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Modeling impacts and adaptations of climate change on soybean (*Glycine max*) production in Himachal Pradesh, India

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ABSTRACT

Soybean [*Glycine max* (L.) Merr.], one of the commercial crops grown under rainfed conditions in Himachal Pradesh produced low yields due to uneven weather conditions. This study presents outcome of a simulation study to evaluate the impact of projected climate change on yields of soybean and simulated adaptations in the face of climate change. During past three decades the region has experienced increase in temperature and decrease in rainfall. The validated InfoCrop model runs for 20 years (1989-2008) to assess impacts of the projected climate change on soybean production. The Root Mean Square Error (RMSE) values were 8.8 days and 190.4 kg/ha for days to maturity and crop yield between simulated and observed yields of five years (2004-08) under two sowing environments. The elevated levels of 50 and 100 parts per million (ppm) carbon dioxide (CO_2) increased soybean yield by 5.0 to 10.2%. The projected yield losses due to elevated levels of temperature by 1 and 2°C alone ranged between 1.3 to 3.5 and 4.5 to 6.0 percent respectively, for all planting windows. The elevated temperature of 1°C coupled with 50 ppm elevated level of carbon dioxide (420ppm) showed increase in yield up to 4.9 percent with shortened average growing period up to 2 days. The further rise of temperature to 2°C with 50 ppm elevated level of carbon dioxide caused increase in simulated yield up to 2.3 percent in simulations of 1989-2008 compared to control conditions. Similarly, 100 ppm elevated level of carbon dioxide with 1°C rise in temperature caused increase in yield between 8.8 to 10.2 percent in all planting windows whereas it was 3.1 to 3.9 percent lesser in 2°C rise in temperature with 100 ppm elevated level of carbon dioxide with compared to 1°C rise in temperature. The climatic grid of 10 percent reduction in rainfall from recent decade 1998-2008 showed small decrease in yield but yield increase of 5.2 to 8.5 percent was observed when coupled with 50 ppm elevated carbon dioxide and 1°C rise in temperature. Hence rise of temperature with elevated carbon dioxide in general increase the yield in region.

Key words: Climate change, InfoCrop, Simulation, Soybean

Indian agriculture contributes to 8% global agricultural gross domestic product to support 18% of world population on only 9% of world's arable land and 2.3% of geographical area (Anonymous 2011a). The reshaping of rainfed agriculture for higher productivity of crops is essential to meet the future demand of foods in the face of changing climatic conditions. Soybean [*Glycine max* (L.) Merr.] is a rich source of oil and protein, provides 25 percent of world's total oil and fat production thus, expected to combat the aggravated problem of malnutrition across the world. Its area has recorded unprecedented growth from 0.03 m ha to 9.30 m ha during the period 1970 to 2010 (Anonymous 2011b). The increasing trends towards fast adaptation of the crop by the farmers', multi use of by-products provide ample scope to increase area under soybean in India. Its cultivation is bound to bring affirmative socio-economic changes in the life of farmers. Globally, India ranks fifth in terms of production of soybean. The low production and productivity levels are mainly due to unpredictable rainfall and erratic onset of south west monsoon which resulted into staggered planting of soybean in major crop growing regions of the country (Anonymous 2012). Soybean is cultivated in Himachal Pradesh during *kharif* season as a pure and component crop with maize as rainfed crops. The crop suffered from severe weather aberrations (onset and recession of monsoon), distribution of rains and total amount of precipitation. Therefore, soybean production has suffered in all parts of the country and this fluctuating soybean production particularly in the state is a matter of concern. Decreasing trends in soybean productivity in recent years attributed to various factors including climatic factors (Sharma and Gupta 2002). In general, weather plays an important role during growing season of the crop on its growth and yield. However, divergence in normal weather may impair the effectiveness of externally applied inputs

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and thus food production. Projected changes in global climate include increasing atmospheric carbon dioxide concentration and temperatures which have significant effects on plants, however, their interactions are not clearly known to date. This may be attributed to the higher photosynthate availability, as a consequence of the higher growth rate under elevated CO_2 (Erice *et al.* 2011). Crop simulation models are used over past 20 to 30 years by scientist to hypothesize ways to improve agricultural production under seasonal and daily variability in weather (Boote *et al*. 2008). The present study was carried out with the objective to study the influence of projected weather parameters (temperature, CO_2 and rainfall) on performance of soybean under sub-humid climate of Himachal Pradesh.

MATERIALS AND METHODS

InfoCrop growth model considers the processes such as crop growth and development (phenology, photosynthesis, partitioning, leaf area growth, storage organ numbers, source: sink balance, transpiration, uptake, allocation and redistribution of nitrogen), effects of water, nitrogen, temperature, flooding and frost stresses on crop growth and development, crop-pest interactions (damage mechanisms of insects and diseases), soil water balance, soil nitrogen balance, soil organic carbon dynamics, emissions of green house gases and climate change module. The basic model is written in Fortran Simulation Translator programming language (Jones *et al*. 2001). More details of the model are provided by Aggarwal *et al*. (2006a, b). InfoCrop has been successfully adapted, calibrated and validated for soybean under Indian conditions.

The input data files required for running the InfoCrop growth model are crop/variety master, soil texture master and weather data files. Crop/variety file is used to enter the crop variety details and its parameters. These parameters the so called genotypic coefficients, characterize the basic physiological behavior of a variety. *Weather file:* daily radiation or bright sunshine hours, daily maximum and minimum temperature, rainfall are essential parameters, whereas wind speed and vapour pressure are the optional parameters required to run the model. In addition to this latitude, longitude and altitude of the area is also required to calculate the solar radiation receipt on the earth surface in the model. *Soil texture file*: For three soil layers depth (mm) the parameters like organic carbon (%), soil texture (sand, silt, clay %), bulk density, hydraulic saturated conductivity and NH_4-N and NO_3-N content are needed. *Plant:* Seed rate, specific leaf area of variety, grain weight. Crop management includes date of sowing, dates of irrigation and fertilizer application.

The standard output comprises dry weight of roots, stem, leaves, grain number and grain yield, leaf area index, N uptake by crop, soil water and N content, evapotranspiration, N and water stress.

For calibration and validation of the model for days to maturity and grain yield of soybean, the observed data were procured from Palampur for two dates of sowings, i e 10^{th} and 20^{th} June for the period of five years (2004-2008). Crop coefficients for soybean were calculated by using information from a wide literature survey. These coefficients were used in the subsequent validation and application. To evaluate model performance and accuracy in prediction, statistical indicator of root mean square error (RMSE) was computed from observed and simulated variables (days to maturity and grain yield of soybean). An excellent parity between observed and simulated phenological events in varied weather condition reflects the consistency in model performance.

The region under study experience sub-humid sub-temperate climate with mean rainfall of 1700 mm during *kharif* season. The crop seasonal climate scenarios/grids of 1 and 2ºC rise in maximum and minimum temperature, elevated carbon dioxide by 50 and 100 ppm and 10% reductions deficit rainfall were used in the model to assess the impact of projected climate variability. The model was run for 20 years from 1989 to 2008 for Palampur weather stations. The weather data of 1989 to 2008 was used and mean simulated yield of 20 years and coefficient of variance were worked out to draw the conclusion. The elevated levels of carbon dioxide, temperature and change in rainfall were compared with control. The control signifies no change in rainfall and temperature and 370 ppm carbon dioxide level or the prevailing climatic conditions in the region.

RESULTS AND DISCUSSION

Validation of model

InfoCrop-soybean was calibrated by two phenological parameters, i.e. days to maturity and grain yield of soybean obtained from All India Coordinated Research project (AICRP) on soybean for recommended package and practice. Simulation of model (2004-08) predicted both the phenological stages with the experimental data. The simulated days to maturity were projected 7 to 12 more to the actually observed in the field (Fig 1). The RMSE values for days taken to maturity were 8.8 days. The economic yield simulated by model corresponded well with that actually observed in the field. The RMSE value for yield was 190.4 kg/ha during *kharif* season at two sowing windows from 2004 to 2008 (Fig 2). Setiyono *et al*. (2010) studied different crop growth models and revealed that simulation of seed yield across the validation sites with CROPGRO-Soybean, Sinclair-Soybean, WOFOST, and SoySim resulted in RMSE values of 0.72, 0.91, 1.61, and 0.46 Mg/ha, respectively.

Simulated impact of climate change on soybean

Impact on planting windows

The simulated results on phenology (Table 1) indicated 10 June sown crop to be the best planting window for soybean under rainfed conditions in Himachal Pradesh followed by 20 June. The recent decade (1999-08) indicated increase of 4.7 to 6.2% in yield and took 1.8 to 3.8 days less for maturity over the first decade (1989-98). On an average

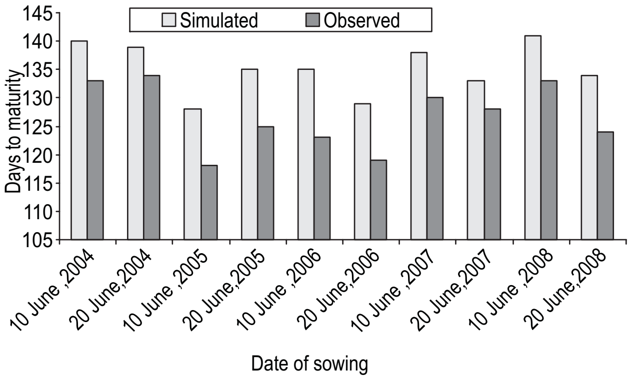

Fig 1 Validation of InfoCrop model for days to maturity of Soybean

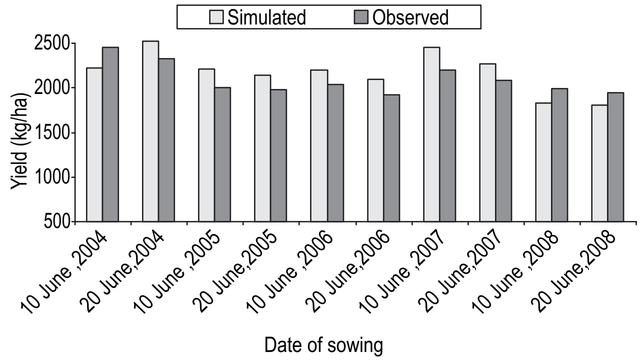

Fig 2 Validation of InfoCrop model for grain yield of Soybean

Table 1 Impact of climate change on soybean yield and days to maturity

Planting window	1989-98		1999-08		Change over 1989-98	
	Yield (kg/ ha)	Days to maturity	Yield (kg/ ha)	Days to maturity	Yield (%)	Days to maturity (No.)
10 June	2214.3 (29.5)	141.8 (11.2)	2338.5 (33.0)	140.0 (5.0)	+ 5.6	- 1.8
20 June	2005.6 (35.5)	138.0 (13.7)	2100.3 (39.2)	135.9 (5.2)	+ 4.7	- 2.1
30 June	1566.4 (51.6)	134.8 (15.0)	1663.4 (54.3)	131.0 (6.2)	+ 6.2	-3.8

The values in parenthesis are the coefficient of variation (%)

141 days were taken for maturity by 10 June sown crop followed by 20 June (137) and 30 June (133) sown crop. The coefficient of variation for yield was higher during the recent decade (1998-08) at all the planting windows under study. On the other hand, days to maturity taken by soybean showed less coefficient of variation during recent decade. The increase in temperature caused forced maturity to crop, thus lessened the variability within days to maturity. Proper sowing date adjustments are necessary for efficient utilization of natural resources under the climate change scenarios (Mall *et al.* 2004).

Impact of elevated carbon dioxide levels

Elevated levels of carbon dioxide (50 and 100 ppm) showed an increase in yield of soybean in all the planting windows from 10 to 30 June. The 50 ppm and 100 ppm elevated levels of carbon dioxide increased soybean yield by 5.0 and 10.2 percent based on 20 years simulated results for early sowing (10 June) under rainfed condition and sub humid sub temperate climate of Himachal Pradesh (Table2). The maturity of crop was advanced by one day in 10 June sowing with elevated CO_2 by 50 and 100 ppm. On the other hand, maturity was delayed by 4 to 5 days in late sowing, i e 30 June. However, no significant change was observed in 20 June sown crop. The highest variability in simulated yield of soybean was observed with 30 June sowing, however, less variation was observed within the same date of sowing at all the three levels of CO_2. At 370 ppm of CO_2,

Table 2 Impact of elevated CO_2 levels on soybean yield (1989-08)

Planting window	1989-08						Increase/Decrease over control			
	Control (370 ppm CO_2)		420 ppm CO_2		470 ppm CO_2		Yield (%)		Days to maturity (No.)	
	Yield (kg/ha)	Days to maturity	Yield (kg/ha)	Days to maturity	Yield (kg/ha)	Days to maturity	50 ppm	100 ppm	50 ppm	100 ppm
10 June	2276.4 (30.7)	141.0 (8.9)	2391.4 (30.6)	139.6 (8.2)	2508.5 (30.5)	140.5 (8.3)	+ 5.1	+ 10.2	–1.4	–0.5
20 June	2052.9 (36.5)	137.0 (6.1)	2155.5 (36.5)	138.0 (10.3)	2260.6 (36.4)	136.9 (10.1)	+ 5.0	+ 10.1	+ 1.0	–0.1
30 June	1614.9 (51.8)	132.5 (8.3)	1699.5 (51.7)	137.4 (11.6)	1778.1 (51.8)	136.4 (11.5)	+ 5.2	+ 10.1	+ 4.9	+ 3.9

The values in parenthesis are the coefficient of variation (%)

the coefficient of variation for days to maturity was 8.9 for 10 June sowing, which increased to 11.6 and 11.5 with elevated level of CO_2 for 30 June sowing at 420 and 470 ppm, respectively. This indicated increased variability with delayed sowing and increasing levels of CO_2. Plants grown at elevated CO_2 had higher efficiency of water, light and nutrient utilization (Jacob *et al.* 2001, Lal *et al*. 1999). Oilseed crops demonstrated better response and attained significant higher total biomass as compared to millets under enhanced CO_2 conditions (Vanaja *et al.* 2006). Early sowing (10 and 20 June) at 50 and 100 ppm elevated CO_2 matured simultaneously with 370 ppm CO_2, but maturity was delayed by 3 days for 30 June sown crop. Plant growth is influenced by above and belowground environmental conditions and increasing atmospheric carbon dioxide (CO_2) concentrations enhances growth and yield of most agricultural crops (Madhua and Hatfield 2013).

Impact of elevated temperature

The simulated yield with 1 and 2°C rise in temperature was compared under rainfed conditions without change in temperature. The temperature rise of 1 and 2°C caused reduction by 1.3 to 3.5 and 4.5 to 6.0 percent, respectively in all planting windows (Table 3). The magnitude of decrease was more in 10 June sown crop. The percent decrease augmented with further increase in temperature to 2°C. One degree rise in temperature caused 1 to 3 days advancement in maturity whereas, 2°C rise in temperature advanced the maturity by 3 to 6 days. The highest variability was observed in both yield and days to sowing with 2°C rise in temperature for all the sowing dates. Less coefficient of variation for days to maturity at 2°C elevation of temperature indicated forced maturity of crop at all planting windows.

Impact of elevated temperature and carbon dioxide

In general, the variability in yield increased and days to maturity decreased with elevated temperature and CO_2 level as well as delayed sowing. The highest coefficient of variation (53.1%) was obtained in soybean yield with 2ºC rise + 420 ppm for 30 June sown crop during both the decade under study. The temperature rise of 1 and 2ºC coupled with 50 ppm elevated carbon dioxide increased the yield in all planting windows (Table 4). The increase was more in 1ºC rise in temperature (3.6 to 4.9%) than 2ºC rise (0.2 to 2.3%) coupled with 50 ppm higher level of carbon dioxide. The further increase in carbon dioxide levels by 100 ppm from 370 ppm with temperature rise of 1 and 2ºC showed increase in yield (Table 5). The magnitude of increase in yield was higher which ranged between 8.8 to 10.2 percent in 1ºC rise temperature compared to 2ºC rise

Table 3 Impact of 1 and 2°C temperature rise on soybean yield (1989-08)

Planting window	1989-08						Increase/Decrease over control			
	Control (370 ppm CO_2)		1ºC rise		2ºC rise		Yield (%)		Days tomaturity (No.)	
	Yield (kg/ha)	Days to maturity	Yield (kg/ha)	Days to maturity	Yield (kg/ha)	Days to maturity	1ºC rise	2ºC rise	1ºC rise	2ºC rise
10 June	2276.4 (30.7)	141.0 (8.9)	2247.3 (29.5)	137.9 (6.0)	2176.4 (31.0)	135.4 (5.5)	–1.3	–4.5	–3.1	–5.6
20 June	2052.9 (36.5)	137.0 (6.1)	2056.4 (36.6)	135.8 (9.4)	1987.5 (36.7)	132.4 (6.1)	–2.3	–5.5	–1.2	–4.6
30 June	1614.9 (51.8)	132.5 (8.3)	1615.8 (52.1)	131.4 (9.2)	1573.8 (53.2)	129.1 (7.6)	–3.5	–6.0	–1.0	–3.3

The values in parenthesis are the coefficient of variation (%)

Table 4 Impact of 1 and 2ºC temperature rise + 420 ppm CO_2 on soybean yield (1989-08)

Planting window	1989-08						Increase/Decrease over control			
	Control		1 °C rise + 420 ppm CO_2		2 °C rise + 420 ppm CO_2		Yield (%)		Days to maturity (No.)	
	Yield (kg/ha)	Days to maturity	Yield (kg/ha)	Days to maturity	Yield (kg/ha)	Days to maturity	1ºC rise	2ºC rise	1ºC rise	2ºC rise
10 Jun	2276.4 (30.7)	141 (8.9)	2361.1 (29.5)	137.9 (6.0)	2281.7 (30.9)	136.4 (5.7)	3.6	0.2	–2.2	–3.3
20 Jun	2052.9 (36.5)	137 (6.1)	2157.6 (36.6)	135.7 (9.3)	2085.3 (36.7)	130.7 (5.9)	4.9	1.6	–0.9	–4.6
30 Jun	1614.9 (51.8)	132.5 (8.3)	1697.0 (52.0)	130.3 (9.0)	1652.5 (53.1)	128.1 (7.5)	4.8	2.3	–1.7	–3.3

The values in parenthesis are the coefficient of variation (%)

Table 5 Impact of 1 and 2ºC rise temperature + 470 ppm CO_2 on soybean (1989-08)

Planting window	1989-08						Increase/Decrease over control			
	Control		1 °C rise + 420 ppm CO_2		2 °C rise + 420 ppm CO_2		Yield (%)		Days to maturity (No.)	
	Yield (kg/ha)	Days to maturity	Yield (kg/ha)	Days to maturity	Yield (kg/ha)	Days to maturity	1ºC rise	2ºC rise	1ºC rise	2ºC rise
10-Jun	2276.4 (30.7)	141 (8.9)	2477.7 (29.7)	137.1 (6.4)	2388.6 (31.1)	135.4 (5.8)	8.8	4.9	–2.8	–4.0
20-Jun	2052.9 (36.5)	137 (6.1)	2259.1 (36.7)	134.3 (9.3)	2183.8 (36.7)	129.4 (5.8)	10	6.4	–2.0	–5.5
30-Jun	1614.9 (51.8)	132.5 (8.3)	1779.9 (51.8)	130.2 (8.9)	1729.0 (53.1)	129.2 (7.6)	10.2	7.1	–1.7	–2.5

The values in parenthesis are the coefficient of variation (%)

in temperature (4.9 to 7.1 %). The 100 ppm elevated level of CO_2 coupled with temperature rise of 1 and 2ºC caused higher increase in yield than 50 ppm elevated CO_2 with increased temperature. Rise in temperature by 1ºC coupled with 50 ppm higher level of CO_2 advanced the maturity of crop up to 2 days, whereas 2ºC + 50 ppm enhanced advanced CO_2 maturity by 3 to 5 days. Further, increase of carbon dioxide by 100 ppm showed similar number of days in advancing the maturity period. Contrary to effects of higher temperatures, elevated levels of CO_2 increased yield and biomass in sub-humid climate. This trend suggested that the expected increase in the plant production, as indicated by Intergovernmental Panel on Climate Change (IPCC) as a consequence of increased CO_2 and temperature, may not hold due to interactions between these abiotic factors (Clausen *et al*. 2011). Elevated CO_2 levels might have compensated the damaging effects caused by high temperature on most of the growth and physiological parameters in soybean (Koti *et al*. 2007). Alexandre *et al.* (2006) conducted study under controlled environment chambers on elevated levels of CO_2, viz. 400 and 700 ppm coupled with day/night temperature combinations of 20/15, 25/20 and 30/15 °C which revealed more vigorous growth of soybean at lower temperatures. The increase in temperature decreased seed weight. In the different temperature combinations seed yield was higher for elevated CO_2 levels.

Impact of elevated temperature, carbon dioxide and receding rainfall

The yield of soybean was highly variable under 370 ppm CO_2 + normal rainfall for all the planting windows as compared to elevated CO_2 and reduced rainfall conditions. Reduction in rainfall simulated for 10 years of weather data revealed benefits in yields over existing conditions. Decrease in rainfall by 10 percent decreased the yield by 1.2 to 1.6 percent, whereas, one degree rise in temperature with 420 ppm carbon dioxide and 10 percent reduction in rainfall increased the yield by 5.2 to 8.5 percent at all the dates of sowing (Table 6). Thus, elevated levels of CO_2 benefited the soybean crop. The simulation study suggested that the

Table 6 Impact of 370 ppm CO_2 + 10% deficit rainfall (Rf) and 420 ppm CO_2 + 1°C rise in temperature + 10% deficit rainfall on soybean yield

Planting windows	Yield(kg/ha)			Percent change	
	Control (370 + normal)	370 ppm CO_2 + (-10% Rf)	420 ppm CO_2+1°C + (-10% Rf)	370 ppm CO_2 + (-10% Rf)	420 ppm CO_2+1°C + (-10% Rf)
10 June	2276.4 (30.7)	2245 (15)	2401 (14)	–1.4	+ 5.2
20 June	2052.9 (36.5)	2028 (17)	2229 (15)	–1.2	+ 7.9
30 June	1614.9 (51.8)	1589 (26)	1765 (25)	–1.6	+ 8.5

The values in parenthesis are the coefficient of variation (%)

lower soil moisture conditions reduced the potential yield of soybean by 28 percent under diverse conditions of Central and Peninsular India. The gap between potential yields of soybean with sufficient and lesser soil moisture was narrowed down with increased rainfall (Bhatia *et al*. 2008). The mean rainfall of the season at Palampur is 1700 mm which is more than the requirement of the crop. Deficient rainfall with uneven distribution during the monsoon season could be a critical factor for the soybean productivity even under the positive effects of elevated CO_2 in the future (Lal *et al*. 1999).

Thus, under rainfed conditions of Himachal Pradesh, 10 June sown crop simulated as best planting window for soybean with increase in yield and lesser days to maturity during recent decade (1998-08). Banterng *et al.* (2010) indicated that the optimum planting dates from June 15 to July 15 produced maximum soybean yield in a rainfed environment from CSM-CROPGRO-Soybean simulations.The projected simulated yield of soybean indicated increase due to elevated levels of 50 and 100 ppm CO_2, whereas simulated yield showed decrease with 1 and 2°C rise in temperature alone in all planting windows from 10 to 30 June under mid hill sub humid conditions. The elevated temperature (2°C) advanced maturity of crops by

5 days with 50 ppm elevation in CO_2. Under prevalent climatic conditions (370 ppm), early sown crop (10 June) produced highest grain yield (2276.4 kg/ha) which was reduced by 29% with delayed sowing (30 June). At increased temperature (2ºC), the loss in early sown crop yield is recovered by 2 and 5% when delayed sowing is coupled with 50 and 100 ppm elevated CO_2, respectively. Under the delayed sowing, the magnitude of loss was reduced with 1ºC temperature rise + 420 ppm CO_2 and 10 percent deficit rainfall by 7%. Thus, under elevated levels of CO_2, temperature and deficit rainfall, delayed sowing proved to be better adaptation for soybean under sub humid sub temperate and rainfed conditions of Himachal Pradesh.

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