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Climate change impacts vis-a-vis productivity of soybean in vertisol of Madhya Pradesh

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ABSTRACT

The impact of climate change on agricultural crops is a major concern and threats to the global food security. It also limits the potential of crops and cropping system in a given area. Therefore, the present study was aimed to assess the combined effect of positive (CO_2 fertilization, lesser temperature and higher rainfall) and negative (higher temperature, lower rainfall) impacts of the futuristic climatic scenarios on productivity of soybean using APSIM (Agricultural Production Systems sIMulator) model. We have followed the Climate-Crop Modeling Project (C3MP) methodology and generated ninety-nine sensitive test to achieve each test's temperature, rainfall and CO_2 concentration range. Using 30 years of climate data (1980-2010) of Central India as base, the simulation results showed that increasing CO_2 concentrations alone resulted in increased soybean yield. Similarly, reduction in rainfall amount indicated negative impact on it. This effect further compounded with increase in temperature and thus, reduced soybean yield. Increasing the temperature with 10% decrease in rainfall declined the soybean yield by 10%. Whereas, increase in temperature along with increase in rainfall also not resulted favorably soybean growth. Decreasing the temperature from the base by 1°C and increasing the rainfall by more than 10% benefitted the soybean productivity, whereas increasing the temperature by 1°C with no change in rainfall resulted decline in soybean productivity by 10-15%.

Keywords: Climate change, CO_2, temperature, rainfall, APSIM, soybean,

In the past few decades' climate change emerged as a serious concern over the globe as it significantly affects agricultural production. It is estimated that climate change is likely to reduce world food levels by roughly 1.5 per cent per decade without any adaptation and mitigation strategies with a plausible range between 0- 4 per cent (Lobell and Gourdji, 2012). In India, more than 700 million populations directly or indirectly depend on agriculture and allied activities for their livelihood, making this sector is most sensitive to climate change. Crop growth is a function of total photosynthate produced by the source and proportion of theassimilate allocated to reproductive sinks (Lemoine *et al.,* 2013). Climatic factors such as temperature, solar radiation, relative humidity and carbon dioxide (CO_2) concentration have been shown to affect the processes of both photosynthesis and dry matter allocation in plants (Mohanty *et al.,* 2015).

Several studies showed that the earth's climate has changed since the middle of the nineteenth century (Kumar, 2016). Increasing atmospheric temperatures and CO_2 concentration along with uncertainties in annual rainfall have caused widespread reduction of yield in previous decade in many parts of globe (Coumou and Rahmstorf 2012; Kumar 2016). In India, Kumar *et al* (2010) found that maize crop is differentially affected in different region of India under future climatic scenarios.

Agricultural production in Madhya Pradesh, India is particularly vulnerable to the impacts of climate change and variability due to its largely rainfed (72% of cultivated area), subsistence nature and the substantial disparities between small-holder farm capacity in applying inputs. It is, therefore, important to have an assessment of the direct and indirect consequences of global warming on productivity of different crops of the state. Soybean is one of the major rainy season crop in the rainfed agro-ecosystem of central and peninsular India. The state Madhya Pradesh contributes 60% of the total area under soybean production in the country. The crop is predominantly grown on vertisols and associated soils with an average crop season rainfall of about 900 mm, though this varies greatly across locations and years. Over the globe, several studies quantitatively examined the warming impacts on soybean grain yields and reported significantly decreased in grain yields with rising temperature during growing season (Rio *et al.*, 2015). But, there have been few studies in India aimed at understanding the nature and magnitude of gains/losses in yields of soybean crop under different climatic scenarios. With this backdrop, the present study was undertaken to examine the combined effects of changes in temperature, CO_2 concentration and rainfall on grain yield and biomass production of soybean in central Indian condition.

MATERIALS AND METHODS

This study was carried out on a vertisol soil of central India located at 23.28^{0}N, 77.48^{0}E. The soil of the experimental site was deep heavy clay (isohyper thermic Typic Haplustert). The top soil (0-15 cm) was low in available N (120 mg kg^{-1}), alkaline permanganate method, medium in available P (5.6 mg kg^{-1}) and high in available K (230 mg kg^{-1}). The pH (1:2), CEC, bulk density of the surface soil 0–15 cm) were 7.8, 46 cmol (+) kg^{-1} soil and 1.30 Mg m^{-3}, respectively, while water holding capacity at saturation, field capacity (-33 kPa) and permanent wilting point (-1,500 kPa) were 62.8, 38.9 and 24.6 % (v/v), respectively. The climate of the experimental site was hot sub-humid type with a mean 132 annual rainfall of 1,130 mm and potential evapotranspiration of 1,400 mm. About 80 per cent of the rainfall occurs during 134 the rainy season, i.e. June to September. Average maximum monthly temperature (40 ^{0}C) was reached in May, while the minimum (9^{0}C) was in January.

A crop growth simulation model 'APSIM' in conjunction with actual and modified long-term historical climate data was used to assess the potential impact of climate change on soybean yield in Bhopal. APSIM consist of well-tested algorithms that deals nitrogen, water, crop residues with climate effects on crop growth (Keating *et al.*, 2003; Mohanty *et al.*, 2016). The changes in the simulated yield potential per unit area for the soybean caused by changes in the temperature, CO_2 concentration and rainfall over the period 1980-2010 for the Bhopal region was investigated during 2012-13. It was assumed that these changes could explain the declining or improvement in yield or yield stagnation of soybean crop in Madhya Pradesh.

The soil parameters required to calibrate the model for simulation of soybean growth include: soil bulk density, saturated soil water content, soil water at field capacity and wilting point, organic carbon, ammonical and nitrate nitrogen etc, are presented in Table 1. Other parameters related to the water balance are first stage soil evaporation coefficient (U =6 mm), Second stage soil evaporation coefficient (CONA), runoff curve number (CN2 = 73), whole profile drainage rate coefficients (SWCON = 0.3). The soil considered is a Vertisol with extractable water capacity of 150 mm up to 120 cm depth.

The simulations were performed for a widely cultivated soybean cultivar (JS 335). The crop parameters used for simulation study were those reported by Mohanty *et al.* (2012). The soybean cultivar matures in about 95 to110 days. A soybean plant population of 45 plants m^{-2} at 30-cm row spacing was used throughout the simulation study. Fertilizer to supply 20 kg ha^{-1} N (as urea) to soybean was applied at the time of sowing. This application was considered the "general purpose" nutrient management in the simulation. The other nutrient management practices such as application of phosphorous, potassium and micronutrients are assumed to be optimal for crop growth. There was no attack of insect pests and diseases during crop growing period.

The methodology of assessing the impact of climate change on simulated soybean yield was based on procedure laid out by the coordinated climate-crop modelling pilot team (C3MP) (McDermid *et al.,* 2015). The C3MP methodology generates 99 sensitivity tests that are designed to efficiently sample the uncertainty space in projected temperature, rainfall, and carbon dioxide changes in the 21st century (Fig 1.). Future climate projections were created by utilizing a 'delta' approach, in which the mean monthly changes in important agro-climatic variables were calculated by taking the difference between the Representative Concentration Pathways-8.5 (RCP8.5) climate scenario and simulated baseline conditions. These monthly mean agro-climatic changes, or deltas, were then applied to the daily baseline weather series for each respective month. By analyzing end-of-century (2077-2099) outputs from the global climate model outputs, the upper and lower bounds of each climate variable were derived and presented in Table 2. These ranges include the projected extremes over the majority of agricultural lands (Taylor *et al.,* 2009). Although by the end of the 21st century have CO_2 higher than 900 ppm in representative concentration pathways

(RCP 8.5), while end-of-century period (2077-2099) has a central year CO_2 concentration of 801ppm. Therefore, 900 ppm was taken as the upper bound for CO_2 so that contributed results will remain relevant in the event that more extreme projections become plausible (Ruane *et al.,* 2014).

The ninety-nine sensitivity tests were generated using 30 years of climate data (1980-2010) as to achieve each test's temperature, rainfall and CO_2 concentration range, resulting in 2970 (99 tests × 30 years) yields. The mean yield was predicted using well calibrated and validated APSIM model. To study how climate change affects the yield variability, the coefficient of variation of yield was also calculated. This enables the least-squares fitting of a quadratic crop model emulator for yield (*Y)* and coefficient of variation (*CV)* for any given experimental location as a function of carbon dioxide concentration (CO_2), temperature change (T), and rainfall change (R) to determine coefficients a-k in each of:

$$Y(CO_2, T, P) = a + b(T) + c(T)^2 + d(P) + e(P)^2 + f(CO_2) + g(CO_2)^2 + h(T*P) + i(T*CO_2) + j(P*CO_2) + k(T*P*CO_2) \text{.......(Eq 1)}$$

$$CV(CO_2, T, P) = a + b(T) + c(T)^2 + d(P) + e(P)^2 + f(CO_2) + g(CO_2)^2 + h(T*P) + i(T*CO_2) + j(P*CO_2) + k(T*P*CO_2) \text{.......... (Eq 2)}$$

The emulator provides for the visualization of each site's sensitivity to the CO_2, temperature and rainfall climate metrics and enables efficient characterization of crop responses to multiple future climate projections. By examining the slope of the emulated response surfaces at the historical baseline climate's location ($\Delta T=0°C$; $\Delta P = 0\%$; $CO_2 = 360$ppm), it is possible to examine the sensitivity of yield to each climate metric. Ruane *et al.,* (2014) has also described that the impacts response surfaces defined by these emulators (statistical representations of models) are a better subject of comparison than the values of specific coefficients.

RESULTS AND DISCUSSION

The effect of climate change could be positive or negative on crop yield depending upon the types of crops, their genotypes and environmental condition. In most of the agricultural crops, increase in temperature decreases the crop yield. Even with minor deviations from the normal weather, the efficiency of extremely applied inputs and food production is seriously impaired. The three dimensional CO_2×T×R showed general decrease in soybean yield under higher temperature, lower rainfall and CO_2 concentration, whereas, increase in yield was observed in cooler, wetter and higher CO_2 environment (Fig 2-4). In particular, an increase in the temperature by 1.5 °C, the grain yield of soybean reduced by 20 per cent. Merely increase or decrease in rainfall did not had much effect on soybean yield, while decreasing the temperature from the current climate by 1°C and increasing the rainfall by more than 10% favoured the soybean yield (Fig 2a). A decrease in rainfall along with an increase in temperature reduced soybean yield give the extent of decease. However, increase in temperature with increase in rainfall also did not favour soybean growth. Increasing the temperature by 1.5 °C along with the increase in rainfall by 50 per cent during soybean growth period reduced the soybean yield by 10 per cent. Beyond 1.5 °C increase in temperature, the increase rainfall did not show any positive impact on soybean yield. Similarly, the CV of the crop yield has been presented in the Fig. 2b which indicated the variation in the data series used for soybean grain yield analysis. The green pattern in the Fig 2b indicated less variability in the mean yield of soybean for that simulation sensitivity tests. Several simulation studies indicated that variation in temperature is more prominent than variation in rainfall. Schlenker and Lobell (2010) showed that impact on maize, sorghum, millet, groundnut, and cassava yield due to temperature changes are much stronger than rainfall changes. Soybean crop in India is also found to be more vulnerable to higher temperature. The thermal stress on the soybean crop at selected sites in India resulted into 12, 18 and 21 per cent decrease in yield under GCMs namely the GFDL, GISS and UKMO, respectively (Mall *et al.,* 2004). Lower yield under high temperature is attributed to shorter life cycles of the crops and its significant impact on leaf ageing or senescence, consequently leads to reduction of the total biomass and grain yields (Deryng *et al.* 2014; Bassu *et al.* 2014).

Further, increase in CO_2 concentration favored soybean growth when the temperature was reduced by 1 degree from the baseline temperature (Fig. 3a). However, with increase in CO_2 the yield reduced by the adverse impact of rise in temperature on crop growth. Even with increasing the temperature by 1 degree and CO_2 concentration to double from the current stage, the yield declined in soybean as high as 15 per cent (Fig. 3a). The variability in the dataset can be seen in the Fig. 3b. Mall *et al.* (2004) used the CROPGRO-soybean model to simulate the impact of climate change on soybean production in India. In their study, all the GCM projected climate change scenarios (at the time of doubling of CO_2 concentrations) predicted decrease in

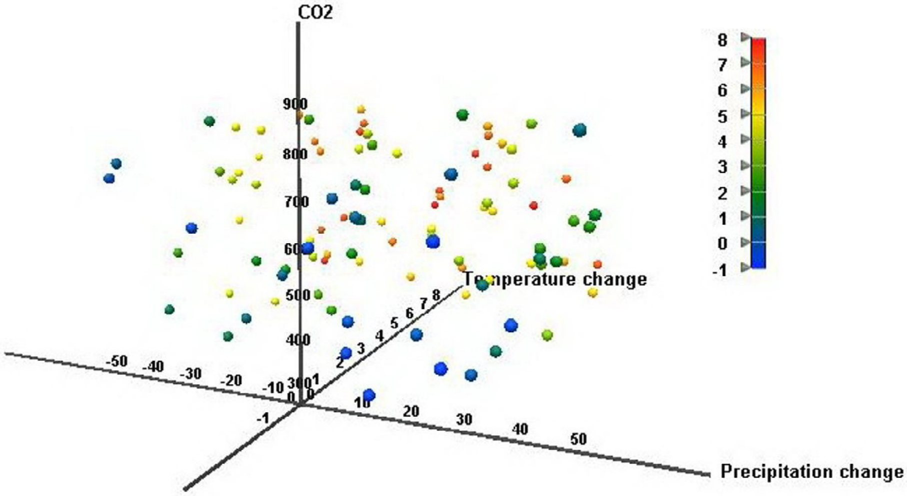

Fig. 1: 3-D representation of ninety-nine sensitivity test following C3MP methodology covering change in carbon dioxide, temperature and rainfall uncertainty space uniformly. (Colour bar indicate the temperature change)

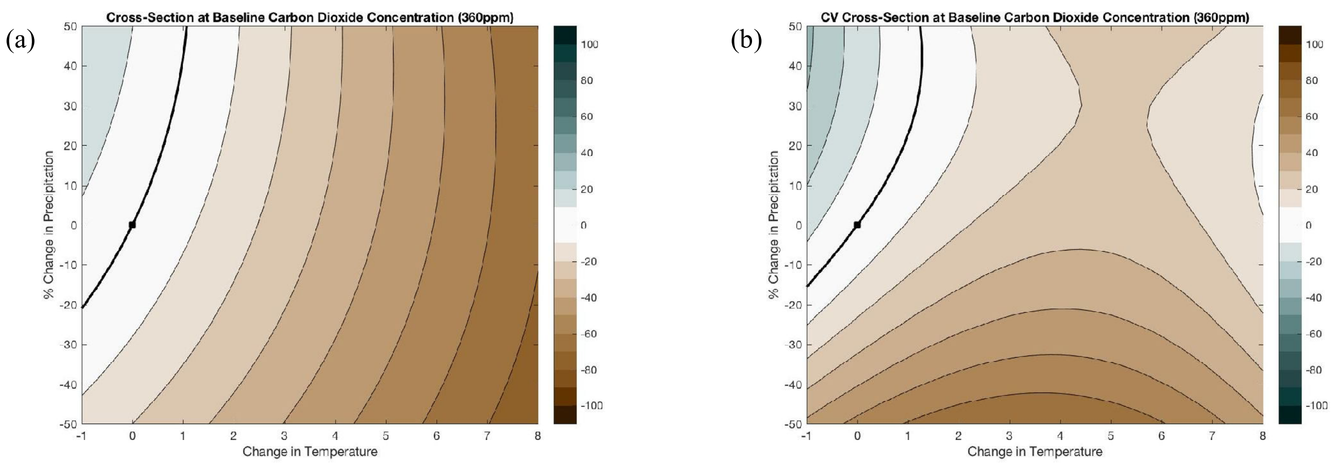

Fig. 2: Simulated (a) soybean grain yield and its (b) coefficient of variation, as affected with changes in temperature and rainfall at constant CO_2 concentration (360 ppm).

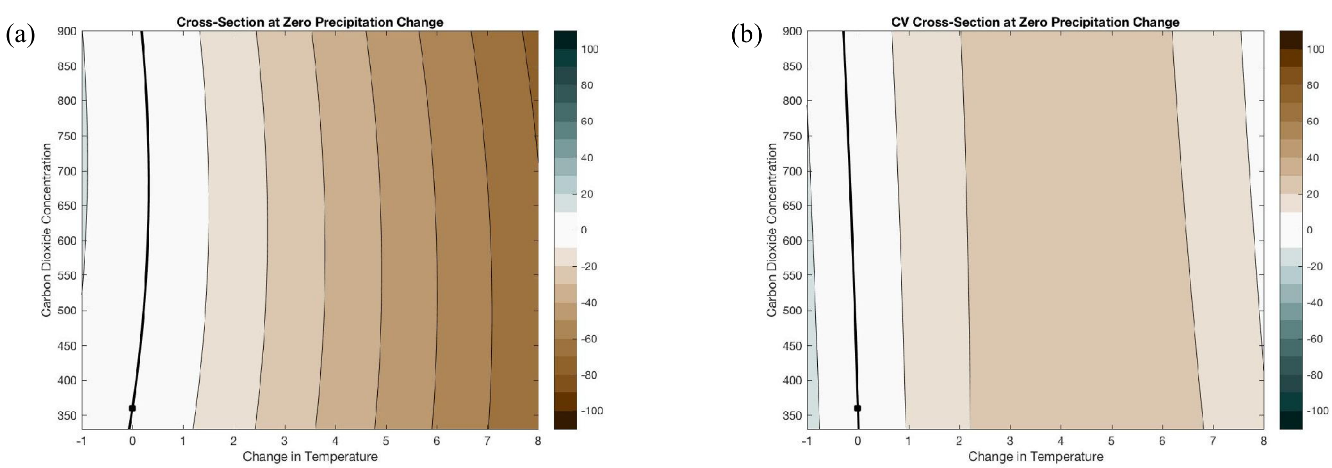

Fig. 3: Simulated (a) soybean grain yield and its (b) coefficient of variation, as affected with changes in temperature and CO_2 concentration, without changes in rainfall.

Table 1: Soil parametrization of APSIM model for the experimental site.

Soil layercm	BD Mg m^{-3}	DUL $m^3 m^{-3}$	SAT $m^3 m^{-3}$	LL 15 $m^3 m^{-3}$	OC %	pH	NH_4-N mg kg^{-1}	NO_3-N mg kg^{-1}
0-15	1.28	0.39	0.51	0.24	0.49	7.8	1.6	15.0
15-30	1.34	0.38	0.49	0.27	0.47	8.0	1.9	12.0
30-60	1.35	0.39	0.47	0.27	0.46	7.9	1.5	8.0
60-90	1.40	0.40	0.45	0.28	0.43	7.9	1.5	4.5
90-120	1.45	0.41	0.45	0.28	0.41	8.0	0.5	3.5

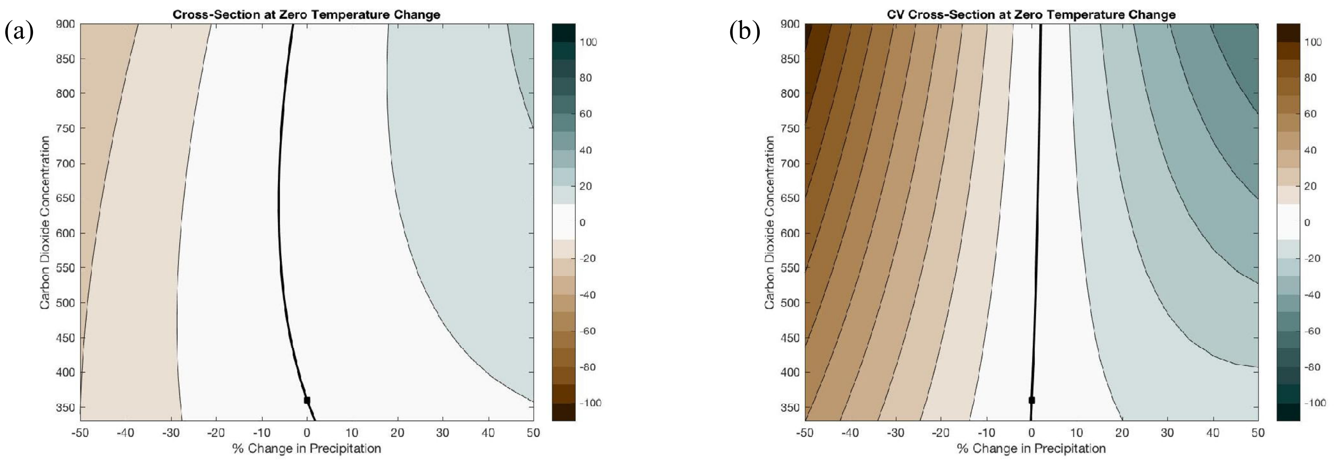

Fig. 4: Simulated (a) soybean grain yield and its (b) coefficient of variation, as affected with changes in CO_2 concentration and rainfall, without changes in temperature.

Table 2: Climate metric ranges for C3MP climate sensitivity experiments.

Climate Metric	Lower bound	Upper bound
T=Temperature change (°C)	-1	+8
P=Rainfall change (%)	-50	+50
CO_2=Carbon Dioxide ppm Concentration	360	900

yields for almost all locations. Mean decline in yields across different scenarios ranged from 14 per cent in Pune (West India) to 23 per cent in Gwalior (Central India). With increase in temperature by 3^0C, there was on an average 7 days' reduction in the growth period of soybean crop. Lal *et al.* (1999) projected 50 per cent increased yield for soybean for a doubling of CO_2 in Central India by using CROPGRO-soybean model. However, a 3°C rise in surface air temperature almost cancels out the positive effects of doubling of carbon dioxide concentration results in reducing the total duration of the crop (and hence productivity) by inducing early flowering and shortening the grain fill period. The effect of climate change scenario of different periods can be positive or negative depending upon the magnitude of change in CO_2 and temperature (Kang *et al,* 2000).

The increase in rainfall usually have positive effects on crop yield. In this study, the simulation results showed that increase in rainfall level to the tune of 18 per cent might not have significant effect on soybean yield. However, with increase in CO_2 level from the current 360 ppm along with increasing the rainfall to 50 per cent, the yield showed a positive trend (Fig. 4a). With increasing the CO_2 level to 750 ppm and rainfall to 50 per cent, the soybean yields increased upto 30 per cent from the current level of production. The coefficient of variation(CV) of the soybean yield data is presented in Fig. 4b. Lal *et al.* (1999) concluded that acute water stress due to prolonged dry spells during monsoon season could be a critical factor for the soybean productivity even under the positive effects of elevated CO_2 in the future.

CONCLUSION

This study revealed that increase in temperature adversely affected the soybean yield. Increase temperature combined with higher rainfall had low impact on soybean yield. However, increase in CO_2 had fertilizing effect on soybean yield but increase in yield was masked by increase in temperature. The variety studied didn't respond to increase in rainfall from the base climate (300 ppm). Increased rainfall (50 per cent) along with increase in CO_2 concentration (750 ppm) favored soybean yield by 30 per cent. However, the findings reported in present investigation depend on the many assumptions built into the crop simulation models, which need to be incorporated in the future studies for better assessment of final yield. However, overall impact of climate change (combined effect) was found negative in our study.

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REFERENCE

Bassu, S., Brisson, N., Durand, J.L., Boote, K., Lizaso, J., Jones, J.W., et al. (2014). How do various maize crop models vary in their responses to climate change factors? *Global Change Biol.,* 20: 2301–2320.

Coumou, D. and Rahmstorf, S. (2012). A decade of weather extremes. *Nat. Clim. Change*, 2: 491–496.

Deryng, D., Conway, D., Ramankutty, N., Price, J., Warren, R. (2014). Global crop yield response to extreme heat stress under multiple climate change futures. *Environ. Res. Lett.*, 9: 034011.

Kang, Y., Khan, S., Ma, X., (2009). Climate change impacts on crop yield, crop water productivity and food security – A review. *Prog. Nat. Sci.,* 19: 1665–1674.

Keating, B.A., Carberry, P.S., Hammer, G.L., Probert, M.E., Robertson, M.J., Holzworth, D., Huth, N.I., Hargreaves, J.N.G., Meinke, H., Hochman, Z., McLean, G., Verburg, K., Snow, V., Dimes, J.P., Silburn, M., Wang, E., Brown, S., Bristow, K.L., Asseng, S., Chapman, S., McCown, R.L., Freebairn, D.M., Smith, C.J. (2003). An overview of APSIM, a model designed for farming systems simulation. *Eur. J. Agron*., 18: 267–288.

Kumar, M. (2016). Impact of climate change on crop yield and role of model for achieving food security. *Environ. Monit. Assess.,* 188: 465.

Kumar, M., Sirhindi, G., Bhardwaj, R., Kumar, S., Jain, G. (2010). Effect of exogenous H_2O_2 on antioxidant enzymes of Brassica juncea L. seedling in relation to 24-epibrassinolide stress. *Ind. J. Biochem. Biophy.*, 47: 378-382.

Lal, M., Singh, K.K., Srinivasan, G., Rathore, L.S., Naidu, D. (1999). Growth and yield response of soybean in Madhya Pradesh, India to climate variability and change. *Agric. Forest Meterol*., 93: 53–70.

Lemoine, R., Camera, S.L., Atanassova, R., Dédaldéchamp, F., Allario, T., Pourtau, N., Bonnemain, J.L., Laloi, M., Coutos-Thévenot, P., Maurousset, L., Faucher, M., Girousse, C., Lemonnier, P., Parrilla, J., Durand, M. (2013). Source-to-sink transport of sugar and regulation by environmental factors. *Front. Plant. Sci*., 4: 272.

Lobell, D.B., Gourdji, S.M. (2012). The Influence of Climate Change on Global Crop Productivity. *Plant Physiol.,* 160: 1686-1697.

Lobell, D.B., Schlenker, W., Costa-Roberts, J. (2011b). Climate trends and global crop production since 1980. *Sci.*, 333: 616–620.

Mall, R.K., Lal, M., Bhatia, V.S., Rathore, L.S., Singh, R. (2004). Mitigating climate change impact on soybean productivity in India: a simulation study. *Agric. Forest Meterol.,* 121: 113–125.

McDermid, S.P., Ruane, A.C., Hudson, N.I., Rosenzweig, C., et al. (2015). The AgMIP Coordinated Climate-Crop Modeling Project (C3MP): Methods and Protocols. In Hillel, D., and C. Rosenzweig (Eds.). *Handbook Clim. Change Agroecosyst.,* 3: 191-220.

Mohanty, M., Sammi Reddy, K., Probert, M.E., Dalal, R.C., Sinha, N.K., Subba Rao, A., Menzies, N.W. (2016). Efficient Nitrogen and Water Management for the Soybean–Wheat System of Madhya Pradesh, Central India, Assessed Using APSIM Model. *P. Natl. A. Sci. Inia B.*, 86: 217-228.

Mohanty, M., Sinha, N.K., Hati, K.M., Sammi Reddy, K., Chaudhary, R.S. (2015). Elevated temperature and carbon dioxide concentration effects on wheat productivity in Madhya Pradesh: a simulation study. *J. Agrometeorol*., 17:185-189.

Rio, A.D., Sentelhas, P.C., Farias, J.R.B., Sibaldelli, R.N.R., Ferreira, R.C., (2015). Alternative sowing dates as a mitigation measure to reduce climate change impacts on soybean yields in southern Brazil. *Int. J. Climatol.* 36: 3664–3672.

Ruane, A., S.P. McDermid, C. Rosenzweig, G. Baigorria, J. Jones, C. Romero, L. Cecil (2014). Carbon-Temperature-Water change analysis for peanut production under climate change: A prototype for the AgMIP Coordinated Climate-Crop Modeling Project (C3MP). *Global Change Biol.,* 20: 394-407.

Schlenker, W. and Lobell, D. B. (2010). Robust negative impacts of climate change on African agriculture. *Environ. Res. Lett.,* 5: 014010.

Taylor, K.E., Stouffer, R.J., Meehl, G.A. (2009). A summary of the CMIP5 Experiment Design. Last accessed February 21st, 2013, at http://cmip-pcmdi.llnl.gov/cmip5/docs/Taylor_CMIP5_design.pdf

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