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Effect of growing environments on agrometeorological indices, heat and radiation use efficiency and yield of rice (*Oryza sativa* L.) in Raipur District of Chhattisgarh

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Abstract

A field experiment under AICRP on Agrometeorology was conducted during the *kharif* season of 2024–25 at the Research and Instructional Farm of Indira Gandhi Krishi Vishwavidyalaya (IGKV), Raipur, Chhattisgarh, to study the effect of different growing environments on agrometeorological indices, heat use efficiency (HUE), radiation use efficiency (RUE) and yield of rice. The experiment comprised three dates of transplanting viz., D₁ (1st July), D₂ (15th July) and D₃ (30th July) and three rice varieties namely MTU-1010, Mahamaya and Vikram TCR. Accumulated growing degree days (GDD) required for physiological maturity ranged from 1983 to 2083 °C days in MTU-1010, 2167 to 2366 °C days in Mahamaya and 2026 to 2280 °C days in Vikram TCR across growing environments. Accumulated photo-thermal units (PTU) ranged from 24710 to 25800 °C Day hours in MTU-1010, 26933 to 28701 °C Day hours in Mahamaya and 25216 to 27732 °C Day hours in Vikram TCR. Helio-thermal units (HTU) varied from 14080 to 15410 °C Day hours in MTU-1010, 15022 to 17378 °C Day hours in Mahamaya and 14198 to 16724 °C Day hours in Vikram TCR. Highest mean heat use efficiency (0.84 g m⁻² °C Day⁻¹) and radiation use efficiency (2.25 g m⁻² MJ⁻¹) were recorded under D₃ (30th July transplanting). Early transplanting (30th July) produced significantly higher average grain yield (3962 kg ha⁻¹) while Mahamaya variety recorded the highest mean grain yield (3741 kg ha⁻¹). The study highlights that optimum transplanting time and varietal selection play a crucial role in improving rice productivity under changing climatic conditions in the Raipur region.

Keywords: Rice, Growing degree days, Photo-thermal units, Helio-thermal units, Heat use efficiency, Radiation use efficiency, Climate variability

Introduction

Rice (*Oryza sativa* L.) is the most important staple food crop of India and plays a vital role in ensuring food security, particularly in Chhattisgarh, popularly known as the “Rice Bowl of India”. Climate variability in the form of altered temperature regimes and changing radiation environment significantly affects crop growth duration, phenology and yield. Agrometeorological indices such as growing degree days (GDD), photo-thermal units (PTU) and helio-thermal units (HTU) are widely used to quantify crop–weather relationships. Heat use efficiency (HUE) and radiation use efficiency (RUE) indicate the efficiency of crops in converting thermal and radiant energy into economic yield. Understanding these indices under different growing environments is essential for developing climate-resilient rice production strategies. Climate change models are predicting in general an increase in temperature, variations in precipitation and radiation levels which are likely to influence the crop production. Several studies with crop growth models have predicted cultivation in mean crop yields as a result of the changing crop environment (Rao *et al.* 2008) ^[12].

Agriculture will be adversely affected by an increase or decrease in amount of rainfall and shifting of time of rainfall. Ramakrishna *et al.* (2002) ^[11] indicated that a temperature increase of 2°C was estimated in Rajasthan to decrease pearl millet production by 10-15%. The rise in mean air temperature over the past 100 years (1850-1899 to 2001-2005) was 0.76°C which will impact the agriculture production.

To evaluate the effects of climate change, different crop models and scenario have been developed and used across the world. The Decision Support System for Agro Technology Transfer (DSSAT) has been found to be most widely used decision support system which included models for cereals, legumes, oilseeds and vegetable crops (Hoogenboom, 2000). DSSAT (Decision Support System for Agro Technology Transfer) is major product of IBSNAT (International Benchmark Sites Network for Agro Technology Transfer).

Methodology

The experiment was conducted during Kharif 2024–25 at the Research and Instructional Farm, IGKV, Raipur (21.16°N latitude, 81.36°E longitude). The experiment was laid out in a factorial randomized block design with three replications. Treatments consisted of three dates of transplanting: D₁ (1st July), D₂ (15th July) and D₃ (30th July), and three rice varieties: MTU-1010, Mahamaya and Vikram TCR. Recommended agronomic practices were followed throughout the crop season. Daily meteorological data were recorded from the agrometeorological observatory located near the experimental site. GDD, PTU and HTU were computed for different phenological stages. Heat use efficiency and radiation use efficiency were calculated using dry matter accumulation and intercepted radiation

Accumulated Growing Degree Days (GDD)

$$\text{GDD} = \sum [(T_x + T_n)/2 - \text{Base temperature}]$$

Where,

T_x = Daily maximum temperature

T_n = Daily minimum temperature

The base temperature which is considered 10 °C for Kharif crops

Accumulated Photothermal Unit (PTU)

PTU is calculated by multiplying GDD with maximum possible

sunshine hours (N) PTU= GDD X N Where, N =maximum possible sunshine hours.

Accumulated Helio Thermal Unit (HTU)

HTU is calculated by multiplying GDD with actual sunshine hours (n).

$$\text{HTU} = \text{GDD} \times n$$

Where, n = actual sunshine hour.

Heat Use Efficiency (HUE)

Heat use efficiency (HUE) for total dry matter was obtained as under

$$\text{HUE (g/m}^2\text{/}^\circ\text{ day)} = \frac{\text{Biomass (g/m}^2\text{)}}{\text{GDD (}^\circ\text{ days)}}$$

Radiation Use Efficiency (RUE) RUE (gMJ⁻¹day⁻¹) = Biomass (g /m²) / IPAR (M J/m²/day)

Where,

IPAR is cumulative intercepted photo synthetically active radiation.

Results and Discussion

a. Accumulated Growing Degree Days (GDD°C days)

Accumulated GDD for completion of the crop growth period varied significantly among varieties and transplanting dates. MTU-1010 required 2083, 2053 and 1983 °C days for physiological maturity under D₁, D₂ and D₃, respectively. Mahamaya variety accumulated the highest GDDs ranging from 2167 °C days (D₃) to 2366 °C days (D₁) while Vikram TCR accumulated 2280, 2106 and 2026 °C days under D₁, D₂ and D₃, respectively. Higher GDDs under early transplanting are due to longer crop duration, whereas delayed transplanting shortened phenophases and reduced heat unit accumulation.

Table 1: Accumulated Growing degree days (GDD) at different growing stages of different rice varieties under different growing environments

Phenological stage	MTU-1010			Mahamaya			Vikram TCR		
2024-25	D ₁	D ₂	D ₃	D ₁	D ₂	D ₃	D ₁	D ₂	D ₃
Tillering	647.0	608.0	604.0	771.0	683.0	671.0	734.0	630.0	624.0
Panicle initiation	1150.0	988.0	961.0	1191.0	1014.0	1099.0	1173.0	1082.0	994.0
Booting	1266.0	1178.0	1095.0	1320.0	1183.0	1304.0	1282.0	1239.0	1140.0
Emergence	1409.0	1281.0	1367.0	1457.0	1350.0	1414.0	1433.0	1966.0	1367.0
50%Flowering	1540.0	1501.0	1488.0	1656.0	1554.0	1550.0	1564.0	1515.0	1488.0
Milking	1816.0	1631.0	1642.0	2131.0	1710.0	1768.0	1857.0	1674.0	1664.0
Dough	1968.0	1786.0	1752.0	2179.0	2049.0	1875.0	2107.0	1941.0	1824.0
Maturity	2083.0	2053.0	1983.0	2366.0	2204.0	2167.0	2280.0	2106.0	2026.0

ZC- Zonal Check V₁: MTU1010 (ZC), V₂: Mahamaya, V₃: Vikram TCR. D₁-01/06/2025, D₂-15/06/2025, D₃-30/06/2025

b. Accumulated Photo-Thermal Units (PTU°C days)

Accumulated PTU required for physiological maturity ranged from 24710 to 25800 °C Day hours in MTU-1010, 26933 to 28701 °C Day hours in Mahamaya and 25216 to 27732 °C Day

hours in Vikram TCR. The highest PTU accumulation was observed under D₁ (1st July transplanting) in all varieties indicating better utilization of temperature and day length during crop growth.

Table 2: Accumulated Photo Thermal Units (PTU) at different growing stages of different rice varieties under different growing environments

Phenological stage	MTU-1010			Mahamaya			Vikram TCR		
2024-25	D ₁	D ₂	D ₃	D ₁	D ₂	D ₃	D ₁	D ₂	D ₃
Tillering	9378	8446	8352	9859	8898	8827	9462	8234	8219
Panicle initiation	14520	12891	12445	15399	14088	13403	14803	14087	12851
Booting	15950	15278	14085	16612	16174	15537	16138	16025	14635
Emergence	17658	16537	15227	18228	18227	17178	19456	17776	17437
50% Flowering	19242	19205	18917	20548	19896	19448	19756	19417	18917
Milking	22426	20840	20725	26067	22519	21456	22906	21362	20980
Dough	24199	22666	22016	26606	25488	24709	25790	24483	22858
Maturity	25800	25521	24710	28701	27290	26933	27732	26420	25216

ZC- Zonal Check V₁: MTU1010 (ZC), V₂: Mahamaya, V₃: Vikram TCR. D₁-01/06/2025, D₂-15/06/2025, D₃-30/06/2025

c. Accumulated Helio-Thermal Units (HTU°C days)

Helio-thermal unit accumulation was highest under early transplanting and decreased with delayed planting. MTU-1010 variety accumulated 15410, 14371 and 14080 °C Day hours under growing environments D₁, D₂ and D₃, respectively. Mahamaya recorded the highest HTU accumulation (17378 °C

Day hours) under D₁, followed by 15711 °C Day hours under D₂ and 15022 °C Day hours under D₃. Vikram TCR variety accumulated HTU values ranging from 14198 to 16724 °C Day hours. Higher HTU accumulation in early sown crops was attributed to longer exposure to bright sunshine hours.

Table 3: Accumulated Helio Thermal Units (HTU) at different growing stages of different rice varieties under different growing environments

Phenological stage	MTU-1010			Mahamaya			Vikram TCR		
	D ₁	D ₂	D ₃	D ₁	D ₂	D ₃	D ₁	D ₂	D ₃
2024-25									
Tillering	5272	4036	2952	5434	4237	3067	5272	3667	3080
Panicle initiation	8337	6171	5878	8698	6650	6592	8535	5507	6952
Booting	8871	7278	7200	9261	7788	8190	8919	7666	7117
Emergence	10161	9134	8012	10589	9134	9035	10389	13166	8698
50% Flowering	11253	9958	9643	12093	10683	9910	11497	9685	9435
Milking	13637	11366	10334	15848	12019	11662	13940	12744	11042
Dough	14946	12213	11745	16193	14956	12570	15655	12956	12333
Maturity	15410	14371	14080	17378	15711	15022	16724	14572	14198

ZC- Zonal Check V₁: MTU1010 (ZC), V₂: Mahamaya, V₃: Vikram TCR. D₁-01/06/2025, D₂-15/06/2025, D₃-30/06/2025

d. Heat Use Efficiency (HUE g/m² degday) and Radiation Use Efficiency (RUE g/m²/MJ)

Heat use efficiency and radiation use efficiency were significantly influenced by growing environments and varieties. Mean HUE values ranged from 0.79 to 0.84 g/m²/° day across growing environments with the highest mean HUE recorded under D₃ (0.84 g/m²/° day). Among varieties, Mahamaya variety recorded the highest mean HUE (0.83 g/m²/° day), followed by MTU-1010 (0.82 g/m²/° day) and Vikram TCR (0.78 g/m²/°

day). The maximum HUE (0.87 g/m²/° day) was observed in Mahamaya under D₃.

Radiation use efficiency varied from 2.07 to 2.34 gMJ⁻¹day⁻¹. The highest mean RUE (2.25 gMJ⁻¹day⁻¹) was recorded under D₃ followed by D₁ (2.16 gMJ⁻¹day⁻¹) and D₂ (2.14 gMJ⁻¹ day⁻¹). MTU-1010 variety recorded the maximum RUE of 2.34 gMJ⁻¹day⁻¹ under D₁ indicating superior radiation conversion efficiency.

Table 4: Accumulated Heat use Efficiency (HUE) and Radiation use efficiency (RUE) for rice varieties under different growing environments

Varieties	Heat use efficiency (g/m ²)				Radiation use efficiency (gMJ ⁻¹ day ⁻¹)			
	D ₁ (1 st July)	D ₂ (15 th July)	D ₃ (30 th July)	Mean	D ₁ (1 st July)	D ₂ (15 th July)	D ₃ (30 th July)	Mean
MTU-1010	0.83	0.79	0.85	0.82	2.34	2.12	2.18	2.21
Mahamaya	0.82	0.81	0.87	0.83	2.29	2.2	2.22	2.24
Vikram TCR	0.75	0.78	0.81	0.78	2.11	2.1	2.07	2.09
Mean	0.80	0.79	0.84		2.16	2.14	2.25	

ZC- Zonal Check V₁: MTU1010 (ZC), V₂: Mahamaya, V₃: Vikram TCR. D₁-01/06/2025, D₂-15/06/2025, D₃-30/06/2025

e. Grain Yield

Grain yield was significantly affected by transplanting dates and varieties. Mean grain yield was highest under D₃ (3962 kg ha⁻¹), followed by D₂ (3548 kg ha⁻¹) and D₁ (3162 kg ha⁻¹). Among varieties, Mahamaya variety recorded the highest mean grain yield (3741 kg ha⁻¹) followed by MTU-1010 (3563 kg ha⁻¹) and Vikram TCR (3468 kg ha⁻¹). Higher yield under early transplanting was attributed to favourable thermal and radiation conditions during critical growth stages.

efficiency, radiation use efficiency and yield of rice were strongly influenced by growing environments and varietal differences. Early transplanting (1st July) resulted in higher accumulation of GDD, PTU and HTUs and produced significantly higher grain yield. Delayed transplanting improved HUE and RUE but reduced overall yield. Among varieties, MTU-1010 performed best in terms of grain yield, while Mahamaya variety showed higher heat and radiation use efficiency. Timely transplanting and appropriate varietal selection can therefore serve as effective adaptation strategies to mitigate the impact of climate variability on rice production in the Raipur district.

Table 5: Grain yield (kg/ha) at different stages in rice as affected by different growing environments and varieties

Varieties	D ₁ (1 st July)	D ₂ (15 th July)	D ₃ (30 th July)	Mean
V1-MTU 1010	3057	3043	3490	3563
V2-Mahamaya	3760	4433	4030	3741
V3-Vikram TCR	3710	3567	4367	3468
Mean	3162	3548	3962	
	SEm ±	CD (P=0.05)	CV%	
Date	710	2130	123.9	
variety	710	NS		
DxV	1230	NS		

ZC- Zonal Check V₁: MTU1010 (ZC), V₂: Mahamaya, V₃: Vikram TCR. D₁-01/06/2025, D₂-15/06/2025, D₃-30/06/2025

Conclusion

The study revealed that agrometeorological indices, heat use

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