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Extinction coefficient and photosynthetically active radiation use efficiency of summer rice as influenced by transplanting dates

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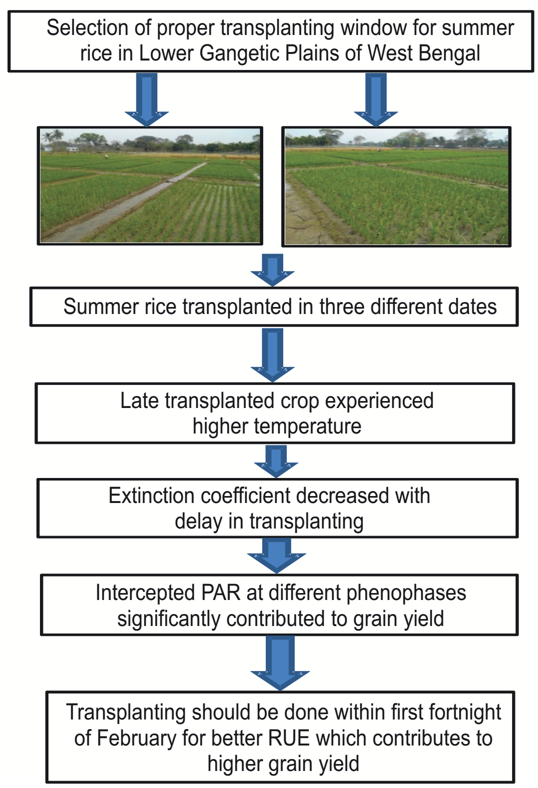
Abstract

Aim : The present study was conducted to quantify the extinction coefficient and photosynthetically active radiation (PAR) use efficiency of widely cultivated variety *"Shatabdi"* under changing dates of transplanting and to suggest the farmers for proper transplanting window in this zone.

Methodology : Thirty five-day-old rice seedlings were transplanted during January and February at three different dates (D_1, D_2 and D_3) at a gap of 14 days with four irrigation regimes under strip plot design having three replications. Plant samples were taken at 14 days interval from each experiment and biometric parameters like LAI etc. and meteorological parameters like Incident PAR were estimated.

Results : The results showed that the extinction coefficient decreased with delay in transplanting. The PAR use efficiency for biomass accumulation ranged from 2.07 to 2.19 g MJ^{-1} when transplanting dates varied from D_1 to D_3. The maximum grain yield was noted under D_1 or D_2 with no significant variation but a sharp reduction in yield was observed under D_3. The PAR use efficiency for grain yield was noted under D_2 (1.23 g MJ^{-1}). The intercepted PAR at different phenophases significantly affected the grain yield.

Interpretation : On the basis of radiation utilization efficiency the crop may be transplanted within first fortnight of February in this zone.



Introduction

Approximately 50% of the world population uses rice as their primary food and the Asians consumes the most (Khush, 2005). Growing demand for rice could be met if the global production increases by 1% annually (Normile, 2008). West Bengal farmers grow rice during rainy season (July – October) with the south-west monsoon rain. The productivity of rice in rainy season is low because of cloudy weather or lack of required radiation prevailing during this period. On the other hand, the popularity of summer rice has been increasing day by day because of its higher productive potential. Rice yield is principally regulated by the quantum of biomass production and harvest index (Huang *et al*., 2016). In reality, there is little scope of increasing harvest index further (Laza *et al*., 2003). Higher grain yield thus depends on biomass production (Zhang *et al*., 2009; Huang *et al*., 2013). Biomass production depends not only on intercepted PAR (Huang *et al*., 2016) but also on the thermal environment and canopy temperature in cereals (Roohi *et al*., 2015). The cumulative intercepted PAR depends on growth duration (De Costa *et al*., 2006; Zhang *et al*., 2009), as well as canopy geometry and morphology such as leaf area, angle and orientation. In West Bengal, farmers transplant the summer rice from January and the transplanting is extended as late as March when temperature rises with the rise in day length. As date of transplanting is delayed, evaporative demand of the atmosphere increases, increased interception of radiation does not benefit the crop in terms of productivity. Increased biomass production depends on LAI of rice. Kiniry *et al*. (2001) reported the highest LAI values of 4 rice cultivars ranging from 9.8 to 12.7. The rate of conversion of intercepted PAR into biomass (PAR use efficiency) for rice is lower than other grain crops. Kiniry *et al*. (2001) reported that the mean radiation use efficiency for rice was 2.39 g above ground biomass per MJ of intercepted PAR.

Therefore, the rice researchers in the Gangetic plains of West Bengal have primary responsibilities to select a transplanting window dates where PAR use efficiency would be higher. Information of rice productivity and PAR interception pattern during rainy season by rice crop is scarce (Basu *et al*., 2014). However, no information is available in case of summer rice where PAR use efficiency has been tested with the adoption of three dates of transplanting. The present study was planned with the aim to select a transplanting window where PAR use efficiency would be higher without substantial reduction in grain yield.

Materials and Methods

Experimental set-up : The experiment was carried out during the winter seasons of 2014 and 2015 at Kalyani "C" Block Farm, BCKV, Kalyani, West Bengal, India. The study site is flat, falls under Gangetic plains and is located at an altitude of 9.75 m above sea level. The experimental site falls under tropical humid climate and experiences three distinct seasons, namely, March to June as summer, June to September as rainy season and October to February as winter. Kalyani receives an average annual rainfall of 1600 mm out of which 1300 mm occurs during monsoon. The soil is entisol having 0.07% nitrogen, 24.06 kg ha^{-1} available phosphorous, 187.45 kg ha^{-1} available K, 0.78% organic carbon with pH 6.92. Thirty five day old rice seedlings (cv. *Shatabdi*) were transplanted on 24th January (D_1), 7th February (D_2) and 21st February (D_3) under four irrigation regimes. The design of experiment was strip-plot, where dates of transplanting were placed in horizontal strip and irrigation regimes were in vertical strips. In the article, to identify the impact of transplanting dates, variations due to irrigation practices were averaged.

Plant samples were taken from 1 m^2 area at 14 days interval from each experiment starting from tiller initiation (TI). Each plant sample were then separated into root, stem, leaf and panicles and later dried in oven at 60°C up to a constant weight to record dry matter accumulation. Observation was recorded at different phenophases like tiller initiation (TI), maximum tillering (MT), panicle initiation (PI), 100% flowering (FL) and milk stage (ML). LAI were calculated from area-weight relationship (Watson, 1963). Extinction coefficient (K) is a measure of radiation attenuation in a particular crop stand. It is inversely related to leaf area index (LAI), *i.e.,* when LAI is high, K value is low, indicating higher attenuation of radiation. The light extinction coefficient was calculated following the method suggested by Kiniry *et al*. (2001).

Observation and computation of PAR : The PAR was measured with the help of Line Quantum Sensor (Model MQ-301, APOGEE, Logan UT, UK). The observations were recorded at 15 days gap during 9:00 to 15:00 hour at one hour interval. The line quantum sensor was designed for measuring the photosynthetically active rdiatiaon (PAR) in applications where the measured radiation was spatially non-uniform (such as within plant canopies). To achieve this, the sensor features a sensing area that is one meter in length. It has a quantum (photon) response through the wavelength range of 400-700 nm for PPFD (photosynthetic photon flux density) as generally preferred for PAR measurements, and has an output in units of micromoles per second per square metre. The PPFD was converted into W m^{-2} using the conversion factor suggested by Monteith and Unsworth (2013).

The Line Quantum Sensor was placed 50 cm above the crop to measure the incident PAR (I_0). The instrument was then placed 25cm above the stagnant water level (horizontally across the row) to measure the incident PAR at the bottom to get the transmitted fraction. The reflected PAR from the crop was measured by simply inverting the sensor and placing it 50cm above the canopy. Interception of PAR was estimated by the following equation :

Intercepted PAR (IPAR) = Incident PAR – Reflected PAR – Transmitted PAR (Dhaliwal *et al*., 2007)

The PAR values were expressed in W m^{-2} in case of cumulative IPAR.

Regression line was fitted with the treatment means of above ground biomass and accumulated IPAR. As per Kiniry *et al*. (2001), the PAR use efficiency is the slope of regression for this above ground biomass (g m^{-2}) as the function of accumulated IPAR (MJ m^{-2})

Statistical analysis : The relationship between biological and environmental parameters was worked out following Gomez and Gomez (1984). Stepwise regression analysis was carried out to find the important relationships between environmental and biological parameters through SPSS (version 16) software.

Results and Discussion

Light transmission depends on the canopy structure as well as LAI of the crop. The results showed that extinction coefficient (K) declined with delay in transplanting. In the first year, the extinction coefficient varied from 0.347 to 0.364 across the dates of transplanting. In second year, the value of extinction coefficient showed quiet large variation than the first year; its value ranged between 0.253 and 0.396. The mean value of extinction coefficient varied from 0.300 to 0.380 throughout the dates of transplanting over the experimentation period. Interception of PAR increased linearly and significantly with the increased LAI (Fig. 1). When LAI = 1.0, 42.16% of incident PAR was intercepted by the crop. Approximately, 61.7% variation in intercepted PAR was explained by variation in LAI. Intercepted PAR at tiller initiation and panicle initiation positively increased the grain yield whereas intercepted PAR at maximum tillering had a significant negative contribution.

The above ground biomass was found to be the linear function of cumulative IPAR (Fig. 2) under different DOTs. Both the slopes and R^2 values varied due to variation of DOTs. The PAR use efficiencies increased gradually with delay in transplanting (from 2.07 g MJ^{-1} to 2.19 g MJ^{-1}). The R^2 value was maximum under D_1 and minimum under D_2 but all the values were above 0.90 indicating the strength of association between IPAR and above ground biomass accumulation in summer rice.

Grain yield was maximum when the crop was transplanted either on D_2 (2014) or D_1 (2015) although no significant difference was noted in between the two dates. Grain yield sharply reduced when date of transplanting delayed by a fortnight (D_3). The mean PAR use efficiencies for grain yield differed due to variation in DOTs. The PAR use efficiencies were higher during second year than first year. The mean PAR use efficiency was maximum under D_2 (1.23 g MJ^{-1}) and minimum under D_3 (0.98 g MJ^{-1}).

Shatabdi is widely used rice cultivar in the Gangetic Plains of West Bengal. This cultivar is cultivated both during rainy and summer seasons. Because of changing thermal environment due to variation of insolation it is necessary to identify the dates of transplanting for better yield and PAR use efficiency. This information is vital to modeler and breeder as well.

The LAI of crop reached maximum at 100% flowering, and thereafter declined due to drying of aged leaves. Kiniry *et al*. (2001) obtained an LAI value of 10 to 12 in rice cultivars in USA, a temperate climate area. The 100% flowering under D_1 attained during 3rd – 8th April when the mean temperature ranged from 29.5 to 32.6°C in the first year and 27.1 to 33.3°C in the second year. Under D_2, the same phenophase was attained when the mean temperature ranged from 30.4 to 33.8°C in the first year and 28.9 to 30.7°C in the second year. Under D_3, this phenophase was recorded when the mean temperature varied from 31.5 to 34.2°C in the first year and 26.2 to 33.6°C in the second year. The LAI build up in the second year was higher because of lower atmospheric temperature than the first year. Transmission of light depends on the extinction coefficient. The changes in "K" value was observed with the seasonal changes. Monteith (1969) reported a "K" value for rice as 0.65 but recent values were lower. Kishida (1973) obtained the values of "K" for rice ranging from 0.5-0.7. Planting pattern also changes "K" value of rice plants. San-oh *et al*. (2006) obtained the "K" value for rice within a range of 0.38 – 0.69 during ripening stage for different planting pattern. Timlin *et al*. (2014) noted the "K" values for maize ranging from 0.28 – 0.58. Tabarzad *et al*. (2016) recorded hourly "K" value for barley crop as 0.584. In the present study, the "K" values ranged from 0.30-0.38 under different DOTs. Low K-values (more upright leaves) are more important for better light penetration into the canopies thus illuminating more leaf area at a lower intensity of PAR so that canopy C-exchange rates could increase. The results of the

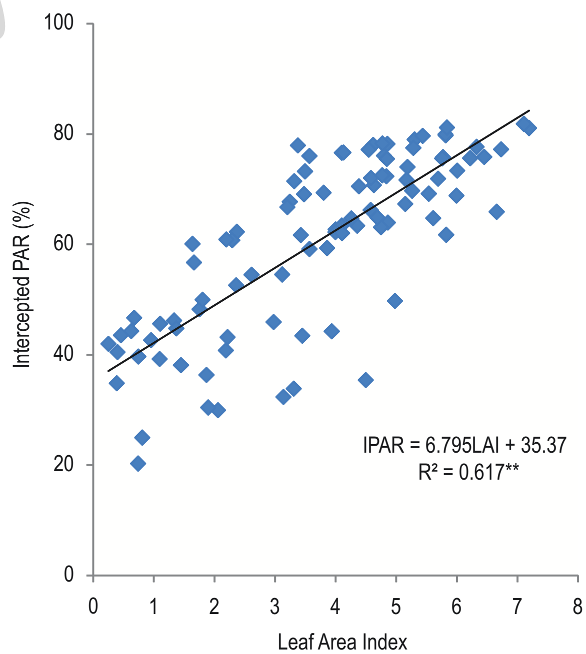


Fig. 1 : Relationship between LAI and Intercepted PAR (%) pooled over phenophases, treatments and experimental year

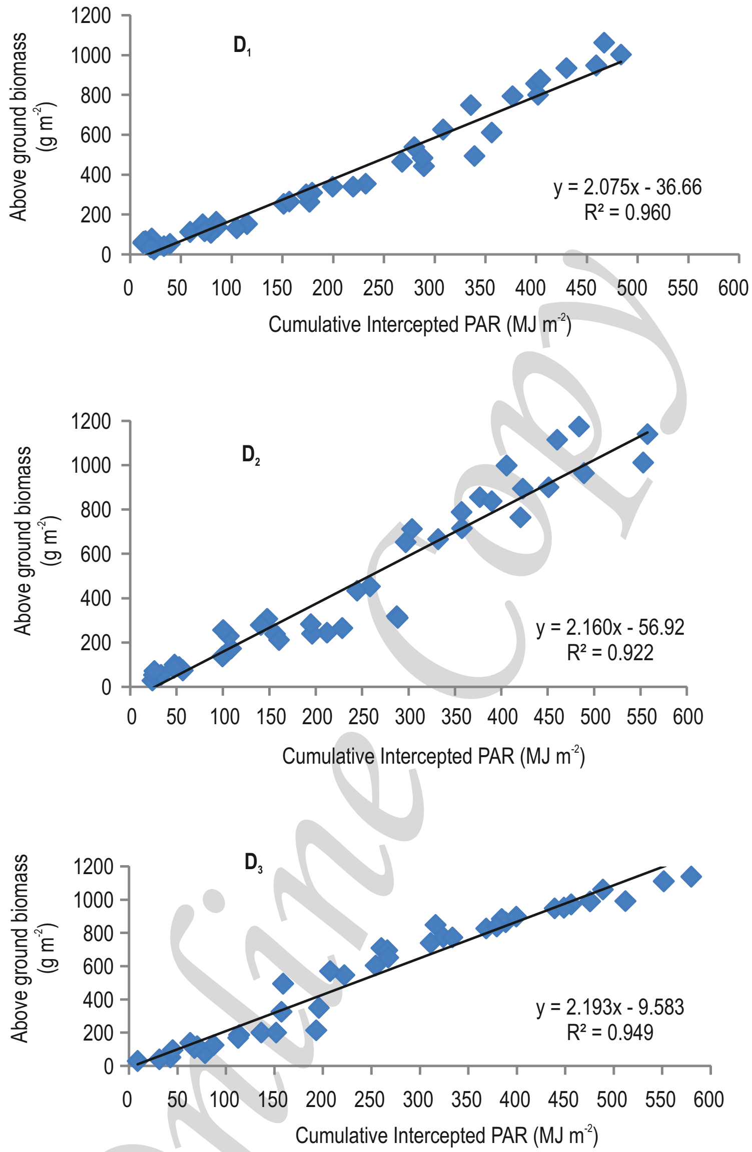


Fig. 2 : Above ground biomass (Y- axis) as a function of cumulative Intercepted PAR (X-axis) for three dates of transplanting (pooled mean of two years); slope indicating PAR use efficiency

present study suggest that "K" values declined gradually with delay in transplanting, although the difference between D_2 and D_3 was marginal.

The PAR interception increased with the increased LAI because of increased canopy volume (Basu *et al*., 2014). San-oh *et al*. (2006) reported that the rate of interception of solar radiation by direct seeded rice increased up to maximum tillering stage because of increased LAI. Increased LAI in other cereals also increased radiation interception by the crop canopy (Timlin *et al*., 2014; Tabarzad *et al*., 2016). The multiple regression equation, $YIELD_{D1} = 1.557+0.024IPAR_{TI}-0.113IPAR_{PI}$ (R^2 is 0.981), showed that the grain yield was positively affected by IPAR at the tiller initiation stage while negatively affected at the panicle initiation stage when the crop was transplanted on 24th January. When transplanting was delayed by a fortnight, the influence of IPAR was positive at flowering stage [$YIELD_{D2} = 7.948-0.028IPAR_{PI}+0.131IPAR_{FL}-0.094IPAR_{ML}$]. The R^2 values reduced to 0.968 indicating gradual weakness in the strength of relationship between IPAR and grain yield. When the transplanting was delayed further by 14 days, IPAR, only at milk stage positively influenced the grain yield [$YIELD_{D3}$= 3.162+0.005$IPAR_{ML}$] with a sharp reduction in R^2 value to 0.680. The result also indicated that IPAR influenced the grain yield during vegetative stage when the crop was transplanted in January. In case of late transplanting, the PAR use efficiency for grain formation was less because of the rising atmospheric temperature rather than intercepted PAR. Sturz *et al*. (2014) also identified increased role of temperature than radiation in rice spikelet formation when transplanting was delayed in tropical environment. The PAR use efficiency for biomass production increased with delay in transplanting, whereas the minimum PAR use efficiency for grain yield was obtained when transplanting was delayed to 21st February. Tabarzad *et al*. (2016) also reported a reduction in RUE for barley grain production when sowing was delayed. Reduction in RUE for grain production due to delay in sowing was evident in other works (Reynold *et al*., 2005; Sun *et al*., 2013). In this case all phenophases were exposed to higher temperature, which increased the photorespiration leading to reduction in grain yield and PAR use efficiency. Reduction in RUE due to late sowing not only caused by high temperature but also the moisture content which affected the sink size and demand for photosynthates during grain filling (Gomez-Macpherson and Richards, 1995; Reynolds *et al*., 2005; Sun *et al*., 2013). The mean PAR use efficiencies obtained in the present experiment under different DOTs were marginally lower to that of obtained by Kiniry *et al*. (2001). The lower PAR use efficiency might be attributed to lower biomass production.

In conclusion it can be stated that transplanting of summer rice during last week of January to the first fortnight of February would be beneficial in terms PAR use efficiency for biomass production as well as grain yield. Delayed transplanting should be avoided due to sharp yield reduction. Late transplanted crop exposed to higher temperature has a detrimental effect on crop production.

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