architecture between cassava and rice. Therefore, the absorption and reflection of radiation affected crop PARa. The rice crop had fewer leaves and a smaller leave size to absorb and reflect solar radiation compared with cassava.

Relationship between accumulative absorbed PAR (PARa) and above-ground biomass and total biomass.

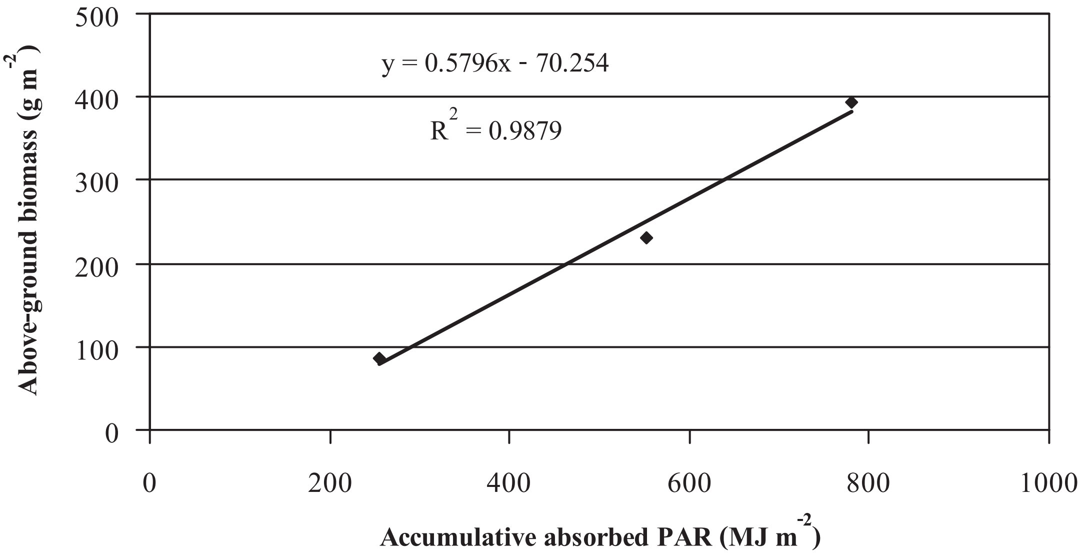
Table 3 indicates that in the rice crop, LAI and PARa were linearly related (Figure 1). This result was different from Curt *et al*. (1998) who reported that the relationship between absorbed photosynthetically active radiation (PARa) and LAI was exponential. The relationships between biomass, either above the ground or total, and PARa were linear. These results were in line with Apakupakul (1995), Curt *et al*. (1998) and O' Connell *et al*. (2004).

The results for the cassava crop were similar to those for the rice crop, where the relationship between LAI and PARa was polynomial, but the relationship between biomass, either above the ground or total, and PARa was linear (Table 3 and Figure 2).

Table 3 Relationship between accumulative absorbed PAR (PARa) and above-ground biomass and total biomass in rice and cassava.

Factor	Form	Equation	R^2
Paddy field rice			
Above-ground biomass	Linear	Y=0.5796x+70.254	0.9879
Total biomass	Linear	Y=0.6588x+39.979	0.9728
Cassava crop			
Above-ground biomass	Linear	Y=1.087x-53.528	0.8445
Total biomass	Linear	Y=4.4217x-1352.1	0.8886

a



b

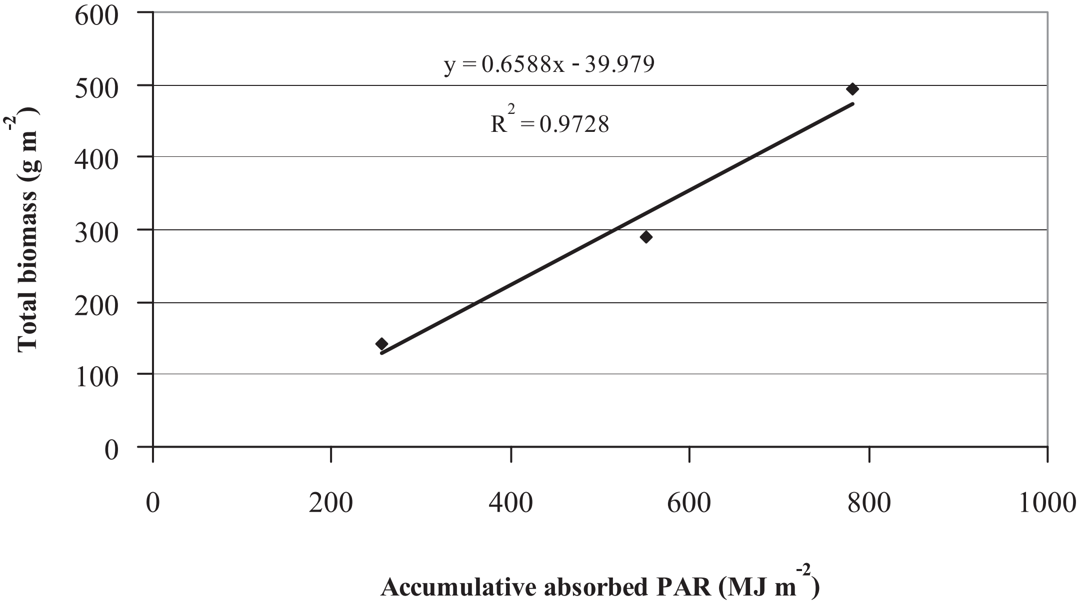


Figure 1 Relationship between accumulative absorbed PAR (PARa) in the rice crop and (a) above-ground biomass; and (b) total biomass.

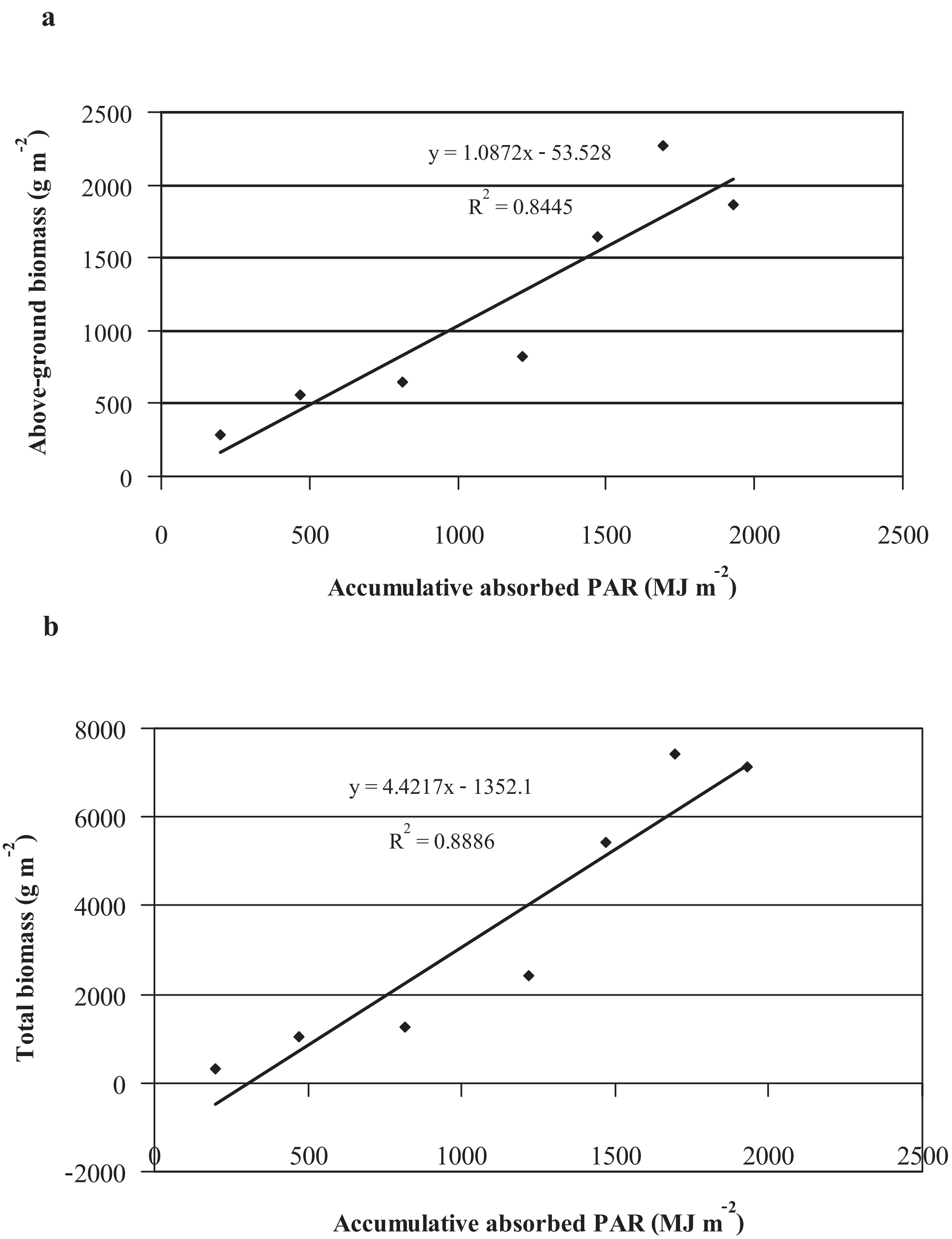


Figure 2 Relationship between accumulative absorbed PAR (PARa) in the cassava crop and (a) above-ground biomass; and (b) total biomass.

Radiation use efficiency (RUE) in rice and cassava fields

RUE in the rice crop was calculated as the slope of the regression line between PARa and above-ground biomass and total biomass (Figure 1). The slope values were 0.58 and 0.66, respectively, with an R^2 value of 0.99 and 0.97, respectively. Apakupakul (1995) reported that the RUE values of wet-sown and transplanted rice for Suphanburi 90 were 2.77 and 3.20 g MJ^{-1}, respectively, and 2.13 and 2.67 g MJ^{-1} for Chieng (Table 4).

Table 4 and Figure 2 show the data for RUE in cassava. The results revealed that cassava had RUE values of 1.09 g MJ^{-1} (above-ground biomass and PARa) and 4.42 g MJ^{-1} (total biomass and PARa). Cassava was reported to have RUE values in the range of 0.44-0.79 (Oka *et al*., 1987).

Comparison of RUE between rice and cassava in Table 4 revealed that cassava RUEs (1.09-4.42 g MJ^{-1}) were greater than rice RUEs (0.58-0.66 g MJ^{-1}). Greater RUEs for cassava compared with rice can be attributed to the greater LAI value of cassava (3.19) than that of rice (2.56), especially during the actively growing period for both crops (Table 2).

CONCLUSION AND RECOMMENDATION

The results of the estimation of solar radiation use efficiency in rice and cassava crops, 9.53 and 10.99 MJm^{-2}, respectively, indicated that PARa in rice and cassava changed ontogenetically. The maximum PARa was observed during the actively growing period. The relationship between PARa and above ground and total biomass was linear for both rice (R^2=0.9675 and 0.9728) and cassava (R^2=0.8445 and 0.8886). The RUE values were 0.58 (for above-ground biomass) and 0.66 (for total biomass) for rice and 1.09 and 4.42, respectively for cassava. It is recommended that RUE for rice could be increased, by increasing the LAI though crop management or the use of new plant types. Additionally, further studies

Table 4 Comparison of radiation use efficiency (RUE) among different rice cultivars and between rice and cassava.

Species	Growing period	PARi ($MJ\ m^{-2}$)	RUE ($g\ MJ^{-1}$)	Reference
Rice (Chieng)	Dry season (May.-Sept.)	6.05	2.77-3.20	Apakupakul (1995)
	Rain season(Oct.-Mar.)	6.08		
Rice (Suphanburi 90)	Dry season (May.-Sept.)	6.05	2.13-2.67	
	Rain season(Oct.-Mar.)	6.08		
Rice (RD. 1)	Early vegetative period(Aug.)	11.71	0.58-0.66	The current study
	Actively growing period(Oct.)	12.78		
	Before harvest period(Nov.)	11.87		
Cassava (Kasetsart 50)	Early vegetative period (Jul.-Aug.)	14.07	1.09-4.42	
	Actively growing period (Sept.-Nov.)	14.17		
	Before harvest period (Dec.-Jan.)	13.75		

should be done in both the rainy and dry seasons under different cropping patterns, crop cultivars and species.

ACKNOWLEDGEMENTS

This research was partially supported by the Graduate School, Kasetsart University, Bangkok, Thailand.

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