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Photosynthetically active radiation variation across transplanting dates and its effect on rice yield in tropical sub-humid environment

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ABSTRACT

Interception of photosynthetically active radiation (PAR) by the rice crop at different phenophases is important for growth and yield variation through radiation utilization by the crop. Identification of intercepted PAR at a particular time point is necessary for understanding the role of PAR. An experiment on rice cultivar Satabdi was conducted at B.C.K.V, West Bengal, India. Twenty five days old seedlings were transplanted from 1st to 29th July at 7 days interval during 2007 and 2008. Interception of PAR was measured at 7.30, 9.30, 11.30, 13.30 and 15.30 h at tillering, panicle initiation, emergence and 100% flowering. Dry matter, yield attributes, yield and PAR use efficiency were estimated. The delay in transplanting reduced the leaf, stem and root dry matter. The mean PAR use efficiency ranged from 3.17 to 3.7 g MJ^{-1} when transplanted within 15th July. Yield attributes and grain yield were reduced with the delay in transplanting. The PAR use efficiency for grain production was drastically reduced after 15th July transplanting. The interception of PAR at 7.30, 9.30 and 15.30 h had a significant contribution for dry matter and grain yield of rice. In the eastern Gangetic plains of India, rice should not be transplanted after 15th July.

Key words: *PAR use efficiency,interception, rice, dry matter, grain yield*

Rice is the most important edible cereal in the world. The dry matter accumulation and yield of crop depend on the solar radiation received by the canopy. Interception of light by the rice canopy depends on the transmissivity and the reflectivity of the rice canopy and its leaf inclination (Maruyama *et al.*, 2007). The relationship between the intercepted radiation and dry matter is known as radiation use efficiency (RUE). The estimation of RUE involves the total solar radiation whereas a certain fraction of the total electromagnetic spectrum is used for photosynthetic purpose. The PAR fraction cannot be estimated from total solar radiation simply by a multiplication factor because the appropriate multiplication factor depends on canopy leaf area index (LAI). Therefore, it is essential to measure the PAR interception directly and RUE should be estimated with this intercepted PAR. The effect of temperature on rice growth is well established (Shimono and Ishii, 2012; Dutta *et al.*, 2012). The growth of crop is a complex process and is the resultant effect of canopy radiation capture, photosynthesis and the conversion of photosynthesis to the biomass (Shimono *et al.*, 2002). During the vegetative and reproductive periods, the limited leaf area and canopy radiation interception were the major reasons for reduced dry matter increase in rice (Shimono *et al.*, 2002). Ahmad *et al.*, (2008) recorded a linear relationship between the total dry matter accumulation and intercepted PAR in rice crop. The investigations on the impact of intercepted PAR on dry matter accumulation yield and PAR use efficiency (PARUE) at the different growth stages as well as the interception of PAR at a particular time point of a day is still not well documented. Shimono and Ishii (2012) suggested that the variation in grain growth could not be fully explained by temperature and solar radiation during ripening stage. The interception of PAR at a particular time point of a day is important in the area where the sky remains cloudy in a particular season. In the Eastern Gangetic plains of India, rice yield has not been increased in spite of good quality seed and fertilizer because of the presence of the cloudy sky during the main rice growing season (June-October). Water is not a limiting during this period as there is plenty of rainfall during monsoon. Therefore, we hypothesized that the identification of intercepted PAR at a particular time point of a day is essential for better dry matter production in rice crop, which will give better yield as an ultimate effect and the present investigation was undertaken.

MATERIALS AND METHODS

The experiment was carried out during *wet* season (June-September) of 2007 and 2008 at the experimental farm of BCKV, (Latitude 22°58′ N, Longitude 88°31′ E and Altitude of 9.75 meter above mean sea level), West Bengal, India.

The experimental site falls under tropical sub-humid climate and experiences three distinct seasons- March to June as summer, June to September as rainy season and October to February as winter; the summer season is humid and receives rainfall with thunderstorm occasionally. The mercury reaches at its maximum during the month of May, whereas the coldest day is usually observed during January. The South West Monsoon season starts during the first week of June and withdraws during 1st week of October. This area receives an average annual rainfall of 1600 mm out of which 1300 mm occurs during monsoon. Nor-Wester shower comes during March, April or May and the area experiences dry spell for long period with concomitant high air temperature.

The experimental soil was entisol. The soil contained 0.07% total N, 22.02 kg available P, 126.00 kg available K ha^{-1} and 0.67% organic carbon. The experimental soil was neutral in reaction with pH-7.45.

The experiment was laid out in a randomized complete block design where the cultivar *Satabdi* (IET 4786) was transplanted on five dates, starting from 1st July to 29th July at 7days interval i.e. 1st July, 8th July, 15th July, 22nd July and 29th July. The treatments were replicated four times with a net plot size of 6m×5m.Twenty five days old seedlings were transplanted in the main field with an inter row spacing of 20cm and intra row spacing of 15cm. The recommended dose of fertilizer was 80:60:60 kg $N-P_2O_5-K_2O$ ha^{-1}, applied through urea, single super phosphate (SSP) and muriate of potash (MOP) respectively.

Five hills were selected from the 2nd row and plants were cut from the ground level. The leaves, stems and roots were separated and dried in hot air oven at 60°C temperature for 72 hours. The summation of the dry weight of stems, leaves and roots gave total dry matter accumulation which was then calculated in terms of g m^{-2}. The yield attributes like number of panicles m^{-2}, number of spikelets $panicle^{-1}$ were recorded as per plant basis. After that, grains were separated from the spikelets and the weight of 1000 grains gave the test weight.The hills from 10 m^2 area were collected for yield estimation and yields from 10 m^2 area were converted on hectare basis.

Photosynthetic active radiation was measured with the help of Line quantum sensor (APOGEE Logan UT, Model no. MQ-301). The observations were recorded at 7.30, 9.30, 11.30, 13.30 and 15.30 hr. on each phenophase to get a picture of diurnal variation of the same.

Intercepted PAR was calculated with the help of following the expression:

$IPAR = PAR_{(o)} - T\ PAR - R\ PAR_{(c)}$ (Dhaliwal *et al.*, 2007)

Where, $PAR_{(o)}$ = the portion of the incident PAR above the canopy

T PAR = transmitted portion of the PAR through the canopy to the soil surface

R $PAR_{(c)}$ = reflected PAR from crop (reflected PAR value at the uppermost layer of the rice canopy).

PAR use efficiency was measured as PARUE $= \frac{\text{Total dry matter accumulation}}{\text{Accumulated intercepted PAR}}$

Stepwise multiple regression analysis and Pearson's correlation coefficients were computed to find the relationship between the important biological and environmental components. The statistical calculation was done by SPSS 7.5 software (SPSS 7.5 copyright, 1997 by SPSS Inc., USA Base 7.5

Application guide).

RESULTS AND DISCUSSION

The interception of PAR during the tillering phase was maximum at 11.30h. Generally the interception increased from 7.30 to 11.30h in most of the cases, thereafter declined (Table 1). The marginal variation in the general trend was observed due to cloud appearance during the monsoon. During tillering phase, mean interception varied from 71.6 to 78.8% under different dates of transplanting. Panicle was initiated during 12th to 19th August under different dates of planting. The mean interception was minimum when the transplanting was done on 29th July. During emergence, the interception was maximum at 13.30 h under 1st July, 8th July and 22nd July plantings, but magnitude of variation in interception in between 11.30 h and 13.30 h was very marginal. However, no such definite trend was recorded during 100% flowering phase.

Interception generally increased with the increase in solar elevation angle. In this latitude, the sun remains at the Zenith at 11.30h, thus, the crop receives maximum insolation (Chakraborty *et al.*, 2008; Jena *et al.*, 2009). Marginal variation was observed due to cloud appearance because the duration of maximum tillering ranged from 30th July to 26th August under different dates of planting and the duration of this phenophase ranged 28-33 days. No definite trend in interception was found during panicle initiation and 100% flowering because of the active monsoon operative during August and September.

Dry matter accumulation in leaf, stem and roots gradually increased from tillering to 100% flowering (Table 2). With the delay in transplanting, the dry matter partitioning declined significantly. The leaf, stem and root dry matter was minimum when the crop was transplanted on 29th July.

Interception of PAR at 9.30 and 15.30h at the tillering stage significantly and positively affected the dry matter production (Table 5). Thirty seven percent variation in dry matter accumulation was contributed by intercepted PAR. At the panicle initiation stage, the interception at 7.30 and 15.30 h had a positive effect on dry matter accumulation. Eighty eighty percent

Table 1. Diurnal variation in intercepted PAR by the rice crop under different dates of transplanting (Mean of 2007 and 2008)

Treatments	7.30	9.30	11.30	13.30	15.30	Mean
Tillering						
1st July	70.45	77.55	83.55	75.75	82.75	78.05
8th July	89.20	82.90	84.20	78.50	59.00	78.80
15th July	71.40	73.70	80.05	73.50	67.95	73.35
22nd July	84.20	80.35	78.75	77.35	55.30	75.20
29th July	59.35	70.50	83.85	75.40	68.90	71.60
Panicle Initiation						
1st July	81.15	73.65	86.70	84.10	85.50	82.20
8th July	88.45	89.10	87.60	86.00	77.70	85.80
15th July	79.80	75.60	83.85	82.20	71.45	78.60
22nd July	84.00	85.05	80.55	87.05	73.85	82.15
29th July	73.50	77.10	76.50	81.35	72.95	76.25
Emergence						
1st July	79.95	83.40	89.30	91.35	84.55	85.70
8th July	87.60	88.90	88.85	90.40	86.45	88.45
15th July	80.30	83.15	87.95	86.05	88.10	85.15
22nd July	83.30	88.80	80.20	90.30	90.05	86.55
29th July	87.25	86.20	88.10	88.05	82.80	86.50
100% flowering						
1st July	86.70	92.45	86.90	91.90	87.95	89.20
8th July	93.25	91.85	91.95	93.10	88.40	91.70
15th July	80.05	85.35	87.95	90.50	89.40	86.65
22nd July	86.70	85.75	82.90	93.00	86.05	86.90
29th July	85.80	85.85	87.05	88.05	89.50	87.25

D_1=1st July, D_2= 8th July, D_3= 15th July, D_4= 22nd July, D_5= 29th July

Table 2. Effect of dates of transplanting on partitioning of dry matter in rice (g m^{-2}) at the different phenophases of rice (Pooled mean of 2007 and 2008)

Treatments	Leaf				Stem				Root			
	Tillering	PI	Emergence	100% flowering	Tillering	PI	Emergence	100% flowering	Tillering	PI	Emergence	100% flowering
1st July	131.0	221.3	403.8	436.8	91.2	268.8	826.3	913.1	42.4	123.3	167.7	168.7
8th July	114.0	226.4	337.9	390.0	95.6	271.1	666.2	862.0	50.4	88.2	135.1	166.6
15th July	108.9	190.8	327.6	312.7	90.7	225.6	703.2	744.1	36.2	72.3	130.9	145.9
22nd July	89.3	156.1	267.1	223.2	73.2	172.5	612.4	514.2	31.6	65.3	101.8	119.5
29th July	88.3	125.4	220.2	246.5	62.7	136.6	415.7	550.3	29.9	52.2	53.5	117.7
S.Em(±)	3.1	9.7	6.9	3.7	7.7	18.3	50.9	33.0	3.2	8.7	11.7	9.5
LSD (P=0.05)	9.2	29.2	20.8	11.0	23.0	54.7	152.6	98.9	9.7	26.1	35.1	28.5

D_1=1st July, D_2= 8th July, D_3= 15th July, D_4= 22nd July, D_5= 29th July; PI= Panicle Initiation

variation in dry matter accumulation could be assigned through the variation in intercepted PAR during this phenophase. During emergence and 100% flowering, similar observation was recorded. Therefore, it could be suggested that the dry matter accumulation was significantly and positively dependent on intercepted PAR at 7.30, 9.30 and 15.30 h during the different phenophases. Ishikawa *et al.*, (2003); Al-Khaffaf *et al.*,(2003) obtained a significant relationship between solar radiation and dry matter accumulation.

The PAR use efficiency was maximum during panicle initiation to emergence irrespective of dates of transplanting (Table 3). The mean PAR use efficiency ranged from 1.91 – 3.7g MJ^{-1} under different dates of transplanting. The PAR use efficiency was minimum under 29th July transplanting, maximum under 15th July transplanting. The mean PAR use efficiency remained high when the crop was transplanted upto 15th July, thereafter it decline rapidly (Table 3).

The mean PAR use efficiency remained high when the crop was transplanted within 15th July. In general, PAR use efficiency was substantially lower in the reproductive phase under all dates of transplanting than the vegetative stage. Reduction in PAR use efficiency during reproductive phase might be attributed to the decline in leaf-nitrogen concentration with its removal for grain filling.This might have reduced the capacity of leaf to accumulate carbon (Campbell *et al.*, 2001). Moreover, a decline in photosynthetically active leaf area also contributed to the reduction in PAR use efficiency during reproductive phase as rice leaves senesced at high rate after 100% flowering, but leaf tissue whether live or dead considered equally in the measurement of intercepted PAR.

Number of panicles per square meter did not differ between 1st July and 8th July transplanting. However, the number of spikelets per panicle significantly reduced with the delay in transplanting. Similar was the trend in case of test weight (Table 4). The grain yield recorded a steady decline with the delay in transplanting. When the crop was transplanted on 8th July, the rate of yield reduction was 94.7 kg day^{-1} ha^{-1}, when compared with the 1st July transplanting. When transplanting was delayed to 29th July, the extent of yield loss was 1120.4 kg day^{-1}ha^{-1}.

Table 3. PAR use efficiency for total dry matter accumulation in rice crop during different phenophases (Mean of 2007 and 2008)

Treatments	PARUE (g MJ^{-1})							
	Transplanting-Tillering	Tillering-PI	PI-Emergence	Mean PARUE (vegetative phase)	Emerge-100% flowering	100% flowering -Harvest	Mean PARUE (reproductive phase)	Mean
1st July	1.84	4.56	5.63	4.01	1.97	1.84	1.91	3.17
8th July	1.63	5.12	5.07	3.94	3.68	1.71	2.70	3.44
15th July	1.79	5.47	7.89	5.05	1.17	2.18	1.68	3.70
22nd July	1.76	4.23	4.60	3.53	1.38	0.66	1.02	2.53
29th July	1.22	1.90	3.68	2.27	2.50	0.23	1.37	1.91

D_1=1st July, D_2= 8th July, D_3= 15th July, D_4= 22nd July, D_5= 29th July; PI= Panicle Initiation;
PARUE = PAR use efficiency

Table 4. Yield attributes, grain yield and PAR use efficiency for grain production in rice under different dates of transplanting (Pooled mean of 2007 and 2008)

Treatments	No. of panicles m^{-2}	Spikelets panicle^{-1}	Test weight (g)	Yield (kg ha^{-1})	Yield PARUE (g MJ^{-1})
1st July	278	67	19.9	3201.2	0.49
8th July	291	62	18.0	2538.1	0.46
15th July	240	57	17.7	2441.8	0.50
22nd July	256	54	16.6	2210.6	0.39
29th July	260	51	16.1	2080.8	0.33
S.Em (±)	15.0	0.8	0.2	52.7	
LSD (P=0.05)	45.0	2.3	0.7	158.0	

D_1=1st July, D_2= 8th July, D_3= 15th July, D_4= 22nd July, D_5= 29th July; PARUE = PAR use efficiency

Table 5. Impact of PAR on dry matter production at the different phenophases and grain yield of rice

Regression Equations
$DM_{tillering}$ = 138.46 + 2.4 $IPAR*_{15.30}$ + 0.58 $IPAR_{9-30}$ R^2 = 0.42 Adj
R^2 = 0.37 SE $_{(Est.)}$ = 25.11
DM_{PI} = - 100.3 + 5.87 $IPAR*_{15-30}$ + 9.1 $IPAR_{7-30}$
R^2 = 0.89 Adj R^2 = 0.88 SE $_{(Est)}$ = 52.46
$DM_{emergence}$ = 52.9 + 20.4 $IPAR*_{15-30}$ + 2.7 $IPAR_{7-30}$- 4.4 $IPAR_{13-30}$ + 2.2 $IPAR_{9-30}$ R^2 = 0.96 Adj
R^2 = 0.95 SE $_{(est)}$ = 53.2
$DM_{100\% flowering}$ = 694.3 + 7.3 IPAR $_{15-30}$ + 10.6 $IPAR*_{9.30}$ - 8.5 $IPAR_{13.30}$ R^2 = 0.88 Adj
R^2 = 0.86 SE (est) = 113.1
Yield = 1220.33 + 19.73 IPAR (Till – 15-30h)+ 10.57 IPAR (PI -15-30h) + 3.04 IPAR (100% F-9.30h)
R^2 = 0.957 Adj R^2 = 0.951 S.E. $_{(Cst)}$ = 98.604
DM= Dry matter, IPAR= Intercepted PAR, PI= Panicle initiation, Till- Tillering, 100% F= 100% Flowering

The yield of rice was also significantly and positively affected by the interception of PAR during tillering and panicle initiation stage at 15.30h and during 100% flowering at 9.30h (Table 5). About 95% variation in yield might be assigned to the variation in intercepted PAR during tillering and panicle initiation stage. Chakraborty (1994) also emphasized on the interception of PAR during morning and afternoon hours for better crop productivity. Chakraborty (1994) stressed on low leaf temperature for better carbon-di-oxide (CO_2) fixation because of low stomatal diffusion resistance of leaf. Campbell *et al.*, (2001) also observed high correlation between CO_2 exchange rate and intercepted PAR in irrigated rice.

The yield loss due to delayed transplanting has been recorded by a large number of workers (Chopra *et al.*, 2003; Welch *et al.*, 2010; Olaleye *et al.*, 2010; Mahajan *et al.*, 2010). Welch *et al.*, (2010) observed the temperature and radiation had significant impact during the vegetative and ripening phases of rice. The increased biomass production after heading in rice is important as it is the determining factor for better grain yield (Murchie *et al.,* 2002; Takai *et al.,* 2006). The PAR use efficiency drastically declined when transplanting was done on 22nd or 29th July (Table 4).

In conclusion, our results show that rice should not be transplanted after 15th of July if the yield reduction is to be avoided in the eastern Gangetic Plains of India. The interception of PAR at 7.30, 9.30 and 15.30 h has a significant and positive contribution for dry matter as well as grain yield of rice. The PAR use efficiency during the reproductive phase (emergence to 100% flowering) is lower than the vegetative phase.

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