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Thermal time requirement and yield of rice (*Oryza sativa* L.) under varying growing environments in changed climatic scenarios of North Western Himalayas

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Abstract
A field experiment was conducted during *kharif* seasons of 2017 and 2018 to study the accumulated growing degree days (GDD), helio-thermal unit (HTU), photo-thermal unit (PTU), heat use efficiency (HUE) at different phenological stages and performance of rice (*Oryza sativa* L.) varieties. The treatment consisted of three cultivars with five dates of transplanting *viz,* 15th June, 25th June, 5th July, 15th July and 25th July in Factorial RBD. The transplanting window selected was having 1- 3 °C change in temperature. Results of present study revealed that the crop transplanted on 15th June acquired maximum growing degree days, photo-thermal unit and helio-thermal unit for tillering, panicle initiation, 50% flowering and physiological maturity which was significantly reduced with subsequent delay in the transplanting time. The grain yield recorded in 15th June (5713 kg ha^{-1}) was statistically at par with 25th June yield (5315 kg ha^{-1}) and with further delay in transplanting date there was reduction in yield. The per cent decrease in grain yield of 25th July transplanting over 15th June transplanting was about 40 to 45%. Among the varieties, the grain yield of variety HPR 2143 was maximum (5002 kg ha^{-1}) followed by HPR 1068 (4682 kg ha^{-1}) and HPR 2880 (3993 kg ha^{-1}).

Keywords: Rice, GDD, PTU, HTU, HUE, grain yield, physiological maturity

Introduction

The rice is most important cereal crop for more than half of the world's population, provides 21% of the total caloric intake (Singh *et al.*, 2017) [17]. Worldwide, it occupies an area of about 164 million ha with a production of 758.9 million tonnes during 2017 (Anonymous 2018) [2]. It is the staple food for more than two-thirds population of the world, especially the people living in Asia where more than 90 per cent of rice is produced and consumed. Indians and occupied area of about is 42.95 million hectares with total production of 112.91 million tonnes and an average productivity of 2585 kg ha^{-1} (Anonymous 2019a)[3]. In Himachal Pradesh also, rice is one of the important cereal crops next to wheat and maize on area basis. The crop is cultivated in an area of 73.70 thousand hectares with a total production of 130.50 thousand tonnes and productivity of 1771 kg ha^{-1} (Anonymous 2019b)[4]. Demand for rice growing is increasing every year, and it is estimated that by 2025 AD, its requirement would be 140 million tonnes. To sustain the present food self-sufficiency and to meet the future food requirement, India has to increase rice productivity by 3% per annum (Kumar *et al.*, 2015) [11]. Rice production is affected by various meteorological variables like rainfall, temperature and solar radiation. Rice crop needs a hot and humid climate. It is best suited to regions which have high humidity, prolonged and bright sunshine and an assured supply of water. Climatic factors such as temperature, rainfall, atmospheric CO_2 and solar radiation are important parameters to rice production. Development refers to the progress of the crop from one phasic stage of next (Gudadhe *et al.*, 2013) [8]. The response of rice cultivars grown at different transplanting environments can be quite different. Alteration of transplanting dates a directly influences growth and development of crops. Thermal time is an independent variable to describe plant development and it can be used as a tool for characterizing thermal response (Dwyer and Stewart, 1986) [6]. The heat unit concept assumes that a direct and linear relationship between growth and temperature is advantageous for the assessment of yield potential of a crop in different weather conditions (Kumar *et al.*, 2014) [10]. The most commonly used agro meteorological indices are growing degree days (GDD), helio thermal units (HTU) and photo thermal units (PTU).

GDD is the most common temperature index which gives the estimate of plant development and harvest date as well as development stages of crop (Qadir *et al.*, 2006) [13]. The phasic development and crop yield are influenced by both temperature and photoperiod. Therefore, it is better to calculate PTU and HTU in addition to GDD. Heat use efficiency (HUE) represents the heat utilization in terms of dry matter accumulation, depends on genetic factors, crop type and sowing time and has great practical application (Rao *et al.,* 1999) [14]. Hence, the study was carried out to find out the heat units requirement and yield of rice under varying growing environments in North Western Himalayas, which may help in understanding of development pattern and process physiology which may constrain productivity of crop under different environments.

Materials and Methods

The study was conducted at Experimental Farm of CSKHPKV, Rice and Wheat Research Centre, Malan during the *Kharif* seasons of 2017 and 2018. Agro climatically, the experimental site falls under sub-temperate humid zone of Himachal Pradesh which is characterized by mild summers and cool winters. The experiment was laid out in factorial RBD design with five dates of transplanting (15th June, 25th June, 5th July, 15th July and 25th July) and four varieties of rice (*viz.,* HPR 1068, HPR 2880 and HPR 2143) with three replications. Rice crop was sown with the row spacing of 20 cm as per treatments. The crop was fertilized with 90 kg N, 40 kg P_2O_5 and 40 kg K_2O. Out of which, 1/3 N and full dose of P_2O_5 and K_2O were applied as basal dose at the time of sowing by broadcasting method. The remaining 2/3 dose of N were given in two equal splits at active tillering stage and 3 weeks after first top dressing. Meteorological data viz., rainfall (mm), maximum and minimum relative humidity (%), maximum and minimum temperature (°C), duration of bright sunshine (hours), wind speed (kmh) etc. were recorded from meteorological observatory of Rice and Wheat Research Centre Malan. Following agro-meteorological indices were computed using the daily meteorological data**.**

GDD (°C day) = ∑ (Tmax+ Tmin) /2-10 (base temperature)
PTU (°C day hour) = ∑ (GDD × day length)
HTU (°C day hour) = ∑ (GDD × actual bright sun shine hours)
HUE (g ha^{-1} °C^{-1} day^{-1}) = Biomass (g / m^2)/ GDD (°C day)

Results and Discussion

Yield attributes

The growth and yield attributes were significantly influenced by transplanting window and varieties. The significantly (Table 1) higher grains panicle^{-1} were recorded in crop transplanted on 15th June (128) which was statistically at par with 25th June (123) transplanted crop and were significantly better than other transplanting windows. Among different varieties, the grains panicle^{-1} recorded in variety HPR 2143 (126) were significantly higher than variety HPR 1068 (115) and HPR 2880 (109). Maximum 1000-grain weight (27.3 g) was recorded on 15th June transplanted crop and among varieties HPR 2143 (26.8 g) recorded significantly higher 1000-grain weight. The higher yield and yield attributing parameters under early transplanting may be attributed to availability of optimum environmental conditions for growth and development of crop which might have enhanced accumulation of photosynthates from source towards sink.

Yield

A perusal of data in Table 1 revealed that significantly higher grain yield was recorded by crop transplanted on 15th June (5713 kg ha^{-1}) which was at par with 25th June transplanted crop (5316 kg ha^{-1}) followed by 5th July, 15th July and 25th July, respectively. The highest yield recorded with 15th June transplanted crop was due to significantly higher effective tillers and grains per panicle as well as 1000 grain weight while lowest yield recorded during last date of transplanting (25th July) was due to the lowest value of all these yield attributes which may be result of the least time taken to maturity as compared to other dates of transplanting. Among the varieties, the grain yield of variety HPR 2143 was maximum (5003 kg ha$_{-1}$) followed by HPR 1068 (4682 kg ha$_{-1}$) and HPR 2880 (3994 kg ha$_{-1}$) during both the years. Similarly, 15th June (7548 kg ha^{-1}) transplanted crop produced significantly higher straw yield and 25th July (5073 kg ha^{-1}) recorded lowest straw yield. The per cent decrease in grain yield of 25th July transplanting over 15th June transplanting was about 40 to 45%. This was due to temperature difference of 1-3 °C among the transplanting windows. Gill *et al.*, (2006) [7] reported that there was reduction in grain yield under delayed transplanting due to reduction in favourable growing period because temperature starts falling during end of September/ beginning of October and reproductive phase coincide with low temperature, which affected plant badly, leading to poor grain filling and low yield. Similarly, Oteng *et al.*, (2013) [12] reported that planting date can have a dramatic effect on crop development and yield. These findings were also supported by Soomro et al., (2001) [18] and Sharma *et al.*, (2011) [16] who observed significant reduction in yield and yield contributing characteristics with delay in transplanting.
Among the varieties, the grain yield of variety HPR 2143 was maximum (6940 kg ha^{-1}) followed by HPR 1068 (6643 kg ha^{-1}) and HPR 2880 (5919 kg ha^{-1}) during both the years.

Table 1: Effect of transplanting dates and varieties on yield and yield attributes of rice (Pooled 2017 and 2018)

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Grains panicle^{-1}	1000-grain weight (g)	Harvest index
Date of Transplanting					
15th June	5713	7548	128	27.3	0.430
25th June	5316	7270	123	26.6	0.421
5th July	4764	6768	118	26.1	0.412
15th July	3876	5839	112	25.1	0.399
25th July	3129	5073	105	24.2	0.381
SE m±	116	112	1.7	0.4	0.004
CD (P=0.05)	407	391	8.3	2.1	0.012
Variety					
HPR 1068	4682	6643	115	26.0	0.410
HPR 2880	3994	5919	110	24.8	0.401
HPR 2143	5003	6940	126	26.8	0.415
SE m±	90	86	1.3	0.3	0.003
CD (P=0.05)	261	251	5.3	1.3	0.008

Growing degree days (GDD)

The GDD was calculated from tillering stage to physiological maturity. The GDD decreased with delay in transplanting in all the growth stages. Sowing date strongly influenced the GDD requirement for a particular developmental stage. Perusal of the data confirmed (Table 2) that postponement of transplanting date resulted in reduction of GDD requirement. The cumulative GDD was highest in crop transplanted on 15th

June (1787 °C day), whereas, lowest was on 25th July (1544 °C day). There was a progressive decrease in GDD as the transplanting date was delayed from 15th June to 25th July at the rate of 2 to 13 per cent, respectively. Approximately 621 - 636 degree days were taken by rice cultivars to complete tillering. For maturity accumulated GDD was 1787 °C day in 15th June, 1748 °C day in 25th June, 1687 °C day in 5th June, 1605 in 15th July and 1544°C day in 25th July. The cumulative GDD decreased with delay in transplanting may be due to low temperature in late transplanted crop. Similar results were also obtained by Abhilash *et al.*, (2017) [1]; Brar *et al.*, (2011) [5]; Sharma *et al.*, (2011) [16] reporting that accumulated growing degree days were higher under early transplanted crop.

Helio thermal unit (HTU)

Analysis of the data presented in Table 2, revealed that postponement of transplanting date decreased the HTU consumption. With delay in transplanting HTU decreased at the rate of 1.9 to 6.06 per cent from 15th June to 25th July. These findings match with those of Kaur and Dhaliwal, (2014) [9] who reported that helio thermal units was maximum in crop transplanted on 15th June as compared to on 30th June and 15th July transplanting. Variety HPR 2143 accumulated higher HTU followed by HPR 2880 and HPR 2143. HTU values varied from1725 to 4034 for tillering, 2762 to 4894 for panicle initiation, 4351 to 5881 for 50% flowering and 7461 to 8267 for physiological maturity of the crop (Table 3).

Photo thermal unit (PTU)

Analysis of the data described that with delay in transplanting date resulted in reduction in PTU requirement (Table 2). Likewise, HTU and GDD, PTU were higher in 15th June transplanting crop at all the phenophases, while the lowest PTU were recorded in the crop transplanted on 25th July for all varieties and transplanting environments. The maximum PTU accumulation °C day hour for attaining maturity was 23813 °C day hour in 15th June followed by and 25th June (23034 °C day hour), 5th July (22013 °C day hour) and least in 25th July (19699 °C day hour). Similar results were found by Sandhu *et al.*, (2013) [15], early transplanted rice accumulated more heat units to attain physiological maturity as compared to late transplanted rice. Therefore, the early transplanted rice produced higher grain yield as compared to late transplanted rice. At physiological maturity stage, higher PTU were recorded in variety HPR 2143 (21959 °C day hr) followed by variety HPR 2280 (21880 °C day hr) and HPR 1068 (21754 °C day hr).

Pheno thermal index (PTI)

The pheno thermal index is expressed as growing degree days per growth days. The highest PTI values were observed in crop transplanted on 15th June (Table 3). Like GDD the PTI values decreased when transplanting was delayed. The lowest PTI values were observed in 25th July transplanted crop. Among varieties, highest PTI values were observed for variety HPR 1068 followed by HPR 2143 and HPR 2880.

Heat use efficiency (HUE)

Total heat energy available to any crop is never completely converted into dry matter even under most favourable agro climatic conditions. Heat use efficiency (HUE) determines the ability of a plant to convert per unit available energy into the economic product. The perusal of data presented in Table 3 revealed that among the dates of transplanting, 15th June transplanted crop exhibited maximum HUE of 0.77 g ha^{-1} °C^{-1} day^{-1} followed by 25th June (0.74 g ha^{-1} °C^{-1} day^{-1}), 5th June (0.72 g ha^{-1} °C^{-1} day^{-1}), 15th June (0.64 g ha^{-1} °C^{-1} day^{-1}) and 25th July (0.56 g ha^{-1} °C^{-1} day^{-1}). Higher HUE were recorded in variety HPR 2143 (0.70 g ha^{-1} °C^{-1} day^{-1}) followed by variety HPR 1068 (0.69 g ha^{-1} °C^{-1} day^{-1}) and HPR 2880 (0.67 g ha^{-1} °C^{-1} day^{-1}), respectively.

Table 2: Effect of transplanting dates and varieties on Agro meteorological indices at different growth stages of rice (Pooled data 2017 and 2018)

Treatments	Tillering	Panicle Initiation	50% flowering	Physiological maturity
Growing degree day (°C days)				
Date of Transplanting				
15th June	694	984	1337	1787
25th June	650	929	1311	1748
5th July	621	895	1255	1687
15th July	594	859	1221	1605
25th July	572	838	1192	1544
Variety				
HPR 1068	621	892	1247	1666
HPR 2880	625	907	1268	1672
HPR 2143	636	904	1271	1683
Helio thermal units (°C day hour)				
15th June	4034	4894	5881	8267
25th June	3092	3815	5431	7910
5th July	2449	3176	4756	7723
15th July	1952	2809	4451	7517
25th July	1725	2762	4351	7461
Variety				
HPR 1068	2644	3459	4885	7761
HPR 2880	2634	3493	4997	7790
HPR 2143	2672	3522	5031	7781
Photo thermal units (°C day hour)				
15th June	9711	13768	18133	23813
25th June	9089	12833	17610	23034
5th July	8685	12176	16705	22013
15th July	8180	11535	15753	20709
25th July	7707	11050	15326	19699
Variety				
HPR 1068	8563	12162	16537	21754
HPR 2880	8657	12284	16761	21880
HPR 2143	8802	12372	16804	21959

Table 3: Effect of treatments on phenol thermal index and heat use efficiency (Pooled 2017 and 2018)

Treatment	PTI	HUE (g ha^{-1} °C^{-1} day^{-1})
Date of Transplanting		
15th June	14.5	0.77
25th June	14.2	0.74
5th July	13.9	0.72
15th July	13.3	0.64
25th July	12.9	0.56
Variety		
HPR 1068	14.0	0.69
HPR 2880	13.9	0.67
HPR 2143	13.9	0.70

Conclusion

The crop transplanted on 15th June accumulated higher growing degree days, photo thermal units and helio thermal units for all the growth stages which were considerably reduced with subsequent delay in transplanting window.

Thus, rice crop transplanted on 15th June recorded the significantly higher grain yield which was at par with 25th June transplanted crop. Among the varieties, HPR 2143 acquired maximum thermal units and produced maximum yield followed by HPR 1068 and HPR 2880.

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