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Impact assessment of climate change through CROPGRO and CERES model for *tarai* region of Uttrakhand

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ABSTRACT

The study aimed impact assessment of climate change through CROPGRO and CERES model for *Tarai* region of Uttrakhand. CERES and CROPGRO models v4.5 were used in this study for assessment of climate change. The results revealed that the CERES and CROPGRO models satisfactorily simulated the temperature, solar radaiation and CO_2 concentration effects on yield. Increase in solar radiation from 1 to 2 MJ m^{-2} day^{-1} for black gram showed decrease in yield by 12 to 15% with root mean square error (RMSE) (222.46), mean bias error (MBE) (-220.50) and percent error (PE) (14.04) while decrease in solar radiation by 1 to 2 MJ m^{-2} day^{-1} showed gradual increase in yield by 1 to 18% of black gram with RMSE (211.02), MBE (+157.00) and PE (13.32). Simulated grain yield of black gram by CROPGRO model under augmented unit of maximum temperature (+1 to +3 °C) demonstrated continuous decrease in yield ranging from 1378 to 860 kg ha^{-1} (13 to 45%). Similarly, under declined units of maximum temperature (-1 to -2^{0}C), showed gradual increase in yield ranging from 1650 to 1682 kg ha^{-1} (4.17 to 19%). Enhancement in CO_2 levels showed gradual increase in yield by 1803 to 2083 kg ha^{-1}, even though decrease in CO_2 level by -120 ppm the yield decreased by 28% for black gram crop. CERES model results exposed that increase in solar radiation from 1 to 2 MJ m^{-2} day^{-1} corroborate increase in yield with RMSE (163.94), MBE (+157.00) and PE (4.14) while, decrease in solar radiation by 1 to 2 MJ m^{-2} day^{-1} showed gradual decline in wheat yield with RMSE (607.14), MBE (+157.00) and PE (4.14). Decrease in CO_2 level by -120 ppm from base, the simulated yield was decreased by 28% for wheat crop with RMSE (1129.00), MBE (-1129.00) and PE (28.50).

Key words:
CERES,
CROPGRO,
Climate change,
Radiation,
Tempreature,
CO_2 concentration

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) is the most widely cultivated food crop in Uttrakhand region. Wheat is grown from November-December and harvested in March-April. It is a *rabi* season irrigated crop. Wheat growth and developmental is influenced by number of factors such as agro-climatic conditions, soil, water regimes and genetic variability. Black gram (*Vigna mungo* L. Hepper) is common pulse crop in the *Tarai* region of Uttrakhand. It is *kharif* season crop, having growth period from July-August to November-December. Global climate variability and change caused by natural processes as well as anthropogenetic factors are major and important environmental issues. Climate change involve in alteration of climatic parameters such as temperature, precipitation, incease in sea level and increase in ultraviolet radiation in the atmosphere of Earth as a result degrading environment changing the growing rate of extinction of species, declining availability of water, loss of fertile land (Manna, *et al.,* 2015). The earth's climate has exhibited marked 'natural' variations and changes, with time scales varying from many millions of years down to a few years. Agricultural sector is perhaps the most sensitive and vulnerable to climate change (Alexandrov and Hoogenboom, 2000). Crop models can help researchers, policymakers, and farmers to make correct decisions on crop management practices, and also for marketing strategies and food security of a country with a deterministic view on the import-export market (Kumar *et al.,* 2012). The DSSAT has been in use for more than 15years in over 100 countries worldwide (Kumar *et al.,* 2014). Exponential growth of CO_2 and other greenhouse gasses in the atmosphere is causing climate change. The Decision Support System for Agrotechnology Transfer (DSSAT) was originally developed by an international network of scientists, cooperating in the International Benchmark Sites Network for Agrotechnology Transfer project (Jones *et al.,* 1998), to facilitate the application of crop models in a systems approach to agronomic research. Pandey *et al.* (2007) reported that under gradual increase in CO_2 concentration from 440 to 660 ppm, the yield levels of wheat crop increased to the tune of 21 to 68% under optimal conditions. Caldag and Saylan (2005) applied the CERES-wheat model during 1997-98 and 1998-99 to determine the sensitivity of the model with the changes in meteorological factors, such as air temperature, precipitation, solar radiation and CO_2 concentration. Bootee *et al.* (2002) explored that the CROPGRO model simulates different grain legume species using external parameter files that describe species process sensitivity to environment plus files describing cultivar differences. Hence, an attempt was made in this study to evaluate the yield of wheat and black gram under variable weather conditions through environmental modifications component of DSSAT model.

2. MATERIALS AND METHODS

Pantnagar is situated at *tarai* belt, foothills of the Shivalik range of Himalayas at 29°1'N, latitude, 79.28°E longitude and at an altitude of 243.8 m above msl. The study site is located in *tarai* belt of India and is characterized by sub humid and sub tropical climate The CERES-Wheat model v4.5 was used for simulation of daily phenological development and growth in response to environmental factors (soils, weather and management). CROPGRO-Dry Bean model version v4.5 was used for black gram in this study. The main time step in CROPGRO is one day, corresponding to the daily weather information, but it computes canopy photosynthesis in hourly time steps using leaf-leve l photosynthesis parameters and hedge-row light interception calculations (Boote *et al.,* 1998).

Although the ability of the CROPGRO model to simulate observed soil water content and yields in different regions has been established (Uehara and Tsuji, 1998), the model is quite complex and requires many model input parameters to be determined. The data base included all relevant information including the different management practices adopted, location specific soil and weather conditions obtained from field experiment conducted during *kharif* and *rabi* seasons at NE Borlaug, Crop Research Center, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttrakhand. In the present study, replicated data of 2007-08 and 2008-09 of wheat and black gram were used in the model calibration and validation processes. Black gram (*V. mungo* L. Hepper) variety Pant urd-31 and Wheat (*T. aestivum* L.) variety UP-2565 was used in this study. Wheat crop were sown on 18 November, 2007 and 1 November 2008 and black gram crop were sown on 7 July, 2007 and 20 July, 2008. The climate scenario simulated for temperature, solar radiation and CO_2 concentration (against base concentration of 330 ppm) looking to the projected climate change scenario (Pandey *et al.,* 2007). Yield of wheat and black gram crops was simulated under the influence of individual parameter as well as combination with others.

The summary measures describe the quality of simulation while the difference measures try to locate and quantify errors. The analysis includes the Mean Bias Error (MBE), Root Mean Square Error (RMSE), and Percent Error (PE).

$$\text{MBE} = \sum_{i=1}^{n} (F_i - O_i)/n \quad ...(1)$$

$$\text{RMSE} = \left[\sum_{i=1}^{n} (F_i - O_i)^2/n\right]^{1/2} \quad ...(2)$$

MAE and RMSE indicate the magnitude of the average error, but provide no information on the relative size of the average difference between forecast (F_i) and observed (O_i). The statistic MBE describes the direction of the error bias. The value of MBE is related to the magnitude of the values under investigation. A negative MBE indicates that the forecasting is smaller in values than those of the corresponding observations. PE is defined as ratio of RMSE to mean observed value ($\bar{O}$) expressed as percentage (Varshneya *et al.,* 2010).

$$\text{PE} = \frac{\text{RMSE}}{\bar{O}} \times 100 \quad ...(3)$$

3. RESULTS AND DISCUSSION

Derivation of Genetic Coefficient

The genetic coefficient required in the CERES and CROPGRO models version 4.5 n estimated by varietal character input is incorporated in the model in the form of "genetic coefficients". An inbuilt program in DSSAT called GENCALC, calculates genetic coefficients, repeated interactions in the model calculations until a close match between simulated and observed phenology, growth and yield obtained. The genetic coefficients determined in CERES and CROPGRO model using the identical management and other conditions as in the field experiments presented in Table 1 and Table 2, respectively. These coefficients were used in the subsequent validation and application.

Model Calibration and Validation

Model calibration is the adjustment of parameters so that simulated values can be compared with observed data.

Table: 1
Genetic coefficients of wheat cultivars used in the CERES-wheat version 4.5 model

Code	Gen.	Parameters
VAR#	IN0701	Identification code or number for a specific cultivar.
VAR. NAME	UP-2565	Name of cultivar.
P1V	38	Relative amount that development is slowed for each day of un-fulfilled vernalization, assuming that 50 days of vernalization is sufficient for all cultivars
P1D	36	Relative amount that development is slowed when plants are grown in one hour photoperiod shorter than the optimum (which is considered to be 20 hours).
P5	750	Degree days above a base of 1^{0}C from 20^{0}C days after anthesis to maturity.
G1	30	Kernel number per unit weight of stem (less leaf blades and sheaths) plus spike at anthesis (g^{-1})
G2	20	Kernel filling rate under optimum conditions (mg day^{-1}).
G3	1.3	Non stressed dry weight of a single stem (excluding leaf blades and sheaths) and spike when elongation ceases.
PHINT	80.0	In determining the vegetative development of wheat, it is necessary to define a term related to leaf appearance, the phyllochron. A phyllochron is defined herein as the interval of time between leaf tip appearances; in the CERES-Wheat model it is the variable PHINT.

Table: 2
Genetic coefficients of black gram cultivars used in the CROPGRO version 4.5 model

Code	Gen.	Parameters
ECO#	Pant black gram- 31	Code for the ecotype to which this cultivar belongs
CSDL	11.17	Critical Sho Critical Short Day Length below which reproductive development
PPSEN	0.04	Slope of the slope of the relative response of development to photoperiod with time (positive for short-day short day plants (1/hour)
EM-FL	33.0	Time between plant emergence and flower appearance (R1)
FL-SH	2.0	Time between first flower and first pod (R3) (photothermal days)
FL-SD	11.0	Time between first flower and first seed (R5) (photothermal days)
SD-PM	28.5	Time between first seed (R5) and physiological maturity (R7) (photothermal days)
FL-LF	7.0	Time between first flower (R1) and end of leaf expansion (photothermal days)
LFMAX	1.0	Maximum Maximum leaf photosynthesis rate at 30 C, 350 vpm CO2, and high light (mg CO2/m2-s)
SLAVR	295	Specific leaf area of cultivar under standard growth conditions (cm2/g)
SIZLF	133	Maximum size of full leaf (three leaflets) (cm2)
XFRT	1.0	Maximum fraction of daily growth that is partitioned to seed + shell
WTPSD	0.55	Maximum weight per seed (g)
SFDUR	11.0	Seed filling duration for pod cohort at standard growth conditions (photothermal days)
SDPDV	3.5	Average seed per pod under standard growing conditions (#/pod)
PODUR	3.5	Time required for cultivar to reach final pod load under optimal conditions (photothermal days)
THRSH	78	The maximum ratio of (seed/(seed+shell)) at maturity (Threshing percentage).
SDPRO	0.235	Fraction protein in seeds (g(protein)/g(seed))
SDLIP	0.030	Fraction oil in seeds (g(oil)/g(seed))

The Genotype Coefficients that influence the occurrence of development stages in the DSSAT can be derived interactively by manipulating the relevant coefficient to achieve the exact match between the simulated and observed days to phenological stages. The genotype coefficients used in simulation modelling for wheat are given in Table 1. The GENCALC software does this type of adjustment automatically and therefore uses the observations of phenological stages from the experiments. The DSSAT model was calibrated using detailed replicated data of the 2007 field trial and tested with the data of the 2008.

Effects of Temperature, Solar Radiation and CO_2 Concentration on Black Gram Yield

The effects of temperature, solar radiation and CO_2 concentration on black gram yield have been presented in Table 3. Simulated grain yield of black gram by CROPGRO model under augmented unit of maximum temperature (+1 to +3°C) demonstrated continues decrease in yield ranging from 1378 to 860 kg ha^{-1} (13 to 45%). The error analysis for enhanced in maximum temperature shows RMSE (534.18) (eq. 1), MBE (-489.33) (eq. 2), and PE (33.72) (eq. 3). Similarly, under declined units of maximum temperature (-1 to -2°C), showed gradual increase in yield ranging from 1650 to 1682 kg ha^{-1} (4.17 to 19%). The error analysis for declined temperature shows RMSE (83.55), MBE (+82.00) and PE (5.27). Likewise, increase in minimum temperature conferred decreasing tendency in yield ranging from 1490 to 1320 kg ha^{-1} (5 to 16%). The error analysis for enhancement in minimum temperature shows RMSE (192.29), MBE (-179.33) and PE (12.14). While, decrease in minimum temperature by 1°C evinced increase in yield as compared to other levels afterwards decline in 2°C illustrated decrease in yield, the lower minimum temperature by 1°C may have auspicious effect on crop. The error

Table: 3
Simulated black gram and wheat yield due to altering of temperature, solar radiation and CO_2 concentration

Change in parameter	Black gram		Wheat	
	Simulated grain yield (kg ha^{-1})	% change from optimal (1584 kg ha^{-1})	Simulated grain yield (kg ha^{-1})	% change from optimal (3961kg ha^{-1})
Maximum temperature (°C)				
+1	1378	-13.01	3938	-0.58
+2	1046	-33.96	3924	-0.93
+3	860	-45.71	3843	-2.97
-1	1650	4.17	3923	-0.95
-2	1682	6.19	3916	-1.13
Minimum Temperature (°C)				
+1	1490	-5.93	3937	-0.61
+2	1404	-11.36	3892	-1.74
+3	1320	-16.67	3801	-4.04
-1	1524	-3.79	3944	-0.43
-2	1468	-7.32	3957	-0.10
Solar radiation (MJ m^{-2} day^{-1})				
+1	1393	-12.06	4073	2.83
+2	1334	-15.78	4164	5.12
-1	1600	1.01	3627	-8.43
-2	1882	18.81	3170	-19.97
CO_2 concentration (Base value 330 ppm)				
+120	1803	13.83	4100	3.51
+220	1964	23.99	4206	6.19
+320	2083	31.50	4236	6.94
-120	1136	-28.28	2832	-28.50

analysis for reduction in minimum temperature shows RMSE (92.35), MBE (-88.00) and PE (5.83).

The biochemical part of plants is controlled by enzyme activity which is temperature dependent. The enzymes are protein in nature and sensitive to temperature. As temperature exceeds cardinal level there is a decline in stomatal opening which may be due to higher CO_2 concentration caused by increased rate of transpiration. The results confirmed that black gram crop is vastly sensitive to both temperature levels; this is due to at higher temperature levels disruption of cell metabolism, production of toxic substances and damage to cellular membrane (Murty, 2002).

The increase in solar radiation from +1 to +2 MJ m^{-2} day^{-1} proved decrease in yield and yield oscillated between 1393 to 1334 kg ha^{-1} (12 to 15%), while decrease in solar radiation by -1 to -2 MJ m^{-2} day^{-1} showed gradual increase in yield by 1600 to 1882 kg ha^{-1} (1 to 18%). The error analysis for enhancement in solar radiation shows RMSE (222.46), MBE (-220.50) and PE (14.04). Black gram being a *kharif* season crop and lower solar radiation during this time may have positive impact of growth and development. Radiant energy transmitted in the form of electromagnetic waves from the sun. The energy from the sun is spread over a broad band of wavelength is known as radiation. The middle part of spectrum which is visible is known as light. It is essential for all plant processes and ranges from 0.4 to 0.7 microns. CROPGRO model dispensed higher grain yield at decreasing solar radiation (-1 to -2 MJ m^{-2} day^{-1}) this is due to elevated solar radiation may have adverse effect on germicidal action, morphogenic effects and large effects on physiological process.

The error analysis for diminution in solar radiation shows RMSE (211.02), MBE (+157.00) and PE (13.32).

CROPGRO simulation model runs were carried out for different CO_2 levels *viz.* +120, +220, +320 ppm and -120 ppm with base values of 330 ppm. The result revealed that increase in CO_2 levels showed bit-by-bit increase in yield by 1803 to 2083 kg ha^{-1} (13 to 31%). The error analysis for augment in CO_2 levels shows RMSE (383.56), MBE (+366.00) and PE (24.21). Although decrease in CO_2 level by -120 ppm the yield was 1136 kg ha^{-1}. The increase in yield under increased CO_2 level may be due to rubisco efficiency under elevated CO_2 level of may require less amount of nitrogen for optimum biomass production. The error analysis for decrease in CO_2 levels shows RMSE (448.00), MBE (-448.00) and PE (28.28) (Table 4). Photosynthetic rates increased at high CO_2 and high nitrogen which might have aided better grain filling and enhanced grain yield (Reddy *et al.,* 1995). Kimball (1983), on the basis of their evaluation of several hundreds of studies of this kind showed an average increment in biomass production in C3 plants more in response to a doubling of CO_2 concentrations. The pulse crops showed a better response to elevated CO_2 levels. Earlier studies with cowpea grown in controlled environmental chambers showed positive growth responses to elevated CO_2 (Mbikayi *et al.,* 1983).

Combined Effects of Temperature and CO_2 Concentration on Black Gram Yield

The Combined effects of temperature and CO_2 concentration on black gram yield have been presented in Table 5. The combined effect of augmented CO_2 concentration at the rate of +120 ppm with 1°C increase in maximum temperature showed increase in yield by 1.77%

Table: 4
Error analysis of simulated black gram and wheat yield due to altering for temperature, solar radiation and CO_2 concentration

Change in parameter	Black gram			Wheat		
	RMSE	MBE	PE	RMSE	MBE	PE
Maximum temperature (°C)						
+1	534.18	-489.33	33.72	72.62	-59.33	1.83
+2						
+3						
-1	83.55	+82.00	5.27	41.65	-41.50	1.05
-2						
Minimum Temperature (°C)						
+1	192.29	-179.33	12.14	101.55	-84.33	2.56
+2						
+3						
-1	92.35	-88.00	5.83	12.35	-10.50	0.31
-2						
Solar radiation (MJ m^{-2} day^{-1})						
+1	222.46	-220.5	14.04	163.94	+157.50	4.14
+2						
-1	211.02	+157.0	13.32	607.14	-562.50	15.33
-2						
CO_2 concentration (Base value 330 ppm)						
+120	383.56	+366.00	24.21	227.28	+219.67	5.74
+220						
+320						
-120	448.00	-448.00	28.28	1129.00	-1129.00	28.50

RMSE : Root mean square error; MBE : Mean bias error ; and PE : Percent error

Table: 5
Simulated black gram and wheat yield due to altering of temperature, solar radiation and CO_2 concentration

Change in parameter			Black gram		Wheat	
			Simulated grain yield (kg ha^{-1})	% change from optimal (1584 kg ha^{-1})	Simulated grain yield (kg ha^{-1})	% change from optimal (3961kg ha^{-1})
+120 (ppm) CO_2 concentration)	+1	Max. T. (°C)	1612	1.77	4175	5.40
(Base value 330 ppm	+2		1214	-23.36	4140	4.52
	-1		1897	19.76	4115	3.89
	-2		1924	21.46	4120	4.01
	+1	Min. T. (°C)	1753	10.67	4107	3.69
	+2		1638	3.41	4096	3.41
	-1		1773	11.93	4138	4.47
	-2		1712	8.08	4168	5.23
+220 (ppm) CO_2 concentration	+1	Max. T. (°C)	1779	12.31	4329	9.29
(Base value 330 ppm)	+2		1329	-16.10	4284	8.15
	-1		2045	29.10	4273	7.88
	-2		2208	39.39	4268	7.75
	+1	Min. T. (°C)	1980	25.00	4303	8.63
	+2		1796	13.38	4236	6.94
	-1		1908	20.45	4299	8.53
	-2		1848	16.67	4319	9.04
+320 (ppm) CO_2 concentration	+1	Max. T. (°C)	1881	18.75	4441	12.12
(Base value 330 ppm)	+2		1443	-8.90	4378	10.53
	-1		2310	45.83	4375	10.45
	-2		2339	47.66	4384	10.68
	+1	Min. T. (°C)	2102	32.70	4414	11.44
	+2		2034	28.41	4322	9.11
	-1		2204	39.14	4403	11.16
	-2		2121	33.90	4446	12.24

Max. T.: Maximum Temperature; Min. T.: Minimum Temperature while at 2°C yield were decreased by 23% (1214 kg ha^{-1}) with RMSE (262.38), MBE (-171.00) and PE (16.56) and decline in 1 and 2°C maximum temperature showed gradual increase in yield by 19% and 21% w with RMSE (326.78), MBE (+326.50) and PE (20.63). The model was also run for the effect of minimum temperature (+1, +2, -1 and -2) at same CO_2 concentration. The result showed that decline in 1°C minimum temperature have positive effect on yield and yield increased by 11% and increase in temperature showed comparatively decrease in yield. The error analysis for CO_2 concentration at the rate of +120 ppm shows RMSE (125.45), MBE (+111.50) and PE (7.92) for 1 to 2 degree enhancement in minimum temperature, similarly the error for 1 to 2 degree reduction in minimum temperature revealed RMSE (161.41), MBE (+158.50) and PE (10.19) at CO_2 concentration (+120 ppm).

CROPGRO model run result for the +220 ppm CO_2 concentration with minimum and maximum temperature combinations showed that increase in maximum temperature by 1°C resulted increase in yield by 12% and 2°C enhancement showed diminishing in yield by 16%. The error analysis for CO_2 concentration at the rate of +220 ppm shows RMSE (226.99), MBE (-30.00) and PE (14.33) for 1 to 2 degree enhancement in maximum temperature, similarly the error for 1 to 2 degree reduction in maximum temperature at same CO_2 level revealed RMSE (161.41), MBE (+158.50) and PE (10.19). While decrease in maximum temperature by 1 to 2°C produce significantly increase in yield by 29 and 39%. Equivalently result at same CO_2 level with minimum temperature (+1, +2, -1 and -2) correspond to higher yield at decrease in minimum temperature 1 and 2°C with yield 20 and 16% higher than normal. The error analysis for CO_2 concentration at the rate of +220 ppm shows RMSE (317.62), MBE (+304.00) and PE (20.05) for 1 to 2 degree enhancement in minimum temperature, similarly the error for 1 to 2 degree reduction in minimum temperature at same CO_2 level revealed RMSE (295.53), MBE (+294.00) and PE (18.66).

CROPGRO model was also run at +320 ppm CO_2 concentration with higher and lower maximum and minimum temperature combinations (+1, +2, -1 and -2). The error analysis for CO_2 concentration at the rate of +320 ppm shows RMSE (232.48), MBE (+78.00) and PE (14.68) for 1 to 2 degree enhancement in maximum temperature, similarly the error for 1 to 2 degree reduction in maximum temperature at same CO_2 level revealed RMSE (740.64), MBE (+740.50) and PE (46.76). At higher concentration levels, decline in 1 to 2°C maximum temperature levels showed burly increase in yield by 45 to 47% similarly decline in minimum temperature by 1 to 2°C showed higher yield. It can further be revealed that at higher CO_2 concentration levels and decline in maximum temperature conceded good results. The error analysis for CO_2 concentration at the rate of +320 ppm shows RMSE (485.19), MBE (+484.00) and PE (30.63) for 1 to 2 degree enhancement in minimum temperature, similarly the error for 1 to 2 degree reduction in minimum temperature at same CO_2 level revealed RMSE (579.99), MBE (+578.50) and PE (36.62) (Table 6).

Vanaja, *et al.* (2007) reported that total biomass was increased by 65% at 700ppm and 39% at 550 ppm CO_2 concentration levels. There is growing evidence suggesting that C3 crops are likely to produce more harvestable products and that both C3 and C4 crops are likely to use less water with rising atmospheric CO_2 in the absence of stressful conditions. However, the beneficial direct impact of elevated CO_2 on crop yield can be offset by other effects of climate change, such as elevated temperatures and altered patterns of precipitation. Changes in food quality in a warmer, high-CO_2 world are to be expected, *e.g.* decreased protein and mineral nutrient concentrations, as well as altered lipid composition (Matta *et al.,* 2009). Further growth and yield of any crop is also largely determined by radiation interception, the efficiency of conservation of intercepted radiation to dry matter and partitioning of dry matter in to grain (Kar and Kumar, 2015).

Effects of Temperature, Solar Radiation and CO_2 Concentration on Wheat Yield

The effects of temperature, solar radiation and CO_2 concentration on black gram yield have been presented in Table 3. Simulated grain yield of wheat by CERES-wheat model under inflated units of maximum temperature (+1 to + 3°C) elucidated slight decrease in yield ranging from 3938 to 3843 kg ha^{-1} (0.58 to 2.97%). The error analysis for enhanced in maximum temperature shows RMSE (72.62), MBE (-59.33) and PE (1.83). Correspondingly under decline units of maximum temperature (-1 to -2°C) affirmed gradual decrease in yield ranging from 3923 to 3916 kg ha^{-1} (0.95 to 1.31%), which is comparatively lower. The error analysis for turn down in maximum temperature shows RMSE (41.65), MBE (-41.50) and PE (1.05). Furthermore, increase in minimum temperature exposed depletion tendency in yield ranging from 3937 to 3801 kg ha^{-1} (0.61 to 4.04%) with RMSE (101.55), MBE (-84.33) and PE (2.56) decrease in minimum temperature by 2°C evinced minor decrease in yield by 0.10 % with RMSE (12.35), MBE (-10.50) and PE (0.31). Subsequently decline in 1 to 2°C maximum temperature delineated decrease in yield, the lower minimum temperature by 2°C may have favourable effect on crop.

At low temperature, water is more viscous, protoplasm less permeable to water and root growth inhibited. The combined effects of these factors cause reduction in water absorption at low temperature. The high temperature also

Table: 6
Error analysis of simulated black gram and wheat yield due to combined altering of temperature and CO_2 concentrations

Change in parameters			Black gram			Wheat		
			RMSE	MBE	PE	RMSE	MBE	PE
+120 (ppm) CO_2 concentration (Base value 330 ppm)	+1	Max. T. (°C)	262.38	-171.00	16.56	197.28	+196.50	4.98
	+2							
	-1		326.78	+326.50	20.63	156.52	+156.50	3.95
	-2							
	+1	Min. T. (°C)	125.45	+111.50	7.92	140.61	+140.50	3.55
	+2							
	-1		161.41	+158.50	10.19	192.59	+192.00	4.86
	-2							
+220 (ppm) CO_2 concentration (Base value 330 ppm)	+1	Max. T. (°C)	226.99	-30.00	14.33	346.23	+345.50	8.74
	+2							
	-1		548.59	+542.50	34.63	309.51	+309.50	7.81
	-2							
	+1	Min. T. (°C)	317.62	+304.00	20.05	310.31	+308.50	7.83
	+2							
	-1		295.53	+294.00	18.66	348.14	+348.00	8.79
	-2							
+320 (ppm) CO_2 concentration (Base value 330 ppm)	+1	Max. T. (°C)	232.48	+78.00	14.68	449.60	+448.50	11.35
	+2							
	-1		740.64	+740.50	46.76	418.52	+418.50	10.57
	-2							
	+1	Min. T. (°C)	485.19	+484.00	30.63	409.59	+407.00	10.34
	+2							
	-1		579.99	+578.50	36.62	464.00	+463.50	11.71
	-2							

Max. T.: Maximum Temperature; Min. T.: Minimum Temperature; RMSE : Root mean square error; MBE : Mean bias error ; and PE : Percent error

inhibit mineral uptake because of denaturation of enzymes involved either directly in mineral absorption or in synthesis of some essential components. The nitrate reductase actively decreased under high temperature resulted in reduction in protein content (Brady and Well, 2005). Aggarwal and Kalra (1994) and Pandey *et al.* (2007) also reported decline in wheat yield due to rise in ambient temperature. Pathak *et al.* (2003) reported based on sensitivity analysis of CERES-wheat model that higher maximum temperature decreased wheat yield significantly.

Exaggeration in solar radiation from 1 to 2 MJ m^{-2} day^{-1} proved increase in yield and yield ranged between 4073 to 4164 kg ha^{-1} (2 to 5%) with RMSE (163.94), MBE (+157.50) and PE (4.14) while decrease in solar radiation by 1 to 2 MJ m^{-2} day^{-1} showed gradual decline in yield by 3627 to 3170 kg ha^{-1} (8 to 19%) with RMSE (607.14), MBE (-562.50) and PE (15.33) (Table 4). CERES-wheat model showed higher grain yield at accretion solar radiation by 1 to 2 MJ m^{-2} day^{-1}. Wheat crop is a *rabi* season crop and gradual increase in solar radiation during this time may have positive impact of growth and development. These verdicts have been in conformity with the findings of Pandey *et al.* (2007) and Aluka (2003) using WTGROWS and InfoCrop models for wheat.

CERES wheat model's weather modification component was carried out for different CO_2 levels *viz.* +120, +220, +320 ppm and -120 with base values of 330 ppm. The result revealed that increase in CO_2 levels showed gradually increase in yield by 4100 to 4236 kg ha^{-1} (3 to 6%) with RMSE (227.28), MBE (+219.67) and PE (5.74). Though decrease in CO_2 level by -120 ppm the yield was 2832 kg ha^{-1} with RMSE (1129.00), MBE (-1129.00) and PE (28.50). Pandey *et al.* (2007) have reported that CO_2 concentration beneficial for higher productivity. Idso and Idso (2000) have also reported that increased CO_2 concentration had resulted in mean yield increases of 70% for cereals.

Combined Effects of Temperature and CO_2 Concentration on Wheat Yield

The combined effects of temperature and CO_2 concentration on wheat yield have been presented in Table 4. The combined effect of augmented CO_2 concentration at the rate of +120 ppm with 1 and 2°C increase in maximum temperature showed increase in yield by 5% (4175 kg ha^{-1}) and 4% (4140 kg ha^{-1}) by way of RMSE (197.28), MBE (+196.50) and PE (4.95) and decline in 1 and 2°C maximum temperature showed gradual increase in but comparatively lower with RMSE (156.52), MBE (+156.50) and PE (3.95). The model was also run for the effect of minimum temperature (+1, +2, -1 and -2) at similar CO_2 concentration levels. The error structure for increase in minimum temperature (1 to 2°C) was of RMSE (140.61), MBE (+140.61) and PE (3.55). The result showed that decline in 1 and 2°C minimum temperature yield increased by 5 and 4%

while increase in minimum temperature by 1 and 2°C also revealed increase in yield with RMSE (192.59), MBE (+192.00) and PE (4.86).

CERES-wheat model was also run for the +220 ppm CO_2 concentration with minimum and maximum temperature combinations result showed that increase in maximum temperature by 1 and 2°C resulted increase in yield by 9 and 8 % with RMSE (346.23), MBE (+345.50) and PE (8.47) and decline in 1 and 2°C maximum temperature showed increment in yield by 7% with RMSE (309.51), MBE (+309.50) and PE (7.81). The error structure for increase in minimum temperature (1 to 2°C) at +220 ppm CO_2 concentration was of RMSE (310.31), MBE (+308.50) and PE (7.83). Equivalently result at same CO_2 level with minimum temperature (+1, +2, -1 and -2) correspond to higher yield at decrease in minimum temperature 1 and 2°C with yield 8 and 9 % higher than normal with RMSE (348.14), MBE (+348.00) and PE (8.79).

The model (CERES-wheat) was also run at +320 ppm CO_2 concentration with higher and lower maximum and minimum temperature combinations (+1, +2, -1 and -2). The error structure reveals that at +320 ppm CO_2 concentration level with enhancement (1 to 2°C) and declining (1 to 2°C) of maximum temperatures the RMSE (449.60), MBE (+448.50), PE (11.35) and RMSE (418.52), MBE (+418.50), PE (10.57), respectively were recorded. At higher concentration levels decline in 1 to 2°C maximum temperature levels showed burly increase in yield by 12 and 10% similarly decline in minimum temperature by 1 to 2°C showed 10% higher yield. The error structure reveals that at +320 ppm CO_2 concentration level with enhancement (1 to 2°C) and declining (1 to 2°C) of minimum temperatures the RMSE (409.59), MBE (+407.00), PE (10.34) and RMSE (464.00), MBE (+463.50), PE (11.71) were recorded (Table 6).

It is observed that at higher CO_2 concentration levels than normal none of the temperature combination revealed decrease in yield. High temperatures reduce the net carbon gain in C3 species by increasing photorespiration; by reducing photorespiration, CO_2 enrichment is expected to increase photosynthesis more at high than at low temperatures, and thus at least partially offsetting the temperature effects of supra-optimal temperatures on yield (Long, 1991). Therefore, yield increases at high CO_2 levels should occur most frequently in regions where temperatures approximate the optimum for crop growth. Conversely, in regions where high temperatures already are severely limiting, further increases in temperature will depress crop yield regardless of changes in CO_2 (Polley, 2002).

4. CONCLUSIONS

In shorten, study revealed that the increase in minimum and maximum temperature reduces the black gram yield, while decrease in maximum temperature have positive increment in yield. At higher solar radiation levels less yields were observed and at lower solar radiation levels higher yield were reported for black gram. The CROPGRO model for black gram shows at higher CO_2 concentration levels (+120, +220 and +330) significant increase the yield, while at +330 ppm CO_2 concentration levels, regarding declining of temperature of by -1 to -2°C, the yield was significantly increased with MBE (+740.50). The CERES model for wheat crop reveals to enhancement in +1 and +2 MJ m^{-2} day^{-1} solar radiation levels shown increase in yield with MBE (+157.50) and increase in CO_2 concentration levels (+120, +220 and +330) extensively increased the wheat yield with MBE (+219.67). Wheat yield exhibited positive effects towards higher CO_2 concentration levels. The CERES-wheat and CROPGRO model's component environment modification was able to simulate grain yield under variable weather conditions. The adaptation strategies for climate change scenario can be evaluated through DSSAT model. Our result confirms the possibility of applying DSSAT to predict the yield of various crops. Assessing such effects is important at the producer as well as at the government level for planning purposes, and models such as DSSAT are expected to play a major role in that area.

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