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Assessment of climate change impact on pulse, oilseed and vegetable crops at Varanasi, India

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ABSTRACT

Decision Support System for Agrotechnology Transfer (DSSAT v4.6.1) was used to study the impact of climate change and variability on productivity of different monsoon (pigeonpea and groundnut) and winter season crops (chickpea, mustard, tomato and potato) at Varanasi. Keeping in view the observed trends in climate variability, productivity of different cash crops were simulated under plausible synthetic climatic scenarios of changes in temperature and carbon dioxide. Productivity of pigeonpea and groundnut in monsoon season and mustard, tomato and potato in winter season decreased with an increase in temperature. Productivity of different pulse, oilseed and vegetable crops increased under expected enhanced CO_2 concentrations. Highest productivity decreased in pigeonpea crop (96.0%) in monsoon season and minimum in tomato crop (4.0%) in winter season with an increase of 3.0 °C in temperature above normal. Highest productivity increase in mustard crop (164.0%) in winter season and lowest in pigeonpea crop (33.0%) in monsoon season were simulated under projected enhanced CO_2 concentration of 760 ppm. Highest counter-balance in productivity of mustard crop (150%) followed by tomato crop (81%) during winter season and lowest in pigeonpea crop (99%) during monsoon season were simulated when an increase in temperature by 3.0 °C above normal under projected enhanced CO_2 concentration of 760 ppm.

Key words: Pulse, oilseed, vegetable, climate change, DSSAT v4.6.1, Varanasi, India

Pigeonpea and groundnut are important monsoon season crops and chickpea, mustard, tomato and potato are important winter season cash earning 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 (temperature, radiation, rainfall and carbon dioxide etc.) and variability can affect the yields of different 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 of water and nutrients (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 three 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. 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;

Gholipoor, 2007, Zacharias *et al.*, 2014; Salack *et al.,* 2015).

MATERIALS AND METHODS

Taking into account the anticipated regional climatic changes, the effects of changes in temperature and carbon dioxide and it's interaction on yield of different cash crops under Varanasi conditions were studied by using DSSAT v4.6.1 (Hoogenboom *et al.*, 2015). Summary of genetic coefficients of cultivars of different monsoon and winter 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°18' North latitude, 83°1' East longitude and 76 m altitude) were analysed to determine climatic variability trends by regressing yearly moving average of weather parameters against time. On the basis of climatic variability trends were observed in the district, three plausible synthetic scenarios of change in temperature (maximum and minimum) i.e. 1. T(-3): 3 °C decrease below normal, 2. T(0): normal, 3. T(+3): 3 °C increase above normal and three plausible synthetic scenarios of change in CO_2 i.e. 1. C380 (CO_2 380 ppm- normal), 2. C470 (50% increase over normal), 3. C760 (100% increase over normal) and it's interactions (9) 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 decremental/ incremental changes to temperature and CO_2 and applying these changes uniformly to baseline/normal climate was employed in the present study, while taking all the other climate variables to be normal (Yadav *et al.*, 2015). The percent change in productivity was calculated from the normal T(O) and C-380.

RESULTS AND DISCUSSION

Effect of temperature change

When maximum and minimum temperatures were changed by ±3.0 °C from normal, productivity, anthesis and maturity of pigeonpea and groundnut during monsoon season and chickpea, mustard, tomato, and potato during winter season affected substantially (Table 2). In general, increasing temperature had negative and decreasing temperature had positive impact on productivity of different pulse, oilseed and vegetable crops except chickpea. Phenology of each crop influenced by change in temperature. Similar findings were also reported by Behboudian and Lai (1994) and Hajarpoor *et al.*(2014). An increase of 3.0 °C in temperature above normal increased anthesis by 15 days and maturity by 16 days in pigeonpea, anthesis by 2 days and maturity by 5 days in groundnut and tuber initiation by 8 days in potato. Whereas, an increase of 3.0 °C in temperature above normal reduced anthesis by 6 days and maturity by 9 days in mustard, anthesis by 0 day and maturity by 12 days in tomato. A shortening of the growth cycle duration is mainly due to the increase in temperature, which accelerates the development phases of different crops. To complete a given phenological stage, a crop needs to accumulate heat (i.e. GDD). Under a warming climate, higher temperatures will result in a more rapid accumulation of GDD and therefore a reduction of some crop development phases and of the crop growth cycles (Salack *et al.,* 2015). Highest decrease in productivity of pigeonpea crop (96.0%) under monsoon season and lowest in tomato crop (4.0%) during winter season were simulated with an increase of 3.0 °C in temperature above normal. The productivity of remaining crops decreased by 35.0 per cent in groundnut under monsoon season and by 18.0 per cent in mustard and 19.0 per cent in potato under winter season with an increase in both temperatures i.e. maximum and minimum temperature by 3.0 °C above normal. High temperature decreases crop production by decreasing photosynthetic function and sugar and starch content, increasing respiration rate, suppressing floral development and hastening crop maturity (Jones, 1992; Abrol and Ingram, 1996). High temperature during reproductive stage causes abnormal development of the male/ female reproductive tissues, poor production of growth regulators in sink tissues, reduced supply of photosynthates, pollen production, pollen viability, fertilization, pod/ fruit/ seed-set/ tuber initiation (potato); all of which lead to poor productivity in pigeonpea (Kesava Rao *et al.*, 2013), groundnut (Prasad *et al.*, 2003; Piara Singh *et al.*, 2014) mustard (Boomiraj *et al.,* 2010; Kumar *et al.,* 2010; Rana *et al.,* 2011), tomato (Moore and Thomas, 1952; Mary *et al.*, 1997; Peet *et al.*, 1998; Ventrella *et al.*, 2012) and potato (Tubiello *et al.*, 2002). In chickpea, increasing temperature had positive and decreasing temperature had negative impact on productivity. Productivity of chickpea crop under winter season increased by 17.0 per cent with an increase in both temperatures by 3.0 °C above normal and decreased by 44.0 per cent with a decrease in both temperatures by 3.0 °C below normal. Cold stress i.e. temperature fall below 8 °C (Nayyar and Kumar, 2005) and also heat stress i.e. temperature (maximum/ minimum) rise above 40/25 °C (Devasirvatham *et al.*, 2012)

Table 1: Genetic coefficients of different cash crops used for simulation

VAR(Crop)	**ECO#**	**G2**	**G3**	**PD**	**P2**	**TC**													
K Badsah (Potato)	IB0001	1000	20	0.2	0.6	20													
	ECO#	**CSDL**	**PPSEN**	**EM-FL**	**FL-SH**	**FL-SD**	**SD-PM**	**FL-LF**	**LFMAX**	**SLAVR**	**SIZLF**	**XFRT**	**WTPSD**	**SFDUR**	**SDPDV**	**PODUR**	**THRSH**	**SDPRO**	**SDLIP**
K 850 (Chickpea)	DESI	11.00	-0.220	41.5	9.9	14.3	58.2	65	1.000	200	10	0.91	0.21	29.0	1.2	18	85	0.216	0.048
Varuna (Mustard)	DFAULT	16.00	-0.006	25.0	10.0	20.5	25.0	2.5	1.035	295	135	1.2	0.003	20.0	22.0	9.0	81	0.230	0.480
NDT-4 (Tomato)	TM0001	11.33	0.000	10.0	6.0	12.0	40	40	1.160	350	300	1.0	0.004	25.0	400	40	9	0.300	0.000
Kaushal (Groundnut)	PN0002	11.80	0.000	22.0	8.0	17.0	60.0	67	1.180	240	17	1.0	0.6	26.0	2.0	27	79	0.270	0.510
Type-21 (Pigeonpea)	PP0002	12.00	0.050	60.0	10.0	25.0	70	75	1.100	320	170	0.8	0.07	60.0	2.9	25	76	0.225	0.015

G2: Leaf area expansion rate after tuber initiation ($cm^2\ m^{-2}\ d$), **G3:** Potential tuber growth rate ($g\ m^{-2}\ d$), **PD:** Index that supresses tuber growth during the period that immediately follows tuber induction, **P2:** Tuber initiation sensitivity to long photoperiods, **TC:** Upper critical temperature for tuber initiation (C), **CSDL:** Critical Short Day Length below which reproductive development progresses with day length effect (for long day plants) (hour), **PPSEN:** Slope of the relative response of development to photoperiod with time (negative for long day plants) ($1\ hr^{-1}$), **EM-FL:** Time between plant emergence and flower appearance (R1) (photothermal days), **FL-SH:** Time between first flower and first pod (R3) (photothermal days), **FL-SD:** Time between first flower and first seed (R5) (photothermal days), **SD-PM:** Time between first seed (R5) and physiological maturity (R7) (photothermal days), **FL-LF:** Time between first flower (R1) and end of leaf expansion (photothermal days), **LFMAX:** Maximum leaf photosynthesis rate at 30 ^{0}C, 350 ppm CO_2, and high light(mg $CO_2\ m^{-2}\ s$), **SLAVR:** Specific leaf area of cultivar under standard growth conditions($cm^2\ g^{-1}$), **SIZLF:** Maximum size of full leaf (three leaflets) (cm^2), **XFRT:** Maximum fraction of daily growth that is partitioned to seed + shell, **WTPSD:** Maximum weight per seed (g), **SFDUR:** Seed filling duration for pod cohort at standard growth conditions (photothermal days), **SDPDV:** Average seed per pod under standard growing conditions (# pod^{-1}), **PODUR:** Time required for cultivar to reach final pod load under optimal conditions (photothermal days), **THRSH:** The maximum ratio of (seed/(seed+shell)) at maturity causes seed to stop growing as their dry weights increase until shells are filled in a cohort. (Threshing percentage), **SDPRO:** Fraction protein in seeds (g(protein) g^{-1}(seed)), **SDLIP:** Fraction oil in seeds (g(oil) g^{-1}(seed)).

Table 2: Effect of change in temperature and carbon dioxide on yield, anthesis /tuber initiation, maturity of different pulse, oilseed and vegetable crops

Weather parameter	Pigeonpea (Pulse)		Groundnut (Oilseed)		Chickpea (Pulse)		Mustard (Oilseed)		Tomato (Vegetable)		Potato (Vegetable)	
	Yield (tha^{-1})	Change (%)	Yield (tha^{-1})	Change (%)	Yield (tha^{-1})	Change (%)	Yield (tha^{-1})	Change (%)	Yield (tha^{-1})	Change (%)	Yield (tha^{-1})	Change (%)
Temperature												
T (-3)	3.0	30	3.7	19	1.0	-44	3.2	88	48	7	57	0
T (0)	2.3		3.1		1.8		1.7		45		57	
T(+3)	0.1	-96	2.0	-35	2.1	17	1.4	-18	43	-4	46	-19
CO_2												
C380	1.5		2.3		1.2		1.1		31		48	
C470	1.8	20	3.1	35	1.7	42	2.3	109	48	55	54	13
C760	2.0	33	3.4	48	2.0	67	2.9	164	58	87	58	21
	Anthesis (Days)	Change (Days)	Anthesis (Days)	Change (Days)	Anthesis (Days)	Change (Days)	Anthesis (Days)	Change (Days)	Anthesis (Days)	Change (Days)	Tuber initiation (Days)	Change (Days)
Temperature												
T (-3)	76	-11	30	1	70	13	74	18	8	1	44	-2
T (0)	87		29		57		56		7		46	
T(+3)	102	15	31	2	49	-8	50	-6	7	0	54	8
CO_2												
C380	88		30		59		60		7		48	
C470	88	0	30	0	59	0	60	0	7	0	48	0
C760	88	0	30	0	59	0	60	0	7	0	48	0
	Maturity (Days)	Change (Days)	Maturity (Days)	Change (Days)	Maturity (Days)	Change (Days)	Maturity (Days)	Change (Days)	Maturity (Days)	Change (Days)	Maturity (Days)	Change (Days)
Temperature												
T (-3)	139	-12	112	3	120	13	136	21	116	27	-	-
T (0)	151		109		107		115		89		-	-
T(+3)	167	16	114	5	98	-9	106	-9	77	-12	-	-
CO_2										-	-	
C380	152		112		108		119		94		-	-
C470	152	0	112	0	108	0	119	0	94	0	-	-
C760	152	0	112	0	108	0	119	0	94	0	-	-

Table 3 (a): Interaction effect of change in temperature and carbon dioxide on yield of different pulse, oilseed and vegetable crops

Season	Crop	Change in temp.	C380		C470		C760	
			Yield (t ha^{-1})	Change (%)	Yield (t ha^{-1})	Change (%)	Yield (t ha^{-1})	Change (%)
Monsoon	Pigeonpea (Pulse)	T (-3)	2.4	33	3.1	72	3.4	89
		T (0)	1.8	-	2.4	33	2.7	50
		T (+3)	0.2	-89	0.02	-99	0.01	-99
	Groundnut (Oilseed)	T (-3)	2.9	16	4.0	60	4.3	72
		T (0)	2.5	-	3.3	32	3.6	44
		T (+3)	1.5	-40	2.1	-16	2.3	-8
Winter	Chickpea (Pulse)	T(-3)	0.8	-38	1.0	-23	1.2	-8
		T (0)	1.3	-	1.8	38	2.2	69
		T (+3)	1.6	23	2.2	69	2.6	100
	Mustard (Oilseed)	T (-3)	1.8	125	3.5	338	4.2	425
		T (0)	0.8	-	1.9	138	2.4	200
		T (+3)	0.7	-13	1.5	88	2.0	150
	Tomato (Vegetable)	T (-3)	33.9	12	50.8	68	60.5	100
		T (0)	30.2	-	47.2	56	57.3	90
		T (+3)	30.0	-1	45.7	51	54.7	81
	Potato (Vegetable)	T (-3)	51.3	-1	57.5	11	61.7	19
		T (0)	51.8	-	57.5	11	61.5	19
		T(+3)	40.7	-21	46.4	-10	50.7	-2

during reproductive growth of chickpea is detrimental to flowering and pod set. Devasirvatham *et al.* (2012) explained that the high temperatures (40/25) reduced pod set and seed number by reducing pollen viability and pollen production per flower, per cent pollen germination. Singh *et al.* (2012) observed that temperatures continue to rise from (29/14) in the beginning of March and reaches around 40/25 till the end of April at Varanasi but it could not touch upper limit (40/25) that detrimental to flowering and pod- set in chickpea even after an increase in both temperatures by 3.0 °C above normal therefore, detrimental effect of high temperature might not appear on Chickpea crop. However, productivity increase by 19.0 per cent in groundnut and 30.0 per cent in pigeonpea during monsoon season, 88.0 per cent in mustard, 7.0 per cent in tomato during winter season with a decrease in both temperatures by 3.0 °C below normal.

Effect of carbon dioxide change

The effect of expected enhanced carbon dioxide change from normal on productivity, anthesis and maturity of different pulse, oilseed and vegetable crops are shown in Table 2. Results of simulation showed that increasing CO_2 concentration had no direct effect on anthesis and maturity of different crops. Similar findings also reported by Behboudian and Lai (1994) and Hajarpoor *et al.*(2014). Productivity of different pulse, oilseed and vegetable crops grown during monsoon and winter season increased under expected enhanced CO_2 concentrations. Highest productivity increase in mustard crop (164.0%) followed by tomato crop (87.0%) under winter season and lowest in potato crop (21.0%) during winter season was simulated under expected enhanced CO_2 concentration of 760 ppm. The productivity increased by 20.0 and 33.0 per cent in pigeonpea, by 35.0 and 48.0 per cent in groundnut under monsoon season; by 42.0 and 67.0 per cent in chickpea, by 109.0 and 164.0 per cent in mustard, by 55.0 and 87.0 per cent in tomato and by 13.0 and 21.0 per cent in potato under expected enhanced CO_2 concentrations of 470 and 760 ppm, respectively from normal. In 2 × CO_2 scenario, grain yield was greater than that of normal simulations; this increase was a result of the improved radiation use efficiency (RUE) and transpiration efficiency (TE) due to increased CO_2 concentration. Different crops benefit from elevated CO_2 concentrations mainly due to increase in photosynthetic rates. Elevated CO_2 generally stimulates leaf-level

Table 3 (b): Interaction effect of change in temperature and carbon dioxide on anthesis of different pulse, oilseed and vegetable crops

Season	Crop	Change in temp.	C380		C470		C760	
			Anthesis (Days)	Change (Days)	Anthesis (Days)	Change (Days)	Anthesis (Days)	Change (Days)
Monsoon	Pigeonpea (Pulse)	T (-3)	76	-11	76	-11	76	-11
		T (0)	87	-	87	0	87	0
		T (+3)	102	15	102	15	102	15
	Groundnut (Oilsseed)	T (-3)	30	1	30	1	30	1
		T (0)	29	-	29	0	29	0
		T (+3)	31	2	31	2	31	2
Winter	Chickpea (Pulse)	T(-3)	70	13	70	13	70	13
		T (0)	57	-	57	0	57	0
		T (+3)	49	-8	49	-8	49	-8
	Mustard (Oilseed)	T (-3)	74	18	74	18	74	18
		T (0)	56	-	56	0	56	0
		T (+3)	50	-6	50	-6	50	-6
	Tomato (Vegetable)	T (-3)	8	1	8	1	8	1
		T (0)	7	-	7	0	7	0
		T (+3)	7	0	7	0	7	0
	Potato (Vegetable)	T (-3)	44	-2	44	-2	44	-2
		T (0)	46	-	46	0	46	0
		T(+3)	54	8	54	8	54	8

photosynthesis, which can be translated into more assimilation and accelerated development. The increasing yield with increase in CO_2 level was attributed to greater LAI and net photosynthetic rates. Results are close conformity with findings of Prasad *et al.* (2003), Piara Singh *et al.*(2014), Manpreet Kaur *et al.* (2013), Zacharias *et al.* (2014), Saxena and Naresh Kumar (2014) and Dubey *et al.* (2014).

Interaction effect of temperature and carbon dioxide change

Productivity, anthesis and maturity of different pulse, oilseed and vegetable crops as affected by change of ± 3.0 °C in temperature and +190 and +380 ppm carbon dioxide concentration from normal (380 ppm) are given in Table 3 (a)-(c). The result of the simulation study shows that there is no interactive effect of change in temperature and CO_2 concentration on phenology of different cash crops [Table 3 (b)-(c)]. The effect of combined climate change scenarios on phenology did not differ with increasing CO_2 scenarios; this indicated that the fastest crop development was only due to the increase in temperature. Phenology responses to climate change may alter the ability of plants to acquire soil resources (water and nutrients) by altering the timing and duration of the deployment of roots and leaves, which drives resource acquisition. This reduced period happens in a significantly wetter part of the year, sufficient to outweigh the lower radiation levels before and during grain filling. Hajarpoor *et al.* (2014) in his simulation results showed that doubling CO_2 concentration had no direct effect on chickpea phenology but its indirect effect through increasing the temperature reduced days to flowering. They also reported that a faster crop development occurred in chickpea with increase in temperature (T+2°C, T+4°C and T+6°C), the growing period from sowing to flowering was shortened and maturity dates were occurred earlier. Productivity decreased by 89.0 per cent in pigeonpea, 40.0 per cent in groundnut during monsoon season; 13.0 per cent in mustard, 1.0 per cent in tomato and by 21.0 per cent in potato during winter season from normal when temperature increased by 3.0 °C above normal at 380 ppm carbon dioxide concentration. Highest counter-balance on productivity of mustard crop (150%) of winter season and lowest in pigeonpea crop (99%) in monsoon season were simulated when an increase in temperature by 3 °C above normal under expected enhanced CO_2 concentration of 760 ppm [Table 3 (a)]. The

Table 3 (c): Interaction effect of change in temperature and carbon dioxide on maturity of different pulse, oilseed and vegetable crops

Season	Crop	Change in temp.	C380		C470		C760	
			Maturity (Days)	Change (Days)	Maturity (Days)	Change (Days)	Maturity (Days)	Change (Days)
Monsoon	Pigeonpea (Pulse)	T (-3)	139	-12	139	-12	139	-12
		T (0)	151	-	151	0	151	0
		T (+3)	167	16	167	16	167	16
	Groundnut (Oilsseed)	T (-3)	112	3	112	3	112	3
		T (0)	109	-	109	0	109	0
		T (+3)	114	5	114	5	114	5
Winter	Chickpea (Pulse)	T(-3)	120	13	120	13	120	13
		T (0)	107	-	107	0	108	1
		T (+3)	98	-9	98	-9	98	-9
	Mustard (Oilseed)	T (-3)	136	21	136	21	136	21
		T (0)	115	-	115	0	115	0
		T (+3)	106	-9	106	-9	106	-9
	Tomato (Vegetable)	T (-3)	116	27	116	27	116	27
		T (0)	89	-	89	0	89	0
		T (+3)	77	-12	77	-12	77	-12
	Potato (Vegetable)	T (-3)	-	-	-	-	-	-
		T (0)	-	-	-	-	-	-
		T(+3)	-	-	-	-	-	-

adverse effect of increase in temperature on productivity of pulse, oilseed and vegetable crops except chickpea were counter-balanced by favourable effect of increasing CO_2 levels. Prasad *et al.* (2003) observed that increasing temperature above 32/22 ^{0}C significantly decreased pollen viability and flower, seed and pod-set under ambient (350 ppm) and elevated CO_2 (700ppm) to a similar extent in groundnut. In general, limiting the global mean temperature change of 2 °C, the elevated CO_2 concentration showed a positive effect in minimizing the negative impacts of climate change on productivity of tomato (Ventrella *et al.*, 2012). Elevated CO_2 generally stimulates leaf-level photosynthesis, which can be translated into more assimilation and accelerated development. 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 the yields. Results are close conformity with findings of Manpreet Kaur *et. al.* (2013), Zacharias *et al.* (2014), Saxena and Naresh Kumar (2014), Piara Singh *et al.* (2014) and Dubey *et al.* (2014). Whereas, productivity increased by 89.0 per cent in pigeonpea and 72.0 per cent in groundnut during monsoon season, 425.0 per cent in mustard, 100.0 per cent in tomato and 19 per cent in potato during winter season from normal when temperature decreased by 3.0 °C below normal under expected enhanced CO_2 concentration of 760 ppm.

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. Such simulation studies can guide us in determining the effect of climate variability and changes in climate on productivity of different pulse, oilseed and vegetable crops and can be used for crop yield forecasting and further policy planning by government.

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