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Research Paper

Diurnal variation of radiation components at three major phenological stages of *Boro* and *Kharif* rice under different management practices in West Bengal

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ABSTRACT

Present study quantifies and compares the diurnal variation of four components of PAR (APAR, IPAR, crop and soil albedo) and net radiation across three key phenological stages for *Boro* and *Kharif* rice under different management practices. Two consecutive field experiments were conducted during 2018 and 2019 at the D Block farm of Bidhan Chandra Krishi Viswavidyalaya, considering 18 treatment combinations of three rice varieties, three spacing and two seedling ages. Weekly observations were taken six times in a day with two hours interval. Results indicated that the maximum values of IPAR (93.53% and 82.62%) were recorded in Triguna variety and minimum value (90.02% and 78.62%) in Heera variety during the reproductive and vegetative stage at 11:30 AM and 5:30 PM respectively in *Boro* season but it reduced by 7-8% in the *Kharif* season indicating the influence of cloudy weather. *Boro* rice consumes the maximum amount of net radiation (689.32 W/m$^{2)}$ in reproductive stage followed by 649.22 W m^{-2} in vegetative and 549.22 W m^{-2} in ripening stages for Triguna variety whereas *Heera* consumes lesser amount (489.23 to 600.22 W m^{-2}), which is significantly lesser in *Kharif* season. The study concluded that components of PAR and net radiation vary significantly across phenological stages, spacing and varieties while the ages of seedling (only 7 days difference) remain relatively unaffected.

Keyword: Diurnal variation, Photosynthetically active radiation (PAR), Albedo, APAR, IPAR *Boro* and *Kharif* seasons

Solar radiation is one of the most significant micrometeorological factors influencing crop growth and development. It plays a crucial role in governing photosynthetic efficiency and energy balance within the crop canopy. The variation in solar radiation throughout the day, commonly referred to as diurnal variation, significantly impacts plant physiological processes, including light interception, radiation absorption, and energy partitioning (Monteith and Unsworth, 2013). Understanding the influence of diurnal variation of radiation on rice growth is essential for optimizing productivity under varying agro-climatic conditions (Sivakumar, 2023).

Rice (*Oryza sativa* L.), a staple food crop in India, is grown across multiple seasons, with *Boro* (dry season) and *Kharif* (wet season) being the two major cultivation periods in the new alluvial zones of West Bengal. These zone experiences distinct radiation regimes due to seasonal differences in cloud cover, solar angle, and atmospheric conditions (Goswami *et al.,* 2021). The efficiency of light utilization in rice depends on key radiation-related parameters such as absorbed photosynthetically active radiation (APAR), intercepted photosynthetically active radiation (IPAR), crop albedo, and soil albedo. These factors influence energy absorption, heat dissipation, and crop productivity across different phenological stages—vegetative, reproductive, and ripening (Aggarwal *et al.,* 2016; Kar and Kumar 2022). In the *Boro* season, clear skies and higher radiation levels enhance IPAR and APAR, promoting robust photosynthesis and biomass accumulation (Sharma *et al.,* 2019). However, increased radiation exposure can also lead to excessive heat stress, affecting crop metabolism. Conversely, during the *Kharif* season, monsoonal cloud cover and frequent rainfall reduce radiation availability, altering IPAR and affecting overall crop growth (Rao *et al.,* 2017). The varying albedo of both the crop canopy and soil surface further modulates the energy balance, influencing microclimatic conditions around the crop (Kumar *et al.,* 2022).

Given the critical role of solar radiation in rice physiology, an in-depth assessment of its diurnal variation across phenological

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stages is necessary to optimize crop management strategies. This study aims to analyse how APAR, IPAR, crop albedo, and soil albedo fluctuate across different times of the day and how these variations influence rice growth in both *Boro* and *Kharif* seasons. Such insights will help improve light use efficiency and enhance yield sustainability in the alluvial regions of West Bengal.

MATERIALS AND METHODS

Experimental details and observations

The field experiment was carried out at District Seed Farm, D Block, Bidhan Chandra Krishi Viswavidyalaya, Kalyani, West Bengal which lays 22º 58′ N latitude and 88º 25′ E longitudes with an elevation of 9 m above mean sea level. The brief description of the two field experiments for two consecutive *Boro* (during 2018-19) and *Kharif* seasons (2019) indicated there was total (18 x 2) 36 treatments with three varieties (Shatabdi, Heera and Triguna), three spacing (20 cm x 15 cm, 20 cm x 20 cm and 15 cm x 15 cm) and two age of seedlings (32 days and 25 days) for the combination of 3 x 3 x 2=18 for two replications.

Photosynthetically active radiation (PAR)

In the context of plants, the most beneficial portion of incoming short-wave radiation is photosynthetically active radiation (PAR), which falls within the wavelength range of 400–700 nm. This range of radiation is essential for photosynthesis. To measure PAR, a line quantum sensor (Model L 191 SA) was utilized. The direct incident PAR was recorded by placing the sensor in two distinct positions: above the rice canopy and at the ground surface below the canopy. This allowed for the measurement of PAR reaching both the canopy and the ground. Additionally, the reflected PAR was measured from the same positions by reversing the orientation of the sensor. This method provided a comprehensive assessment of both the incoming and reflected PAR at different levels within the rice field. Large numbers of observation of radiation data were taken from the field experiments at daily six times namely 7:30 AM, 9:30 AM, 11:30 AM 01:30 PM, 3:30 PM and 95:30 PM with 7 days interval for the entire growing period for three varieties. The definition and brief description of four components of PAR and net radiation are given below.

Absorbed PAR (APAR)

The absorbed photosynthetically active radiation (APAR) was calculated using the equation proposed by Gallo and Daughtry (1986):

$$APAR\% = [\{(PAR_0 + RPAR_s) - (TPAR + RPARc)\} / PAR_0] \times 100$$

Where PAR_0 represents the incident PAR on the rice canopy, $RPAR_s$ is the reflected portion of PAR from the soil surface, TPAR denotes the transmitted portion of the incident PAR that passes through the canopy to the soil surface and RPARc refers to the reflected portion of PAR from the crop canopy.

Intercepted PAR (IPAR)

Intercepted PAR (IPAR) refers to the portion of photosynthetically active radiation (PAR) that is absorbed by the plant canopy during its growth. It can be calculated using the following equation proposed by Dhaliwal *et al.,* (2007):

$$IPAR\% = \{(PAR_0 - TPAR - RPARc) / PAR_0\} \times 100$$

Where PAR_0 represents the total incident PAR that reaches the crop canopy, TPAR denotes the transmitted portion of the incident PAR that passes through the canopy and reaches the soil surface and RPARc is the reflected portion of PAR that bounces off the crop canopy and does not contribute to plant absorption.

Albedo from crop surface (α_c)

The albedo from the crop surface is calculated as the ratio of the reflected PAR from the crop canopy (RPARc) to the total incident PAR on the canopy (PAR_0). It is expressed as a percentage using the following formula:

$$\alpha_c = (RPARc / PAR_0) \times 100$$

Albedo from ground soil surface (α_s)

The albedo from the ground soil surface, denoted as α_s, is calculated as the ratio of the reflected photosynthetically active radiation (PAR) from the soil surface ($RPAR_s$) to the transmitted photosynthetically active radiation (PAR) through the crop canopy to the soil surface (TPAR). This ratio is expressed as a percentage using the following formula:

$$\alpha_s = (RPAR_s / TPAR) \times 100$$

This calculation provides a measure of the reflectivity of the soil surface in relation to the amount of PAR that passes through the crop canopy and reaches the ground. By determining the albedo of the soil surface, we can better understand how much of the incoming PAR is reflected into the atmosphere versus how much is absorbed by the soil or used by the plant.

Net radiation

Net radiation represents the sum of net shortwave and net longwave radiation fluxes and serves as a measure of the energy available at the ground surface. It is calculated using the following equation:

$$R_N = R_{SW}bal + R_{LW}bal$$

Where, $R_{SW}bal$ is the net shortwave radiation which is defined as the difference between incoming and reflected solar radiation and $R_{LW}bal$ is the net longwave radiation as calculated by the difference between emitted and absorbed terrestrial radiation. The measurement of net radiation over the rice crop was taken using a net radiometer for the entire crop growing period.

RESULTS AND DISCUSSIONS

Diurnal variation of PAR components in Boro rice

How the four different micro meteorological parameters of PAR along with net radiation varied at three major phenological stages of rice like vegetative, reproductive and maturity has been compared across three varieties for *Boro* rice in 2018-19 in Fig. 1

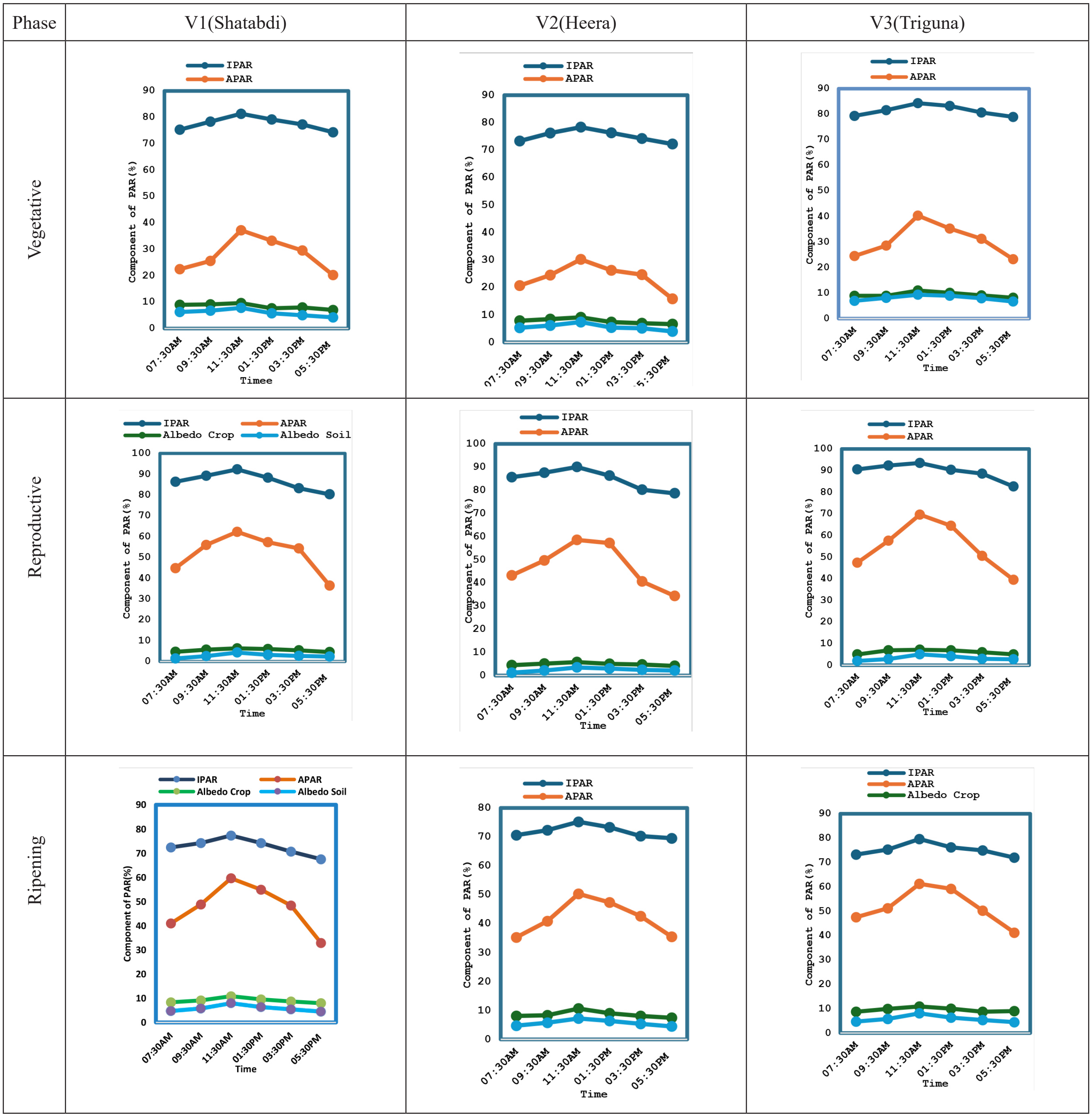

Fig. 1: Diurnal variation of IPAR, APAR, crop albedo and soil albedo on three different varieties and phenological stages for *Boro* rice for 32 days age of seedlings.

and in Fig. 2 for Kharif rice in 2019 and results obtained in different phenological stages were discussed in the following section.

***Vegetative stage*:** In general Fig. 1 indicates that the Triguna variety demonstrated the highest efficiency in light capture in the vegetative stage, with an IPAR of 84.32%, surpassing both Shatabdi (81.36%) and Heera (78.35%) at 11:30 AM. This indicates Triguna's superior ability to intercept incident radiation. Additionally, Triguna recorded the highest APAR at 40.32%, reflecting its strong radiation utilization potential. In comparison, Shatabdi showed a moderate APAR of 37.22%, while Heera exhibited the lowest at 30.22%, suggesting comparatively weaker efficiency in converting intercepted light into absorbed radiation. In terms of reflectance, Triguna exhibited the highest crop albedo at 10.98% and soil albedo at 9.32%, indicating a greater proportion of incident radiation reflected back. Shatabdi followed with a crop albedo of 9.64% and soil albedo of 7.82%, reflecting slightly lower radiation than Triguna. Heera, despite having the lowest IPAR, also had the lowest crop albedo (9.12%) and soil albedo (7.42%), indicating reduced reflectance and potentially greater radiation retention within the crop canopy

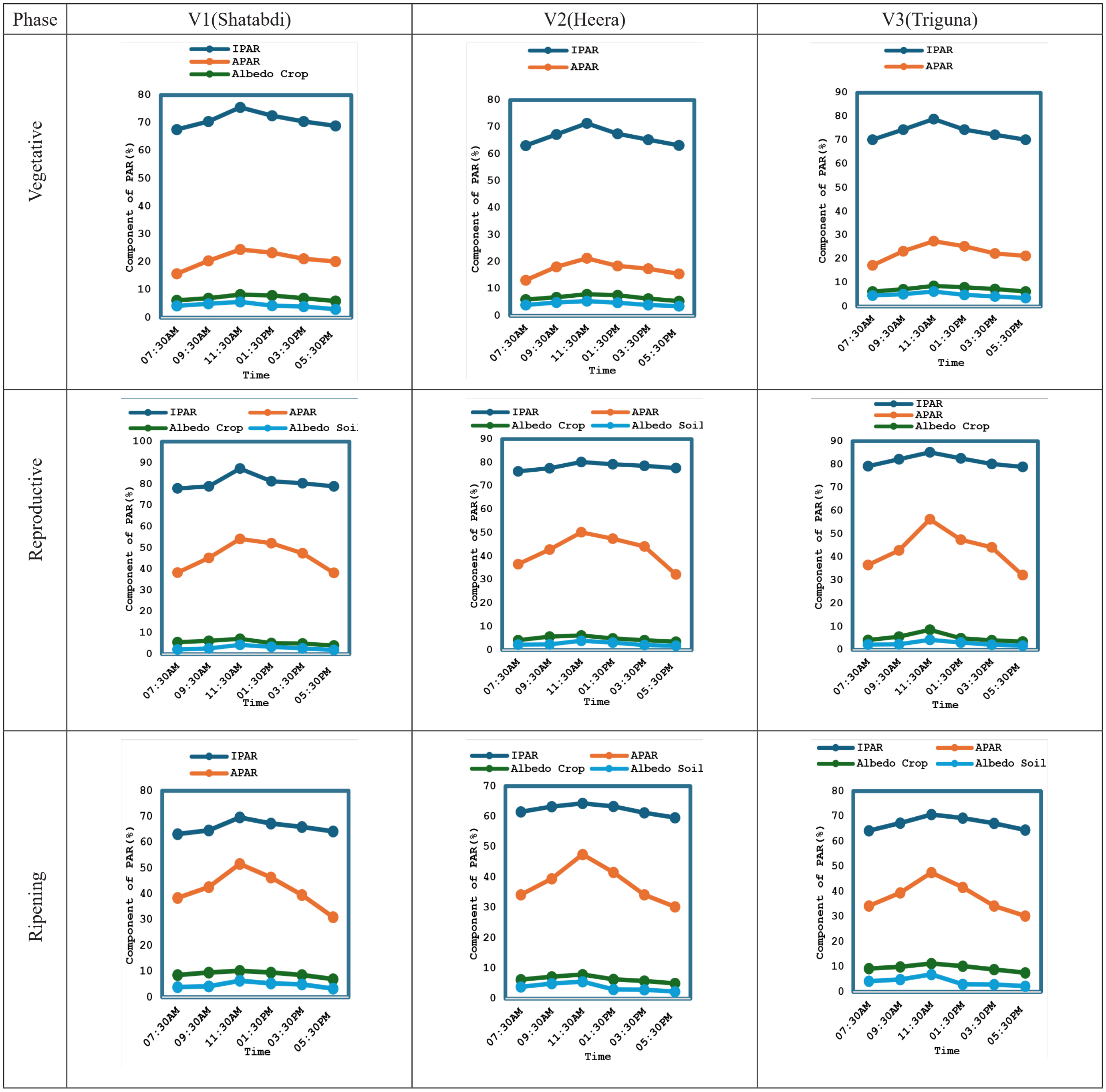

Fig. 2: Diurnal variation of IPAR, APAR, crop albedo and soil albedo on three different varieties and phenological stages for *Kharif* rice for 32 days age of seedlings

and soil. Overall, Triguna emerged as the most efficient in both interception and absorption of radiation, though it also reflected the highest proportion of incident radiation. Shatabdi maintained a moderate balance between absorption and reflection, while Heera, despite a competitive IPAR, exhibited the lowest APAR, implying relatively lower radiation utilization efficiency during the vegetative stage.

***Reproductive stage*:** In the reproductive stage, IPAR increased across all varieties, reaching its peak. Triguna recorded the highest IPAR at 93.53% and APAR at 69.65%, showcasing its superior radiation interception and absorption efficiency. The minimum value of crop albedo (7.15%) and soil albedo (5.02%) was noticed in reproductive phage compared to other pheno-phages because of maximum canopy cover and minimal soil exposure of the crop. Shatabdi exhibited an IPAR of 92.32%, slightly lower than Triguna, while its APAR increased to 62.32%, reflecting enhance photosynthetic activities. While the recorded lower values of crop albedo (6.32%), and soil albedo (4.30%), indicating more radiation absorption and reduced reflection. On the other hand, variety Heera, showed the lowest APAR (58.54%), IPAR (90.02%), crop albedo (5.74%), and soil albedo (3.46%), indicating lowest light utilization but lesser

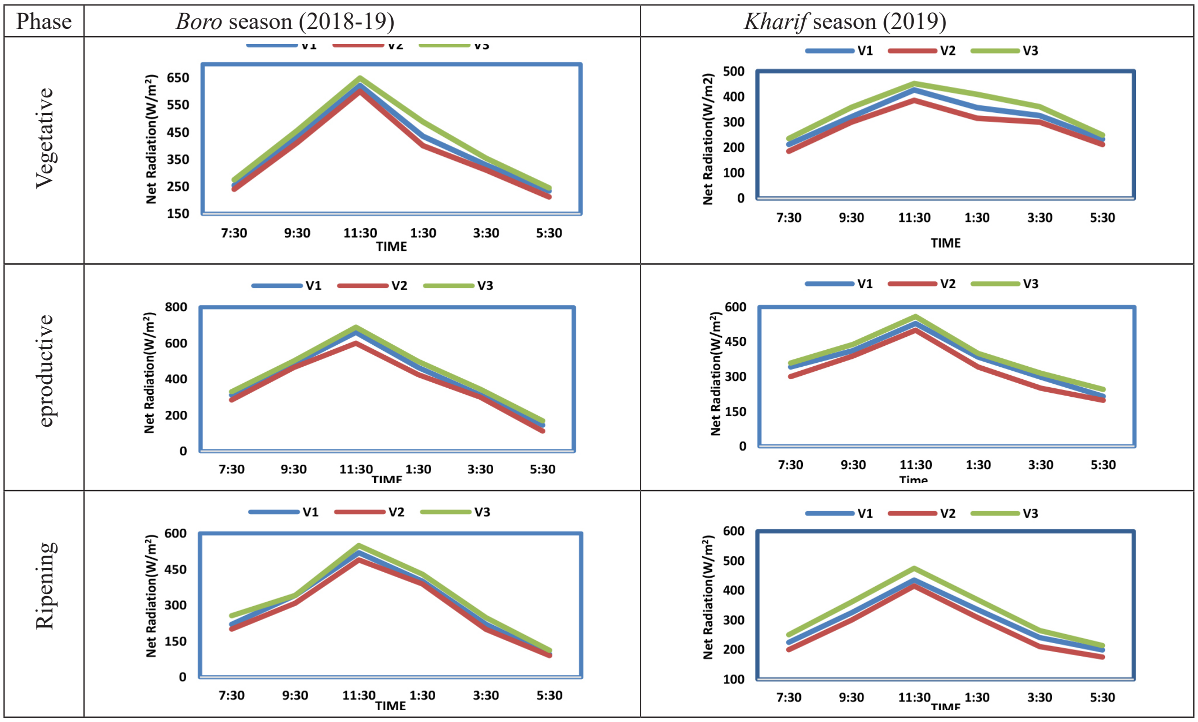

Fig. 3: Diurnal variation of net radiation (W m^{-2}) for 32-day age of seedling of *Boro* and *kharif* seasons.

radiation absorption compared to Shatabdi and Triguna. Overall, the reproductive phage is considered as the ideal or favourable phage for photosynthesis activities through optimum radiation utilization by higher values IPAR and APAR and lower values of crop and soil albedo compared to other two major phenological phages.

Ripening stage: It is the phase where crop stops its growth and development and reaches to its maturity. In this phage, all three varieties showed lowest IPAR and APAR values and highest crop and soil albedo compared to other two stages. But based on varieties and phenological phases wise, Triguna maintained the highest values of IPAR (79.65%), APAR (61.25%), and crop albedo (10.91%), and soil albedo (8.09%) compared to Shatabdi and Heera. In this phage, the Shatabdi recorded IPAR of 77.33%, APAR of 59.62%, showing a decline trend with respect to reproductive stage. The highest crop albedo and soil albedo by 10.85%, and 7.95%, respectively compared to other two phages confirming increased reflectance as the crop matured. Heera recorded the lowest IPAR (75.22%) and APAR (50.32%) in this stage, indicating reduced photosynthetic efficiency. Crop albedo increased to 10.64%, and soil albedo remained at 7.23%, showing increased radiation reflection due to canopy senescence.

Diurnal variation of PAR components in Kharif rice

During the *Kharif* season, rice varieties exhibited distinct variations in radiation interception, absorption, and reflectance across different growth stages as shown in Fig. 2.

Vegetative stage: The values of PAR components as observed for *Kharif* rice showed similar trend of diurnal variation as Boro rice for all varieties with a reduced magnitudes during vegetative stage. All component of PAR showed maximum record at 11:30 and minimum record at 5:30PM. The performance across varieties indicates Triguna exhibited the highest IPAR (78.95%), APAR (27.50%), crop albedo (8.95%) and soil albedo (6.31%,) followed by Shatabdi with a IPAR (75.62%), APAR (24.52%), crop albedo(8.32%)and soil albedo (5.69%), while Heera exhibited lowest values of IPAR (73.25%), APAR (21.32%), crop albedo (8.01%) and soil albedo (5.45%) in utilization of PAR components and reflectance of crop and soil albedo for maintaining the Photosynthesis activities in vegetative phase.

Reproductive stage: Again, reproductive stage is also very crucial stage in case of *Kharif* rice for all varieties of rice where all component of PAR showed maximum magnitudes of IPAR, APAR, crop and soil albedos being best performer is the Triguna followed by Shatabdi and Heera. In each case the measured values of PAR components showed a reduce values by 10%, 8%, 2% and 1.2% of IPAR, APAR, soil and crop albedos respectively compared to Boro rice in vegetative stages.

Ripening stage: In case of ripening stage again all PAR component showed similar diurnal variation with maximum values at 11:30PM and minimum at 5:30 AM as per the variation of Boro rice. In this stage APAR and IPAR showed minimum records and crop and soil albedo indicate maximum values compared to other two phenological stages. It also to be noted that variety wise performance indicated that Triguna>Shatabdi>Heera. Evey case the measures values were reduced for *Kharif* rice compared Boro rice.

Net radiation : The diurnal variation of net radiation (Wm^{-2}) was compared for three major phenological stages of *Boro* and *Kharif* rice after transplanting of 32 days age of seedlings for three rice varieties and results were graphically displayed in Fig. 3. In general, it was noticed that net radiation started to show an increasing trend from 7 DAT i.e., starting of vegetative stage to attain its maximum values at 84 DAT i.e., in the reproductive stage, thereafter it started

Table 1: Phenological stage wise total daily variation of PAR components (%) and net radiation (Wm^{-2}) across varieties and cropping seasons

Stage	Parameter	*Boro* season			*Kharif* season		
		Shatabdi	Heera	Triguna	Shatabdi	Heera	Triguna
Vegetative	IPAR (%)	80.22	78.90	81.35	70.98	68.77	72.87
	APAR (%)	28.03	23.68	30.50	20.91	18.26	22.36
	Crop Albedo (%)	8.34	8.04	9.38	7.08	6.78	8.73
	Soil Albedo (%)	6.61	6.02	7.98	4.99	4.21	5.48
	Net radiation (Wm^{-2})	396.77	364.78	422.29	312.26	283.14	343.85
Reproductive	IPAR (%)	88.04	84.72	89.65	80.81	78.21	82.41
	APAR (%)	54.25	47.25	55.85	45.97	42.27	49.27
	Crop Albedo (%)	5.42	4.89	6.15	5.23	4.80	5.80
	Soil Albedo (%)	2.76	2.39	3.28	2.27	2.02	2.72
	Net Radiation (Wm^{-2})	312.32	301.32	330.67	290.32	284.32	315.54
Ripening	IPAR (%)	72.02	71.88	75.23	65.84	62.20	67.17
	APAR (%)	47.60	44.32	51.78	41.65	37.89	46.89
	Crop Albedo (%)	9.08	8.62	9.54	7.91	6.44	8.34
	Soil Albedo (%)	5.64	4.35	6.12	4.70	3.77	5.77
	Net Radiation (Wm^{-2})	299.56	279.73	322.76	275.36	260.32	310.32

to show a decline and finally attain its lowest value in the ripening stage. In all varieties the maximum net radiation was recorded at 11:30 PM with a value of 600.32 - 689.22 Wm^{-2} in *Boro* rice and 500.02-549.32 Wm^{-2} for *Kharif* rice in the reproductive stage. In particular Shatabdi showed maximum net radiation of 660.32 W/m^2, which is similar to the net radiation obtained from the results of Bhattacharya *et al.,* (2012) over New Alluvial zone of West Bengal. Among varieties, Triguna consumes maximum net radiation and Heera utilizes fewer amounts for all phenological stages and cropping seasons.

Early morning variations were minimal among varieties, but by 11:30 AM, significant differences emerged. The maximum net radiation values were recorded at 11:30 AM compared to other times of the day. During the panicle initiation stage, which falls in the vegetative phage, net radiation was relatively low compared to reproductive stage, with 649.22 – 600.22 Wm^{-2} for *Boro* rice and 451.32 – 385.22 Wm^{-2} for *Kharif* rice. As the crop grew, net radiation increased, reaching peaks values in the reproductive stage both for *Boro* and *Kharif* rice. After the peak, net radiation gradually declined. During the physiological maturity stage, the mean values of net radiation dropped to 530 Wm^{-2} for *Boro* rice and 480 Wm^{-2} for *Kharif* rice.

Mean PAR components and net radiation

The variation of various components of mean values of PAR components in percent (%) and net radiation (Wm^{-2}) across varieties, cropping seasons and phenological stages which are summarised in Table 1.

The measure values of IPAR and APAR for both the *Boro* and *Kharif* rice were shown their peak values at 11:30 AM during the reproductive stage across all varieties, reflecting the healthy growth through increased photosynthetic activities. Triguna consistently exhibited the highest IPAR by 89.65%, 81.35% and 75.23% for the reproductive, vegetative and ripening stages respectively whereas for *Boro* rice wheres these values were lesser by ~7-8% for *Kharif* rice across three stages highlighting its superior radiation interception and absorption followed by Shatabdi (88.04%, 80.22% and 72.02%) and Heera (84.72%, 78.90% and 71.88%) as per above mentioned three stages respectively (Table 1). Heera variety for *Boro* rice indicates the minimum crop albedo (4.89%) and soil aldebo (2.39%) during the reproductive stage which slightly higher than *Kharif* rice. Higher values of IPAR and APAR demonstrating enhanced absorption efficiency, while soil albedo was significantly reduced due to increased canopy shading, minimizing soil reflectance. As crops matured into the ripening stage, both crop and soil albedo increased (1-2%), signifying reduced absorption and increased reflection caused by senescence, chlorophyll degradation, and leaf drying. Although there were a noticanble variation of IPAR values in different phenological stages, the avarage IPAR across three stages are 82.03 % for Triguna, 80.09% for Shatabdi and 78.50% for Heera Varitiety for the entire growing period for *Boro* rice which also slightly higher than *Kharif* rice. The total accumulated net radiation for three phenological resulted from Table 1 indicates that the Triguna, Shatabdi and Heera varieties consumed 1075.72 Wm^{-2} (422.29 Wm^{-2} for vegetative stage, 330.67 Wm^{-2} for reproductive and 332.76 Wm^{-2} for ripening stages), 1008.65 Wm^{-2} (396.77 Wm^{-2} for vegetative stage, 312.32 Wm^{-2} for reproductive and 299.56 Wm^{-2} for ripening) and 945.23 Wm^{-2} (364.78 Wm^{-2} for vegetative stage, 301.32 Wm^{-2} for reproductive and 279.763 Wm^{-2} for ripening stage) for the entire growing periods for *Boro* rice while the accumulated net radiation for *kharif* rice were 969.71 Wm^{-2}, 877.64 Wm^{-2} and 827.78 Wm^{-2} for Triguna, Shatabdi and Heera which were significantly reduced compared to *Boro* rice. Results obtained from this study for net radiation is to some extent similar to the finding of Xing *et al.,* (2017) in the lower reaches of the Yangtze River, China. Various micrometeorological conditions of solar radiation expose to the *Boro* and *Kharif* rice during various phenological stages as indicated through different amount of radiation interception, absorption, and reflectance across varieties, ultimately influencing their growth patterns, biomass accumulation, and yield potential significantly. Selecting suitable variety with higher radiation utilization efficiency during the reproductive stage could be beneficial for maximizing crop productivity in varying environmental conditions.

CONCLUSIONS

The study of absorbed and intercepted photosynthetically active radiation (APAR and IPAR), crop albedo, soil albedo, and net radiation across different phenological stages of rice crops revealed that radiation absorption and interception are at their lowest level during the early stages of crop growth, with significant increases during the flowering phase, followed by a gradual decline as the crop reaches physiological maturity. The data also suggests that both crop and soil albedo played a role in the overall radiation balance, influencing the crop's energy uptake and growth. Understanding these patterns is crucial for optimizing crop management practices and improving yield predictions, as it helps to assess the crop's response to environmental conditions over time. The findings contributed to a deeper understanding of rice crop physiology, guiding efforts to enhance crop productivity in different growing seasons.

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***Conflict of Interest*:** The authors declare that they have no conflict of interest.

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***Data availability*:** Data to be provided on request

Authors contribution: **S. THAKUR:** Data collection, Data analysis, Manuscript preparation, Visualization; **L. DAS:** Conceptualization, Supervision, Methodology, Editing; **S.G. MUNDHE:** Review collection, Editing;

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