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SIMULATION OF YIELD AND ITS COMPONENT TRAITS OF RICE (*ORYZA SATIVA* L.) VARIETIES GROWN IN INDO-GANGETIC PLAINS OF BIHAR UNDER PROJECTED CLIMATE CHANGE

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SUMMARY

A study was planned to analyse the impact of climate change on growth and yield of three rice varieties differing in duration viz. Saket 4 (short duration variety), Sita (medium duration variety) and Radha (long duration variety) using simulation model INFOCROP. Crop growth and physiological parameters were recorded and used for simulation and validation in INFOCROP model. Crop growth and yield data were simulated for Pusa, Bihar, alongwith weather data from 1997 to 2005 and used for projecting the performance of rice varieties for future scenario of 2020, 2050 and 2080 with respect to A2 climate change scenario. The reproductive development of rice delayed by elevated CO_2. Higher CGR and LAI were recorded in short and medium duration variety under future climate change scenario as compared to the present conditions. The yield trend was similar in the varieties up to 2050 and the maximum being at 2050 and declined thereafter in 2080. In long duration variety (Radha), maximum yield was projected at 2020. It was observed that shorter duration variety (SDV) perform better than medium / longer duration varieties under scenarios for 2020, 2050 and 2080. The results suggest that SDVs can be better proposition under future climate change scenarios for growing in Indo-gangetic plains of Bihar.

Key words: **Climate change, future scenarios, growth and yield, rice physiology**

INTRODUCTION

The atmospheric CO_2 concentration is projected to double the end of this century (IPCC 2007), due to human activities. Increasing green house gases and rise in mean temperature levels will lead to global warming and change in climate which would have a direct bearing on production of food crops like rice. Rice is the most important cereal crop and more than half of the world's population depends on it as their staple food. Since most of the rice produced is consumed at the place of production and very little is left for trade compared to other cereals (FAO 2005), a slight gap between rice demand and supply could lead to critical food insecurity. Further, the demand for rice will be acute from the ever-limited land as the world population is projected to reach 9.1 billion by 2050 (UN 2009). Thus, it is essential to produce rice more efficiently under future elevated CO_2 scenarios. It has generally been observed that the biomass production of early-maturing cultivars during a full growing season is smaller than that of late-maturing cultivars resulting from a lower use of energy and resources namely solar radiation, temperature, and CO_2 (Shimono *et al.* 2009). The increase in CO_2 concentration in the atmosphere is reported to enhance the growth and yield of C_3 crops such as rice (Allen

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1990). However, increased crop growth and yield due to CO_2 fertilization (Ainsworth *et al.* 2006) was observed to be negated by increase in temperature (Bachelet *et al.* 1993, Mathews *et al.* 1997), which ultimately leads to forced maturity of the crop (Yadav *et al.* 1987, Mathauda *et al.* 2000).

Pathak *et al.* (2003) reported about the trends of climatic potential and on-farm yields of rice and wheat in the indo-gangetic plains and suggested that increase in minimum temperature were the reason for declining yield potential. Aggarwal *et al* (2010) projected that by 2080 rice yield will decline by 23% in A2 scenario in the upper ganga region comprising of south west Uttarkhand and north west Uttar Pradesh. Mathews *et al.* (1997) have simulated the impact of climate change on rice in Asia using two rice crop simulation modes viz. ORYZA1 and SIMRIW. They suggested using shorter maturing varieties to allow a second crop to offset the potential decline in crop yield in higher latitude areas. However, Shimono *et al.* (2009) has suggested that growth enhancement before flowering is a useful criterion for selecting rice varieties capable of adapting to elevated CO_2 irrespective of the crop duration.

The indo-gangetic plain of Bihar is a low productivity area of rice owing to abiotic stresses like water logging as well as drought. These problems could be aggravated in future scenarios where increase in frequency of floods and drought are predicted in general (Haris *et al.* 2010, Subash *et al.* 2011). Hence this study was taken up to analyze the impact of climate change on crop growth and yield parameters of promised rice varieties differing in maturity duration using simulation model INFOCROP.

MATERIALS AND METHODS

Three rice varieties differing in maturity were grown at experimental farm of ICAR RCER, Patna, India. Saket 4 was a short duration variety (SDV) with maturity of 110 days, Sita was a medium duration variety (MDV) with maturity of 130 days, and Radha was a long duration variety (LDV) with maturity of 150 days. The varieties were grown under field condition following standard practices and with recommended dose of fertilizer during *kharif* 2007 and 2008 season. Crop growth and physiological parameters were recorded as per standard procedures and statistical analysis was done following Gomez and Gomez (1984). Crop specific genetic coefficients obtained from these experiments were utilized to calibrate and validate the INFOCROP model for rice yields. Thereafter the model was run for observed weather of 1997-2005 and the simulation results of crop growth and yield data were taken into consideration and used for projecting the performance of varieties according to the present (as indicated by observed in tables and figures) and predicted future scenarios of 2020, 2050 and 2080. Statistical analysis was done using the simulated data of individual years as random replication points.

The IPCC's Special Report on Emission Scenario (SRES) based on the third assessment report, which describes future scenarios predicting greenhouse gas emissions, was used in the current study. Among various scenarios, A2 scenario was selected for the current study, which is a high emission scenario and describes a very heterogeneous world with a focus on self-reliance and preservation of local identities. CO_2 concentration for SRES A2 scenario increases from the current levels of 384 ppm to 414 ppm, 522 ppm and 682 ppm for 2020, 2050 and 2080, respectively. General Circulation Models (GCM) predictions of Hadley Center Coupled Model ver.3 (HADCM3) were used to generate the future scenarios of 2020, 2050 and 2080. Maximum and minimum temperature during rice growing season under different scenarios are shown in Fig. 1.

First of all the GCM predictions were incorporated into the observed weather for generating the scenarios of 2020, 2050 and 2080, after which the varietal parameters were calculated for use in INFOCROP model. Initial values for coefficients was first supplied for running the model according to cultivar characteristics, then minor adjustments were made to calibrate the model thus reducing the difference between simulated and observed parameters, mainly maturity duration and grain yield. The most matching values were worked out to validate the model output (Table 1). After calibrating and validating the model, it was run for Pusa, Bihar with the same agronomic practices and cultivars as used for validation purpose. The simulation runs were done and the morpho-physiological parameters such as

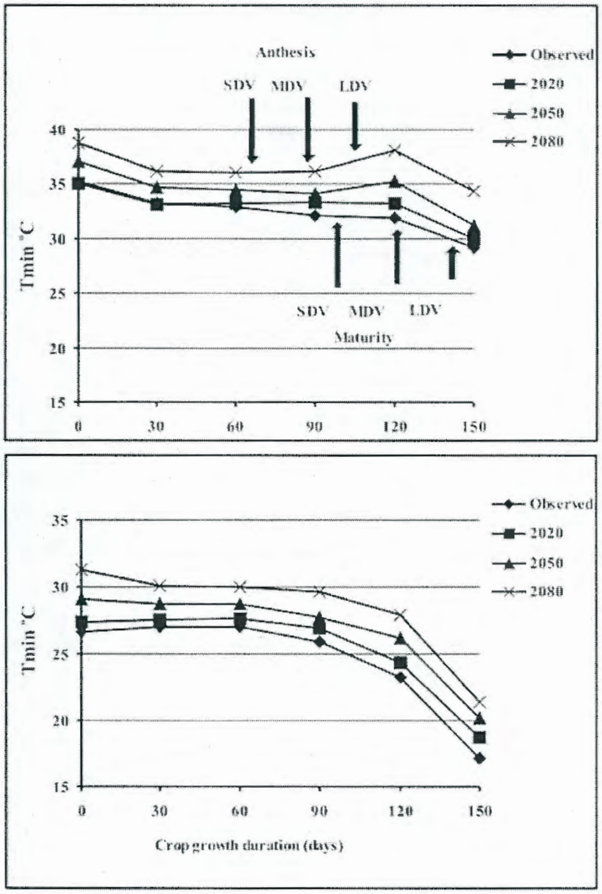

Fig. 1. Maximum temperature (Tmax) and minimum temperature (Tmin) during growth of SDV, MDV, LDV of rice under projected time periods (anthesis and maturity period are indicated).

Table 1. Validation of INFOCROP Model for rice crop

Variety	Coefficient of efficiency	RMSE (Root mean square error) kg/ha	MAE (Mean abs-olute error) kg/ha
SDV (Saket 4)	71%	234.15	197.00
MDV (Sita)	74%	78.95	65.67
LDV (Radha)	82%	93.31	64.33

leaf area, crop growth rate, total dry matter, grain yield, grain number and crop duration were generated and these results were compared to analyze impact of climate change on rice growth and yield at Pusa falling in Indo-Gangetic Plains of Bihar.

RESULTS AND DISCUSSION

In the short duration rice variety – Saket 4, the simulated Leaf Area Index (LAI) and Crop Growth Rate (CGR) decreased at 2020 in comparison to the observed values (Fig. 2) but increased thereafter at 2050 and 2080. LAI showed positive correlation with CGR (r^2= 0.94). The change in Total Dry Matter (TDM) and yield were non-significant at 2020 when compared to observed weather. However both the traits increased at 2050 but thereafter, at 2080, only TDM increased but grain yield declined. The decline in yield may be due to less number of filled grains in 2080 when compared to 2050 (Table 2). Lesser filled grain at 2080 may be due to spikelet sterility induced by higher ambient temperature prevalent during crop growing season. The harvest index (HI) was almost 50% up to 2050 but declined drastically at 2080 reaching 30.98%.

The trend of simulated LAI and CGR in medium duration variety (Sita) was found to be similar to that of SDV (Fig. 2). Both of these traits decreased at 2020 (but CGR increased thereafter at 2050 and 2080) as compared to the 2007 and 2008. However, the traits showed least correlation with each other (r^2=0.04). TDM and yield increased at 2050 but thereafter at 2080 only TDM increased but yield declined. This may be due to lesser number of filled grains in 2080 similar to SDV (Saket 4). HI declined progressively from 2020 to 2080 reaching 21.71%.

In case of LDV Radha, the simulated LAI and CGR increased at 2020 but decreased thereafter at 2050 and 2080 (Fig. 2). LAI showed positive correlation with CGR (r^2= 0.84). TDM increased progressively at 2020, 2050 and 2080 scenarios when compared to values for observed weather. However, yield increased slightly at 2020 and declined thereafter at 2050 and 2080. There was positive correlation between yield and filled grain. HI declined progressively for 2020 followed by more decline in 2050 and further decline in 2080 reaching 33.02%.

In SDV, LAI was found to be more in 2050 and 2080, when compared to simulated values under 2020 time period and observed weather (Fig. 3). Peak of LAI was observed at 60 DAS in observed, 2020 and 2050

Table 2. Projected mean crop growth and yield of short duration rice variety Saket-4 for different future time periods

Parameter	LAI	TDM (kg/ha)	Yield (kg/ha)	Total grain No.	Filled grain No.	% filled grain	Test wt. (g)	Duration (days)	HI (%)
Observed	2.31	7376.59	3681.43	158402571	139598286	88.12	22.38	106.00	49.91
2020	2.12	7124.56	3640.74	157419714	138520571	88.11	22.24	105.29	51.10
2050	2.46	8617.13	4233.57	181084857	164136429	90.71	21.91	108.00	49.13
2080	2.76	9382.01	2906.47	176556857	139529429	78.82	21.20	115.00	30.98
CD 0.05	0.43	1136.22	1133.14	28808989	20897461	6.01	0.83	3.84	2.58

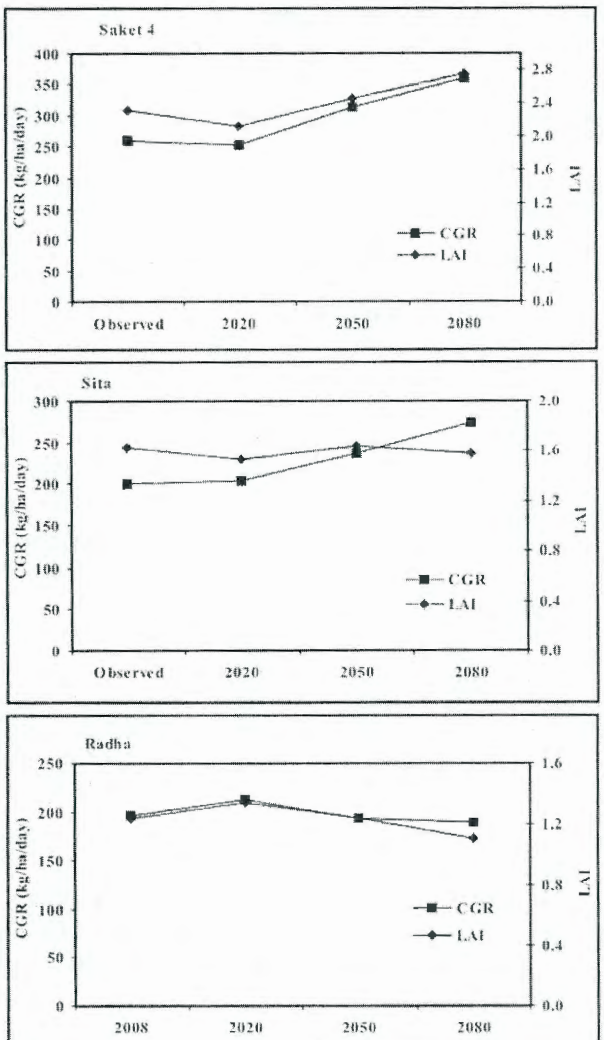

Fig. 2. LAI and CGR of short (Saket 4), medium (Sita) and long (Radha) duration varieties of rice under projected time periods.

while it was delayed by 10 days in case of 2080 scenario. Maximum LAI was observed in 2080 even during the reproductive phase in SDV and MDV indicating more leaf growth per unit area which has led to more biomass (TDM) and less HI. Shift in attaining peak LAI (~10 days) was also observed in LDV (Radha).

The yield trend was similar in Saket 4 and Sita up to 2050, maximum being in 2050 which declined thereafter for 2080 time period (Table 2 and 3). In Radha, maximum yield was projected at 2020, though it was non-significant when compared to yield values under observed weather (Table 4). It was observed that SDV performed better than MDV/LDV under scenario for 2020, 2050 and 2080 in indo-gangetic plains of Bihar. This was in contrast to the earlier findings where yield decline was projected in Tamil Nadu (Srivani *et al.* 2007) and upper gangetic plains of south west Uttarkhand and North West Uttar Pradesh (Aggarwal *et al.* 2010). Pathak *et al.* (2003) also showed a negative time trends of on farm rice yields in districts of upper gangetic plains (Ludhiana, Karnal, Delhi, Pantnagar). However, they also observed positive trends of rice yields in districts of lower indo-gangetic plains (Kanpur, Faizabad, Varanasi and 24 Paragnas). In the present study also Bihar which falls under lower gangetic plains, the rice yield has been projected to increase upto 2020 in all the three varieties. The increase in yield was maintained even upto 2050 in SDV and MDV and thereafter declined. Filled grain decreased at 2050 in MDV/LDV and in all varieties at 2080. The drastic decline in percentage of filled grain (41.56%) at 2080 in the case of MDV (Sita) might have contributed to lesser grain yield and lesser harvest index. Minor

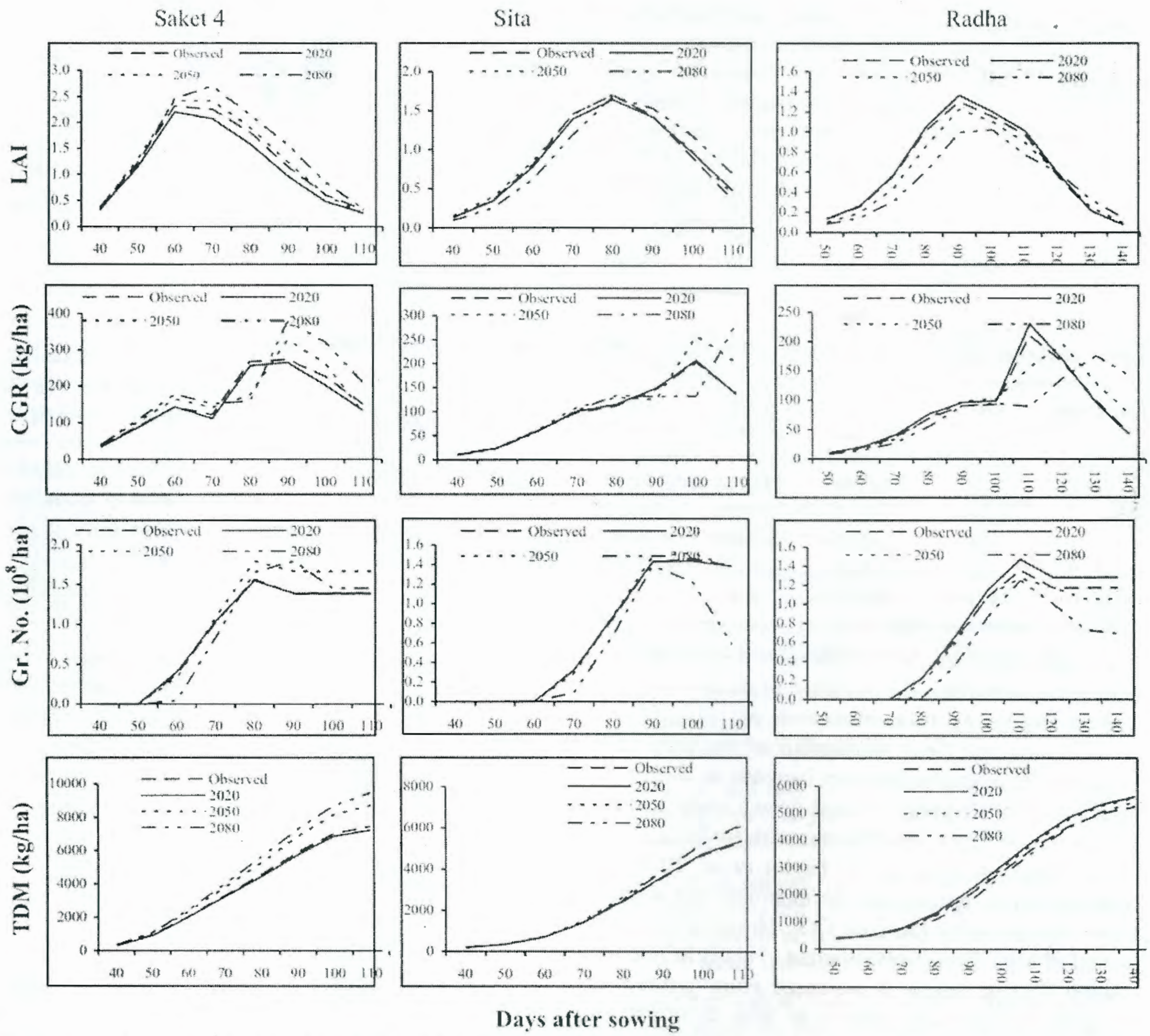

Fig. 3. LAI, CGR (kg/ha), Grain number (10^8/ha) and TDM (kg/ha) in respect of three rice varieties under projected time periods.

decline in thousand-grain weight was observed in SDV and it was almost non-significant in MDV/LDV. There was not much difference in duration of the crop among SDV and LDV, although it was found to be increasing in 2080. However, the duration of MDV increased in 2080 significantly. CGR in general was found to be low in different scenarios across all the varieties (Table 5). The peak CGR of Saket4 was recorded at 90 DAS in 2050 and 2080 instead of 80 DAS in observed and 2020 situation. This indicates delay of about 10 days in reproductive development stage. Similarly, the peak CGR of Sita was observed at 100 DAS in 2020 and 2050, however, the same was achieved only at 110 DAS in 2080 indicating slower growth with elevated CO_2 and high temperature. In the case of LDV Radha peak CGR was observed at 110 DAS under observed weather and 2020, however, the peak was observed at 120 and 130 DAS in 2050 and 2080, respectively. The slower growth

Table 3. Projected mean crop growth and yield of medium duration rice variety Sita for future periods

Parameter	LAI	TDM (kg/ha)	Yield (kg/ha)	Total grain No.	Filled grain No.	% filled	1000 grain wt. (g)	Duration (days)	HI (%)
Observed	1.62	7397.63	3141.29	140903286	129211871	91.62	21.31	122.29	42.46
2020	1.53	7406.49	3057.69	139390500	129949914	92.93	20.80	119.86	41.28
2050	1.63	8201.97	3253.37	143976157	128096057	88.96	22.01	121.71	39.67
2080	1.58	6657.23	1444.97	133517743	53685329	41.56	22.73	128.43	21.71
CD 0.05	NS	1367.78	483.40	6932563	20507675	13.71	NS	3.64	3.26

Table 4. Projected mean crop growth and yield of long duration rice variety Radha for future periods

Parameter	LAI	TDM (kg/ha)	Yield (kg/ha)	Total grain No.	Filled grain No.	% filled	1000 grain wt. (g)	Duration (days)	HI (%)
Observed	1.24	6927.49	2858.54	124769643	107227857	86.28	23.97	142.86	41.26
2020	1.34	7182.77	2973.90	135015700	117773186	87.34	23.05	140.14	41.40
2050	1.24	7247.20	2618.00	122594614	99126943	80.01	23.86	141.86	36.12
2080	1.11	5342.59	1764.20	117120643	65378700	55.44	24.49	150.43	33.02
CD 0.05	NS	1232.20	236.82	NS	21806572	19.37	NS	4.08	3.82

rate might have resulted in increased crop duration among the varieties. The increase in duration may be due to the delay in completion of reproductive development and final maturation of the crop under elevated CO_2 scenario. Similar increase in duration of crop was also reported in plants grown under elevated CO_2 in one of FACE experiments with soybean (Castro *et al.* 2009) and tree crops (Taylor *et al.* 2008). An overall delay in reproductive development was observed with soybean under elevated CO_2. However shortened period of seed filling was reported. This is in line with present finding, where in increased grain number was reported but % filled grain was less. Craufurd and Wheeler (2009) predicted delay in tassel initiation and increase in duration of maize crop under future climate scenarios owing to increased supra optimal temperature. In the present study also the prevalence of higher temperature above the optimum temperature (20-29°C for ripening stage, Yoshida 1978) required for rice at 2080 scenario during the cropping season (Fig. 1) might have retarded crop growth rate and thereby delayed the completion or maturation of the crop. Moreover, it was observed that SDV will experience less increase in T_{max} than MDV and LDV during anthesis to physiological maturity (Fig. 1), which might have given them the edge over other varieties for higher grain filling. MDV experienced higher increase in T_{max} followed by LDV during anthesis to maturity in 2050 and 2080. It is also reported that diurnal temperature delayed flowering and increased leaf number in rice (Yin and Kropff 1996). Increase in leaf number might have contributed to

Table 5. Projected CGR (kg/ha/day) in Saket 4, Sita and Radha during reproductive phase under different time periods

Variety	DAS	Observed	2020	2050	2080
Saket 4	70	124.97	115.74	145.06	156.73
	80	266.89	253.79	166.59	151.11
	90	260.14	252.30	313.87	359.17
	100	217.59	196.22	258.19	321.10
Sita	80	97.27	101.81	112.16	128.00
	90	141.79	162.52	114.24	121.16
	100	187.00	175.18	237.47	123.28
	110	127.69	105.27	184.85	266.47
Radha	100	85.87	90.62	94.71	88.36
	110	196.14	212.21	152.21	84.74
	120	153.08	153.13	179.84	123.20
	130	96.89	88.40	120.27	167.91

increased CGR and TDM, as in this study also higher LAI was observed under condition (Fig. 2). Delay in grain formation stage to the tune of 10 days was observed in 2080 in all the three varieties. The shift in days to obtain peak grain number was also observed in SDV in 2080. However, there was no difference of the peak in MDV and LDV (Fig. 3).

Harvest index (HI) declined in all varieties at 2050 and later. In SDV, HI declined only at 2080. Maximum decline in HI was observed in Sita followed by Saket 4 and Radha at 2080. As evident from Table 2, 3, and 4 the decline in HI at 2080 may be due to greater decline in grain yield when compared to TDM in Sita indicating poor partitioning of dry matter. In Radha, a greater reduction in TDM was observed than grain yield, resulting in lesser decline of HI. However, in case of Saket 4 increase in TDM was observed at 2080 when compared to observed weather, resulting in reduced HI. The genetic improvement over the past century in grain yield of major field crops have been closely associated with enhanced HI which has reached its theoretical maximum and further increase can only be possible by enhancing the TDM of the plants. The decline of HI and increase of TDM in future climate as observed in this study in SDV and MDV, offers scope for improvement in crop productivity by enhancing the HI.

The above results suggested that SDVs of rice could be better proposition under future climate change scenarios for growing in Indo-gangetic plains of Bihar. In conclusion, the reproductive development of rice might be directly affected by elevated CO_2 and higher temperature resulting in delay in maturation showing a potential agronomic risk of exposure to supra-optimal temperature at maturity. On a practical scale the productivity of rice-wheat cropping system in the indo-gangetic plains will also be in danger. Since delayed rice harvest due to delayed maturation may create potential risk of delayed wheat sowing which can expose the wheat crop to terminal heat stress during the reproductive phase in the *rabi* season.

Furthermore, the reproductive duration of rice and possibly other plants will be directly affected by rising atmospheric CO_2 apart from higher temperature during reproductive phase. Hence, it is necessary to quantify the direct effects of rising CO_2 on important crops to project or predict development of crops in future climate change scenario. Therefore, it is necessary to tailor the management option such as changing the date of sowing, growing heat tolerant rice and wheat varieties, etc. to overcome the adverse effects of climate change in the plains of Bihar in particular and indo-gangetic plains of India in general.

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