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Assessment of climate change impact on productivity of different cereal crops in Varanasi, India

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ABSTRACT

Decision Support System for Agrotechnology Transfer (DSSAT v4.5) Cropping System Model (CSM) was used to study the impact of climate change and variability on productivity of different *kharif* (rice, maize, *jowar* and *bajra*) and *rabi* crops (wheat and barley) at Varanasi. Keeping in view the observed trends in climate variability, productivity of different *kharif* and *rabi* crops were simulated under plausible synthetic climatic scenarios of changes in temperature, solar radiation and carbon dioxide. Productivity of *kharif* crops *viz*. rice, maize, *jowar* and *bajra* and *rabi* crops *viz*. wheat, and barley decreased with an increase in temperature or a decrease in solar radiation above normal. However, productivity of different *kharif* and *rabi* crops increased under expected enhanced CO_2 concentrations. Highest productivity decreased in barley crop (40.7%) of *rabi* season and minimum in rice crop (5%) of *kharif* season with an increase of 3.0 ^{0}C in temperature from normal. Whereas, maximum productivity decreased in barley crop (5.0%) of *rabi* season and minimum in *jowar* crop (1.8%) of *kharif* season with a decrease of 2.5 per cent in solar radiation from normal. Highest productivity increase in barley crop (58.2%) of *rabi* season and lowest in *jowar* crop (4.2%) of *kharif* season were simulated under expected enhanced CO_2 concentration of 660 ppm. The maximum decrease in productivity of barley crop (45%) in *rabi* season and minimum in rice crop (7%) in *kharif* season were simulated when a decrease in temperature by 3 ^{0}C and solar radiation by 2.5 per cent from normal. Highest counter-balance on productivity of rice crop (13%) in *kharif* season and lowest in *barja* crop (-23%) of *kharif* season were simulated when an increase in temperature by 3 ^{0}C from normal under expected enhanced CO_2 concentration of 660 ppm.

Key words: Crop simulation model DSSAT, climate change, cereals, rice, maize, wheat.

Rice, maize, *jowar* and *bajra* are the predominant *kharif* crops and wheat and barley are the predominant *rabi* crops of Varanasi district. Crop productivity which is highly dependent on climatic changes and variability will need to be maintained at a higher level to meet the future food demands of increasing population. Climatic changes and variability (temperature, radiation, rainfall and carbon dioxide) can affect the yields of different *kharif* and *rabi* crops through their direct as well as indirect effects such as weather-induced changes in incidence of insect-pests (Cammell and Knight,1992), diseases (Fand *et al.*, 2012) and requirement or availability of water for irrigation (Panda *et al.*, 2003). The direct effects of increased levels of CO_2 are generally beneficial to vegetation though global warming and other climatic changes may have a range of negative or positive impacts depending on complex interactions among managed and unmanaged ecosystems (Rosenzweig and Parry, 1994; Long *et al.*, 2006). The past two decades have witnessed globally a rapid increase in the awareness about climatic changes and triggered widespread apprehension amongst scientists and governments about their global implications (Cooper *et al.*, 2009; Byjesh *et al.*, 2010). According to IPCC (2007) the CO_2 levels will increase to 605–755 ppm by 2070 and warming of 1.5°C by 2015–50 and 3.0°C by 2050–2100. Hume and Cattle (1990) have reported that although the solar radiation received at the surface will be variable geographically, on an average it is expected to decrease slightly by about 1.0 per cent. Recent studies on changes in climate predicted by global climate models (GCMs) suggest that in addition to thermal stress due to global warming, stress on water availability in tropical Asia is likely to be exacerbated in future. In view of futuristic changes in climate, it is imperative to assess their impact on crop productivity for a given region. Simulation techniques are easy, time-saving and economical for studying the influence of climatic variability on growth and yield of the crops. Several such attempts have been made for predicting productivity of different crops under changing climatic conditions (Tubiello *et al.*, 2002; Hundal and Kaur, 2007; Zacharias *et al.*, 2014).

MATERIALS AND METHODS

Taking into account the anticipated regional climatic changes, the effects of changes in temperature, solar radiation and carbon dioxide and interaction of temperature, solar radiation and carbon dioxide on yield of different *kharif* and *rabi* crops under Varanasi conditions were studied by using DSSAT v4.5. Summary of genetic coefficients of cultivars of different *kharif* and *rabi* crops used in simulation are given in Table 1. The model was calibrated and validated with experimental data of each crop. After validation of model the sensitivity analysis were carried out by changing in input weather parameters. Daily historical weather data at Varanasi (25^{0}18' north latitude, 83°1' east longitude and 76 metre above mean sea level) were analysed to determine climatic variability trends by regressing yearly moving average weather parameter against time. On the basis of climatic variability trends observed in the district, plausible synthetic scenarios of normal and increase or decrease, and interactions of temperature (maximum and minimum) and solar radiation were generated for the simulation study. The widely accepted approach to analyse possible effects of different climatic parameters on crop growth and yield by specifying the incremental changes to climatic parameter and applying these changes uniformly to baseline/normal climate was employed in the present study (Hundal and Kaur, 2007). In this study one variable at a time was modified and its effect on productivity of different *kharif* and *rabi* crops were studied, while taking all the other climate variables to be normal. The major reason for using incremental variable 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 productivity of crops.

RESULTS AND DISCUSSION

Effect of temperature change

When maximum and minimum temperatures were changed by ±3.0 °C from normal, productivity of rice, maize, *jowar*, *bajra*, wheat and barley affected substantially (Table 2). In general, increasing temperature had negative and decreasing temperature had positive impact on productivity of different *kharif* and *rabi* crops. Highest productivity decreased in barley crop (40.7%) of *rabi* season and minimum in rice crop (5%) of *kharif* season were simulated with an increase of 3.0 ^{0}C in temperature from normal. The productivity of remaining crops decreased by 11.8 per cent in maize, 19.3 per cent in *jowar*, 37.0 per cent in *bajra* under *kharif* season and by 18.9 per cent in wheat under *rabi* season with an increase in both temperatures by 3.0 °C from normal. However, productivity increased by 13.1 per cent in rice, 22.9 per cent in maize, 25.0 per cent in *jowar*, 55.1 per cent in *bajra* during *kharif* season and by 6.3 per cent in wheat and 34.9 per cent in barley during *rabi* season with a decrease in both temperatures by 3.0 °C from normal. Yield reductions in different *kharif* and *rabi* crops due to increasing temperature are mediated through reduction in crop and grain filling duration and grain number. 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 (Manpreet Kaur *et al.*, 2013; Saxena and Naresh Kumar, 2014; Dubey *et al.*, 2014; Bapuji Rao *et al.*, 2015; Zacharias *et at.*, 2014; Mishra *et al.,* 2015).

Effect of solar radiation change

The effect of 2.5 per cent decrease or increase in solar radiation from normal on productivity of different *kharif* and *rabi* crops are shown in Table 2. In general, crop productivity increased with an increase in radiation level above the normal value and vice versa. It is observed that increasing solar radiation had positive and decreasing solar radiation had negative impact on productivity of different *kharif* and *rabi* crops. Maximum productivity decrease in barley crop (5.0%) of *rabi* season and minimum in *jowar* crop (1.8%) of *kharif* season were simulated with a decrease of 2.5 per cent in solar radiation from normal. The productivity of remaining crops decreased by 2.3 per cent in rice, 2.1 per cent in maize, 4.1 per cent in *bajra* during *kharif* season, and by 2.2 per cent in wheat during *rabi* season with a decrease of 2.5 per cent in solar radiation from normal. Whereas,

Table 1: Genetic coefficients of different *kharif* and *rabi* crops used for simulation

Rice (HUR 3022)		Maize (Kanchan)		*Jowar* (CSV 3)		*Bajra* (PHB 14)		Wheat (HUW 510)		Barley (K 125)	
P_1	300	P_1	275	P_1	440	P_1	140	P_1V	34	P_1V	10
P_2R	150	P_2	0.5	P_2O	13.5	P_2O	13.5	P_1D	85	P_1D	20
P_5	290	P_5	500	P_2R	190.1	P_2R	155	P_5	895	P_5	650
P_2O	11.8	G_2	800	P_5	620	P_5	580	G_1	20	G_1	20
G_1	45	G_3	8	G_1	9	G_1	2	G_2	30	G_2	40
G_2	0.02	PHINT	38.9	G_2	4.5	G_4	0.5	G_3	1.4	G_3	1.5
G_3	1			PHINT	59	PHINT	43	PHINT	93	PHINT	65
G_4	0.8			P_3	177.5						
				P_4	81.5						
				P_2	142						
				PANTH	687.5						
				PBASE							
				PSAT							

<u>Rice:</u> P_1:Time period for vegetative phase, P_2R : Photoperiod sensitivity coefficient, P_5:Time period from grain filling to physiological maturity, P_2O : Critical day length, G_1: Potential spikelet number coefficient, G_2: Single grain weight, G_3: Tillering coefficient, G_4: Temperature tolerance coefficient, **<u>Maize:</u>** P_1: same as rice, P_2: Photoperiod sensitivity coefficient, P_5: same as rice, G_2: Potential kernel number, G_3: Potential kernel growth rate, PHINT: Leaf tip appearances Interval, ***Jowar*:** P_1: same as rice, P_2O: same as rice, P_2R : same as rice, P_5: same as rice, G_1: Leaf size, G_2: Partitioning of assimilates to the panicle, PHINT : same as maize, P_3: Thermal time from to end of flag leaf expansion to anthesis, P_4: Thermal time from anthesis to beginning grain filling, P_2: Thermal time from the end of the juvenile stage to tassel initiation under short days, PANTH: Thermal time from the end of tassel initiation to anthesis, PSAT: Critical photoperiod, PBASE: Ceiling photoperiod, ***Bajra*:** P_1: same as rice, P_2O : same as rice, P_2R : same as rice, P_5: same as rice, G_1: same as *jowar*, G_4: same as G_3 of *jowar*, PHINT : same as maize, **Wheat and Barley**, P_1V: Vernalization sensitivity coefficient, P_1D: Photoperiod sensitivity coefficient, P_5: Grain filling phase duration, G_1: same as rice, G_2: same as rice, G_3: Dry weight of a single tiller at maturity, PHINT: same as maize.

Table 2: Effect of change in temperature, solar radiation and carbon dioxide on productivity of different *kharif* and *rabi* crops

Weather parameter	Rice		Maize		*Jowar*		*Bajra*		Wheat		Barley	
	yield ($kg\ ha^{-1}$)	Change (%)	yield ($kg\ ha^{-1}$)	Change (%)	yield ($kg\ ha^{-1}$)	Change (%)	yield ($kg\ ha^{-1}$)	Change (%)	yield ($kg\ ha^{-1}$)	Change (%)	yield ($kg\ ha^{-1}$)	Change (%)
Temperature												
T-3	5701	13.1	4246	22.9	5809	25.0	7184	55.1	6402	6.3	6477	34.9
T+0	5042	0	3454	0	4645	0	4631	0	6025	0	4802	0
T+3	4790	-5.0	3047	-11.8	3747	-19.3	2915	-37.0	4884	-18.9	2849	-40.7
Solar radiation												
S-2.5%	5066	-2.3	3507	-2.1	4648	-1.8	4708	-4.1	5646	-2.2	4474	-5.0
S+0%	5188	0	3583	0	4735	0	4911	0	5775	0	4712	0
S+2.5%	5280	1.8	3657	2.0	4818	1.8	5110	4.1	5890	2.0	4942	4.9
Carbon dioxide												
C330	4777	0	3494	0	4649	0	4606	0	5305	0	3732	0
C445	5125	7.3	3555	1.7	4707	1.2	4830	4.9	5712	7.7	4492	20.4
C660	5632	17.9	3698	5.8	4845	4.2	5294	14.9	6294	18.7	5904	58.2

Table 3: Interaction effect of change in temperature (T) and solar radiation (S) on yield of different *kharif* and *rabi* crops

Season	Crop	Temperature	S-2.5%		S+0%		S+2.5%	
			Grain yield ($kgha^{-1}$)	Change (%)	Grain yield ($kgha^{-1}$)	Change (%)	Grain yield ($kgha^{-1}$)	Change (%)
Kharif	Rice	T-3	5535	10	5740	14	5828	16
		T+0	4964	-2	5043	0	5120	2
		T+3	4700	-7	4779	-5	4891	-3
	Maize	T-3	4161	20	4247	23	4328	25
		T+0	3384	-2	3456	0	3523	2
		T+3	2976	-14	3047	-12	3118	-10
	Jowar	T-3	5717	23	5809	25	5900	27
		T+0	4561	-2	4646	0	4728	2
		T+3	3667	-21	3749	-19	3827	-18
	Bajra	T-3	6970	50	7184	55	7397	60
		T+0	4420	-5	4633	0	4839	4
		T+3	2734	-41	2916	-37	3095	-33
Rabi	Wheat	T-3	6296	4	6406	6	6504	8
		T+0	5907	-2	6032	0	6136	2
		T+3	4735	-22	4886	-19	5031	-17
	Barley	T-3	6236	30	6484	35	6712	40
		T+0	4542	-5	4803	0	5060	5
		T+3	2645	-45	2848	-41	3054	-36

productivity was increased by 1.8 per cent in rice, 2.0 per cent in maize, 1.8 per cent in *jowar*, 4.1 per cent in *bajra* during *kharif* season, and by 2.0 per cent in wheat and 4.9 per cent in barley during *rabi* season with an increase in solar radiation by 2.5 per cent from normal. Increase in solar radiation favoured increase in the growth and yields, whereas decrease in solar radiation favoured reduction in growth and yields. Similar findings were also reported by Hundal and Kaur (2007), Mishra *et. al.*(2015).

Effect of carbon dioxide change

The effect of expected enhanced carbon dioxide change from normal on productivity of different *kharif* and *rabi* crops are shown in Table 2. Productivity of different *kharif* and *rabi* crops increased under expected enhanced CO_2 concentrations. Productivity increased by 7.3 and 17.9 per cent in rice, by 1.7 and 5.8 per cent in maize, by 1.2 and 4.2 per cent in *jowar*, by 4.9 and 14.9 per cent in *bajra* during *kharif* season and by 7.7 and 18.7 per cent in wheat and by 20.4 and 58.2 per cent in barley under expected enhanced CO_2 concentrations of 445 and 660 ppm, respectively from normal. The increasing yield with increase in CO_2 level was attributed to greater LAI and net photosynthetic rates. Similar findings were also reported by Manpreet Kaur *et al.* (2013), Zacharias *et at.* (2014), Saxena and Naresh Kumar (2014) and Dubey *et al.* (2014).

Interaction effect of temperature and solar radiation change

Productivity of different *kharif* and *rabi* crops as affected by change of ± 3.0 °C in temperature and ±2.5 per cent in solar radiation from normal are presented in Table 3. The interactive effects of increasing temperature above normal and decreasing radiation below normal revealed a cumulative adverse effect on productivity of all *kharif* and *rabi* crops. The maximum decrease in productivity of barley crop (45%) in *rabi* season and minimum in rice crop (7%) in *kharif* season were simulated when a decrease in temperature by 3 ^{0}C and solar radiation by 2.5 per cent from normal. The productivity of remaining crops decreased by 14.0 per cent in maize, 21.0 per cent in *jowar*, 41.0 per cent in *bajra* during *kharif* season and by 22.0 per cent in wheat during *rabi* season when temperature increased by 3.0 °C and solar radiation decreased by 2.5 per cent from normal. While productivity increased by 16.0 per cent in rice, 25.0 in maize, 27.0 in *jowar*, 60.0 in *bajra* during *kharif* season and by 8.0 per cent in wheat and 40.0 per cent in barley during *rabi* season when temperature decreased by 3.0 °C and solar radiation increased by 2.5 per cent from normal. The

Table 4: Interaction effect of change in temperature and carbon dioxide (C) on yield of different *kharif* and *rabi* crops

Season	Crop	Temperature	C330		C445		C660	
			Grain yield (kgha^{-1})	Change (%)	Grain yield (kgha^{-1})	Change (%)	Grain yield (kgha^{-1})	Change (%)
Kharif	Rice	T-3	5324	11	5645	17	6134	27
		T+0	4812	0	4991	4	5324	11
		T+3	4193	-13	4739	-2	5438	13
	Maize	T-3	4191	25	4220	25	4326	29
		T+0	3365	0	3430	2	3568	6
		T+3	2927	-13	3014	-10	3201	-5
	Jowar	T-3	5768	26	5785	27	5873	29
		T+0	4560	0	4614	1	4762	4
		T+3	3619	-21	3722	-18	3901	-14
	Bajra	T-3	6929	62	7118	66	7505	75
		T+0	4276	0	4539	6	5076	19
		T+3	2612	-39	2832	-34	3301	-23
Rabi	Wheat	T-3	6045	7	6316	12	6846	21
		T+0	5635	0	6002	7	6438	14
		T+3	4234	-25	4820	-14	5599	-1
	Barley	T-3	5409	44	6307	68	7716	105
		T+0	3755	0	4554	21	6095	62
		T+3	2031	-46	2614	-30	3901	4

productivity of a crop can be taken as a product of rate of biomass accumulation (solar radiation-dependent) and growth duration (ambient air temperature-dependent). The results of the simulation indicate that these climatic variations could affect growth and yield of crops in the region. Highest potential productivity of a crop is therefore obtained in regions where crop duration is more under relatively low temperatures unless the radiation level is high. Increased shading associated with enhanced cloudiness may lead to spikelet sterility in *kharif* crops. Similar findings were also reported by Hundal and Kaur (2007), Byjesh *et al.* (2010) and Mishra *et al.* (2015).

Interaction effect of temperature and carbon dioxide change

Productivity of different *kharif* and *rabi* crops as affected by change of ± 3.0 °C in temperature and +115 and +330 ppm carbon dioxide concentration from normal are given in Table 4. The results of the simulation study for interactive effects of increasing temperature and CO_2 concentration revealed that the adverse effect of increase in temperature on productivity of rice, maize, *jowar*, *bajra* and barley were counter-balanced by favourable effect of increasing CO_2 levels. Productivity decreased by 13.0 per cent in rice, 13.0 per cent in maize, 21.0 per cent in *jowar*, 39.0 per cent in *bajra* during *kharif* season and by 25.0 per cent in wheat and 46 per cent in barley from normal when temperature increased by 3.0 ^{0}C from normal at 330 ppm carbon dioxide concentration. However, productivity increased by 27.0 per cent in rice, 29.0 per cent in maize, 29.0 per cent in *jowar*, 75.0 per cent in *bajra*, 21.0 per cent in wheat and 105 per cent in barley from normal when temperature decreased by 3.0 ^{0}C from normal under expected enhanced CO_2 concentration of 660 ppm. Highest counter-balance on productivity of rice crop (13%) in *kharif* season and lowest in *barja* crop (-23%) of *kharif* season were simulated when an increase in temperature by 3 ^{0}C from normal under expected enhanced CO_2 concentration of 660 ppm. Field Crops benefit from elevated CO_2 concentrations mainly due to increase in photosynthetic rates. However, increase in temperatures likely to offset this benefit due to CO_2 or even reduce the yields because cardinal temperatures influences crop physiological process and reproduction, thereby influencing grain yield. Similar findings were also reported by Manpreet Kaur *et. al.* (2013), Jacharias *et at.* (2014), Saxena and Naresh Kumar (2014) and Dubey *et al.* (2014).

CONCLUSION

The positive role of carbon dioxide in enhancing photosynthesis and productivity of plant is expected to counteract the negative effects of increase in temperature and decrease in solar radiation. Such simulation studies can guide us in determining the effect of climate variability and changes on productivity of different *kharif* and *rabi* crops and can be used for crop yield forecasting and further policy planning by government.

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