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Evaluating the impact of intra-seasonal change in temperature and solar radiation on phenology and yield of rice using CERES-rice model in Punjab

KULDEEP KAUR and PRABHJYOT KAUR

Department of Climate Change and Agricultural Meteorology

Punjab Agricultural University, Ludhiana – 141 004, India

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e mail : prabhksidhu@gmail.com

सार – चावल वैश्विक और भारतीय आबादी का मुख्य भोजन है और इसकी उत्पादकता जलवायु परिवर्तन के प्रति संवेदनशील है। जलवायु परिवर्तनशीलता में प्रेक्षित रुझानों को ध्यान में रखते हुए, तापमान में परिवर्तन (+0.5, +1.0, +1.5, +2.0, +2.5, +3.0 डिग्री सेल्सियस सामान्य से)और सौर विकिरण (+2.5, +5.0, +10.0, +12.5, +15.0, +20.0% सामान्य से) में अंतर और विकास की अवधि के दौरान उनके संयुक्त अन्योन्य क्रियाशील(इंटरैक्टिव) प्रभाव, अर्थात् समूची ऋतु, वनस्पति विकास की अवस्था, अनाज के दाने भरने की अवस्था, 0-30 दिन प्रत्यारोपण के बाद (डीएटी), 30-60 डीएटी, 60-90 डीएटी के जलवायु परिदृश्यों के तहत सीईआरईएस-चावल मॉडल का उपयोग कर के चावल की घटना विज्ञान और उपज का आकलन किया गया। आम तौर पर, तापमान में सामान्य से अधिक होने पर, सीईआरईएस-चावल मॉडल ने चावल की खेती के घटना विज्ञानिक विकास में प्रगति और इसके विपरीत होने का पूर्वानुमान किया है। सामान्य तौर पर,रोपाई की विभिन्न तिथियों के लिए चावल की उपज में वृद्धि तापमान में कमी और विकिरण में वृद्धि होने पर पाई गई और उल्टा होने पर विपरीत पाई गई। तापमान सामान्य से अधिक होने पर,सीईआरईएस-चावल मॉडल ने संपूर्ण ऋतु परिवर्तन के दौरान चावल की उपज में अधिकतम कमी दर्शाई है, इसके बाद चावल के दाने भरने के चरण और पौधे के वृद्धि की अवस्था में घटते क्रम में परिवर्तन हुआ। पौधे के विकास की अवधियों में, उपज में अधिकतम कमी 0-30 डीएटी (प्रारंभिक वनस्पति) पाई गई, उसके बाद 30-60 डीएटी (देर से वनस्पति) और 60-90 डीएटी (अनाज भरने)में घटते क्रम में पाई गई। गर्मी और विकिरण प्रतिबल की स्थितियों में, अनाज के दाने भरने का चरण और प्रारंभिक वनस्पति विकास चरण अधिक सुभेद्य था। CERES-चावल मॉडल के पूर्वानुमानों से पता चला है कि चावल cv. PR-118 (लंबी अवधि की खेती) की किस्म cv.PR-115 (छोटी अवधि की खेती) की तुलना में गर्मी और विकिरण प्रतिबल के प्रति अधिक सहनशील थी। इसलिए अनाजकी अच्छीउपज और फसल सूचकांक को बनाए रखने के प्रति सहनशील गुणों के कारण इसकी खेती की सिफारिश की जा सकती है।

ABSTRACT. Rice is a staple food of global as well as Indian population and its productivity is vulnerable to climate change. Keeping in view the observed trends in climate variability, phenology and yield of rice were simulated using CERES-Rice model under climatic scenarios of changes in temperature (+0.5, +1.0, +1.5, +2.0, +2.5, +3.0 °C from normal) and solar radiation (+2.5, +5.0, +10.0, +12.5, +15.0, +20.0% from normal) and their combined interactive effects during differential growth periods, *i.e.*, whole season, vegetative phase, grain filling phase, 0-30 days after transplanting (DAT), 30-60 DAT, 60-90 DAT. In general, with a rise in temperature from normal, the CERES-Rice model predicted advancement in phenological development in rice and *vice versa*. In general, the increase in yield of rice cultivars for different transplanting dates was observed with decrease in temperature and increase in radiation and *vice-versa*. With rise in temperature from normal, CERES-Rice model showed maximum decrease in grain yield of rice during whole season change followed by grain filling phase change and vegetative phase change in decreasing order. Among the growth periods, maximum decrease in yield was observed in 0-30 DAT (early vegetative) followed by 30-60 DAT (late vegetative) and 60-90 DAT (grain filling) in decreasing order. Under the conditions of heat and radiative stress, grain filling phase and early vegetative phase was more vulnerable. The CERES-Rice model predictions showed that rice cv. PR-118 (long duration cultivar) was more tolerant to heat and radiative stress than cv. PR-115 (short duration cultivar) and hence may be recommended for cultivation due to its tolerant traits towards maintaining its good grain yield and harvest index.

Key words – CERES-Rice model, Growth periods, Phenology, Solar radiation, Temperature, Yield.

1. Introduction

Climate change induced global warming indicate that the mean global temperature has increased by about 0.85 °C from 1880 to 2012 (IPCC, 2013). Specifically, the last three decades have been the warmest on record. The increase in annual temperature in 2030's as compared to present, *i.e.*, 1961-1990 (referred as 1970's) lies between 1.7 and 2.2 °C, with maximum temperature increasing by 1-4 °C. Extremes in the minimum and maximum temperature range are expected to increase into the future, but night temperatures are increasing more rapidly than the day temperatures (NAPCC, 2008). This will result into the increased respiration rates and there by reduced yield of many field crops. Complex and extreme events such as aridity, drought, heat wave flood, cyclones and stormy rainfall are expected to leave much greater impacts on the human society than the gradual changes in the climate.

In Punjab the maximum and minimum temperature are projected to increase from the baseline (1960-90) by 2.9 and 4.9 °C, respectively during mid century (2021-50) and by 5.8 and 7.4 °C, respectively during end century (2071-2100) under A1B scenario (Kaur and Kaur, 2016). The most challenging task is to reduce the global food security threat caused by climate change in the 21st century while maintaining the sustainability in agriculture. A number of crop simulation models have been widely used to evaluate the possible impacts of climate variability on crop production and especially to analyze crop yield-climate sensitivity under different climate scenarios.

Crop phenology is highly dependent on high temperature stress. Several workers have reported that high temperature during flowering stage induces spikelet sterility which might be due to anther indehiscence in *kharif* crops. whereas, high temperature during reproductive stage reduces pollen viability, fertilization, seed set and grain filling in *rabi* crops (Kour *et al.*, 2013; Saxena and Kumar, 2014; Dubey *et al.*, 2014; Rao *et al.*, 2015; Zacharias *et at.*, 2014; Mishra *et al*., 2015). Tao *et al.* (2008) reported that duration of rice crop was reduced under elevated temperature. The high temperature stress limits the photosynthetic production capability of rice, which generally originate from the higher reducing rate of leaf photosynthetic velocity under high temperature stress (Yao *et al.*, 2007; Venkatramanan and Singh, 2009). The simulation study conducted by Kaur and Hundal (2010) using the CERES-Rice model revealed that an increase in temperature by 2 °C from normal led to decrease in leaf area index, biomass and grain yield of rice by 12.3, 7.3 and 7.5%, respectively from normal.

Sunshine hour is an important factor in rice growth as bright sunny weather during flowering is necessary for obtaining high grain yield in rice (Karuna and Dhaliwal, 2020). Sattar *et al*. (2017) have reported that bright sunshine hours up to 7 to 8 hours were necessary for the growth of rice. Mahajan *et al.* (2009) had also reported that low radiation during the flowering phase led to spikelet sterility and hence decreased grain yield. Kaur *et al.* (2021) reported that in Punjab state a combination of high temperature coupled with clear sunny (total seasonal sunshine ~ 900-1000 h) and dry (low relative humidity) days are needed for proper growth, development and yield of rice.

Changes in climatic conditions are inevitable and signatures are clearly visible. Since simulation techniques are simple, time saving and economical for studying the influence of changes in temperature and solar radiation under differential growth periods of rice. So, CERES-Rice model was used in evaluating the changes in phenology and yield of rice cultivars under variable levels of changes in temperature and solar radiation.

2. Materials and method

2.1. *Crop model used*

In the present study CERES-Rice model was first calibrated for its eight genetic coefficients for rice cultivars, *i.e*., PR-115 and PR-118 using the actual field data for the crop year 2012 (Table 1) and later validated using data for crop years 2013 and 2014. The statistical comparison of the observed and simulated results of the phenological events and yield of rice cultivars sown under three dates of transplanting for two crop years are given in Table 2.

2.2. *Scenarios of temperature and solar radiation*

The CERES-Rice model was used to study the effect of changes in intra-seasonal temperature by (±0.5, ±1.0, ±1.5, ±2.0, ±2.5, ±3.0 °C from normal) and solar radiation (±2.5, ±5.0, ±10.0, ±12.5, ±15.0, ±20.0% from normal) for two cultivars of rice, *i.e*., PR-115 (short duration) and PR-118 (long duration) under three dates of transplanting, *i.e*., 15, 22 and 29 June. The temperature and solar radiation were increased as well as decreased during whole season, vegetative phase, grain filling phase, 0-30 days after transplanting (DAT), 30-60 DAT and 60-90 DAT. In this study one variable at any given time was modified and its effect on phenology and yield of rice was examined, while all other climatic variables to be normal. The major reason for using incremental variables scenarios is that they capture a wide range of potential changes. Subsequently the combination of two variables was interactively modified to assess their combination effect on growth and yield of crop.

TABLE 1

Genetic coefficients of rice cultivars used in the CERES-Rice model (Kaur, 2018)

Cultivar	P1 (°C d)	P2R (°C d)	P5 (°C d)	P20 (hours)	G1	G2 (g)	G3	G4
PR 115	690	160	450	12.0	65.0	0.0254	1.03	1.00
PR 118	880	285	585	12.8	50.0	0.0253	1.00	1.00

TABLE 2

Statistics of observed and simulated phenology and yield of rice using pooled data of *kharif* 2013 and 2014 (Kaur, 2018)

Variable	Mean			Std. Dev.		r-Square	Mean Diff.	Mean Abs. Diff.	RMSE	d-Stat.	Used Obs.	Total Obs.
	Observed	Simulated	Ratio	Observed	Simulated							
Anthesis days	96	95	1.00	10.12	8.28	0.75	0	4	5.11	0.92	12	12
Maturity days	131	128	0.97	7.63	12.17	0.67	-3	5	8.11	0.83	12	12
Grain Yield kg/ha	5752	5650	0.98	428.2	386.21	0.65	-102	216	277.10	0.88	12	12

TABLE 3

Deviation (days) in phenological stages of rice cultivars under different transplanting dates with intra-seasonal change in temperature (°C) using CERES-Rice model

Transplanting date/Cultivar	Normal	Whole season		Vegetative phase		Grain filling phase		0-30 DAT		30-60 DAT		60-90 DAT	
		-1 to -3 °C	+1 to +3 °C	-1 to -3 °C	+1 to +3 °C	-1 to -3 °C	+1 to +3 °C	-1 to -3 °C	+1 to +3 °C	-1 to -3 °C	+1 to +3 °C	-1 to -3 °C	+1 to +3 °C
Anthesis stage													
D_1:15 June													
PR 115	85	+2 to +6	-1 to -4	+1 to +5	-1 to -4	+1 to +3	-1 to -3	+1 to 0	-1 to -2	+1 to +3	-1 to 0	+1 to +2	-1 to -3
PR 118	103	+1 to +8	-1 to -3	+1 to +4	-1 to -3	+1 to +3	-1 to -2	+1 to 0	-1 to 0	+1 to +3	-1 to -2	+1 to 0	-1 to -2
D_2:22 June													
PR 115	84	+2 to +6	-1 to -4	+1 to +3	-1 to -5	+1 to +3	-1 to -3	+1 to 0	-1 to -2	+2 to +3	-1 to -3	+1 to +2	-1 to -2
PR 118	100	+2 to +10	-1 to -5	+1 to +4	-1 to -2	+2 to +4	-1 to -2	+1 to 0	-1 to -2	+1 to +4	-1 to -2	+1 to +2	-1 to -3
D_3:29 June													
PR 115	83	+2 to +6	-1 to -4	+1 to +3	-1 to -4	+1 to +3	-1 to -3	+1 to 0	-1 to -2	+1 to +3	-1 to -2	+1 to +2	-1 to -2
PR 118	100	+1 to +8	-2 to -3	+1 to +3	-2 to -3	+2 to +5	-1 to -3	+1 to +2	-1 to -2	+1 to +2	-1 to -2	+1 to +3	-1 to -2
Physiological maturity stage													
D_1:15 June													
PR 115	113	+3 to +9	-1 to -4	+1 to +6	-1 to -4	+1 to +5	-1 to 0	+2 to 0	-1 to -2	+1 to +4	-1 to -2	+1 to +3	-1 to -2
PR 118	140	+2 to +12	-1 to -3	+1 to +3	-1 to -3	+2 to +8	-1 to -4	+1 to +2	-1 to 0	+1 to +2	-1 to -2	+1 to +4	-1 to -3
D_2:22 June													
PR 115	113	+2 to +9	-1 to -3	+1 to +4	-1 to -6	+2 to +6	-1 to -2	+1 to 0	-1 to 0	+2 to +4	-1 to 0	+1 to +4	-1 to 0
PR 118	137	+3 to +13	-1 to -6	+1 to +4	-1 to -2	+2 to +8	-2 to -4	+1 to 0	-1 to 0	+1 to +4	-1 to 0	+1 to +4	-1 to -2
D_3:29 June													
PR 115	113	+3 to +10	-1 to -3	+1 to +3	-1 to -2	+1 to +6	-1 to -3	+1 to 0	-1 to -2	+2 to +4	-1 to 0	+1 to +4	-1 to -2
PR 118	136	+4 to +15	-2 to -4	+1 to +4	-1 to 0	+3 to +11	-1 to -4	+1 to 0	-1 to 0	+1 to +3	-1 to -2	+1 to +6	-1 to -2

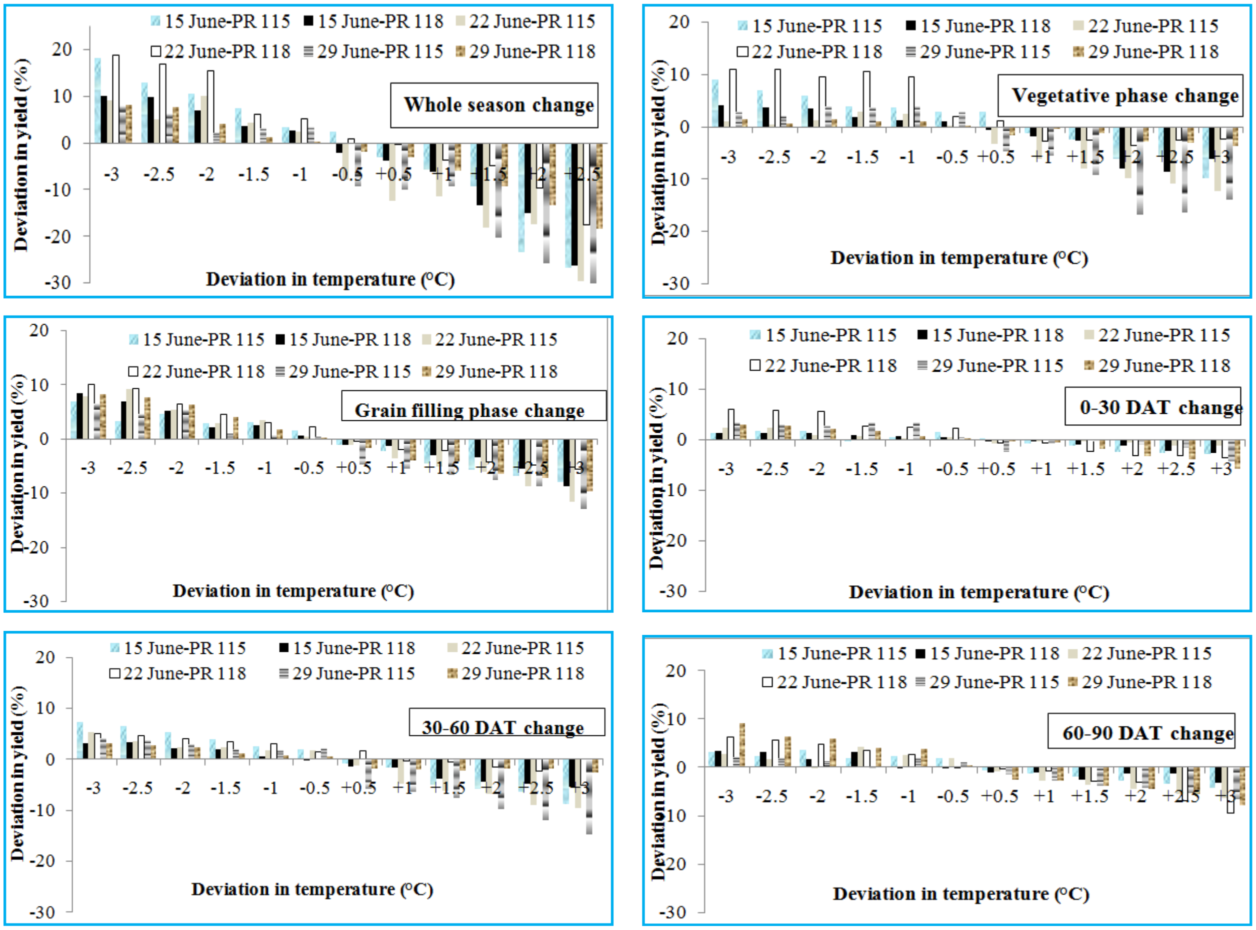

Fig. 1. Effect of intra-seasonal change in temperature from normal on rice yield using CERES-Rice model

3. Results and discussion

3.1. *Effect of temperature change on rice*

3.1.1. *Phenology*

With the imposition of increase/decrease in temperature the CERES-Rice model predicted advancement/delay in phenology (Table 3). The model predicted that under elevated temperature environment the phenology of rice cultivars was advanced maximum - in whole season exposure followed by vegetative phase and grain filling phase. On the other way, order of decrease followed was 60-90 DAT, 30-60 DAT and 0-30 DAT. Under cool temperature environment, the physiological maturity of rice cultivars was delayed maximum for the whole season exposure followed by exposure during grain filling phase, vegetative phase, 30-60 DAT, 60-90 DAT and 0-30 DAT in decreasing order. Hence with increase or decrease in temperature during whole season, the growth duration is highly vulnerable and the early transplantation period (0-30 DAT) is least vulnerable. These results are in agreement with the previous findings of Kaur and Hundal (2007) wherein the CERES-Rice model responded to change in temperature by advancing / delaying the anthesis and physiological maturity. The results of the control environment experiments on rice conducted by Rani and Maragatham (2013) also showed that the days taken to attain maturity were reduced under elevated temperature of 4 °C (96 days) and 2 °C (102 days) when compared to the ambient temperature (108 days). Kaur and Kaur (2014) also reported a reduction in growth duration of rice cultivars under elevated temperature conditions within a temperature gradient tunnel. Several workers (Venkataraman, 2004 and Srivani *et al.*, 2007) reported that with increase in temperature the requirement of growing degree days is met in shorter period which results in reduction in crop duration.

3.1.2. *Yield*

With the imposition of increase/decrease in temperature the CERES-Rice model predicted that the cv

TABLE 4

Deviation (days) in phenological stages of rice cultivars under different transplanting dates with intra-seasonal change in solar radiation (%) using CERES-Rice model

Transplanting date/Cultivar	Normal	Whole season		Vegetative phase		Grain filling phase		0-30 DAT		30-60 DAT		60-90 DAT	
		-2.5 to -20%	+2.5 to +20%	-2.5 to -20%	+2.5 to +20%	-2.5 to -20%	+2.5 to +20%	-2.5 to -20%	+2.5to +20%	-2.5 to -20%	+2.5 to +20%	-2.5 to -20%	+2.5 to +20%
Anthesis stage													
D_1:15 June													
PR 115	85	-	-1 to 0	-	-1 to 0	-	-	+1 to 0	-1 to 0	-	-	-	-
PR 118	103	+1 to 0	-1 to 0	-	-1 to 0	-	-	-	-	-	-	-	-
D_2:22 June													
PR 115	84	-	-1 to 0	-	-	-	-	+1 to 0	-	-	-	-	-
PR 118	100	+1 to 0	-1 to 0	-	-1 to 0	-	-	+1 to 0	-1 to 0	-	-	-	-
D_3:29 June													
PR 115	83	+1 to 0	-1 to 0	-	-1 to 0	-	-	-	-	-	-	-	-
PR 118	100	-	-	-	-	-	-	-	-	-	-	-	-
Physiological maturity stage													
D_1:15 June													
PR 115	113	+1 to 0	-1 to 0	+1 to 0	-1 to -2	+1 to 0	-1 to 0	-	-	-	-	-	-1 to 0
PR 118	140	+1 to +2	-1 to 0	+1 to +2	-1 to -2	+1 to 0	-1 to 0	-	-	-	-	-	-1 to 0
D_2:22 June													
PR 115	113	-	-1 to 0	+1 to 0	-1 to 0	+1 to 0	-1 to 0	-	-	-	-	-	-1 to 0
PR 118	137	-	-1 to 0	-	-1 to 0	+1 to 0	-1 to 0	-	-	-	-	-	-
D_3:29 June													
PR 115	113	-	-1 to 0	+1 to 0	-1 to 0	+1 to 0	-1 to 0	-	-	-	-	-	-1 to 0
PR 118	136	-	-	-	-1 to 0	+1 to 0	-1 to 0	-	-	-	-	-	-

PR-118 (long duration) was more tolerant to heat stress than cv. PR-115 (short duration) (Fig. 1). Amongst the three transplantation dates, CERES-Rice model predictions revealed that with the imposition of heat stress, maximum reduction in yield of rice occurred under 29 June transplanting followed by 22 June and 15 June. The CERES-Rice model predicted that under temperature stress environment, maximum reduction in grain yield of rice was observed in whole season exposure followed by grain filling phase, vegetative phase, 30-60 DAT, 60-90 DAT and 0-30 DAT in decreasing order. On the other hand, under cool temperature environment, maximum increase in grain yield of rice observed in whole season followed by grain filling phase, vegetative phase, 30-60 DAT, 60-90 DAT and 0-30 DAT in decreasing order. Hence the grain filling phase and 30-60 DAT (*i.e.*, flowering phase) in rice are most responsive to increase as well as decrease in temperature.

Yadav *et al.* (2015) reported that when maximum and minimum temperatures were changed by ±3.0 °C from normal, rice productivity with increasing / decreasing temperature was decreased / increased upto 5 / 13.1% from normal. Rani and Maragatham (2013) in control condition experiments found that under elevated temperature of 4 °C and 2 °C, the grain yield was reduced by 23 and 13.3%, respectively from the ambient which may be attributed to the increase in sterile florets and lesser crop growth duration.

3.2. *Effect of solar radiation change on rice*

3.2.1. *Phenology*

With the imposition of increase and decrease in solar radiation from normal, the CERES-Rice model predicted no significant effect on anthesis stage of rice crop

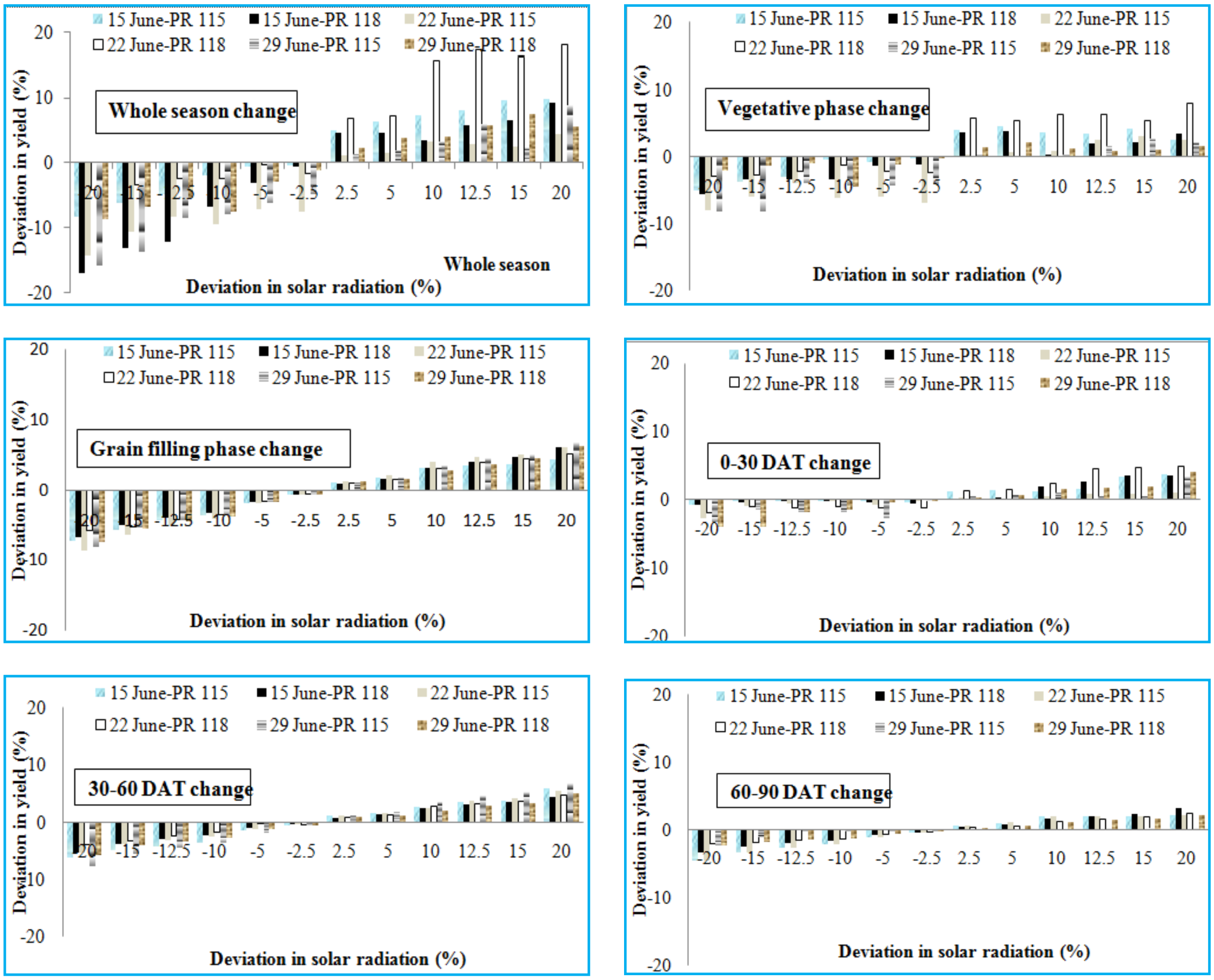

Fig. 2. Effect of intra-seasonal change in solar radiation from normal on rice yield using CERES-Rice model

(Table 4). But with the imposition of radiation enrichment environment from normal during different growth periods, maximum advancement in physiological maturity of rice cultivars was observed more for whole season followed by vegetative phase, grain filling phase, 60-90 DAT, 30-60 DAT and 0-30 DAT in decreasing order. With the imposition of radiative stress during different growth periods, the response of rice cultivars in attaining physiological maturity, maximum delay was observed for grain filling phase followed by whole season, vegetative phase, 0-30 DAT, 60-90 DAT and 30-60 DAT in decreasing order. The earlier study by Kaur and Hundal (2007) also showed that increase in solar radiation favoured growth and yield of rice and *vice versa*.

3.2.2. *Yield*

With the imposition of increase / decrease in solar radiation the CERES-Rice model predicted that the cv. PR-118 (long duration) was more tolerant to heat as well as radiative stress than cv. PR-115 (short duration) (Fig. 2). Amongst the three transplantation dates, CERES-Rice model predictions revealed that with the imposition of radiative stress, maximum reduction in yield of rice occurred under 29 June transplanting followed by 22 June and 15 June. But under radiative enrichment environments, that maximum increase in yield of rice occurred under 22 June transplanting followed by 29 June and 15 June, so 22 June is more suitable for rice transplantation. The CERES-Rice model predicted that under radiative enrichment environment maximum increase in grain yield of rice was observed in whole season followed by grain filling phase, vegetative phase, 30-60 DAT, 0-30 DAT and 60-90 DAT in decreasing order. On the other hand, under radiative stress environment, maximum decrease in grain yield of rice observed in grain filling phase followed by whole season, vegetative phase, 30-60 DAT, 60-90 DAT and 0-30 DAT

TABLE 5

Deviation (days) in phenological stages of rice cultivars under different transplanting dates with intra-seasonal change in temperature (°C) and solar radiation (%) using CERES-Rice model

Transplanting date/Cultivar	Normal	Whole season		Vegetative phase		Grain filling phase		0-30 DAT		30-60 DAT		60-90 DAT	
		-1°C/-5% to - 3°C/-20%	+1°C/+5% to +3°C/+20%	-1°C/-5% to -3°C/-20%	+1°C/+5% to +3°C/+20%	-1°C/-5% to -3°C/-20%	+1°C/+5% to +3°C/+20%	-1°C/-5% to -3°C/-20%	+1°C/+5% to +3°C/+20%	-1°C/-5% to -3°C/-20%	+1°C/+5% to +3°C/+20%	-1°C/-5% to -3°C/-20%	+1°C/+5% to +3°C/+20%
Anthesis stage													
D_1:15 June													
PR 115	85	+2 to +6	-1 to -6	+3 to +5	-1 to -5	+1 to +2	-1 to 0	+1 to 0	-1 to -2	+1 to +3	-1 to 0	+1 to 0	-1 to 0
PR 118	103	+1 to +8	-1 to -4	+2 to +4	-1 to -3	+1 to +3	-1 to 0	+1 to 0	-1 to 0	+1 to +3	-1 to -2	+1 to 0	-
D_2:22 June													
PR 115	84	+2 to +6	-1 to -8	+2 to +3	-1 to -5	+1 to 0	-1 to 0	+1 to 0	-1 to -2	+1 to +3	-1 to 0	+1 to 0	-1 to 0
PR 118	100	+2 to +10	-1 to -5	+1 to +4	-1 to -4	+1 to +4	-1 to 0	+1 to +2	-2 to -3	+1 to +4	-1 to -2	+1 to 0	-
D_3:29 June													
PR 115	83	+2 to +6	-1 to -4	+1 to +3	-1 to -5	+1 to +2	-1 to 0	+1 to +3	-1 to 0	+1 to +2	-1 to 0	+1 to 0	-
PR 118	100	+3 to +8	-1 to -3	+1 to +3	-1 to -2	+1 to +5	-1 to -2	+1 to 0	-1 to -2	+1 to +3	-1 to 0	+1 to 0	-1 to 0
Physiological maturity stage													
D_1:15 June													
PR 115	113	+3 to +12	-1 to -5	+1 to +6	-1 to -6	+1 to +5	-1 to 0	+2 to 0	-2 to -3	+1 to +4	-1 to -2	+1 to +3	-1 to -2
PR 118	140	+2 to +14	-1 to -3	+1 to +3	-1 to -3	+2 to +8	-2 to -4	+1 to +2	-1 to -2	+1 to +2	-1 to -3	+1 to +4	-1 to -3
D2:22 June													
PR 115	113	+2 to +11	-1 to -8	+1 to +4	-1 to -5	+2 to +6	-1 to -2	+1 to +2	-1 to -2	+1 to +4	-1 to 0	+1 to +3	-1 to 0
PR 118	137	+3 to +18	-2 to -4	+1 to +4	-1 to -6	+2 to +8	-2 to -4	+1 to +2	-1 to -2	+1 to +4	-1 to -2	+1 to +4	-1 to -3
D3:29 June													
PR 115	113	+2 to +11	-1 to -2	+1 to +3	-2 to -5	+1 to +6	-1 to -3	+1 to +3	-1 to -2	+1 to +3	-1 to 0	+1 to +3	-1 to -2
PR 118	136	+4 to +20	-1 to -3	+1 to +4	-1 to -3	+3 to +11	-1 to -4	+1 to +2	-1 to -2	+1 to +4	-1 to -2	+1 to +6	-1 to -3

in decreasing order. Similar results on effect of solar radiation on rice (Kaur and Hundal, 2007; Yadav *et al.*, 2015; Mishra *et al.*, 2015) showed that rice productivity increased with an increase in radiation level above the normal value and *vice versa*.

3.3. *Interactive effect of temperature and solar radiation change on rice*

3.3.1. *Phenology*

With the imposition of increase / decrease in temperature and solar radiation the CERES-Rice model predicted advancement/delay in anthesis and physiological maturity (Table 5). The CERES-Rice model should not have predicted change in anthesis when temperature and solar radiation was increased as well as decreased during 60-90 DAT as the anthesis in rice cultivars would have occurred before the stress period. The CERES-Rice model predicted that under temperature stress and radiative enrichment environment maximum advancement in physiological maturity of rice was observed more for vegetative phase followed by whole season, 30-60 DAT, 60-90 DAT, grain filling phase and 0-30 DAT in decreasing order. On the other hand, under cool temperature and radiative stress environment, maximum delay in physiological maturity of rice was observed for whole season followed by grain filling phase, vegetative phase, 30-60 DAT, 60-90 DAT and 0-30 DAT in decreasing order. The CERES-Rice model responded to increase in temperature and solar radiation by advancing the anthesis and decrease in temperature and solar radiation by delaying the anthesis stage. These results are in concurrence with the earlier findings of Kaur and Hundal (2010).

3.3.2. *Yield*

With the imposition of increase/decrease in temperature and solar radiation the CERES-Rice model

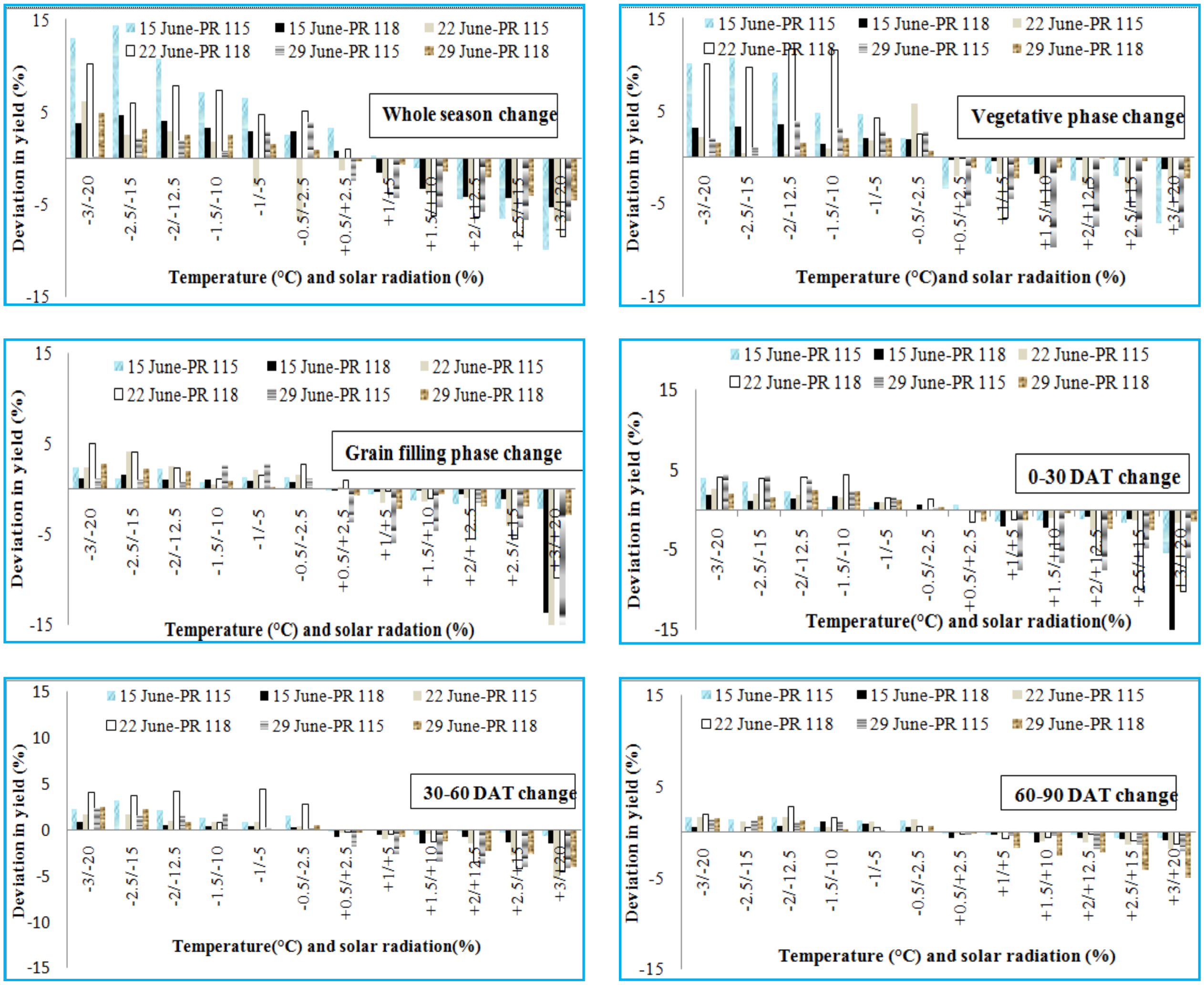

Fig. 3. Interactive effect of intra-seasonal change in temperature and solar radiation from normal on rice yield using CERES-Rice model

predicted that the cv. PR-118 (long duration) was more tolerant to heat as well as radiative stress than cv. PR-115 (short duration) (Fig. 3). Amongst the three transplantation dates, CERES-Rice model predictions revealed that with the imposition of heat stress, maximum reduction in yield of rice occurred under 22 June transplanting followed by 29 June and 15 June. But under radiative stress environments, 22 June is more suitable for rice transplantation. The CERES-Rice model predicted that under temperature stress and radiative enrichment environment maximum reduction in grain yield of rice was observed in whole season followed by grain filling phase, vegetative phase, 0-30 DAT, 30-60 DAT and 60-90 DAT in decreasing order. On the other hand, under cool temperature and radiative stress environment, maximum increase in grain yield of rice observed in whole season followed by vegetative phase, grain filling phase, 0-30 DAT, 30-60 DAT and 60-90 DAT and in decreasing order. The CERES-Rice model responded to increase in temperature and solar radiation by decrease in the grain yield and *vice versa*. These results are in concurrence with the findings of Amgain *et al.* (2006) that by increasing both maximum and minimum temperature by 4 °C along with an increase in solar radiation by 1MJ/m^2/day, the yield of rice was decreased by 32%.

4. Conclusions

Temperature has a profound effect on inception and completion of a phenological stage and yield. The results of the simulations studies indicate that under temperature stress the phenological stages were advanced and under cool environment conditions the phenological stages were delayed from the ambient temperature conditions. Among the two cultivars of rice the susceptibility of the cultivar to high temperature stress was maximum in cv. PR-115 (short duration) as compare to PR-118 (long duration). Under temperature stress conditions grain yield was decreased and *vice versa*. A specific minimum number of heat units are required by a crop for completion of any phenological stage. The yield of rice cultivars, in general, under different transplanting dates was decreased with increase in temperature and decrease in radiation and vice-versa. Under the anticipated change in temperature and solar radiation the simulation results showed that cv. PR-118 may be recommended for cultivation due to its tolerant traits towards maintaining its yield as well as harvest index which are the most important determinants of high productivity of a cultivar.

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