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Mitigating future climate change effects on wheat and soybean yields in central region of Madhya Pradesh by shifting sowing dates

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ABSTRACT

The present work focuses on (1) estimation of future yield of wheat and soybean crop under RCPs scenario 2.6, 4.5 and 8.5 for years 2020, 2050 and 2080 using FAO AquaCrop yield simulating model and (2) assessment of shifting planting date as adaptation measure to mitigate climate change impact for Sehore district, Madhya Pradesh. Statistically downscaled General Circulation Model CanESM2 data was used as input to AquaCrop for generation of future data. The AquaCrop yield model was first checked for its suitability and accuracy in prediction of yield for years 2000–2015, model nash sutcliffe efficiency 0.79, 0.84, RMSE 300.7, 104.4 and coefficient of determination (R^2) 0.91, 0.88 were obtained for wheat and soybean crops, respectively. The results depicts that RCP 8.5 shows the highest impact with reduction in wheat and soybean yield for projected year 2080. Under the changed climate, shifting planting date from of wheat from 15th November to 30th November and 1st July to 10th July for soybean resulted in least decline in crop yields and surfaced as a practical adaptation measure for sustaining future yields.

Key words: AquaCrop, general circulation model, soybean, wheat

Sustainability of wheat and soybean crop yields is of great concern for the food security of the ever-increasing population and livelihood of farmers. Both the crops are highly dependent on favourable weather conditions (Bal *et al.,* 2004; Bhagat *et al.,* 2017). Since unusual atmospheric events are becoming usual events, to make future agriculture remunerative, risk-free and sustainable credible, objective and innovative scientific alternatives to tackle the stress impacts needs to be explored (Bal and Minhas, 2017). However, there are ways by which the adverse impacts can be mitigated and agriculture can be adapted to changing scenarios. However, various studies suggest that sustenance of the cropping system can be realized by planting suitable cultivars at the appropriate date with adequate fertilization and irrigation (Mahajan *et al.,* 2009; Jalota *et al.,* 2012; Pramod *et al.,* 2017).

Soybean (*Glycine Max* L.) and Wheat (*Triticum aestivum* L.) are the two major crops grown at a large scale in Central India with wheat and soybean yield of 2993 kg ha^{-1} and 831 kg ha^{-1}, respectively estimated for the year 2015-16 (Anonymous, 2017). It is important to employ yield models and conduct climate change studies to avoid and prepare for food crisis in the future. Crop models play an important role in climate crop studies, as well as only reduce time and cost consumed in the field experiments (Steduto *et al.,* 2009). The impact of climate change on different crops (wheat, maize, pearl millet, paddy and groundnut) of Gujarat was studied using InfoCrop and DSSAT models. The results indicated that climate change will adversely affect the yields of different crops. The maximum yield reduction (-61%) is projected in wheat and lowest in pearl millet (-<8%) (Patel *et al.*, 2015). In another study the APSIM -Wheat modules was used to simulate the growth and development of wheat crop on a daily time-step in Bhopal region. It was concluded that a 1 °C temperature increase without elevated CO_2 concentration, reduced wheat grain yield by 8.4% (Mohanty *et al.,* 2015). APSIM model was also employed in central India for soybean crop. This study revealed that increase in temperature adversely affected the soybean yield. Increase temperature combined with higher rainfall had low impact on soybean yield. However, increase in CO_2 had fertilizing effect on soybean yield but increase in yield was masked by increase in temperature. (Mohanty *et al.,* 2017).

AquaCrop model is a menu-driven program with a well-developed user interface and is preferred for simulation of yields of various crops (Raes *et al.,* 2009; Foster *et al.,* 2017). AquaCrop model was validated under full and deficit irrigated wheat production in Iran. The RMSE obtained was less than 10% and it was concluded that AquaCrop is valuable tool for simulating the effect of irrigation scenarios on wheat yield (Andarzian *et al.*, 2011). In North China, the performance assessment of AquaCrop model for soil water, soil evaporation, biomass and yield of soybeans was done. Four years of soybean data were used to calibrate and validate AquaCrop model. The Nash Sutcliffe efficiency was found to be 0.82 and biomass and yield predictions were good with a yield of RMSE of 302 kg ha^{-1} (Paredes *et al.*, 2015). CROPGRO-Soybean model was employed at Jabalpur to find the impact of climate change on the yield. RCP 8.5 showed a marginal decline of 0.07% in yield by 2020 from normal, while by the year 2050 RCP 2.6 and 8.5 showed decline in crop yield by 0.59% and 1.12% from baseline (Walikar *et al*., 2018). AQUACROP yield simulation model was used to estimate yield of soybean at Ujjain district in Madhya Pradesh. Here the average simulated yield of 13 years was found to be 1.052 ton/ha and the average observed yield was found to be 1.003 t ha^{-1}, which is very close to simulated data (Mohammad *et al.*, 2018).

The GCMs constitutes the climate system in a simplified form and prove to be powerful tool in finding the impacts of climate change (Johnson and Sharma, 2009). Climate change also creates an adverse effect on agriculture yield of crops thus GCM downscaling is necessary to reach to most precise prediction of climate (Balvanshi and Tiwari, 2018). Adjusting planting date to synchronize plant growth stages with optimum temperatures seems to be a practical and eco-friendly approach to sustain yields under elevated temperature conditions (Jalota *et al.*, 2012). Keeping in view the economic importance of soybean and wheat production in Central India, the present study was conducted employing the AquaCrop and CANESM2 climate model to (1) study impact of changing climate on crop yields of soybean and wheat during the years 2020, 2050 and 2080, and (2) select a suitable trans-/planting date to ensure least decline in crop yields in the Sehore district of Madhya Pradesh. For this, the baseline dataset from GCM and observed yield data (2000-2015) were used to check the accuracy of the AquaCrop model. The future yield was modelled in AquaCrop for year 2020, 2050 and 2080 under RCP 2.6, RCP 4.5 and RCP 8.5 emission scenarios. The percent change in yield of wheat and soybean was calculated and depicted in Table 2 ahead. The future yields of wheat and soybean after shifting the planting dates is given under Table 3 and 4.

MATERIALS AND METHODS

The present study has been carried out for Sehore district located at 23.2050 ^{o}N latitudes 77.085 ^{o}E longitudes in Madhya Pradesh which comes under Vindhyachal Range in the middle of Malwa region. The Sehore district encompasses an area of 6578 sq. km and has an average rainfall of 1217.7 mm. Aquacrop model needs inputs of weather data, crop characteristics, soil and crop management datasets. The historic data from year 2000 to 2015 is used for model calibration and evaluation. For computing future generation of yield data from the model, GCM CanESM2 (grid size 2.790 x 2.812, Canadian Centre for Environment and Climate change, Canada) was employed with future projections RCP 2.6, RCP 4.5 and RCP 8.5 for the years 2020, 2050 and 2080. The capability of the model was evaluated with the actual yield and simulated yield from 2000 – 2015 years period. Furthermore, Statistical Downscaling Model (SDSM) was employed and downscaled CanESM2 data was given as input to AquaCrop to predict future yield for the years 2020, 2050 and 2080 of wheat and soybean crops. The percentage change in yield was compared with average yield of the years 2000 - 2015.

The Aqua Crop model accuracy in simulating yield was evaluated using:

Nash Sutcliffe efficiency (E) as described by Nash and Sutcliffe (1970) for the period 2000 - 2015.

$$E = 1 - \frac{\sum_1^n (O_i - P_i)^2}{\sum_1^n (O_i - \bar{O})^2} \quad (1)$$

Coefficient of determination, r^2

The squared value of the coefficient of correlation is termed as coefficient of determination. Mathematically it is expressed as follows:

$$r^2 = \left(\frac{\sum_{i=1}^n (O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^n (O_i - \bar{O})^2}\sqrt{\sum_{i=1}^n (P_i - \bar{P})^2}} \right)^2 \quad (2)$$

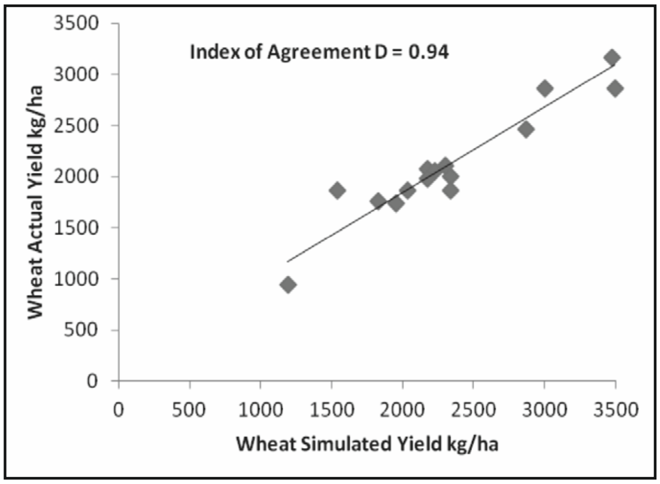
The range of this evaluation parameter lies between 0 and 1 which describes how much of the observed dispersion is explained by the prediction.

Root mean square error, RMSE

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^n (P_i - O_i)^2} \quad (3)$$

A models fit improves as RMSE approaches zero.

Where O_i is the actual data, P_i is the modeled or predicted data and $\bar{O}$ is the mean of the observed data. The E value (ranges -∞ to 1), E = 1 means perfect match between observed and modelled data, E = 0 means modelled values are as accurate as the means of the observed data and E < 0 means that the observed mean is better than the simulated value. The RMS Error, R² and deviation was calculated for wheat and soybean is shown in Table 1.



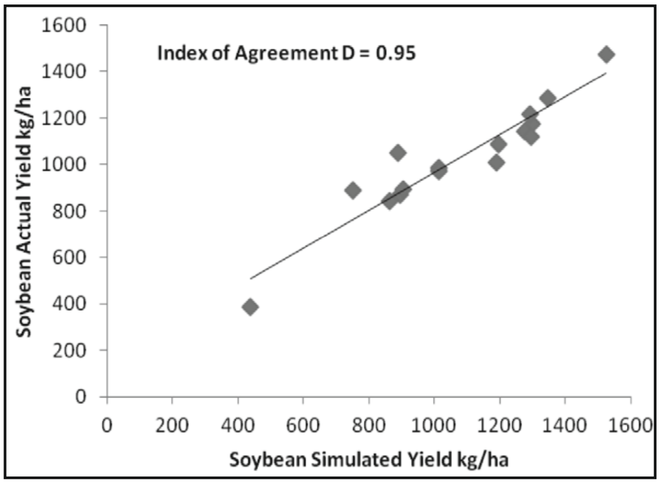


Fig. 1 : Index of agreement between actual and simulated yield in wheat and soybean

Table 1: AquaCrop NSE, RMSE, Deviation and R^2 for wheat and soybean (yield in kg ha^{-1})

Year	Wheat			Soybean		
	AY	SY	Deviation	AY	SY	Deviation
2000	2178	2070	76.36	895	871	16.97
2001	2032	1869	115.25	1013	986	19.09
2002	1829	1763	46.66	1014	974	28.28
2003	2299	2108	135.05	1298	1176	86.26
2004	2228	2051	125.15	751	890	98.28
2005	1952	1735	153.44	1276	1140	96.16
2006	2339	2002	238.29	888	1050	114.55
2007	2339	1862	337.28	1197	1086	78.48
2008	1191	945	173.94	1293	1214	55.86
2009	1544	1870	230.51	1526	1472	38.18
2010	2175	1980	137.88	1190	1009	127.98
2011	3477	3165	220.61	906	895	7.77
2012	2870	2460	289.91	863	845	12.72
2013	3000	2864	96.16	438	386	36.76
2014	3522	3285	167.58	1348	1285	44.54
2015	3500	2865	449.01	1296.6	1120	124.87
	NSE		0.79		NSE	0.84
	R^2		0.91		R^2	0.88
	RMSE		300.7		RMSE	104.4

Table 2: Percent change in yield for wheat and soybean (yield in kg ha^{-1})

Average yield	Year 2020			Year 2050			Year 2080		
	RCP 2.6	RCP 4.5	RCP 8.5	RCP 2.6	RCP 4.5	RCP 8.5	RCP 2.6	RCP 4.5	RCP 8.5
Wheat (2404.68)	2312	2304	2259	2238	2196	2140	2201	2087	1990
% change in yield	-3.85	-4.19	-6.06	-6.93	-8.68	-11.04	-8.47	-13.21	-17.24
Soyabean (1074.53)	1105	1078	1024	1076	1003	986	994	975	905
% change in yield	2.84	0.32	-4.7	0.14	-6.66	-8.24	-7.49	-9.26	-15.78

RESULTS AND DISCUSSION

Model performance was evaluated from actual yield (AY) and simulated yield (SY) as mentioned in Table 1. For estimating percent variation in the yield for future years (2020, 2050, 2080), the average of (2000-2015) years yield data was employed (Table 2).

The Aqua Crop NSE for soybean was found to be 0.84 which is greater than the NSE of 0.79 for wheat. Wheat showed deviation in yield in the range of 46.66 to 449.01 kg ha^{-1} and soybean showed less deviation in the range of 7.77 to 124.87 kg ha^{-1} (Table 1). The RMSE and index of agreement exhibited for wheat was 300.7 and 0.94, respectively while RMSE and index of agreement exhibited for soybean was 104.4 and 0.95, respectively (Table 1 & Fig. 1).

Table 3 : Percent change in yield for wheat from in average yield (2404.68 kg ha^{-1}) with changed planting dates

Planting date	Climate scenario	2020		2050		2080	
		Yield	% change	Yield	% change	Yield	% change
-15 days	RCP 2.6	2280	-5.18	2193	-8.80	2128	-11.50
	RCP 4.5	2272	-5.51	2104	-12.50	1995	-17.03
	RCP 8.5	2177	-9.46	2043	-15.04	1904	-20.82
-10 days	RCP 2.6	2304	-4.18	2208	-8.17	2170	-9.75
	RCP 4.5	2286	-4.93	2149	-10.63	2061	-14.29
	RCP 8.5	2195	-8.71	2086	-13.25	1918	-20.23
-5 days	RCP 2.6	2310	-3.93	2220	-7.68	2186	-9.09
	RCP 4.5	2295	-4.56	2158	-10.25	2074	-13.75
	RCP 8.5	2246	-6.59	2108	-12.33	1943	-19.19
+5 days	RCP 2.6	2310	-3.93	2224	-7.51	2193	-8.80
	RCP 4.5	2301	-4.31	2188	-9.01	2079	-13.50
	RCP 8.5	2250	-6.43	2138	-11.09	1986	-17.41
+10 days	RCP 2.6	2329	-3.14	2380	-1.02	2340	-2.68
	RCP 4.5	2305	-4.14	2324	-3.35	2294	-4.60
	RCP 8.5	2261	-5.97	2230	-7.26	2083	-13.37
+15 days	RCP 2.6	2335	-2.85	2385	-0.81	2352	-2.19
	RCP 4.5	2318	-3.60	2340	-2.68	2302	-4.27
	RCP 8.5	2274	-5.43	2248	-6.51	2190	-8.92

Impact of climate change on wheat and soybean crop yield

The future yield for the years 2020, 2050 and 2080 under emission scenarios RCP 2.6, 4.5 & 8.5 was simulated using AquaCrop and CANESM2. The planting date of wheat was 15th November and 01st July for soybean crop. The percent variation in wheat and soybean yields were compared to the average yield (2000-15) data (Table 2).

The negative effect of climate change was found on wheat yield which is maximum under the RCP 8.5 as 17.24% decline in year 2080 while soybean shows a decline of 15.78% in yield under RCP 8.5 in the same year. Hence the year 2080 can be assumed to have the highest vulnerability for wheat and soybean under RCP 8.5 scenario (Patel *et al.*, 2018). The RCP 2.6 scenario for soybean with lesser greenhouse emission results in increase in yield of 2.84% in 2020, hence RCP 2.6 is least resilient (Walikar *et al.*, 2018; Patel *et al.*, 2018).

Mitigation by changing the plantation dates

Climate change poses a serious threat to the food and livelihood security possessing large tract of land under arid environment, lower forest coverage and expanding desertification is at a greater risks (Singh *et al.,* 2019). The percent change in crop yields of wheat and soybean under different climate scenarios as affected by different planting dates is shown ahead (Table 4 and 5). Under the future climate, simulated yield of wheat undergoes least reduction by shifting transplanting date from normal transplanting date 15th Nov to 30th Nov. (Table 4). With further shifting of the planting date (-15 days, -10 days, -5 days, +5 days, +10 days), the simulated yield shows high decline. By shifting the planting date in soybean from 1st July to 10th July, least reduction in future yield was observed.

CONCLUSION

The future climate at Sehore region would lower the crop yields of both wheat and soybean if planted during the existing normal planting dates. The maximum decrease in yields was found to be for the year 2080 under RCP scenario 8.5. The reduction in crop yields, both in 2050 and 2080 can be minimized by shifting the planting date of wheat from 15th Nov to 30th Nov and shifting planting date of soybean from 1st July

Table 4: Percent change in yield for soybean from in average yield (1074.53 kg ha^{-1}) with changed planting dates from the normal (July 1)

Planting date	Climate scenario	2020		2050		2080	
		Yield	% change	Yield	% change	Yield	% change
-15 days	RCP 2.6	1092	-1.62	1046	-2.67	920	-14.38
	RCP 4.5	1024	-4.70	951	-11.4	875	-18.56
	RCP 8.5	938	-12.70	908	-15.49	807	-24.89
-10 days	RCP 2.6	1095	1.90	1059	-1.44	938	-12.70
	RCP 4.5	1029	-4.23	960	-10.65	900	-16.24
	RCP 8.5	940	-12.51	914	-14.93	856	-20.33
-5 days	RCP 2.6	1104	-2.74	1072	-0.23	983	-8.51
	RCP 4.5	1048	-2.46	986	-8.23	924	-14.00
	RCP 8.5	993	-7.58	948	-11.77	878	-18.28
+5 days	RCP 2.6	1119	4.13	1086	1.06	995	-7.40
	RCP 4.5	1070	-0.42	1001	-6.84	951	-11.49
	RCP 8.5	1021	-4.98	983	-8.51	895	-16.70
+10 days	RCP 2.6	1146	6.65	1109	3.20	1028	-4.33
	RCP 4.5	1087	1.16	1027	-4.42	982	-8.61
	RCP 8.5	1038	-3.39	1000	-6.93	918	-14.56
+15 days	RCP 2.6	1120	4.23	1094	1.81	1004	-6.56
	RCP 4.5	1072	-0.23	1011	-5.91	958	-10.84
	RCP 8.5	1028	-4.33	985	-8.33	907	-15.59

to 10th July without altering the current soil, water and crop management practices. It was also found that the FAO AquaCrop model is highly efficient in simulating crop yield of wheat and soybean and also useful in formulating coping strategies for future climate scenarios to minimize the agricultural risks as well as mitigating the negative impacts of climate change.

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