CLIMATE CHANGE IMPACT OVER INDIAN AGRICULTURE – A SPATIAL MODELING APPROACH

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ABSTRACT

The large-scale distribution of crops is usually determined by climate. We present the results of a climate-crop prediction based on spatial bio-physical process model approach, implemented in a GIS (Geographic Information System) environment using several regional and global agriculture-environmental databases. The model utilizes daily climate data like temperature, rainfall, solar radiation being generated stocastically by in-built model weather generator to determine the daily biomass and finally the crop yield. Crops are characterized by their specific growing period requirements, photosynthesis, respiration properties and harvesting index properties. Temperature and radiation during the growing period controls the development of each crop. The model simulates geographic/spatial distribution of climate by which a crop-growing belt can also be determined. The model takes both irrigated and non-irrigated area crop productivity into account and the potential increase in productivity by the technical means like mechanization is not considered. All the management input given at the base year 1995 was kept same for the next twenty-year changes until 2015. The simulated distributions of crops under current climatic conditions coincide largely with the current agricultural or specific crop growing regions. Simulation with assumed weather generated derived climate change scenario illustrate changes in the agricultural potential. There are large regional differences in the response across the country. The north-south and east-west regions responded differently with projected climate changes with increased and decreased productivity depending upon the crops and scenarios separately. When water was limiting or facilitating as non-irriagted and irrigated area crop-production effects of temperature rise and higher CO_2 levels were different depending on the crops and accordingly their production. Rise in temperature led to yield reduction in case of maize and rice whereas a gain was observed for wheat crop, doubled CO_2 concentration enhanced yield for all crops and their several combinations behaved differently with increase or decrease in yields. Finally, with this spatial modeling approach we succeeded in quantifying the crop productivity which may bring regional disparities under the different climatic scenarios where one region may become better off and the other may go worse off.

1. INTRODUCTION

Since the beginning of the industrial age, the concentration in the atmosphere has increased from 280 to 350 parts per million (Bazzaz and Fajer, 1992). The increase of CO_2 in the atmosphere has been more rapid in recent years. The major reason for this increase is due to the intensive use of fossil fuels, such as oil, coal and gas. The destruction of carbon sinks by excessive land use and deforestation might be another important cause for the atmospheric CO_2 increase over the last 100 years (Hougton et. al., 1990). It has been projected from historical data and simulation models that the CO_2 level in the atmosphere will reach 600 ppm in the last half of the next century (Strain, 1987). The increase of CO_2 and several other greenhouse gases such as methane, nitrous oxide and chlorolurocarbons (CFCs) could cause an increase in global temperature of about 4.2C and possibly a change in precipitation patterns and amounts in some regions (Kimball et al., 1993).

The rise of CO_2 level in the atmosphere and the concomitant climate change will have a direct impact on agriculture. Hence it is important to understand how the climate change can influence crop production. Crop simulation models can be used to predict this impact. These models can provide a way to estimate crop production under climate-changed conditions. Research on crop simulation has concentrated on determining the relationship between crop growth, yields and environmental variables through field experiments as well as simulated experiments. The two major goals in crop modeling are to better understand the processes associated with crop growth and yield to use crop model to improve crop management to obtain the highest production (Jones, et al., 1989). However, crop growth and development processes are very complicated. Crop production is a site-specific phenomenon. Crop growth and yield are related to soil type, weather condition and crop management practices. Different locations have different soil types and weather conditions. Hence, crops produced in different places vary considerably due to changes of these geographically related, or georeferenced data.

In recent times, several scientists/researchers have attempted to link crop models with GIS. Thornton (1991) discussed the possibility of linking GIS with crop models on a farm, regional and national level. Hoongenboom and Thornton (1990) applied GIS and bean, maize and sorghum crop models to test potential of linked systems for agrotechnology transfer in Guatemala. The crop model CERES-SORGHUM, using IBSNAT standard input/output data formats, was linked to GIS to assist decision making in estimating sorghum production in Indian semiarid tropics. Calixtte et al. (1992) developed an agricultural and Environmental Geographic Information System (AEGIS), which combined DSSAT crop models with GIS to assess the impact of different agricultural practices of Puerto Rico.

All these model linking reported above had been done using vector GIS by linking their attribute, whereas in reality the agricultural-environemtnal modelling need to be done using raster GIS (means each piece of land should get simulated based on their pixel size defined by user depending on data availability). In practice, many GIS operations are used in sequence to compute an attribute that is the result of a computational model. A computational model is understood here as a simplified mathematical representation of reality. For instance, the channel flow at the outlet of the catchment is computed after the relevant hydrological processes have been translated into mathematical equations – thus, after reality has been approximated by a suitable computational model. Using GIS for the evaluation of computational models is identified here by term *'spatial modelling with GIS'*.

Although after extensive review, till date, the author has not found any model, which can simulate a country agricultural productivity spatially and then do the prediction in different scenarios of global warming as a theme of this paper. Keeping this in mind the author took this challenge to develop a spatial biophysical crop model. For this we tried to find the available suitable crop-environment model which can simulate the maximum no. of crop using one model and having all these functionality to incorporate them in one. Erosion Productivity Impact Calculator (EPIC) (Williams, J. R. and Sharpley, A.N.,1989) was selected to develop "Spatial-EPIC" (Satya et.al, 1988) as it gives an opportunity to model more than 80 crops with having different parameters for each crop under a single compact model framework. The development of "Spatial-EPIC" at University of Tokyo added a new spatial dimension of the original EPIC developed by USDA/ARS. Therefore, the model developed is used to quantify spatially the possible effects of a climate change scenarios on three major cereal crops (maize, wheat and rice) for entire Indian nation.

2. Impact of Climate Change

Until recently, variations of climate in time and space that farmers have long since learned to live with have obscured the consequences of man's interference with the chemistry of atmosphere. However, the International Panel for Climate Change recently decided that "the balance of evidence" supports the conclusion that current warming, estimated as about 0.2C per decade when averaged globally, is a consequence of human activity.

At this stage it is helpful to distinguish between the impact of climate on the potential production of crops when yields are unconstrained by nutrient shortage or by disease, for example, and actual production when constraints are present. Contemporary attempts to predict the impact of climate change on yield by simulation are concerned almost exclusively with actual production using the model Spatial-EPIC developed because the impact of constraints of yield can be modelled to great extent particularly in management side with resource to assumptions based on blend of climate change past experiences and guess work. For some crop species and in some regions, it is likely that the indirect effect of climate change of production through changes in the behaviours of pests, diseases and weeds will ultimately prove more significant than the direct consequences for photosynthesis, development and other physiological processes. Below are the scenario assumed for the expected climate change and their quantified impacts in terms of productivity and other environmental consequences.

3. Climate change scenarios

Scenarios of climate change were developed in order to estimate their effects on crop yields which may be severe in coming days as per the speculations going on throughout the world. A climate change scenario is defined as a physically consistent set of changes in meteorological variables, based on generally accepted projections of concentrations of carbon dioxide (CO_2, thought to be the likely cause of future climate change). The set of scenarios used is intended to capture a range of possible effects and set limits on the associated uncertainty. The scenarios for this study were created by changing, observed daily data from the current daily-observed historical climatic data (1978-91). Under an assumption of climate change many sensitivity scenarios were conducted to test crop model responses to a range of temperature (+2deg.C and -2deg.C) and precipitation (+/-25%) increase and decreases. This type of sensitivity cum impact of global climate change analysis is dissociated from the processes that influence climate (temperature and precipitation are physically related in any given region), it does provide better understanding of the factors affecting crop model responses. It can also help to identify climatic thresholds of critical impacts. Sensitivity tests were carried out at 50km-cell size resolution for whole India. The reason for keeping whole India simulation at the course resolution is due the fact that all the management data were available on their state level. The sensitivity test results were not utilised for economic analysis under the model due to their lack of realism, e.g., temperature change at high latitudes is predicted to be greater than the global mean in winter (IPCC, 1990a), rather than increase by 2°C in all regions of the India throughout the year. Farm-level adaptations were not tested in the sensitivity studies under the scope of this paper.

4. RESULTS AND DISCUSSION

The "Spatial-EPIC" model was applied to the entire Indian nation. Three major cereal crops maize, wheat and rice were selected mostly on two year crop rotation sequence for making the runs. The amount of fertiliser applied were state level average reported statistical time series for 1970 to 1995 at five-year interval. It is assumed that the climate change may bring significant increases in irrigation to compensate moisture losses caused by increased evapotranspiration. Irrigation frequency and its amount was applied to the satellite derived USGS 1km global land cover irrigated area under tuning with increase in fertiliser application. In general 600-1000mm depth of water volume was given to all three crops depending upon the crop rotation, growing season and their sequences to the irrigated pixels. During the simulation the amount of seeds used for all three different crops were the state wise reported statistics varying from one to other states per hectare. The seeding rate is solely responsible for plant population and was found different depending on the economic condition, mechanised farming and other resources prevailed states. Thirteen-year historical climate data from 1978-1991 for each WMO stations falling under India were used as the climate data source for simulation. The following two scenarios as explained in previous section were generated: (a) baseline scenario in which 13 years historical climate data were used; (b) the 13 year historical climatic data modified by increasing maximum and minimum temperatures and rainfall by ±2C and ± 25% increase or decrease respectively to the present CO_2 level 330ppm and elevated level to 550 ppm.

4.1 Effect of climate change on crop yield

The impact of changes in temperature varied with the crop and the direction (positive or negative) of the change imposed. Higher temperatures accelerates crop development, reduced leaf are duration, decreased seasonal interception of photosynthetically active solar radiation, and decreased yields. These effects were more marked with rice where reduction in yield found to be 10-12% than that of normal case (no change) in most of the states at the same time one or two state did now showed any effect too. In fact, there was not much of impact of a 2°C increase of temperatures on yield of maize (say ± 5%). In case of winter wheat the effects were rather beneficial (yield enhancement by of 15 and 20% with 2°C temperature increase in wheat growing region. Because the increase in temperature during the cool winter helped in proper development of crop phenology and hence yielded a better productivity. Due to weather conditions the maize-wheat-rice cropping system is being widely practiced in all these three major crops growing areas used in this study, a 2°C cooling was more detrimental than an equal warming in case of rice for few states whereas sometimes did not showed much difference at the same time wheat showed strong impact on yield reduction throughout. Maize responded positive increase in their yield than of the no change condition by 4-6% in general except one or two states. Reduced temperature delayed crop development, the growing season and was extended beyond the limit for favourable weather conditions for growth, and yields were reduced by 6-8% in case of rice and wheat in general. But as we know the India is full of diversity and has its own crop growing belt due to the different ago-ecological characteristics throughout the country hence, rice showed detrimental effect only in the rice growing belt like, West bengal, Orissa, Andhara Pradesh, Tamilnadu whereas some states hardly shows much of impact due to decrease in temp by 2°C. This was not the case with winter wheat, however, whose yields actually decreased by 7-10% in general. Winter crops usually have growing season available after maturity, although the extended growing season increases the risk of water shortage and stress under dryland conditions.

Within the range of change selected for this study, a decrease in precipitation was predicted to have greater impact on yields of rice and wheat than an increase in temperatureure. For winter wheat both effects (reduced precipitation and warming) had important and similar impacts on yield. As expected for rainfed farming in general, climate change scenario with increased precipitation led to increase yields for all crops .

5. Conclusions:

In general, the main influence of temperature in the model is that it determines the development rates of the crop. Higher temperature lead to higher development rates for all the crops. Hence, rise in temperature commonly lead to earlier crop emergence, advanced flowering and earlier ripeness of the crop and thus a shorter growing period earlier to the year. In particular the winter wheat found to be benefited with increased temperature as it helps in the proper development of leaf area in early stages when usually the temperature are low.

Also, changes in available amount of water can have far greater effects of crop yield than changes in temperature or radiation. In southern India due to large irrigated land it becomes more favorable to grow rice under low radiation levels with sufficient water. The outcome of various simulation runs showed different effects throughout the country due to different climatic, technological, soil and economic conditions they prevail in present yields and under different assumed climate change scenario (see map 1 to 4). As we know, a change in climate will not only involve a change in temperature but will also effect other weather variables when total precipitation changes by 20-25% but the current seasonal pattern remains, small effects on yield are expected as many of the region are experiencing this due to inter-annual change in rainfall.

Increased CO_2 concentration was influenced and has increased simulated yields of all crops, although in different proportions: 12-18% for maize, 10-20% for wheat and 8-20% for rice to most of their major growing regions, which is an accordance with other data from literature (Cure and Acock, 1986;

Goudriaan and Unsworth, 1990; Idos and Idso, 1994). Since the effect was more or less same throughout the main growing region the yield pattern over the country did not changed much if we assume the alone increase in concentration of CO_2 in the atmosphere whereas it behaves totally different when we consider the change in temperature or rainfall in the area. The reason is higher CO_2 concentration effects the stomatal resistance, thereby decreasing transpiration. The effect of increase in yield was found more in non-irrigated (water-limited) area under increased CO_2 concentration. This increase under water-limited circumstances is also found in CO_2 enrichment experiments (Kimball and Idso, 1983; Cure and Acock 1986; Idso and Idso, 1994). The results reported under this research must be interpreted cautiously because they are based on simulation of rain-fed agriculture potentials and other limiting (absence of damage by pests, diseases and weeds) or enhancing factor like irrigation (assumes no physical extension of irrigated areas) which are not taken into account. However, the results give a good indication of potential crop shifts and magnitudes of yield (as shown in map 1 to 4) changes over whole India rather than regional level alone.

This analysis further illustrates that with current GIS base modeling, available global cum regional databases and model approaches, it is further possible to create comprehensive models which can be used to assess the impacts of a changing climate on crop distribution and productivity. Such models should be linked to integrated land-cover models are needed to understand the interaction between different components of the earth's system and to be able to evaluate the consequences of different polices of global, national cum regional changes.

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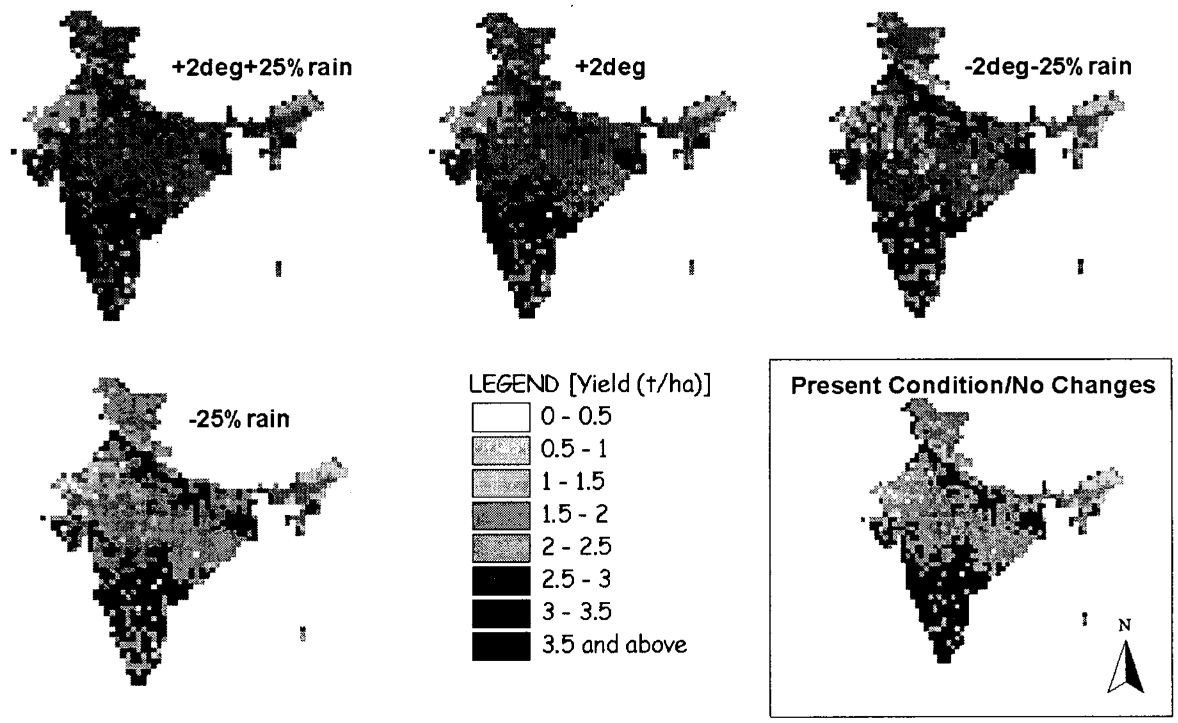
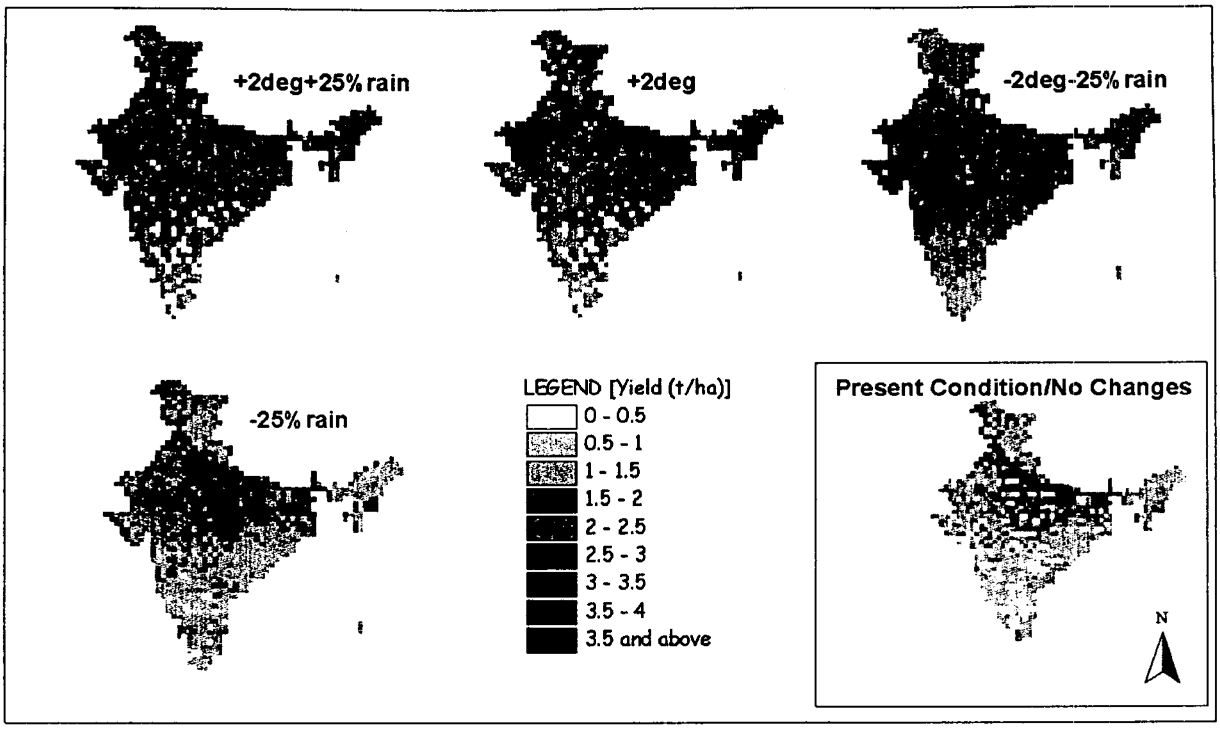
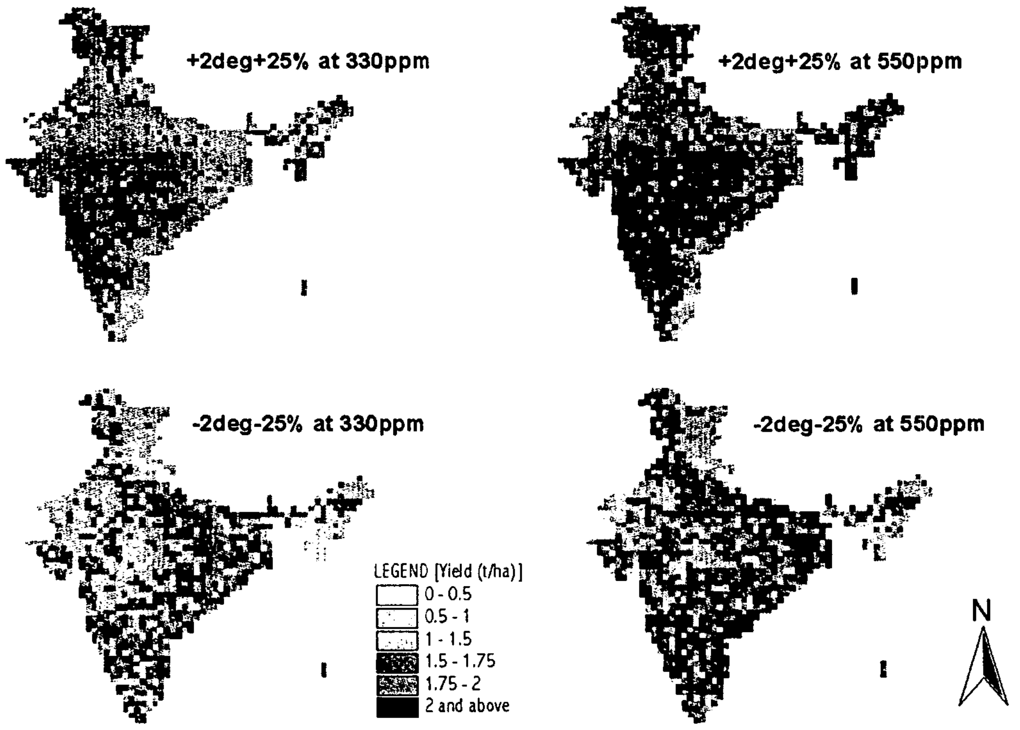


Map 1. Impact of climate Change Scenarios over Maize Crop



Map 2. Impact of climate Change Scenarios over Wheat Crop



Map 3. Example of CO2 fertilization effect (330 ppm to 550 ppm) over Rice Crop