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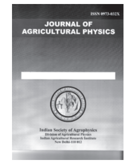

Research Article

PAR Interception Pattern and Radiation Use Efficiency in Wheat

SWETA GOUTAM[1], ABDUS SATTAR[2]*, RATNESH KUMAR JHA[2], RAVI RANJAN KUMAR[2], S.P. SINGH[2], GANGADHAR NANDA[1], GULAB SINGH[2] AND BISWAJIT PRAMANICK[1]

[1]Department of Agronomy, [2]Centre for Advance Studies on Climate Change, Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar

ABSTRACT

An experiment with wheat crop was conducted at Dr. Rajendra Prasad Central Agricultural University during *rabi* season of 2022-23 to assess the variation in intercepted photosynthetically active radiation (PAR) in relation to wheat phenology, leaf area index (LAI) and biomass. Radiation use efficiency (RUE) of wheat varieties used in the experiment was also worked out to assess their responses to resource environment for higher yield. In the experiment, 5 dates of sowing (10th November, 20th November, 30th November, 10th December and 20th December) were used as main plot factor and 3 varieties (HD 2967, Rajendra *Genhu* 3 and DBW187) as sub-plot factor. Intercepted PAR, LAI and plant biomass were recorded at critical growth phases of the crop. The results of the study revealed that PAR interception depended on sowing environment, growth stage and LAI. The crop sown on 20th November, 2022 recorded the highest PAR interception (78.7%), influencing wheat yield significantly. Significant relationship of PAR with LAI and biomass was observed. The highest RUE (3.51 g MJ^{-1}) was associated with HD 2967 variety followed by DBW 187, which recorded the RUE of 3.35 g MJ^{-1}. The maximum grain yield, biomass and leaf area index were associated with the crop planted on 20th November. This might be due to congenial thermal environment experienced by the crop sown on this date. The higher radiation interception and RUE of the crop sown on this date might have contributed to achieving higher yield.

Key words: PAR interception, Wheat, LAI and biomass

Introduction

Wheat is not only the major source of food but also an important crop for national food security due to its prominent share in food grain buffer stock. Among the cereals, wheat occupies 2nd position after rice in India. It covers an area of 29.58 Million hectares and production of 99.70 Million tons and its productivity is around 3.37 ton per ha. In Bihar, wheat covers an area of 2.2 Million hectares with a total production of 6.22 Million tons. The productivity of wheat is about 2.83 tons per hectare (DES, 2022).

Among the crop production factors, proper time of sowing and spacing play a major role in deciding the growth and yield of wheat. Date of sowing is considered as the most important non-monetary input affecting the yield of wheat- as early sowing faces high temperature during the initial stages and low temperature during reproductive period, and late sowing forces the crop to face high temperature during flowering to maturity phases. It has tremendous bearing on growth and yield of wheat. Therefore, it is important that wheat is planted in optimum times (15-30 November) for higher yield. Thus, by adjusting/altering date of sowing, favourable microclimate can be created for better

*Corresponding author,
Email: sattar.met@gmail.com

harnessing of immediate environmental resources, leading to higher yield.

Crop development is fundamentally dependent on the canopy's ability to intercept solar radiation. Interception of photosynthetically active radiation (PAR) is vital component for analysis of crop growth and yield estimation. The usage of radiation, dry matter loss due to respiration, assimilation of nutrients into sections of the crop that can be harvested economically, and length of crop growth are all factors that are influenced by radiation and temperature of the environment. Efficiency of radiation conversion into dry matter depends on plant characteristics and ambient factors. Apart from temperature, wheat crop growth is primarily influenced by intercepted photosynthetically active radiation (Abbate *et al.,* 1997).

In this backdrop, it is essential that interaction of wheat with prevailing radiation regime under different sowing environment needs to be assessed for better understanding of contribution of radiation for producing plant biomass. PAR, which is directly utilized by the crop for growth and development has thus a direct relation with leaf area index and plant biomass. The information on amount of solar radiation more specifically photosynthetically active radiation (PAR) and its interception within canopy and canopy temperature are of utmost importance in developing cause and effect relationship. Singer *et al*. (2011) noted that the amount of light that is reflected by the crop canopy depends on the microclimate, water dynamics, and physiological activities taking place in the canopy. The interception of light by the crop canopy is complicated and is affected by the solar angle, the orientation of the plant row, the canopy architecture, the diffuse proportion of incoming radiation, and the leaf optical properties.

Hence, studying the interception pattern with respect to growth stages under varying sowing dates is of paramount importance. It is important that the effect of micro-environment on wheat growth and yield in relation to radiation interception is assessed for higher productivity. Keeping all these in mind, an experiment was conducted with the objective to assess the variation of PAR interception and radiation use efficiency in wheat canopy.

Materials and Methods

The experiment was conducted at the research farm of Dr. RPCAU, Pusa, Samastipur, Bihar. The coordinates of the research farm are 25.98' N and 85.66' E. having an elevation of 52 m above mean sea level. It has a sub-humid sub-tropical monsoon climate. The variation in temperature during the experimental period is presented in Fig.1. The crop was planted on 5 dates of sowing viz. D1:10 November, D2: 20 November, D3: 30 November, D4:10 December and D5: 20 December with prominent varieties of the region viz. V1: HD 2967, V2: Rajendra *Genhu* 3 and V3: DBW187). The design of the experiment was split plot with date of sowing as main plot factor and varieties as sub-plot factor. Normal package and practices were adopted for raising the crop. Three irrigations were applied to the crop viz., CRI, late jointing and flowering stages.

Photosynthetically Active Radiation (PAR) was measured at different phenological stages with the help of Line Quantum Sensor (Apogee, Model HHT-K20). It measured Photosynthetic Photon Flux Density (PPFD), which is expressed as ìmol m^{-2} s^{-1}. The data was converted into MJ m^{-2} day^{-1} for calculating radiation use efficiency of the crop. The direct incident PAR above and below the crop was measured by placing the sensor 50 cm above the crop and soil surface, within the crop canopy keeping the sensor horizontal to the surface. The reflected PAR was measured from the same positions by simply inverting the sensor of the instrument. All the observations were taken at different phenological stages of the crop, viz. tillering, booting, anthesis, milking, dough and physiological maturity. Three components of PAR were measured as follows:

i) PAR_0=Incoming PAR measured above crop canopy, with sensor facing upward 50 cm above canopy,

ii. PARts=Transmitted PAR at the soil surface, measured by placing sensor upward at the soil surface,

iii) PARrc=Reflected PAR from canopy, measured by inverting sensor at 50 cm above the canopy (Hipps *et al*., 1983).

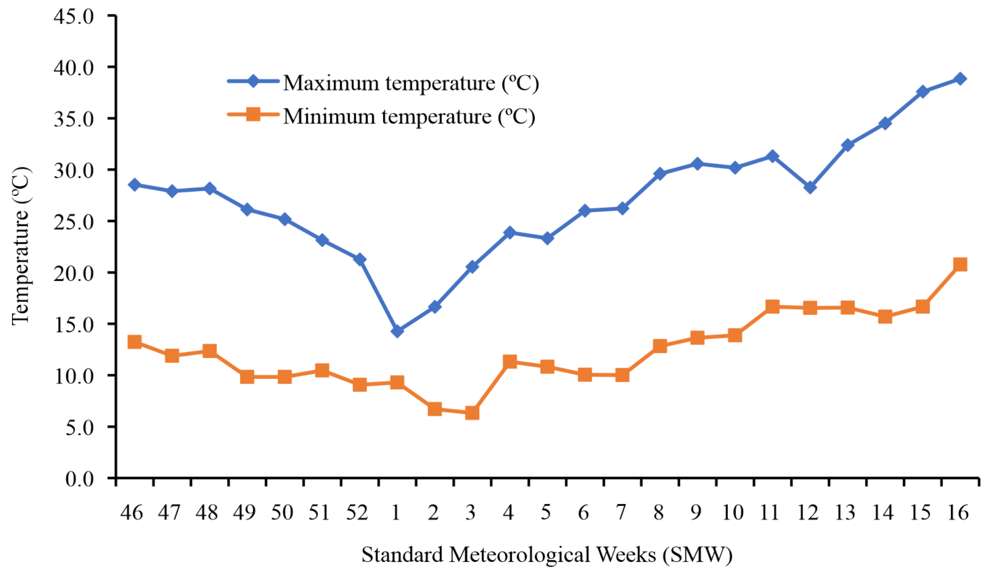

Fig. 1. Temperature variation during the wheat growing period of 2022-23

Intercepted PAR (IPAR) was computed as follows:

Intercepted PAR (IPAR) = (PAR_0 – PARts)

(Nobel, 1980)

Percent IPAR = [(IPAR ×100)/ PAR_0]

Radiation use efficiency (RUE) of three varieties was estimated as the slope of the linear regression between biomass and cumulative intercepted radiation in g MJ^{-1} at different growth phases (Kukal and Irmak, 2020).

Results and Discussion

PAR interception patten in wheat canopy

The mean intercepted PAR (%) revealed that the highest values were observed uniformly in all the treatments having the variety V3 followed by the V2 variety, whereas the V1 variety showed the lowest values of intercepted PAR (Table 1). The highest interception (78.7%) was recorded in the crop sown on 20^{th} Nov (D2) at anthesis stage with variety V2 followed by the crop sown on same date with variety V1. At tillering stage when averaged over three varieties, the highest PAR (%) (47.4%) was observed in the crop sown on 10^{th} Dec followed by D2, D5, D3 and D1, probably due to the favourable weather regime that influenced the growth and consequently, interception pattern at initial stage of the crop sown on this date. At booting stage, when averaged over three varieties, the highest PAR (%) (63.0%) was observed in crop sown on 30 Nov followed by D2, D5, D4 and D1. At anthesis stage, when over three varieties, the highest PAR (%) (71.7%) was observed for 2^{nd} dates of sowing i.e. 20 Nov (D2) followed by D3, D4, D5 and D1. Similarly, at milking stage, when averaged over 3 varieties the highest PAR (%) (54.6%) was associated with the crop sown on D4 (10 Dec) followed by D5, D1, D2 and D3. At physiological maturity stage, when averaged over three varieties, the highest PAR (%) (41.7%) was observed for crop sown 20 Nov (D2) followed by D1, D5, D3 and D4. The highest intercepted PAR was achieved in anthesis stage, perhaps due to greater foliage density. It is evident from the aforesaid results that light interception within crop canopy is complicated and it is affected by sun angle, row direction, plant architecture, diffuse radiation and optical properties of leaves (Xue *et al.*, 2015). In the study, intercepted PAR (%) increased from tillering to anthesis in wheat sown on all dates viz. 10 Nov, 20 Nov, 30 Nov, 10 Dec and 20 December and decreased thereafter.

Variation in intercepted PAR (% IPAR) as a function of leaf area index (LAI)

Variation in IPAR (%) as influenced by leaf area index (LAI) at different growth stages for different

Table 1. Intercepted PAR (%) under different varieties and sowing dates at different phases of growth of wheat

Dates of sowing	Varieties	Tillering	Booting	Anthesis	Milking	Dough	Physiological maturity	Mean
D1	V1	31.0	34.4	59.1	52.0	33.2	30.3	40.0
(10 November)	V2	28.1	35.5	57.3	51.2	35.8	33.1	40.2
	V3	34.4	47.2	59.3	52.5	44.0	41.5	46.5
	Mean	31.2	39.0	58.6	51.9	37.7	35.0	
D2	V1	43.6	60.5	59.7	52.0	42.3	31.8	48.3
(20 November)	V2	48.1	71.3	58.2	51.2	51.7	42.9	53.9
	V3	48.9	73.8	57.2	52.5	58.1	50.5	56.8
	Mean	46.9	68.5	58.4	51.9	50.7	41.7	
D3	V1	23.8	71.7	55.0	52.0	29.0	22.7	42.4
(30 November)	V2	29.0	76.5	66.9	51.3	33.2	27.3	47.3
	V3	47.5	78.7	66.9	52.5	41.5	36.4	53.9
	Mean	33.4	75.6	62.9	51.9	34.6	28.8	
D4	V1	47.1	56.3	56.2	60.6	33.1	20.9	45.7
(10 December)	V2	43.8	51.4	67.1	53.2	36.2	24.6	46.1
	V3	51.3	47.4	65.7	59.4	42.9	32.5	49.9
	Mean	47.4	51.7	63.0	57.7	37.4	26.0	
D5	V1	44.9	57.0	52.3	54.3	39.5	28.5	46.1
(20 December)	V2	47.6	58.1	65.4	54.9	42.3	31.8	50.0
	V3	45.1	55.1	59.5	53.6	48.3	38.9	50.1
	Mean	45.9	56.7	59.1	54.3	43.4	33.1	
Table mean		41.0	58.3	60.4	53.6	40.7	32.9	
SEm (±)		4.1	3.7	2.4	2.8	1.4	1.5	
CD (p=0.05)		12.0	10.7	7.1	8.0	4.0	4.5	

sowing dates (D1, D2, D3, D4 and D5) shows that IPAR (%) and LAI followed similar increasing and decreasing trend at different phenological stages (Fig. 2). LAI increases from tillering stage to anthesis stage and decreases thereafter. The same trend was observed for IPAR (%) across different phenological stages. Kumar *et al.* (1998) noted that higher percentage of PAR interception coincided with higher leaf area index. Under field conditions, crop development depends on the canopy's capacity to capture incoming radiation and convert it into new biomass, which is a function of leaf area index (LAI) and canopy architecture.

Relationship between accumulated intercepted PAR and biomass

Dates of sowing of the crop produced differential radiation environment leading to significant variation in intercepted PAR at different phenological stages (Table 2). The crop planted on D2 date produced maximum biomass followed by D1, D3, D4 and D5. Crop sown on D2 intercepted the highest amount of intercepted PAR. Chakravorty *et al.* (2008) reported that higher interception increases biomass production. In the study, it was also observed that biomass increases from tillering to physiological maturity and decreased at harvesting stage due to crop senescence. Lindquist *et al.* (2005) reported that biomass accumulation is a direct function of intercepted radiation. Delayed sowing led to lower accumulation of biomass. Delay in sowing results in high temperature and high thermal condition, which accelerates crop development, decreases crop duration and consequently, lesser biomass production.

Considering the PAR interception pattern and its utilization, the highest proportion of interception was achieved by the crop sown on 20th November. The

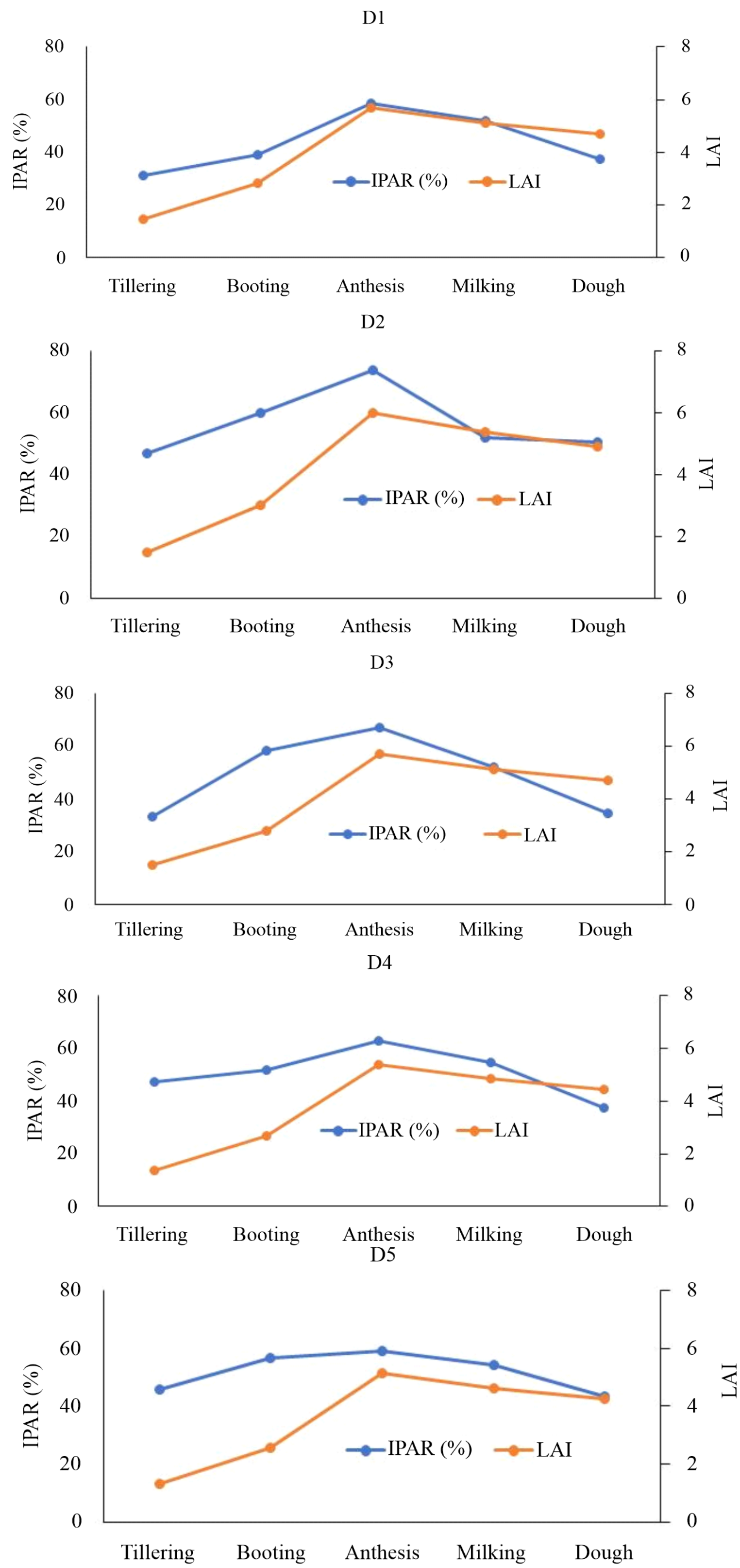

Fig. 2. Variation of percent IPAR (% IPAR) in relation to leaf area index (LAI) at different growth stages of wheat for D1 (10 November), D2 (20 November), D3 (30 November), D4 (10 December) and D5 (20 December) dates of sowing

Table 2. Intercepted PAR (Watts m^{-2}) and biomass (gm^{-2}) under different dates of sowing at various phenological stages of wheat

Growth stages	Sowing Dates									
	D1 (10 November)		D2 (20 November)		D3 (30 November)		D4 (10 December)		D 5 (20 December)	
	IPAR (Watts m^{-2})	Biomass (gm^{-2})	IPAR (Wattsm^{-2})	Biomass (gm^{-2})	IPAR (Wattsm^{-2})	Biomass (gm^{-2})	IPAR (Wattsm^{-2})	Biomass (gm^{-2})	IPAR (Watts m^{-2})	Biomass (gm^{-2})
Tillering	1452.4	58.5	2067.0	66.6	1670.0	54.7	1915.5	49.8	2087.3	47.4
Booting	2404.5	236.5	3848.6	249.2	4050.6	221.3	3331.3	215.3	3607.0	211.4
Anthesis	4166.3	585.5	5093.6	599.2	4929.8	571.3	4630.5	537.4	4958.9	471.7
Milking	5088.3	863.0	5931.1	882.0	5586.8	693.0	5540.9	639.0	5686.4	553.0
Dough	5542.5	966.5	6813.5	979.2	6158.0	788.0	6352.7	730.0	6349.4	655.0
Physiological Maturity	6704.7	1006.5	7963.2	1019.2	7050.1	828	7344.3	767.9	7770.2	689.8

Table 3. Grain yield, leaf area index (LAI), biomass and radiation use efficiency (RUE) of wheat sown on different dates

Sowing dates	Grain yield (t ha^{-1})	Length of ear head (cm)	LAI	Biomass (g m^{-2})	Accumulated IPAR (MJ m^{-2})	RUE (g MJ^{-1})
D1 (10 Nov)	4.10	10.8	5.8	1006.5	235.1	4.28
D2 (20 Nov)	4.35	11.1	6.0	1019.2	216.3	4.71
D3 (30 Nov)	3.66	10.4	5.7	828.0	231.9	3.57
D4 (10 Dec)	3.18	9.2	5.4	767.9	246.9	3.11
D5 (20 Dec)	2.84	10.8	5.2	689.8	253.6	2.72
Mean	3.62	10.5	5.6	862.3	236.7	3.67
S.Em (±)	0.04	0.1	0.2	5.1	6.6	0.07
CD (P=0.05)	0.10	0.4	0.5	14.7	19.2	0.19

higher grain yield and greater accumulation of biomass for the crop sown on 20th November could be explained partly from the fact that this date intercepted the maximum PAR and showed greater PAR conversion efficiency (Table 3).

Radiation use efficiency of wheat varieties

The slope of linear relationship between biomass and cumulative IPAR indicates the efficiency with which crop can convert radiation into biomass. Radiation use efficiency (RUE) of different wheat varieties (Fig. 3) showed that the highest radiation use efficiency (3.51 g MJ^{-1}) was recorded for the variety V1, followed by variety V3, which recorded the radiation use efficiency of 3.35 g MJ^{-1} and the minimum radiation use efficiency was observed in V2 variety (3.25 g MJ^{-1}). Sheehy *et al*. (2004) reported that radiation use efficiency of wheat ranged from 2 to 4 g MJ^{-1} depending on the environmental condition. Vashisth *et al.* (2020) also observed RUE of wheat crop to the extent of 3.97 g MJ^{-1}.

Conclusions

The highest intercepted PAR (78.7%) was recorded in crop sown on 20th November (D2) at anthesis stage with variety V2 (Rajendra *Genhu* 3) followed by the crop sown on the same date with variety V1 (HD 2967). It was observed that the highest interception by 20th November-sown crop was achieved as a result of maximum foliage density and leaf area index. Intercepted PAR (%) kept on increasing from tillering to anthesis stage and decreased thereafter. Significant relationship between intercepted PAR with biomass and leaf area index

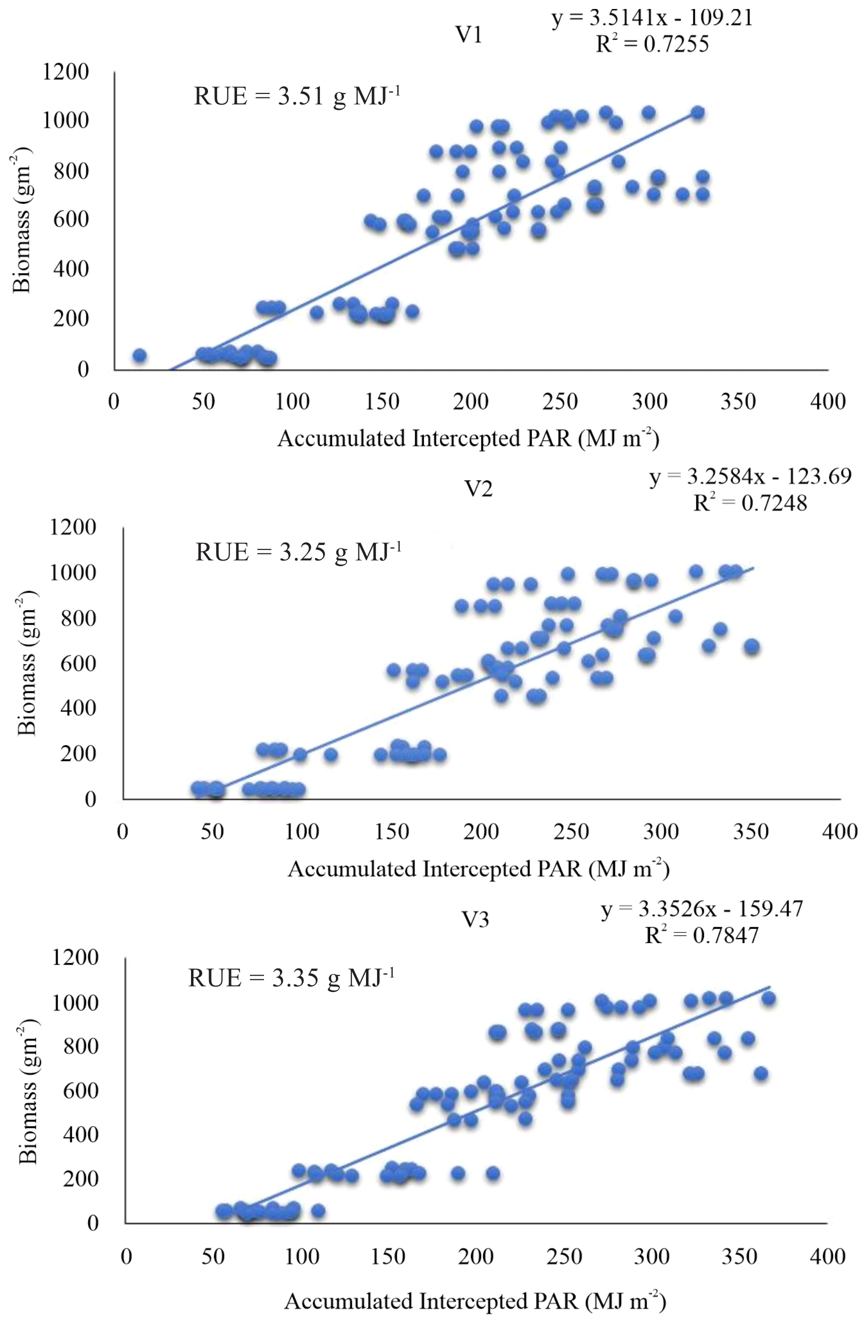

Fig. 3. Radiation use efficiency (RUE) of V1 (HD 2867), V2 (Rajendra *Genhu* 3) and V3(DBW 187) varieties of wheat

were observed. Sowing times significantly affected the radiation use efficiency (RUE) in wheat. Among all the dates of sowing, D2 (20th November) followed by D1 (10th November) recorded the highest RUE (4.71 g MJ^{-1} and 4.28 g MJ^{-1}, respectively), signifying optimum condition for producing maximum biomass. Among the varieties, HD 2967 achieved the highest RUE (3.51g MJ^{-1}).

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