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A CASE STUDY

Climate change vulnerability assessment through environment modification component of DSSAT model for wheat and urd in Uttrakhand

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ABSTRACT : The study aimed the impact assessment of climate change through DSSAT model for *Tarai* region of Uttrakhand. The results revealed that the DSSAT model logically simulated the temperature, solar radiation, day length and CO_2 concentration effects on yield of wheat and urd. Increase in maximum and minimum temperature by +1 to +3^{0}C, solar radiation +1 to +3 MJ m^{-2} day^{-1}, CO_2 concentrations +120 to +330 ppm from the base values 330 ppm, day length +1 to +3 hour/day for urd crop showed decline in yield by 23 to 71 per cent, while wheat crop performance under such conditions revealed increase in yield by 10 to 14 per cent. Similarly, urd crop performance under decrease in maximum and minimum temperature by -1 to -3^{0}C, solar radiation -1 to -3 MJ m^{-2} day^{-1}, CO_2 concentrations -120 to -330 ppm from the base values 330 ppm, day length -1 -to -3 hour/day also exposed large decline in yield 22 to 98 per cent and wheat yield declined by 28 to 91 per cent. The analysis revealed that the DSSAT model may play great role in climate change impact assessment for different crops.

Key Words :
DSSAT model, Climate change, Radiation, Tempreature, CO_2 concentration, Day length

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A change of climate which is attributed directly or indirectly to human activity that alters the composition of global atmosphere and that is in addition to climate variability observed over comparable time period. Climate change is one of the greatest environmental, social and economic threats facing the planet. Climate change is very harmful from the agriculture point of view. Productivity of crops is also determined by the weather conditions prevailed during the growing season. There are different weather requirements for different crop growth stages. A crop simulation model is a principal tool needed to bring agronomic sciences in to the information age. Through these crop models, it became possible to simulate a living plant through the mathematical and conceptual relationship which governs its growth in the soil atmospheric continuum (Thornley, 1976). The crop growth models are helpful to assess the impact of climate change on the stability of crop production under different management options (Hoogenboom *et al*., 1995). The DSSAT generates future weather scenarios by helping the model to make more reliable predictions, anticipating the variability in weather conditions (Jame and Cutforth, 1996). Earlier studies also focused on the use of a weather generator programme to understand the effects of weather variability on agricultural prediction (Muchow *et al.*, 1991; Baffaut *et al*., 1996; Jones and Thornton, 1997; Luo *et al*., 2003). Integrating the effects of soil, crops, weather and management options, DSSAT also provides the facility to evaluating the reliability of model outputs, allowing users to compare simulated outcomes with real world results.

Experimental Methodology

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 the mean sea level. 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-model version v4.5 was used for blackgram in this study. 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 N.E. Borlaug, Crop Research Centre, 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 blackgram were used in the model calibration and validation processes. Blackgram [*Vigna mungo* (L.) Hepper] variety Pant urd- 31 and wheat (*Triticum aestivum* L.) variety UP-2565 were used in this study. Wheat crop was sown on 18 November, 2007 and 1 November, 2008 and black gram crop was sown on 7 July, 2007 and 20 July, 2008. The climate scenario simulated for temperature (± 1 to 3^{0}C), solar radiation (± 1 to 3 MJ m^{-2} day^{-1}), day length (± 1 to 3 hours) and CO_2 concentration (± 120, 220 and 320 ppm against present concentration of 330 ppm) looking to the projected climate change scenario (Pandey *et al.,* 2007).

Experimental Findings and Discussion

The results obtained from the present investigation are presented below :

Derivation of genetic co-efficient :

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

Combined effects of temperature, solar radiation, day length and CO_2 concentration on black gram yield :

The combined effects of temperature, solar radiation, day length and CO_2 concentration on blackgram yield have been shown in Table 3. The combined run of CROPGRO model for yield at elevated 1^{0}C maximum temperature, 1^{0}C minimum temperature, 1 MJ m^{-2} day^{-1}, 1 hour day^{-1} day length and 120 ppm CO_2 concentration (base value 330 ppm) notified decrease in yield by 23 per cent (1210 kg ha^{-1}). One of the most consistent effects of elevated atmospheric CO_2 on plants is an increase in the rate of photosynthetic carbon fixation by leaves. Plants therefore, regulate the degree of stomatal opening (related to a measure known as stomatal conductance) as a compromise between the goals of maintaining high rates of photosynthesis and low rates of water loss. As CO_2 concentrations increase, plants can maintain high photosynthetic rates with relatively low stomatal conductance. Experiments, growth under elevated CO_2 decreases stomatal conductance of water by an average of 22 per cent (Ainsworth and Rogers, 2007). This would be expected to decrease the overall plant water use, although the magnitude of the overall effect of CO_2 will depend on how it affects other determinants of plant water use, such as plant size, morphology, and leaf temperature. Similarly decrease in all parameters (2^{0}C maximum temperature, 2^{0}C minimum temperature, 2 MJ m^{-2} day^{-1}, 2 hour day^{-1} day length and 220 ppm CO_2 concentration) had negative impact on yield by 1046 kg ha^{-1} (decrease from optimal 33.96 %). Moreover, model performance at high values of weather modifications parameters (3^0 C maximum temperature, 3^0C minimum temperature, 3 MJ m^{-2} day^{-1}, 3 hour day^{-1} day length and 320 ppm CO_2 concentration) revealed significantly decrease in yield by 71 per cent with blackgram yield 455 kg ha^{-1}. CROPGRO model was also run for the lower combinations of weather parameters, model performance under subjacent values of weather parameters*viz.*, -1^0C maximum temperature, -1^0 C minimum temperature, -1 MJ m^{-2} day^{-1} , -1 hour day^{-1} day length and -120ppm CO_2 concentration (base value 330 ppm) revealed higher yield as compared to elevated values of weather parameters. Under such conditions, the yield was 1224 kg ha^{-1} which was 22 per cent lower than optimal run but comparatively higher. Solar radiation facilitates photosynthesis, which allows the plants to survive and convert light energy to chemical energy. In particular, plants produce oxygen

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

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°C from 20°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).
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 co-efficients of blackgram cultivars used in the CROPGRO model version 4.5

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 (R_1)
FL-SH	2.0	Time between first flower and first pod (R_3) (photothermal days)
FL-SD	11.0	Time between first flower and first seed (R_5) (photothermal days)
SD-PM	28.5	Time between first seed (R_5) and physiological maturity (R_7) (photothermal days)
FL-LF	7.0	Time between first flower (R_1) and end of leaf expansion (photothermal days)
LFMAX	1.0	Maximum leaf photosynthesis rate at 30 C, 350 vpm CO_2 and high light (mg CO_2/m_2-s)
SLAVR	295	Specific leaf area of cultivar under standard growth conditions (cm_2/g)
SIZLF	133	Maximum size of full leaf (three leaflets) (cm_2)
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)

and carbohydrates, which, in turn, enable to breathe and produce energy.

While further decrease in all weather parameters revealed remarkably decline in yield by 258 and 18 kg ha^{-1} (83 and 98 % less). Temperature effects on the rates of biochemical reactions may be modelled as the product of two functions, an exponentially increasing rate of the forward reaction and an exponential decay resulting from enzyme denaturation as temperatures increase. The shape of this function also describes temperature effects on most biological functions, including plant growth and development. The function can be categorized by the three cardinal temperatures - minimum, optimum and maximum. Modellers frequently simplify the relationship into a stepwise linear function. The stepwise linear function has a plateau rather than an optimum

Table 3 : Simulated blackgram and wheat yield due to combined altering of temperature, solar radiation, CO_2 concentration and day length

	Blackgram (CROPGRO model)		Wheat (CERES model)	
Change in parameters	Simulated grain yield (kg ha^{-1})	% change from optimal (1584 kg ha^{-1})	Simulated grain yield (kg ha^{-1})	% change from optimal (3961 kg ha^{-1})
+1 (°C) max.T. +1 (°C) min.T. +1 (MJ m^{-2} day^{-1}) solar radiation +120 (ppm) CO_2 concentration (base value 330 ppm) +1 (hours) day length	1210	-23.61	4380	10.58
+2 (°C) max.T. +2 (°C) min.T. +2 (MJ m^{-2} day^{-1}) solar radiation +220 (ppm) CO_2 concentration (base value 330 ppm) +2 (hours) day length	1046	-33.96	3900	-1.54
+3 (°C) max.T. +3 (°C) min.T. +3 (MJ m^{-2} day^{-1}) solar radiation +320 (ppm) CO_2 concentration (base value 330 ppm) +3 (hours) day length	455	-71.28	4531	14.39
-1 (°C) max.T. -1 (°C) min.T. -1 (MJ m^{-2} day^{-1}) solar radiation -120 (ppm) CO_2 concentration (base value 330 ppm) -1 (hours) day length	1224	-22.73	2822	-28.76
-2 (°C) max.T. -2 (°C) min.T. -2 (MJ m^{-2} day^{-1}) solar radiation -220 (ppm) CO_2 concentration (base value 330 ppm) -2 (hours) day length	258	-83.71	569	-85.63
-3 (°C) max.T. -3 (°C) min.T. -3 (MJ m^{-2} day^{-1}) solar radiation -320 (ppm) CO_2 concentration (base value 330 ppm) -3 (hours) day length	18	-98.86	332	-91.62

temperature.

Combined effects of temperature, solar radiation, day length and CO_2 concentration on wheat yield :

Crop simulation models are useful tools to account for the complexity of plant and crop responses to variation in water supply and weather and are increasingly used to assess the possible impact on food production of future global change. The combined effects of temperature, solar radiation, day length and CO_2 concentration on blackgram yield have been presented in Table 3. The combined run of CERES-wheat model's weather modification component for yield at elevated 1^0C maximum temperature, 1^0C minimum temperature, 1 MJ m^{-2} day^{-1}, 1 hour day^{-1} day length and 120 ppm CO_2 concentration (base value 330 ppm) illustrated increase in yield by 10 per cent with grain yield 4380 kg ha^{-1}, while decrease in all parameters (2^0 C maximum temperature, 2^0C minimum temperature, 2 MJ m^{-2} day^{-1}, 2 hour day^{-1} day length and 220 ppm CO_2 concentration) had pessimistic impact on yield by 3900 kg ha^{-1} (decrease from optimal 1.54 %). Wheat, barley and other small grains are cool season crops. Accordingly, they develop best when temperatures are cool; yield is favoured by daily maximum temperatures. During grain filling, high temperatures reduce the rate of photosynthesis, thereby reducing the amount of starch available to the developing kernel. Rates of grain fill actually accelerate with increasing temperatures, but the maximum kernel weight is reduced due to a dramatically shortened grain filling period. This is particularly true if night temperatures are also high. The reduction in kernel weight can be attributed to a reduction in the deposition of starch. So, though kernel size is reduced with high temperatures, the amount of protein deposited in the kernel will largely be unaffected, resulting in kernels with a high concentration in protein. Limitation of water supply reduces wheat productivity in many parts of the world. Increased atmospheric CO_2 concentration, CO_2 tends to increase wheat growth and yield more under drought conditions as compared with conditions with unlimited water supply. This has been explained by the reduction in stomatal conductance and water use induced by CO_2 elevation. Effects of CO_2 on wheat also depend on weather conditions, e.g. temperature. However, the overall understanding of the interactive effects of drought and CO_2 on wheat in relation to climatic conditions is limited. One could say that is good news, but in a year like this, there will almost certainly be no premium for high protein, so the value of the higher protein will not begin to make up for the loss of yield. As growers begin harvest, they should expect to see smaller kernels, lower yields and high proteins as a result of the high temperatures we have experienced during these last few weeks. Furthermore, for late planted crops, yields will be substantially reduced because of the added impact of higher temperatures during the vegetative stage on spike size and tiller numbers. Furthermore, model performance at elevated values of weather modifications parameters (3^0C maximum temperature, 3^0C minimum temperature, 3 MJ m^{-2} day^{-1}, 3 hour day^{-1} day length and 320 ppm CO_2 concentration) revealed again increase in yield by 14 per cent with yield 4531 kg ha^{-1}, this is may be due to higher CO_2 concentration, solar radiation and temperature levels may have positive effect of photosynthesis. CERES-wheat model was also run for lower combinations of weather parameters, model performance under lower values of weather parameters at -1^0 C maximum temperature, -1^0 C minimum temperature, -1 MJ m^{-2} day^{-1}, -1 hour day^{-1} day length and -120 ppm CO_2 concentration (base value 330 ppm) revealed lower yield as compared to elevated values of weather parameters. Under such conditions, the yield was 2822 kg ha^{-1} which was 28 per cent lower than optimal run. While further decrease in all weather parameters revealed extreme decline in yield by 569 and 332 kg ha^{-1} (85 and 91 %). Absorption of light in excess of photosynthetic utilization by green plant leaves may lead to a reduction in the potential efficiency of photosystem, which persists in low light or darkness and is regarded as the major cause of "photoinhibition of photosynthesis" (Baker and Bowyer, 1994). It has been shown for many plant species that photoinhibition of photosynthesis does occur under natural conditions (Long *et al.*, 1994). Although the effects of UV light, particularly those of the biologically more active UV light, on plants and specifically on photosynthesis have been extensively investigated, little information is available on plant responses to ambient UV radiation. With a few exceptions, published studies have involved the application of artificial supplementary UV light, often creating conditions unlikely to occur in nature.

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