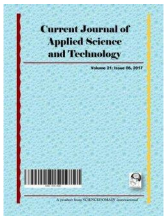

Current Journal of Applied Science and Technology

29(6): 1-14, 2018; Article no.CJAST.44574
ISSN: 2457-1024
(Past name: British Journal of Applied Science & Technology, Past ISSN: 2231-0843,
NLM ID: 101664541)

The Influence of Photo-thermal Quotient on the Growth and Yield of Summer Rice under Varying Dates of Transplanting and Irrigation Regimes in Lower Gangetic Plains of India

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Authors' contributions

This work was carried out in collaboration between all authors. Author PKC performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors SB, RN and SS managed the analyses of the study, preparation of final manuscript and field data observation. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/CJAST/2018/44574
Editor(s):
(1) Dr. Teresa De Pilli, Assistant Professor, Department of Science of Agriculture of Food of Environment (SAFE), University of Foggia, Via Napoli, Italy.
Reviewers:
(1) Sahjahan Ali, Sylhet Agricultural University, Bangladesh.
(2) Miguel Aguilar Cortes, Universidad Autonoma Del Estado De Morelos, Mexico.
Complete Peer review History: http://www.sciencedomain.org/review-history/26781

Received 18 July 2018
Accepted 03 October 2018
Published 23 October 2018

Original Research Article

ABSTRACT

Aims: The selection of transplanting windows of summer rice based on temperature and solar radiation is an important task to keep the production potential of this crop under changing climate scenario especially with deficit irrigation management.
Methodology and Study Design: Two years field experiment (2014 and 2015) was conducted in the Lower Gangetic Plains of Eastern India where the popular rice cultivar *Satabdi* seedlings of 35 days old, were transplanted on three dates with 14 days interval (24th January, 7th February and 21st February) as the main plot treatment. Four irrigation regimes [continuous ponding (I_1); intermittent

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ponding (I_2) during 20 to 65 days after transplanting (DAT) (irrigation applied 3 days after disappearance of standing water); irrigation depth is 0.05 m; intermittent ponding (I_3) during 20 to 65 DAT (irrigation applied 5 days after disappearance of standing water); irrigation depth is 0.05m, and shallow depth deficit irrigation (I_4) during 20 to 65DAT; irrigation depth is 0.03m.] were chosen as the sub-plot treatment. The design of the experiment was strip-plot.

Conclusion: It was found that aboveground biomass and panicle weight showed a linear function of the cumulative photo-thermal quotient (PTQ). From the regression analysis, it was found that PTQ at panicle initiation (PI) stage significantly and positively affected the grain yield. The present experiment identified that the summer rice could be transplanted from last week of January to the first fortnight of February with the I_2 irrigation management when the impact of PTQ on grain yield and biomass production was maximum. The mean grain yield was 6.51t ha^{-1} compared to the general practice though they are not significantly different and the mean biomass production was 41.63 g m^{-2}. The maximum temperature of 34.4 – 37.0°C and a minimum temperature of 22.0 – 22.5°C with radiation energy of 16.37 – 23.97 MJm^{-2} at PI stage were found congenial for good yield in summer rice.

Keywords: Biomass; dates of transplanting; deficit irrigation; photothermal quotient; yield.

1. INTRODUCTION

The principal rice growing area of West Bengal is the Gangetic Plains where farmers cultivate at least two rice crops in sequence. The summer season rice is transplanted during December to February where the planting window is shifted from the cool season to warmer environment. The shift of the thermal and radiation environment causes a significant effect on the growth and yield of the crop. The recent trend in increasing temperature during winter season has affected the growth and yield of the crop in the present decade [1,2,3,4,5,6]. Future projection indicates that the temperature will rise in the range of 1.2-2.5°C in 2050 and warming will be observed in the pre-monsoon and winter seasons [7]. In addition, a declining trend of solar radiation has been observed in some regions with the increase in aerosol concentration and atmospheric pollutants during winter season [8,9]. In the Gangetic Plains, winter season experiences extreme foggy weather which reduces the inception of solar radiation.

Rice production needs much more water than the other crops. Approximately 500 litres of water are required to produce 1 kg of irrigated rice [10]. Adoption of deficit irrigation management may lead to a reduction in biomass production and yield of the crop [11,12]. The Bengal farmers use underground water to irrigate their rice crop which has invited the arsenic contamination in the ecosystem [13]. Planting window selection and adoption of controlled irrigation may help the cultivator to achieve a good yield of rice if the thermal and radiation environment are quantified. This will also help to reduce the arsenic load in the ecosystem. The combined effect of temperature and radiation on the growth and yield of the crop may be evaluated through the photo-thermal quotient (PTQ). The PTQ is defined as the ratio of the total solar radiation in MJ m^{-2} day^{-1} to the mean daily temperature minus a base temperature. The PTQ changes when planting window changes [14,15,16]. A volume of literature is available on the combined effect of solar radiation and temperature on different crops [Wheat: 17, 18, 19, 14, 20; Rice: 21, 6; Sunflower: 22]. The effect of temperature and radiation in different phonological stages of rice was examined by a few scientists [6]. The combined effect of solar radiation and temperature as PTQ has been examined in upland crops [Wheat: 15, 23, 16; Pea: 24]. However, the effect of PTQ under deficit irrigation management on the growth and yield of rice has not been reported yet.

The objectives of this study are

i. Assessment of PTQ requirement for the onset of important phenophases of rice under different planting windows.
ii. To work out the relationship between PTQ and growth attributes of rice under different planting windows and deficit irrigation management and
iii. To identify the relationship between yield and PTQ during vegetative and reproductive phases.

2. MATERIALS AND METHODS

2.1 Experimental Site

The site of the experiment is located at the University Research Farm, Kalyani, which falls in the lower Indo-Gangetic Plains of West Bengal, India. The latitude, longitude and the altitude of the site are 22°58´N, 88°31´E and 9.75 m above the mean sea level respectively. The soil is *Entisol,* clay loam in character. The experimental soil contains 0.78% organic C, 0.07% N, 24.06 kg ha^{-1} available P and 187.45 kg ha^{-1} available K. The mercury reaches its maximum during May and the coolest day is observed during January; the highest and the lowest temperatures are around 40°C and 6°C respectively. The annual rainfall is around 1600 mm, out of which 1300 mm occurs during South-West monsoon spanning from June to the first week of October.

2.2 Details of the Experiment

The field experiment was carried out in the winter season of 2013-14 and 2014-15. In every season, 35 days old rice seedling of the *Shatabdi* (IET-4786) variety was transplanted under three different planting windows (D_1:24th January, D_2: 7th February and D_3: 21st February) to expose the rice crop to three different sets of thermal and radiation environments. Four irrigation regimes were adopted [continuous ponding (I_1); intermittent ponding (I_2) during 20 to 65 DAT (irrigation applied 3 days after disappearance of the standing water); irrigation depth was 0.05 m; intermittent ponding (I_3) during 20 to 65 DAT (irrigation applied 5 days after disappearance of the standing water); irrigation depth was 0.05m and shallow depth deficit irrigation (I_4) during 20 to 65DAT; irrigation depth was 0.03m.]. The dates of transplanting were confined in horizontal strips (main plot), and the irrigation regimes were kept in the vertical strip (sub-plot). The experiment was laid out as strip-plot design with a plot size of 8 m× 3.5 m having three replications. Around each sub-plot treatment, a 2 m wide channel was constructed to restrict the water movement from one plot to another plot. The plot bund was covered with polythene sheet to control the seepage as well. The crop was raised adopting standard agronomic practices. The fertiliser doses were N 80kg ha^{-1}, P_2O_5 60 kg ha^{-1} and K_2O 60 kg ha^{-1}. The sources of NPK fertilisers were urea, single super phosphate and muriate of potash respectively. Out of the total nitrogenous fertiliser, 50% was applied before transplanting to increase nitrogen use efficiency, 25% on the 21th day after transplanting (DAT) and the rest was on 60th DAT. The crop was kept free of weed and pest by adopting proper pest and weed control measures.

2.3 Crop and Weather Data

The daily maximum and minimum temperatures during the experimental period were collected from the Agrometeorological Observatory located near of the experimental field. Both the maximum and minimum temperatures were recorded twice a day at 7 and 14 hours local mean time. The maximum and minimum temperatures were recorded with the help of thermometers housed in a Stevensons' Screen. The aboveground biomass was recorded at tiller initiation (TI), maximum tillering (MT), panicle initiation (PI), 100% flowering (FL) and milk stages (ML) of the rice crop. The panicle weight was recorded from the emergence of panicle to the milk stage day to day basis. The yield of the crop was recorded from a 2×2 m^2 net plot area in each treatment combinations and replications.

2.4 Solar Radiation

Daily global solar radiation (GSR) data were computed with the help of well known Angstrom equation (1924). This was related to the monthly average daily global radiation to the average daily sunshine hours which were collected from the nearby observatory.

2.5 Photothermal Quotient (PTQ)

PTQ is calculated daily during the crop growing period based on Ortiz-Monasterio's method [14]. If $T < 4.5$, PTQ per day = 0; if $4.5<T<10$, PTQ per day = solar radiation*[(T-4.5)/5.5]/5.5; if $T>10$, PTQ per day = solar radiation/(T-4.5); where T is daily mean temperature [(maximum temperature + minimum temperature)/2] and PTQ is expressed as $MJm^{-2}day^{-1}°C^{-1}$.

2.6 Statistical Analysis

All the relevant data were analysed, and the relationships between growth parameters were worked out using SPSS (version 16) software and Excel Stat.

3. RESULTS AND DISCUSSION

3.1 Shifting of Thermal and Radiation Environment

Changes in transplanting windows from late January to late February alter the thermal and radiation environment of the growing span of the crop (Table 1). The maximum, minimum temperatures and solar radiation increased substantially when transplanting was shifted from D_1 to D_2, especially during the vegetative and 100% flowering stages. The panicle initiation (PI) and milk stages (ML) under D_2, experienced lower temperature as compared to D_1 in both the years. When the transplanting was shifted to D_3, the vegetative, reproductive and ripening phases experienced higher maximum and minimum temperatures in comparison to D_2.

3.2 PTQ Requirement

The mean PTQ requirement reduced remarkably when the transplanting was delayed (Table 2). The mean PTQ requirement reduced by 37.6, 9.0, 4.3 and 3.6% respectively during tiller initiation (TI), maximum tillering (MT), panicle initiation (PI) and milk stages (ML) when transplanting was shifted from D_1 to D_3. Only at the 100% flowering stage (FL) PTQ requirement increased marginally due to delay in transplanting.

3.3 Above Ground Biomass

The aboveground biomass (AGBM) during maximum tillering and milk stages were significantly higher under D_2 compared to D_1. When the crop was transplanted on D_3, no significant differences did exist between D_2 and D_3 regarding the biomass accumulation. The I_2 level irrigation gave maximum biomass at these two phenophases. The results also showed that the shallow level deficit irrigation (I_4) recorded minimum biomass accumulation (Table 3).

3.4 Grain Yield

The grain yield did not record any significant differences when transplanted either on D_1 or D_2; however drastic yield reduction was recorded when the transplanting was delayed by a fortnight (D_3). Both the continuous submergence (I_1) and the I_2 level irrigation management recorded no significant variation in grain yield (Table 4), although a marginal increase in grain yield was recorded under I_2. The maximum yield reduction was noted under I_3 irrigation management.

The PTQ requirement declined either due to the increased temperature or global solar radiation. It was noted that the reduction of PTQ in wheat crop occurred because of delayed sowing (16). The maximum and minimum temperatures and the global solar radiation affected the panicle weight when transplanting dates were changed (Table 5). Under D_2, maximum and minimum temperature and GSR was positively correlated to the panicle weight of the rice crop, because the D_2 transplanted crop experienced lower thermal regime during PI stage which facilitated the crop to build up the panicle properly. Higher temperature during panicle initiation shortens the panicle length and produces aborted spikelets.

Table 1. Shifting of thermal and radiation environment due to shifting of planting windows in summer rice

Dot	Phenophase	T_{MAX}(°C)		T_{MIN}(°C)		GSR (MJ m^{-2})	
		1st Year	2nd Year	1st Year	2nd Year	1st Year	2nd Year
D_1	TI	27.8	30.4	13.4	13.0	20.86	19.48
	MT	32.0	35.0	16.0	15.5	21.93	22.02
	PI	39.3	37.2	22.5	24.5	24.08	22.41
	FL	38.2	33.0	26.9	21.2	21.25	22.73
	ML	42.0	36.6	26.0	24.5	24.03	21.99
D_2	TI	30.0	34.5	15.9	21.0	19.58	19.67
	MT	35.3	36.4	17.6	16.8	23.46	23.74
	PI	37.0	34.4	22.0	22.5	23.97	16.37
	FL	41.0	35.4	26.5	25.5	23.70	19.06
	ML	41.5	35.0	26.8	21.5	24.52	24.43
D_3	TI	30.7	33.4	15.8	14.0	22.92	23.19
	MT	36.7	37.5	23.0	22.5	22.68	22.65
	PI	39.0	35.0	24.0	23.5	24.40	21.15
	FL	41.5	35.0	26.8	21.5	24.52	24.43
	ML	36.4	36.5	23.5	27.0	23.35	22.71

(TI= Tiller Initiation, MT= Maximum Tillering, PI= Panicle Initiation, FL= 100%Flowering, ML= Milk stage)

Table 2. Requirement of PTQ (MJm^{-2}day°C^{-1}) for the onset of different phenophases in summer rice under different DOTs

Dot	Phenophases														
	TI			MT			PI			FL			ML		
	1st Year	2nd Year	Mean	1st Year	2nd Year	Mean	1st Year	2nd Year	Mean	1st Year	2nd Year	Mean	1st Year	2nd Year	Mean
D_1	26.03	23.53	24.78	29.20	23.96	26.58	19.24	19.33	19.28	8.81	8.43	8.62	12.70	12.21	12.46
D_2	21.54	17.74	19.64	26.30	25.51	25.90	13.62	12.61	13.11	10.23	9.78	10.01	8.22	8.78	8.50
D_3	16.57	14.34	15.45	24.34	24.10	24.22	11.35	10.77	11.06	10.67	10.96	10.82	7.85	8.09	7.97

Table 3. Aboveground rice biomass (gm^{-2}) at maximum tillering (MT) and milk stage (ML) under different DOTs and irrigation regimes.

	MT									
	1st year					2nd year				
DOT/I	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean
D_1	6.07	5.84	4.67	5.26	5.46	5.84	5.34	4.76	4.9	5.21
D_2	5.56	9.9	9.32	6.91	7.92	9.78	12.81	12.49	10.73	11.45
D_3	8.23	7.86	7.51	5.77	7.34	13.08	13.19	9.23	7.19	10.67
Mean	6.62	7.87	7.16	5.98		9.57	10.45	8.83	7.61	
	Irrigation	DOT	Irrigation XDOT			Irrigation	DOT	Irrigation XDOT		
SEm(+)	0.06	0.05	0.06			0.06	0.05	0.08		
LSD at 5%	0.25	0.26	0.23			0.23	0.27	0.3		

	ML									
	1st year					2nd year				
DOT/I	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean
D_1	38.53	34.68	30.07	31.72	33.75	35.46	34.87	30.24	31.79	33.09
D_2	33.53	41.9	37.39	35.66	37.12	30.03	41.36	40.28	35.4	36.76
D_3	41.62	36.89	35.63	31.71	36.46	40.14	38.79	36.61	33.21	37.19
Mean	37.89	37.82	34.36	33.03		35.21	38.34	35.71	33.46	
	Irrigation	DOT	Irrigation XDOT			Irrigation	DOT	Irrigation XDOT		
SEm(+)	0.13	0.16	0.18			0.08	0.11	0.14		
LSDat5%	0.54	0.81	0.65			0.32	0.56	0.51		

Table 4. Grain yield (tha^{-1}) of summer rice under different DOTs and irrigation regimes

	Grain yield									
	1st year					2nd year				
DOT/I	I_1	I_2	I_3	I_4	**Mean**	I_1	I_2	I_3	I_4	**Mean**
D_1	6.63	6.22	4.95	5.37	5.79	6.82	6.7	5.47	5.75	6.19
D_2	5.66	6.46	5.29	5.84	5.81	5.97	6.57	5.43	6.13	6.03
D_3	5.2	5.14	4.97	4.58	4.97	5.27	5.02	4.57	4.3	4.79
Mean	5.83	5.94	5.07	5.26		6.02	6.1	5.16	5.39	
	Irrigation	DOT	Irrigation XDOT			Irrigation	DOT	Irrigation XDOT		
SEm(+)	0.03	0.02	0.06			0.05	0.03	0.05		
LSD at 5%	0.13	0.1	0.23			0.2	0.17	0.17		

Table 5. Association among panicle weight, maximum temperature, minimum temperature and global solar radiation

Dot	Maximum temperature and panicle weight		Minimum temperature and panicle weight		GSR and panicle weight	
	1st year	2nd year	1st year	2nd year	1st year	2nd year
D_1	0.996**	-0.287	0.715*	-0.158	0.989**	-0.437
D_2	0.920**	0.808**	0.901**	0.059	0.636*	0.882**
D_3	-0.543	0.829**	0.036	0.573	-0.839**	0.534

*(*significant at 5% and ** significant at 1% levels)*

Cumulative PTQ significantly related to the aboveground biomass irrespective of dates of transplanting (DOTs). Aboveground biomass was the linear function of cumulative PTQ. When the crop was transplanted on D_1, 82.4% variation in aboveground biomass was explained through the variation in PTQ (Fig. 1). R^2 values declined marginally when transplanting was delayed. It is evident from the Fig. 1 late January transplanted crop achieved more or less 800 gm^{-2} when the cumulative PTQ value around 100 $MJm^{-2}day°C^{-1}$. As the dates of transplanting delayed, the same amount of biomass was achieved with the lesser contribution of cumulative PTQ (for D_2 cumulative PTQ value lowers to around 80 and in D_3 it was around 75 $MJm^{-2}day°C^{-1}$). Surprisingly the slope of the curve had become steeper with delayed transplanting (Fig. 2). Cumulative PTQ increased the biomass accumulation under all irrigation regimes tested, although the minimum R^2 value was obtained under the I_3 regime (Fig. 2). If examined, the contrasting pattern of the slope between continuous submergence (I_1) and where water was applied 5 days disappearance (I_3) that is the extreme dryness, it would have showed a steeper sloping pattern in continuous submergence treatment; whereas other two treatments showed no special contrast in the sloping pattern. In the present experiment, the above ground biomass accumulation showed the linear function of the PTQ.

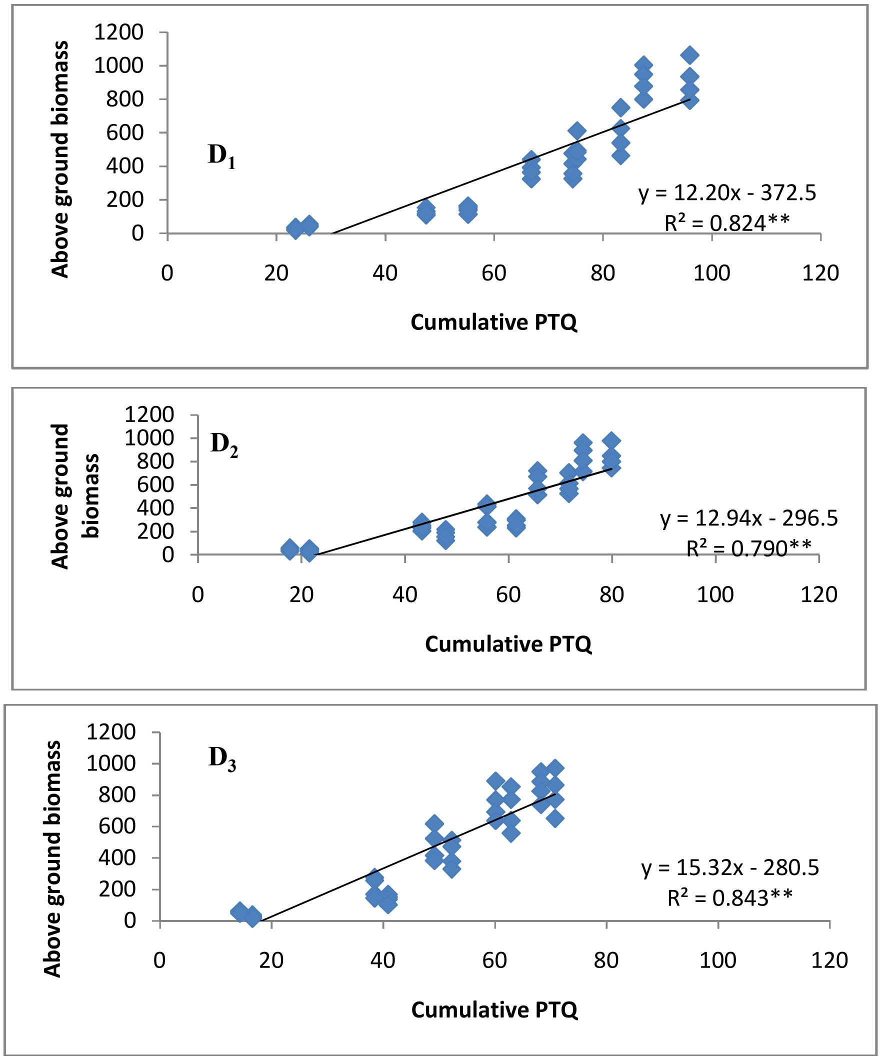


Fig. 1. Effect of cumulative PTQ ($MJm^{-2}day°C^{-1}$) on aboveground biomass accumulation (gm^{-2}) on summer rice as influenced by different dates of transplanting (pooled over experimental years and irrigation regimes)

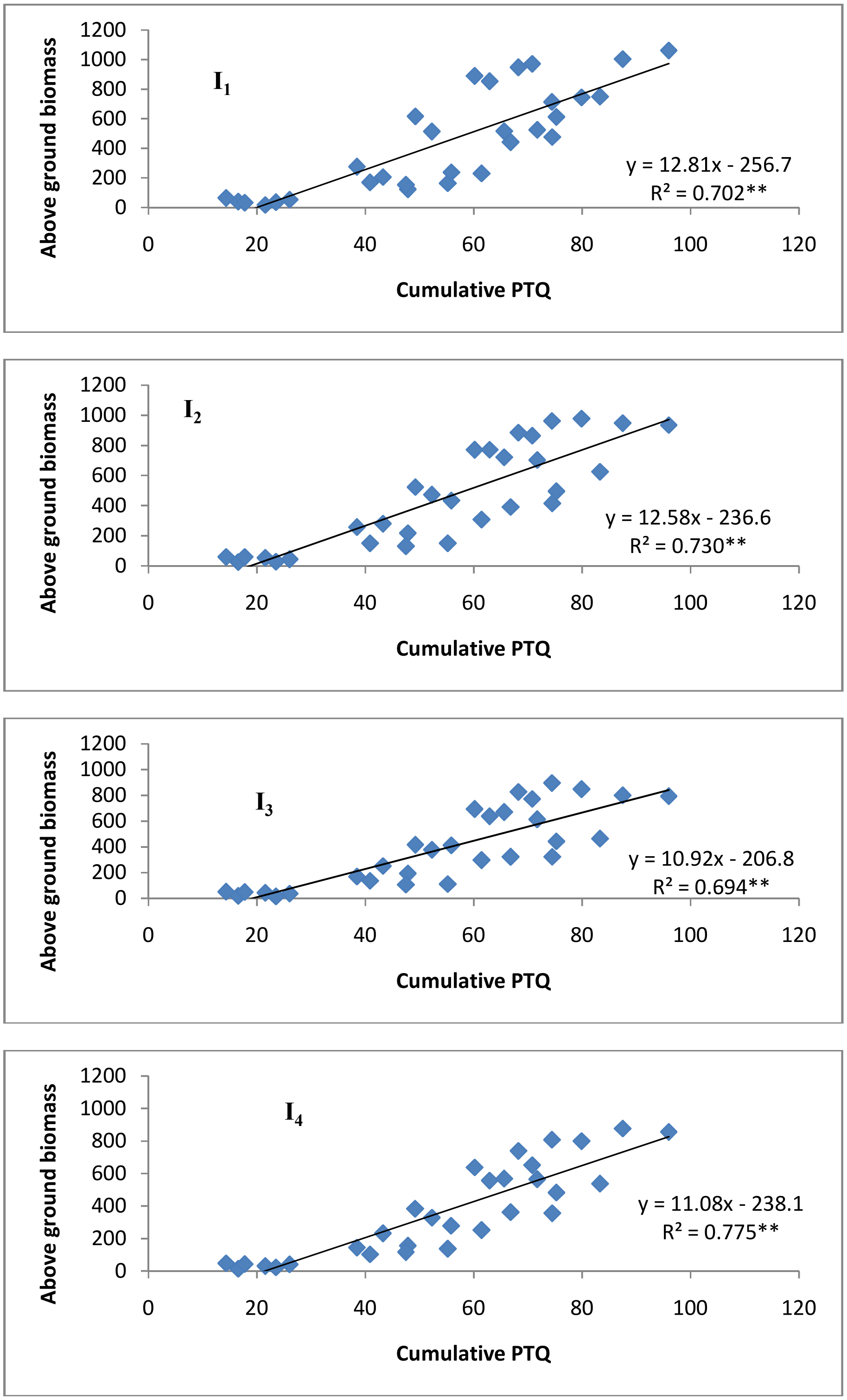
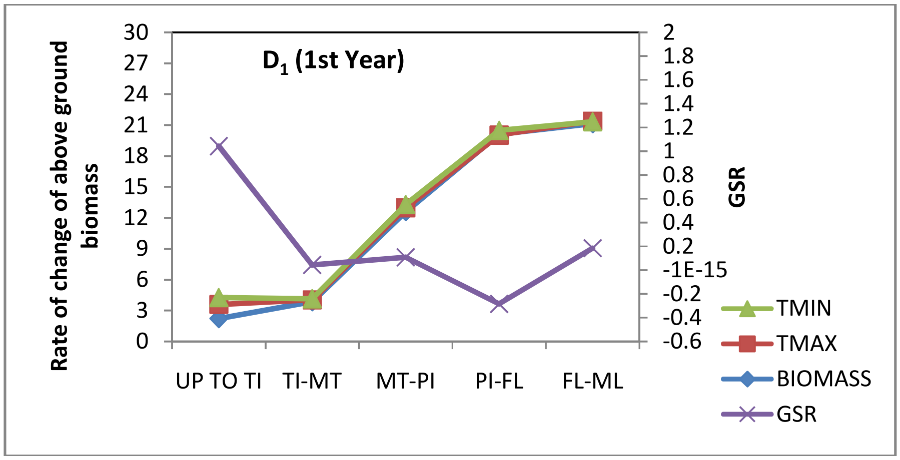
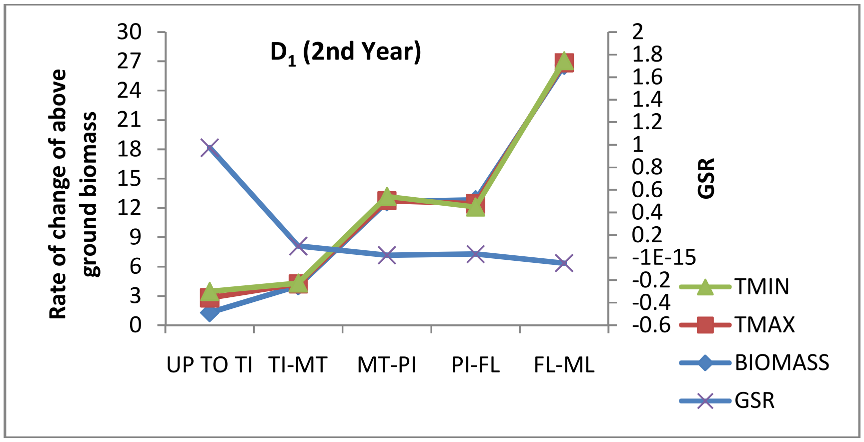


Fig. 2. Effect of cumulative PTQ (MJm^{-2}day°C^{-1}) on aboveground biomass accumulation (gm^{-2}) on summer rice under different irrigation regimes (pooled over experimental years and DOTs)

The rate of change of aboveground biomass *i.e.* crop growth rate (CGR) was initially influenced by GSR up to maximum tillering; later on, it was more affected by the maximum and minimum temperatures (Fig. 3). In the case of the first date of transplanting, the effect of GSR was almost similar beyond the maximum tillering in both the experimental year. The influence of GSR on AGBM was more prominent under the second date of transplanting whereas under third date, the trend of GSR was similar to that of the first date. Under the second date, the CGR increased up to flowering and remained static up to the milk stage; whereas under third date CGR declined beyond the flowering stage. As the dates of transplanting were delayed, crop phonological stages entered into the warm thermal environment and therefore, the importance of GSR on biomass accumulation declined. The later stage depletion of CGR was due to the drying of aged leaves and stems. Increased temperature at the later stage increased leaf respiration to decline the biomass development. Under the I_2 level 1250, 1500 and 1750 m^3 of irrigation water per hectare were saved compared to continuous submergence under D_1, D_2 and D_3 respectively. Therefore a marginal decline in the aboveground biomass accumulation may be accepted by the farmers if the I_2 level of water management is practised. Moreover, the I_2 level of irrigation under D_2 recorded a marginal increase in the grain yield. A linear increase in grains per meter square or yield with the increase in PTQ in the wheat crop was also observed by scientists (23, 16). It was observed that if the panicle weight was separated from the total biomass accumulation, PTQ had a linear and significant relationship irrespective of DOTs or irrigation regimes.

Apart from this, it was also observed that the strength of the relationship between PTQ and panicle weight was closer when water stress was imposed or DOTs were altered (Figs. 4 and 5).





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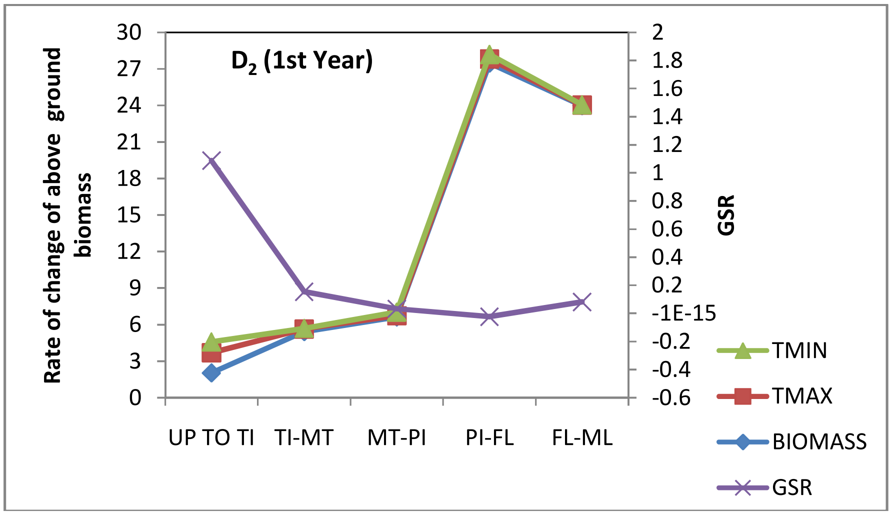
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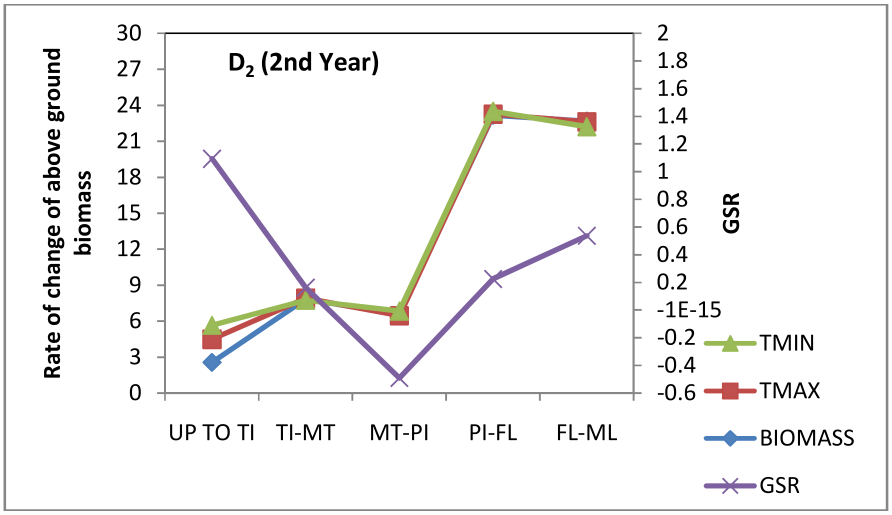
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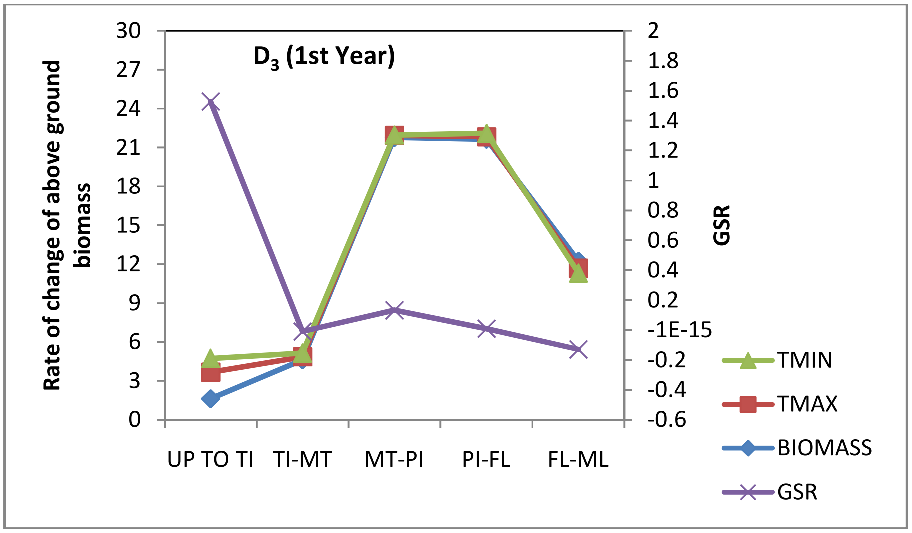
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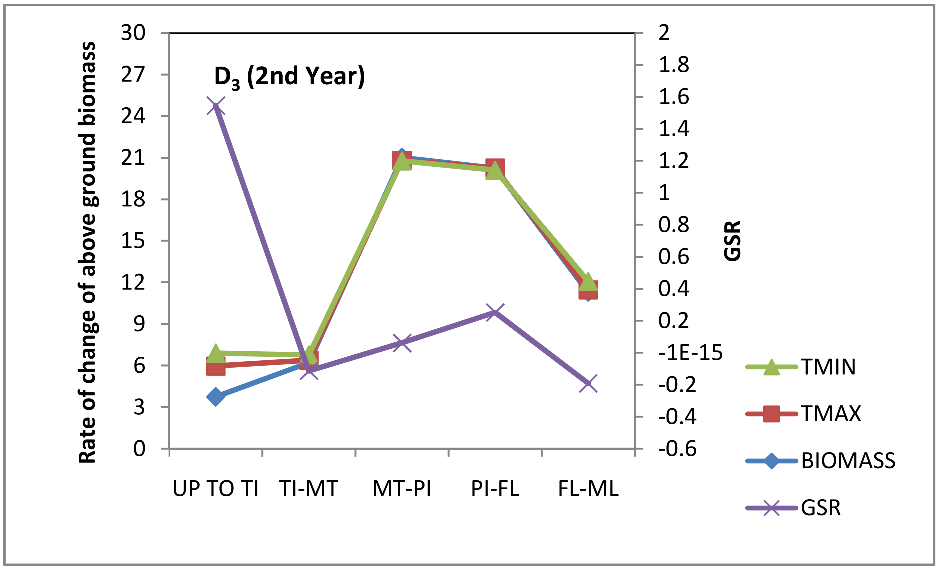
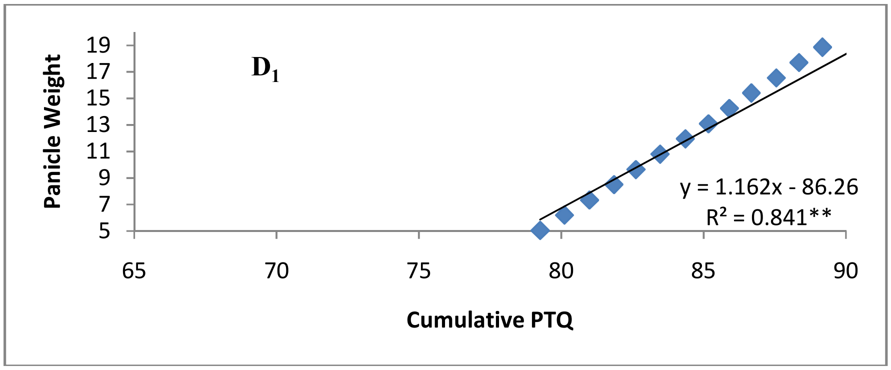


Fig. 3. Pattern of rate of change in aboveground biomass ($gm^{-2}day^{-1}$) with respect to changes in maximum and minimum temperature (°C day^{-1}) and GSR ($MJm^{-2}day^{-1}$) under different transplanting dates.

The R^2 value was maximum under the I_2 level of irrigation where grain yield was also maximum. This indicated that both the temperature and radiation had influenced the panicle weight. The panicle weight linearly increased with the increase in PTQ irrespective of the DOTs, the slope of the curve was maximum under D_1 and gradually declined with the shifting of the transplanting windows. Shifting of DOTs from the cool environment to the warm indicates the shift of temperature and radiation level. The panicle weight becomes more sensitive with the increase in temperature which reduces the slope. Increase in temperature and radiation level also increased the strength of relationship as evident from the R^2 values. The PTQ significantly affected the grain yield during the reproductive phase. The stepwise regression analysis showed that PTQ at the PI stage positively influenced the grain yield whereas at the milk stage it had a negative influence (Y_{DOT} = $9.215+0.605_{PI}-0.502_{ML}$, R^2= 0.538, Adj R^2 = 0.494, SE = 0.512). The temperature and radiation sensitivity on yield components and yield by using PTQ was also evident in the studies of various scientists (25, 14, 16). However, these studies were confined to the wheat crop only.



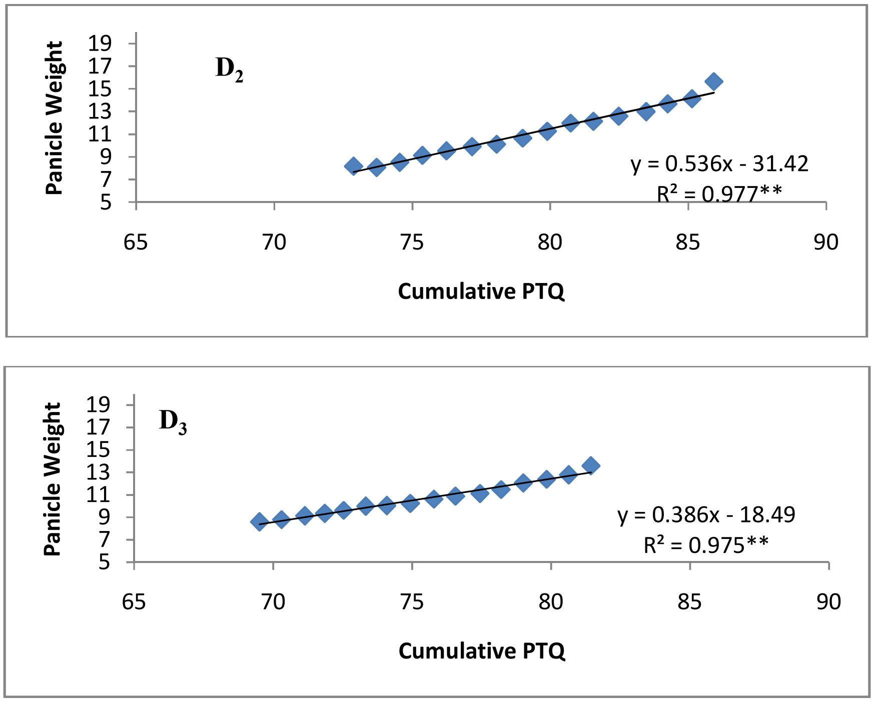
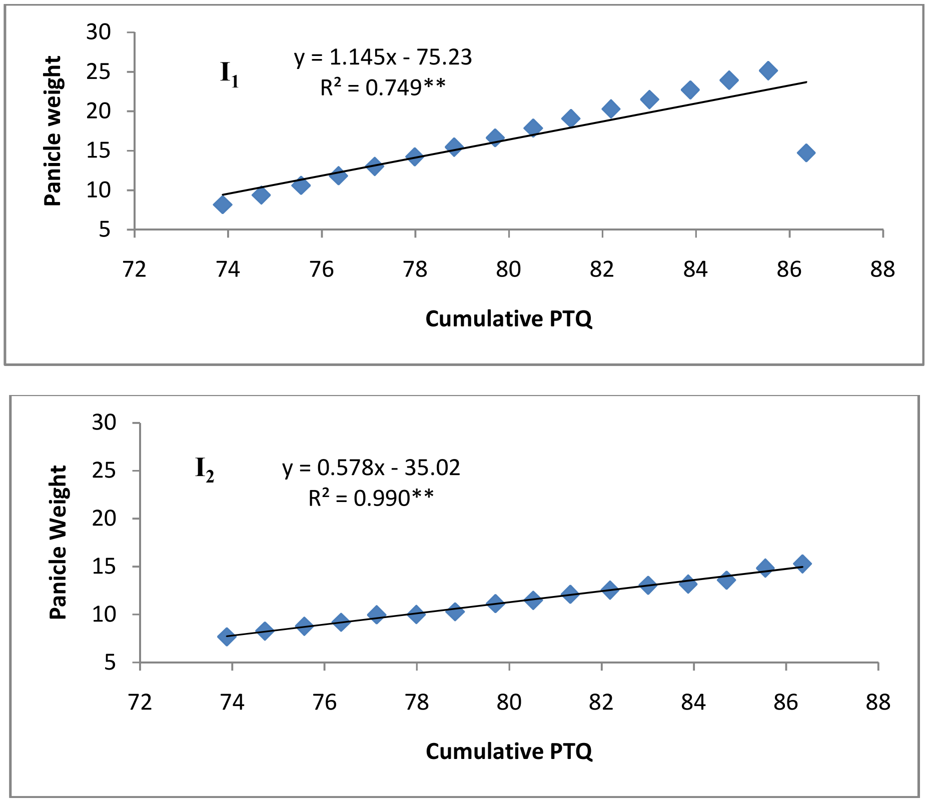


Fig. 4. Relationship between cumulative PTQ (MJm^{-2}day°C^{-1}) and panicle weight (gm^{-2}) of summer rice under different dates of transplanting (pooled over experimental years and irrigation regimes)



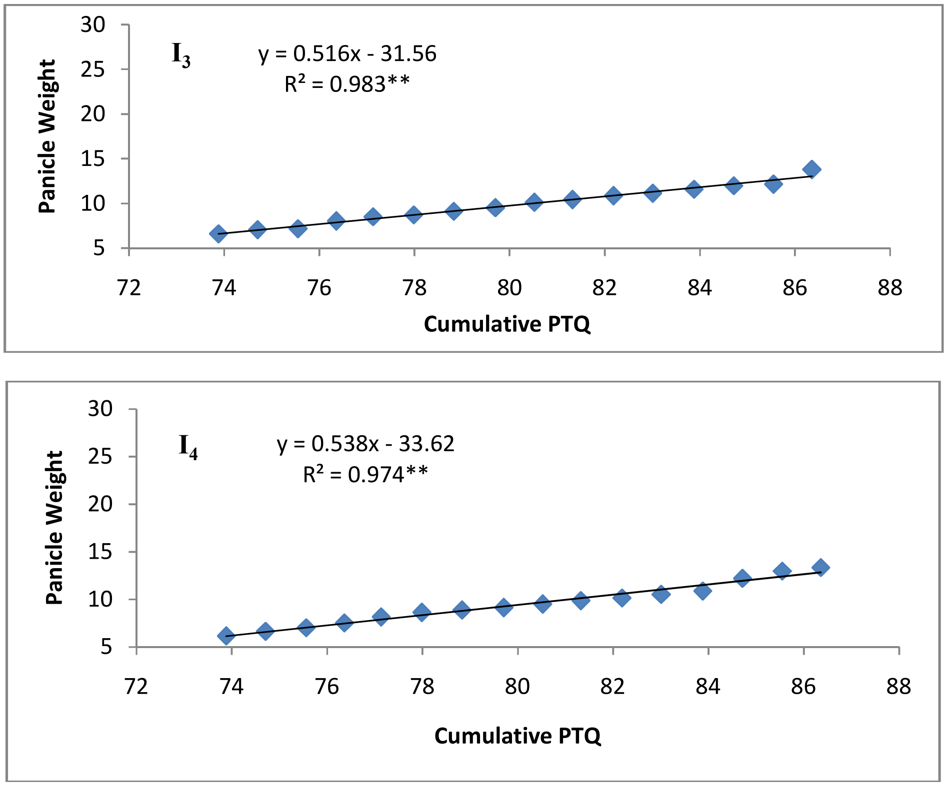


Fig. 5. Relationship between cumulative PTQ (MJm^{-2}day°C^{-1}) and panicle weight (gm^{-2}) of summer rice under different irrigation regimes (pooled over experimental years and DOTs)

4. CONCLUSION

In the present study, the influence of PTQ on the growth and yield of rice crop indicated that the effect of PTQ was more pronounced during the reproductive phase of the crop. Shifting of transplanting window forces the crop to tolerate altered temperature and radiation regimes which indicates less yield as well as from the point of view of water productivity. In conclusion, it may be stated that the transplanting of summer rice from 3rd week of January to 1st fortnight of February with the I_2 (when water was applied 3 days after disappearance) irrigation regime adopted during 20 – 65 DAT would be beneficial in terms of saving water and for biomass production as well as grain yield. The adoption of this irrigation practice may save 125 – 150 cm of irrigation water without any substantial reduction in grain yield.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
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