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Modelling Adaptation Strategies to Mitigate Climate Change Impact in Wheat under Mid-Hill Regions of Himachal Pradesh

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Abstract: A field study was carried out during *Rabi* season of 2015-16 and 2016-17 at Department of Agronomy, CSK HPKV, Palampur, Himachal Pradesh (India) to calibrate the DSSAT-CERES-wheat model for four wheat varieties (viz., HS-490, VL-829, VL-892 and VL-907) grown on five different sowing dates (viz., October 20, November 5, November 20, December 5 and December 20) in split plot design with three replications. The objective was to evaluate varietal response and sowing time as adaptive strategies to climate change, along with the effect of irrigation scheduling. Results revealed that delayed sowing either on 5th and 20th December proved a better adaptive strategy to climate change. Similarly, varieties VL-829 and VL-907 were more capable to eliminate the harmful impacts of climate change, compared to other two varieties. The simulation results also elucidated that increasing the frequency of irrigations from one to four nullified the impact of climate change and led to a yield increase ranging from 2.23% to 7.95% for various sowing dates and 4.02-5.00 % for varieties- One extra (total four) irrigation further amplified the positive impact of irrigation by increasing wheat yield by 4.93- 10.88% for sowing dates and 6.88- 7.84% for varieties. However, the positive impact of irrigation declined under projected climate scenarios for the 2050s and 2080s. Ultimately, delayed sowing either of VL-829 and VL-907 varieties up to December 20 and increase in number of irrigations from two (each at 35 and 75 DAS) to five (each at 30, 60, 90, 120 and 145 DAS) appeared as best adaptive strategies for wheat crop of this region. The DSSAT-CSM-CERES model (V4.6) fairly simulated the overall yield comprises of grain and biomass of selected wheat cultivars therefore, it can be well suited for crop yield simulations studies under different sowing environments.

Key words: DSSAT-CERES model • Adaptation • Irrigation • Sowing date • Wheat • etc.

Introduction

India is considered as one of the primary wheat producing nations globally, with cultivation on about 30.5 million hectares and yielding a production of 112.18 million tones. In Himachal Pradesh it is cultivated on 319 thousand hectares with total production of 564 million tonnes with the productivity of 17.8 q/ha (Anonymous 2021). However, various agronomic and climatic factors limit the realization of the full genetic yield potential of wheat varieties. Climatic variability has heightened the crop's vulnerability to erratic weather conditions, which has become more pronounced with ongoing climate change. Climate change cause significant reduction in wheat yields unless proper crop management practices and suitable cultivars are adopted (Kenneth et al. 2008; Ruiz-Ramos et al 2017). Optimizing sowing time is a critical strategy for mitigating the adverse effects of elevated temperatures, especially during the grain filling stage, and for improving overall productivity under early, normal, and late sown conditions (Gupta et al. 2020a). Optimizing sowing environments can significantly enhance crop growth and yield. Sowing at the optimal time maximizes the genetic potential of a specific variety by providing optimum growth factors such as temperature, light, humidity and rainfall (Gupta et al. 2020). Agricultural scientists all over the world are trying to develop adaptation measures for crops to tackle the negative impact of climate change so that reduction in crop yield can be minimized. In order to take decisions on developing adaptation measures to tackle adverse effect of climate change, a sound understanding of effect of climate factors on crop production and their interaction among themselves should be established (Banerjee et al. 2016; Chenu et al 2017). The field experiment under modified weather condition and CO_2 concentration using closed chamber is costly affair, therefore agricultural decision making strategies under climate change condition are not readily available. In this context, crop growth simulation models offer great help in understanding the impact of various climate elements on crop production, hence, can be used to study the effect of projected climate on crop production (Webber et al 2018; Muller and Pierre 2019). The crop simulation studies also facilitate to evaluate the effects of different agronomic adaptation options under future climatic scenario (Bulatewicz et al 2009). Now days, computer operated crop simulation models has become important tool to simulate the effect of changing climatic scenarios for developing the most suitable and site-specific strategies (Li et al. 2011). Therefore, the objective of this study was to evaluate the impact of climate change on wheat production and to identify effective adaptation strategies through optimization of sowing dates, varietal selection, and irrigation scheduling, using the DSSAT-CERES-Wheat model.

Materials and Methods

A field investigation was conducted at, Department of Agronomy, CSK HPKV, Palampur, Himachal Pradesh (latitude 32° 6' N, longitude 76° 3' E and altitude about 1290.8 m above sea level) during the *Rabi* seasons of 2015-16 and 2016-17. The field experiment was conducted in split plot design with five dates of sowing (October 20, November 5, November 20, December 5 and December 20) in main plots and four varieties of wheat (*viz.,* VL-829, VL-907, VL-892 and HS-490) in sub-plots with three replications. The soil of the experimental field was silty clay loam in texture, acidic in reaction, medium rich in available nitrogen, phosphorus, and organic carbon, but high rich in available potassium. Agro-climatically, the experimental area comes under sub-temperate and sub-humid zone distinguished by acute winters (3.5-13.4ºC) and high rainfall (up to 2500 mm) with mild summers (19.0-31ºC).The 78 percent of the annual rainfall is received during monsoon (June to September) period. The period of onset of south west monsoon is last week of June. Winter rains usually occurs during December to February by western disturbances. Daily meteorological data *viz*., rainfall (mm), maximum and minimum relative humidity (%), maximum and minimum temperature (°C), duration of bright sunshine (hours), wind speed (kmh^{-1}) etc. were recorded from Agrometeorological observatory, CSK HPKV, Palampur. During first year (2015-16) crop season (October to May), minimum temperature ranged from 1.7 to 19.4°C and maximum temperature was 14.3 to 32.7°C which was 14.6 to 32.1°C and 1.7 to 18.9°C, respectively during 2016-17. Range of the sunshine duration was 3.4-11.0 hours day^{-1} (2015-16) and 2.3-10.6 hours day^{-1}(2016-17).Well distributed rainfall of 435.6 and 481 mm was experienced by crop during 2015-16 and 2016-17. Rainfall is the key climatic variable which is the primary source of water in the area, any deficit or excess of rainfall during the critical crop growth stages determines productivity of crop. Decreasing trend in annual rainfall and rainy days by -4.58 mm/year and -0.13 days/year, respectively in H.P. have been observed by Jaswal et al. (2015). If the decreasing trends in rainfall and rainy days continue in future, it might impact agriculture and related sectors in the state.

Cultivar specific genetic coefficient of every wheat cultivar (VL-829, VL-907, VL-892 and HS-490) were derived following the repeated iterations until a close match between observed and simulated phenology, growth and yield were achieved in the model calculations following Mishra et al. (2015). DSSAT-CERES-wheat crop growth simulation models were utilized for assessing the potential impact of climate change on plant growth. In this study, IPCC projections followed for climate change were CO_2 concentrations of 414, 522 and 682 ppm and temperature levels of 1.3, 2.9 and 5.2 °C for the years 2020s, 2050s and 2080s, respectively.

Results

Modeled adaptation strategy under climate change scenarios

Adaptation to global warming and climate change involves specific initiatives and measures aimed at mitigating the vulnerability to the effects of climate change (IPCC, 2007).While these efforts can significantly reduce adverse impacts and enhance beneficial outcomes; they do not guarantee complete avoidance of losses. Because of the change in climate supported by increase in temperature and CO_2 concentration level, adaptation is an essential strategy at all scales to complement the efforts in climate change mitigation.

Climate change mitigation through input optimization

After examining the data revealed that under early sowing there was a slight decrease in simulated grain as well as the biological yield. In contrast, delayed sowing led to an increase in simulated yields relative to observed values. This suggests that sowing time plays a pivotal role in the crop's resilience under projected climate conditions.

Date of sowing

In early sown crop i.e. October 20 followed by November 5 and November 20 there was higher reduction in grain as well as biological yield under climate change scenario of 1.3°C+414 ppm in 2020s, 2.9°C+552 ppm in 2050s and 5.2°C+682 ppm in 2080s .Whereas, lower reduction in the crop yield was obtained under late sowing on December 5 and December 20 (Table 1).Thus, the late sown wheat crop mightier be the first choice of easy adaptation practice under changing climate. These results are consistent with those of Gupta et al. (2020), who also reported that wheat sown later in the season performed better under elevated temperature scenarios due to avoidance of critical grain filling periods coinciding with peak heat stress.

Table 1: Effect of climate scenarios on yield (kg ha^{-1}) in different date of sowing

Date of sowing	**Observed**	**At present/ simulated (380 ppm)**	**2020s**	**2050s**	**2080s**
			1.3°C+414 ppm	**2.9°C+522 ppm**	**5.2°C+682 ppm**
Grain yield					
20th October	3449	3377	3150 (-6.8%)	3138 (-7.1%)	2948 (-12.8%)
5th November	3863	3832	3580 (-6.6%)	3545 (-7.5%)	3352 (-12.6%)
20th November	4065	4070	3802 (-6.6%)	3743 (-8%)	3596 (-11.7%)
05th November	3276	3401	3275 (-3.7%)	3193 (-6.2%)	3046 (-10.5%)
20th November	3187	3351	3246 (-3.2%)	3160 (-5.7%)	3000 (-10.5%)
Biological yield					
20th October	8832	8388	7845 (-6.5%)	8226 (-2%)	7402 (-11.9%)
5th November	9967	9802	9149 (-6.8%)	9642 (-1.7%)	8507 (-13.3%)
20th November	10462	10760	10017 (-6.9%)	10585 (-1.7%)	9290 (-13.7%)
05th November	8316	8480	8284 (-2.4%)	8358 (-1.5%)	7926 (-6.6%)
20th November	8241	8048	7830 (-2.7%)	7947 (-1.3%)	7556 (-6.2%)

Varietal selection

Adaptive capacity varies among different varieties. Among the varieties, there was minimum reduction variation in the observed and simulated yield of wheat (Table 2). Higher reduction in the grain and biological yields was observed in varieties VL-892 and HS-490 under different climate change scenarios. The yielding ability of remaining two varieties (VL-829 and VL-907) was comparatively stable over different scenarios hence; late sowing may as another adaptive measure to climate change.

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Variety	Observed	At present/ simulated (380 ppm)	2020s	2050s	2080s
			1.3°C+414 ppm	2.9°C+522 ppm	5.2°C+682 ppm
Grain yield					
VL- 829	3726	3652	3469 (-5%)	3443 (-5.7%)	3234 (-11.4%)
VL- 907	3771	3772	3587 (-4.8%)	3550 (-5.8%)	3379 (-10.4%)
VL- 892	3255	3370	3170 (-5.9%)	3099 (-7.9%)	2950 (-12.4%)
HS- 490	3519	3630	3417 (-5.8%)	3330 (-8.2%)	3190 (-12.1%)
Biological yield					
VL- 829	9780	9944	9455 (-4.8%)	9803 (-1.4%)	8948 (-9.7%)
VL- 907	10167	10101	9616 (-4.6%)	10004 (-1%)	9096 (-9.5%)
VL- 892	8163	8120	7672 (-5.4%)	7932 (-2.3%)	7246 (-10.6%)
HS- 490	8545	8217	7757 (-5.5%)	8066 (-1.8%)	7255 (-11.4%)

Irrigation scheduling

For contriving the effective adaptive measures under climate change scenarios effect of irrigations scheduling was simulated using DSSAT-CERES-Wheat (V 4.6) model (Table 3).

The irrigation amount was kept constant at 50 mm, while the frequency of was increased from 2 to 5.

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Irrigation scheduling (1) (simulated normal condition)	**Irrigation scheduling (II)**	**Irrigation scheduling (III)**	**Irrigation scheduling (IV)**
Days after sowing			
35	35	30	30
75	70	70	60
-	110	110	90
-	-	135	120
-	-	-	145

The variation of grain yield of different varieties under varying climate change scenarios and irrigation scheduling (Table 4) revealed that grain yield increased with more number of irrigations after pre showing irrigation. With increase in frequency of irrigations the actual grain yield was raised than simulated values obtained with two irrigations application. Increased irrigation frequencies reduced the effect of climate change, compared to current simulated value. The reduction in yield was lowest with five irrigations followed by four and three irrigations application. Different sowing dates in all three type of irrigation scheduling revealed the similar trend although, early sowing recorded more yield reduction compared delayed and late sowings. Under various climate change scenarios, the lowest yield reduction was attained under late sown wheat. The reduction was minimum under fourth irrigation scheduling (5 irrigation) followed by third irrigation scheduling. Among the varieties, the simulated values followed same trend as field condition. Varieties VL-892 and HS-490 exhibited higher grain yield reduction compared to VL-829 and VL-907 across various irrigation scheduling under different climate change scenarios (Table 5). These findings corroborate the conclusions of Webber et al. (2018) and Fahad et al. (2017), who reported that precise

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irrigation scheduling can significantly reduce the negative impacts of heat and moisture stress under changing climate.

Similarly, biological and grain yield (Table 4 and Table 5) exhibited the same trends. Fourth and third irrigation schedules recorded higher biological yield and showed minimum reduction under various climate change scenarios. Likewise, early sowing on October 20 November 05 showed more decline inthe biological yield than crop sown on December 5 and December 20 crop. Almost similar patterns were recorded for different varieties. Cultivar VL-829 and VL-907 performed more consistent performance over HS-490 and VL-892. Similar observations were made by Lobell et al. (2011), who suggested that adaptation through irrigation management can buffer crop productivity even under highly variable future climates.

Conclusion

Wheat crop is affected by both the biotic and the abiotic factors including genetic, physiological, pest, disease, temperatures and rainfall etc. Wheat productivity in the mid-hill regions of Himachal Pradesh is increasingly challenged by climate variability. Determination of cultivar specific optimum sowing time is crucial for good crop growth and yield.

Table 4: Yield (Grain and biological) and percent change in yield obtained in different climate change scenarios under different date of sowing in different irrigation scheduling (Mean of 2 years)

Date of sowing	Simulated grain yield				2020s (1.3°C+414 ppm)				2050s (2.9°C+522 ppm)				2080s (5.2°C+682 ppm)			
					(Decrement or increment percent in simulated values)				(Decrement or increment percent in simulated values)				(Decrement or increment percent in simulated values)			
	Irrigation scheduling (1)	Irrigation scheduling (2)	Irrigation scheduling (3)	Irrigation scheduling (4)	Irrigation scheduling (1)	Irrigation scheduling (2)	Irrigation scheduling (3)	Irrigation scheduling (4)	Irrigation scheduling (1)	Irrigation scheduling (2)	Irrigation scheduling (3)	Irrigation scheduling (4)	Irrigation scheduling (1)	Irrigation scheduling (2)	Irrigation scheduling (3)	Irrigation scheduling (4)
20th Oct.	3377	3614	3819	4004	-7.03	-1.03	2.23	4.93	-7.13	-3.25	1.93	3.65	-12.80	-7.05	-4.35	-2.20
05th Nov	3832	4074	4276	4512	-6.98	-0.23	2.23	5.25	-7.53	-1.88	1.48	3.83	-12.55	-7.03	-4.58	-2.33
20th Nov.	4070	4324	4489	4771	-6.95	-0.15	2.33	5.33	-8.03	-2.28	0.28	2.80	-11.68	-6.03	-4.45	-1.88
05th Dec.	3402	3639	3835	4028	-0.75	2.55	7.83	10.45	-6.15	0.18	1.85	4.80	-10.45	-3.33	-2.98	0.15
20th Dec.	3351	3593	3802	3980	-1.03	3.90	7.95	10.88	-5.70	2.30	2.78	6.23	-10.50	-3.28	-2.93	0.18
	Simulated biological yield															
20th Oct.	8388	8788	9159	9863	-6.53	-1.75	1.00	4.38	-1.38	0.00	8.13	9.45	-11.85	-7.90	-3.98	-1.53
05th Nov	9803	10133	10565	11423	-6.75	-1.83	1.13	4.33	-0.73	0.83	8.83	10.20	-13.25	-9.55	-5.93	-3.35
20th Nov.	10760	11197	11581	12561	-6.93	-1.58	1.80	4.60	-1.68	0.15	6.85	8.93	-13.73	-10.23	-6.78	-4.05
05th Dec.	8480	9055	9234	10026	-2.35	0.95	2.28	7.33	-2.53	0.78	7.73	9.18	-6.63	-3.28	0.05	3.48
20th Dec.	8048	8298	8827	9428	-2.73	0.88	2.50	7.23	-1.50	1.28	8.23	9.90	-6.15	-2.70	0.78	4.08

Table 5: Yield (Grain and biological) and percent change in yield obtained in different climate change scenarios under different varieties in different irrigation scheduling interval (Mean of 2 years)

Variety	Simulated grain yield				2020s (1.3°C+414 ppm)				2050s (2.9°C+522 ppm)				2080s (5.2°C+682 ppm)			
					(Decrement or increment percent in simulated values)				(Decrement or increment percent in simulated values)				(Decrement or increment percent in simulated values)			
	Irrigation scheduling (1)	Irrigation scheduling (2)	Irrigation scheduling (3)	Irrigation scheduling (4)	Irrigation scheduling (1)	Irrigation scheduling (2)	Irrigation scheduling (3)	Irrigation scheduling (4)	Irrigation scheduling (1)	Irrigation scheduling (2)	Irrigation scheduling (3)	Irrigation scheduling (4)	Irrigation scheduling (1)	Irrigation scheduling (2)	Irrigation scheduling (3)	Irrigation scheduling (4)

VL-829	3652	3897	4103	4315	-4.28	1.42	4.78	7.70	-5.68	0.20	2.96	5.62	-11.44	-4.66	-3.68	-0.84
VL-907	3772	4015	4217	4446	-4.28	1.60	5.00	7.84	-5.82	0.80	2.84	5.74	-10.38	-3.80	-3.52	-0.42
VL-892	3370	3612	3800	3993	-4.88	0.40	4.02	6.88	-7.94	-1.86	0.82	3.34	-12.42	-6.28	-4.08	-1.72
HS-490	3631	3872	4057	4281	-4.74	0.62	4.24	7.04	-8.18	-3.08	0.02	2.34	-12.14	-6.62	-4.14	-1.88
	Simulated biological yield															
VL-829	9945	10475	10705	11657	-4.76	-0.42	2.00	5.86	-0.96	0.76	8.32	9.96	-9.72	-6.00	-2.54	0.44
VL-907	10101	10651	10848	11835	-4.56	-0.32	1.90	5.92	-0.68	1.52	8.58	10.40	-9.54	-6.24	-2.96	0.26
VL-892	8120	8430	8905	9534	-5.42	-0.94	1.50	5.26	-2.60	0.18	7.34	8.78	-10.60	-7.30	-3.42	-0.66
HS-490	8217	8421	9034	9615	-5.48	-0.98	1.56	5.24	-2.00	-0.04	7.56	8.98	-11.42	-7.38	-3.76	-1.14

The DSSAT-CERES-wheat model simulations also confirmed that by increasing the irrigation frequency from one to four, the adverse effect of climate change was nullified and consequently, yield was increased by 2.23-7.95 %for sowing dates and 4.02-5.00 % for varieties. Likewise, application of an additional irrigation (in 4th irrigation schedule), the beneficial impact of irrigation on the crop yield further increased by 4.93-10.88% for sowing dates and 6.88- 7.84%for varieties. Although the benefits of increased irrigation declined under the 2050s and 2080s projections, these strategies still offered considerable resilience. Overall, the sowing of any of the two wheat varieties (VL-829 and VL-907) up to 20th December with increased frequency of irrigation from two (each at 35 and 75 DAS) to five (each at 30, 60, 90, 120 and 145 DAS) were appeared as the best adaptive strategies to climate change for mid-hill regions of Himachal Pradesh.

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