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Modelling the impact of climate change on rice production in India

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सार - देश में धान के उत्पादन पर पड़ने वाले जलवायु परिवर्तन के प्रभाव का विश्लेषण करने के लिए उत्तरी पश्चिमी भारत में पी.आर. 106, मध्य भारत में आई. आर. 36 और दक्षिणी भारत में धान की जया किस्मों के लिए सेरेस - राइस समूह अनुकरण मॉडल अंशशोधित और प्रमाणित किया जाता है। अगली शताब्दी के मध्य तक भारतीय उपमहाद्वीप में अच्छे जलवायविक परिवर्तन के संभावित परिदृश्य हेतु ग्रीन हाउस से निकलने वाली गैसों और सल्फेट वायुविलयों (ऐरोसॉलस्) में होने वाले उत्सर्जनों को ध्यान में रखते हुए जर्मनी के दोयत्शेस क्लाईमारेशएनसेंन्त्रुम में किए गए कपल्ड वायुमंडल महासागर मॉडल के प्रयोग को इस अध्ययन के लिए अपनाया गया है। अपनाए गए इन परिदृश्यों से दक्षिणी भारत में लगभग 1.5° सें. के क्रम में और 1980 के दशक की तुलना में 2040 - 49 के दशक में उत्तरी पश्चिमी भारत एवं मध्य भारत में 1° सें. के क्रम में औसत सतह तापमान में वृद्धि तथा दक्षिणी भारत में 2 मि.मी. प्रतिदिन के क्रम से वर्षा में वृद्धि का पता चला है जबकि उत्तरी पश्चिमी भारत और मध्य भारत में क्रमशः -1 मि. मी. और -1.5 मि.मी. के लगभग नाममात्र की मानसून वर्षा की कमी का पता चलता है। पादप के आई.पी.सी.सी. विज़नस एज़ यूजुअल परिदृश्य के प्रक्षेपण में अगली शताब्दी के मध्य तक उपयोग के लिए संभावित 460 पी.पी.एम. के लगभग CO_2 के सांद्रण का उपयोग भी फसल मॉडल अनुकरण (सेरेस - राइस V3 मॉडल) के लिए किया गया है।

देश के विभिन्न भागों में जलवायु परिवर्तन के परिदृश्य के संबंध में किए गए अनुकरण के अध्ययनों का विश्लेषण और उनकी व्याख्या इस शोध पत्र में की गई है।

ABSTRACT . The CERES-Rice crop simulation model, calibrated and validated for the varieties PR106 in NW India, IR36 in central India and Jaya in south India, is used for analysing the effect of climate change on rice productivity in the country. Plausible climate change scenario for the Indian subcontinent as expected by the middle of the next century taking into account the projected emissions of greenhouse gases and sulphate aerosols, in a coupled atmosphere-ocean model experiment performed at Deutsches Klimarechenzentrum, Germany, is adopted for the study. The adopted scenario represented an increase in monsoon seasonal mean surface temperature of the order of about 1.5°C over the south India and 1°C over northwest and central India in the decade 2040-49 with respect to the 1980s and an increase in rainfall of the order of 2 mm per day over south India while the simulated decrease of the order about -1 mm and -1.5 mm over northwest and central India respectively. The IPCC Business-as-usual scenario projection of plant usable concentration of CO_2 about 460 PPM by the middle of the next century are also used in the crop model simulation (CERES - Rice V3 Model).

Simulation studies carried out with the climate change scenarios over different parts of the country are analysed and interpreted.

Key words – Crop model, Rice production, Climate change, Green house gas, Coupled atmosphere ocean model.

1. Introduction

Changes in the atmospheric composition due to anthropogenic increase in green house gases etc., lead to changes in the radiative balance of the earth and consequent alterations in temperature, circulation pattern and the weather. The after effect of these changes are likely to manifest as major climate changes over the

TABLE 1

Regional scenarios of changes in temperature and rainfall in the country

Region	Temperature (°C)	Rain (mm/day)
NW India	+1.0	-1.0
Central India	+1.0	-1.5
South India	+1.5	+2.0

surface of the earth. Numerical models of the atmosphere have proved to be a very good tool in the assessment of the effect of increasing green house gases on the earth's climate (Washington and Daggupaty, 1975; Manabe and Wetherald, 1975; Manabe *et al.*, 1992). These studies predicted an increase of about 0.3 °C/decade during the next century as a result of accumulation of green house gases in the atmosphere (IPCC, 1992). The effect of the build up of sulphate aerosols in the atmosphere and its ability to increase the albedo of the atmospheric system, thereby cooling the earth atmosphere has also been recognised by the IPCC.

Lal *et al.* (1995) have examined the possible climate change scenario for the Indian subcontinent as expected by the middle of the next century, taking into account the projected emission of green house gases and sulphate aerosols. The results suggested an increase in annual mean surface air temperature of 1°C over the Indian subcontinent in the 2040s with respect to the 1980s. Warming during the monsoon season was found to be less pronounced than during the winter months. Another important finding of the experiment was that the warming of the Indian subcontinent is likely to be lower in magnitude as compared to the adjacent Indian ocean, resulting in a decline of the land-sea thermal contrast, the primary factor responsible for the onset of summer monsoon circulation. As a consequence, contrary to simulations which consider only CO_2 forcing, a decline in monsoon rainfall was simulated over some parts of India. Regional scenarios of changes in temperature and rainfall over different parts of India is illustrated in Table 1.

The climatic elements which affect plant growth and development, hence agriculture in a wider sense, *viz*. CO_2 concentration, temperature, precipitation, radiation, humidity and wind speed are likely to be altered with the increased build up of green house gases in the atmosphere (Sinha, 1993). In India, the mean annual air temperature for the period 1901-88 as represented by 73 stations revealed a significant warming of 0.4°C /100 years, which is comparable to the global mean trend of 0.5°C/100 years (Sikka and Pant, 1991). The relationship between climatic change and agriculture is particularly important, as world food production is under pressure from a growing population. Weather still plays a vital role in agricultural productivity in Asia despite of the innovations and technological advances. Rice is the second most important crop in the world after wheat, with more than 90% currently grown in Asia. It has been estimated that rice production needs to increase by 70% over the coming decades to meet the demands of population growth. Hence it is vital to understand the effect of climate change on growth, development, water use and productivity of rice crop in India. There are two approaches to address this problem. First, measurement of the direct effects of the altered weather parameters and CO_2 concentration on the crop growth in a phytotron, glass houses, open top chamber *etc* ; secondly, modelling the plant growth development and yield. Crop simulation model approach provide us with an opportunity of building scenarios of agricultural production in changed climates. The Crop Environment Resource Synthesis (CERES) models have been extensively used for assessment of the impact of climatic change on agricultural crop production (Rao and Sinha, 1994; Gennadiy and Larisa, 1994; Rosenzweig and Iglesias, 1994; Otavio *et al.*, 1994).

TABLE 2

Stations and period of weather data for the study

Name of the station	Latitude	Longitude	Period of data
Ludhiana	30.56	75.53	1974-1995
Hissar	29.10	75.46	1969-1995
Delhi	28.40	77.00	1968-1994
Jabalpur	23.15	79.97	1969-1997
Raipur	21.27	81.60	1971-1997
Kasargod	12.52	74.98	1954-1992
Pattambi	10.52	76.22	1951-1992
Ollukara	10.68	76.25	1960-1985
Kottayam	9.18	76.50	1954-1991
Kayamkulam	8.48	76.95	1969-1992

The objective of the present study is to evaluate the effect of climatic change as expected by the middle of the next century taking into account the projected emissions of greenhouse gases and sulphate aerosols, in a coupled atmosphere-ocean model experiment (Lal *et al.*, 1995), on rice production in the Indian subcontinent. The CERES-Rice V3. (Singh *et al.*,1994) crop growth simulation model which has already been evaluated by different workers for its suitability in Indian climate, is used under study.

TABLE 3

Transplanting dates and water holding characteristics at different locations

Name of the station	Transplanting Date	Soil depth (cm)	Lower/drained upper limit (mm)	Extractable water content (mm)
Ludhiana	1st July	60	36/ 117	81
Hissar	1st July	60	36/ 117	81
Delhi	1st July	60	42/ 123	81
Jabalpur	15th July	90	166/274	108
Raipur	24th July	90	153/270	117
Kasargod	8th June	100	72/176	104
Pattambi	8th June	100	72/176	104
Ollukara	8th June	100	72/176	104
Kottayam	8th June	100	72/176	104
Kayamkulam	8th June	100	72/176	104

2. Materials and Methods

2.1. *Baseline Climate Data*

A widely accepted approach to analyse the possible effects of different climate changes on crop yield is to determine the incremental changes (anomalies) to temperature, precipitation, CO_2 *etc.* and to apply these changes uniformly to a baseline climate *e.g.* the daily climatic records at a weather station (Rosenzweig and Iglesias, 1994). In this study, long term weather data from 10 locations representing different regions of the country has been used as baseline climate data. These sites (Table 2) have climate records ranging from 24 to 42 years providing maximum and minimum temperature, precipitation and bright sunshine hours on a daily basis throughout the record. Daily solar radiation was derived from sunshine hours. These data form the base line climate data for the climate change impact experiments carried out in this paper. The baseline climate data as modified by the climate change scenario based anomalies is used further in crop simulations to bring out its effect on crop yield.

2.2. *Crop growth model and it's validation*

2.2.1. *Crop growth model*

Crop models which share a common input and output data format have been developed by International Benchmarkk Sites Network for Agrotechnology Transfer (IBSNAT) (Singh *et al.*, 1994) and embedded in a software package called the Decision Support System for Agrotechnology Transfer (DSSAT). The DSSAT itself (Tsuji *et al.*, 1994) is a shell that allows the user to organize and manipulate crop, soil and weather data and to run crop models in various ways and analyse their outputs. The simulation of rice growth was performed with the CERES-Rice V3. model embedded in DSSAT. The IBSNAT models were employed for the simulation of crop response to climate change because they have been already validated for a wide range of climates all over the world and are independent of location or soil type encountered.

The CERES-Rice model simulates the following processes on a daily basis, *viz.* (1) Phenological development of the crop as it is effected by the genetic characters of the crop variety studied and weather; (2) growth of leaves, stems and roots; (3) biomass accumulation and partitioning among leaves, stem, panicle, grains and roots; (4) soil water balance and water use by the crop; (5) soil nitrogen transformations and uptake by the crop (Alocilja and Ritchie, 1988). The phenological stages simulated by the model are (1) Sowing or transplantation, (2) germination, (3) emergence, (4) juvenile phase, (5) panicle initiation, (6) heading, (7) beginning of grain filling, (8) end of grain filling and (9) physiological maturity. Simulation of the duration of each phenological stage makes use of the concept of thermal time or degree days and photoperiod as defined by the genetic characteristics of the crop. The model also simulates increases in photosynthesis and changes in evapotranspiration driven by increases in atmospheric CO_2; these responses are known as the "direct" effects of CO_2 (Acock and Allen, 1985).

2.2.2. *Input data*

The input data required to run the CERES-Rice V3. Model include daily weather data, soil albedo, soil water

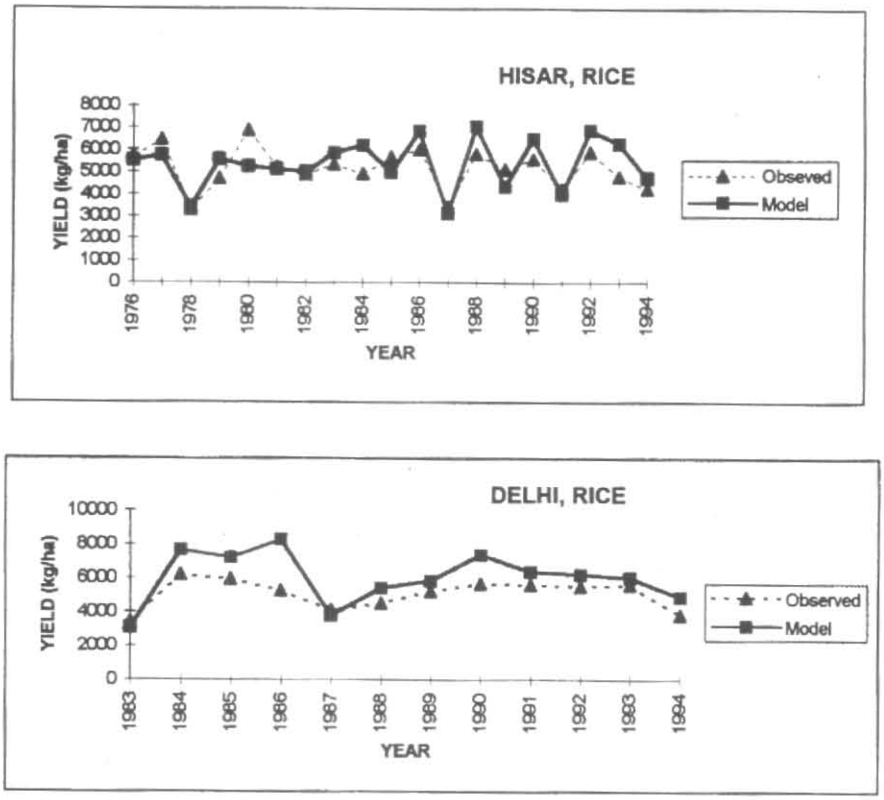

Fig. 1. Model and observed variation in rice yield at Hisar and Delhi

drainage constant, field capacity, wilting point and initial soil moisture in different layers as well as maximum root depth, crop genetic coefficients and management practices (plant population, plant row spacing and nitrogen application). Other input files include chemical and physical description of the soil profile with separate information for each horizon, initial organic matter in the soil at the beginning of the experiment, initial soil water content, nitrogen concentration and pH for each layer of the soil profile, dates and amount of irrigation required for irrigation management, dates amount and types of fertilizer required for fertilizer management, planting date and depth, row and plant spacing and other information for crop management, cultivar-specific characteristics and genetic coefficient, and crop specific characteristics.

Crop cultivars considered in the study are PR106 in NW India under irrigated condition, IR 36 in central India (irrigated at Jabalpur and rainfed at Raipur) and Jaya in south India under rainfed conditions. Water and nitrogen management in the model is as per agronomical recommendations widely accepted in the region. Other crop management conditions are chosen as per the current field practices at the selected sites. Soil textures taken are mainly sandy loam, clay loam and shallow sandy loam in northwest, central and south part of India respectively. The optimum dates of transplanting, soil depth and water holding characteristics for selected sites are given in Table 3. The terms lower limit and drained upper limit correspond to the permanent wilting point and field capacity, respectively (Ritchie *et al.*, 1986). Total extractable soil water is a function of soil physical characteristics as well as rooting depth.

2.2.3. *Genetic coefficients*

Crop genetic input data , which explains how the life cycle of a rice cultivar responds to its environment, are not usually available. The genetic coefficient are crucial because they strongly influence the simulation of growth and development of the crop and therefore, these genetic coefficients were derived iteratively following Hunt's method (Hunt *et al.*, 1993). This involves determining values of the phenology coefficients and then values of the coefficients describing growth and grain development. Minimum crop data sets required for these calculations

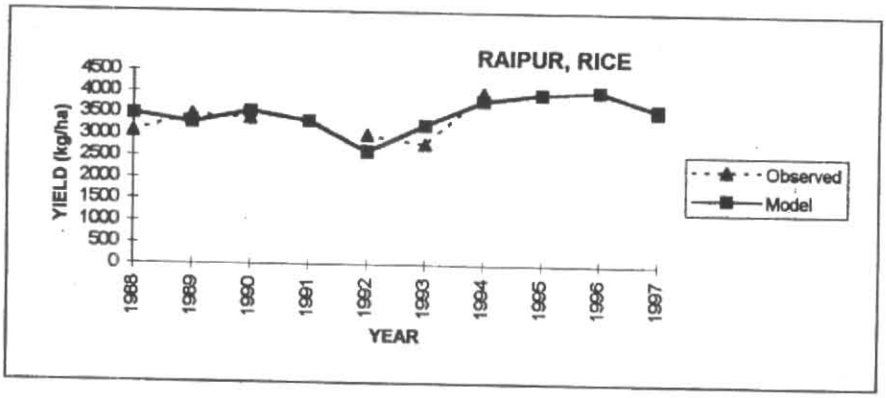

Fig. 2. Model and observed variation in rice yield at Raipur

included dates of transplanting, panicle initiation, anthesis, physiological maturity, grain yield, above-ground biomass, grain density and weight, number of grains per spike and maximum leaf area index. The CERES -Rice model uses eight genetic coefficients *viz.*, P1, P2O, P2R, P5, G1, G2, G3 and G4. The first four coefficients are related to phenological development aspects and last four are related to growth and grain development aspects of the rice crop. The details on these coefficients are as described below

P1	Time period (expressed as growing days [GDD] in °C over a base temperature of 9°C) from seeding emergence during which the rice plant is not responsive to change in photoperiod. This period is also referred to as the basic vegetative phase of the plant.
P2O	Critical photoperiod or the longest day length (in hours) at which the development occurs at a maximum rate. At values higher than P2O development rate is slowed, hence there is a delay owing to longer day lengths.
P2R	Extent to which phasic development leading to panicle initiation is delayed (expressed as GDD in °C) for each hour increase in photoperiod above P2O.
P5	Time period in GDD (°C) from beginning of grain filling (3-4 days after flowering) to physiological maturity with a base temperature of 9°C.
G1	Potential spikelet number coefficient as estimated from the number of spikelets per g of main culm dry weight (less lead blades and sheaths plus spikes) at anthesis. A typical value is 55.
G2	Single grain weight(g) under ideal growing conditions, *i.e.* non-limiting light, water, nutrients and in the absence of pest and disease.
G3	Tillering, coefficient (scaler value) relative to IR64 cultivar under ideal conditions. A higher tillering cultivar would have a coefficient greater than 1.0.
G4	Temperature tolerance coefficient. Usually 1.0 for varieties growth in normal environments. G4 for japonica-type rice growing in a warmer environment would be 1.0 or greater. Like wise, the G4 value for indica-type rice in very cool environment or season would be less than 1.0.

Genetic coefficients used in the model for genotype PR106 and IR36 (Lal, 1999) and Jaya (Saseendran *et al.*, 1998) are given in Table 4.

2.2.4. *Model validation*

In order to understand the adequacy of the CERES Rice model in simulating crop yields in response to historical climate variability, validation of the model have been carried out by many researchers based on crop yield data available from experimental sites at India. Lal *et al.* (1998) has carried out the comparison of observed versus the model simulated yield values at Hissar and Delhi in NW India (Fig. 1). In the figure, the model yield simulates represents those of the variety PR106 and observed is the

TABLE 4

Genetic coefficients for different genotypes in the agroclimatic conditions of India

Growth and development aspects of rice crop	Genetic coefficient		
	PR106	IR36	Jaya
Development aspects			
Juvenile phase coefficient	800.0	450.0	830.0
Critical photoperiod	12.1	11.7	15.0
Photoperiodism coefficient	70.0	149.0	50.0
Grain-filling duration coefficient	475.0	350.0	277.0
Growth aspects			
Spikelet number coefficient	60.0	45.0	72.8
Single grain weight	0.021	0.023	0.028
Tillering coefficient	1.0	1.0	1.0
Temperature tolerance coefficient	1.0	1.0	1.1

average yield at the station for a number of varieties including PR106. But both the series of data represents the same agromanagement and cultural practices. Notwithstanding the above, the simulated and observed means were not significantly different ($p > 0.01$). In central India at Raipur, a comparison of observed versus model simulated yields carried out by Lal (1999) for the genotype IR36 (Fig. 2) depicts that the model realistically simulates the year to year variations in yields. Result shows that the percent variation in simulated over observed value is -0.6. Validation results on phenology aspect indicates that simulated pre-anthesis duration varied within 3 percent of observed whereas the post-anthesis duration was same as observed. For genotype Jaya in south India, the model validation results (Saseendran *et al.,* 1999) showed that, in eight experiments with different planting dates under rainfed conditions, the flowering date was predicted within an error of four days and the date of crop maturity within an error of two days. The grain yield predicted by the model was within an error of 3% for both transplanting dates but the straw yield prediction was within an error of 27%. Thus it is seen that model simulates the phenology and yield for selected cultivars in different parts of country reasonably well accounting the effect of daily weather on rice crop. So, the CERES Rice model can be suitably applied for simulation of rice yield and its duration under changed weather scenario.

2.3. *Physiological effects of CO_2*

CO_2 is vital for photosynthesis, and hence for plant growth. The evidence is that increases in CO_2 concentration would increase the rate of plant growth (Cure, 1985; Cure and Acock 1986). In some crop plants, the reduction in stomatal opening caused by high CO_2 result in reduced transpiration per unit leaf area while enhancing photosynthesis. Thus, there is a net increase in water use efficiency. Kimball (1983) estimated from a compilation of green house and experimental studies a mean crop yield increase of 33 +/-6% for a doubling of CO_2 from 300 to 600 ppm for a range of agricultural crops.

The CERES - Rice model makes use of the methods derived from Peart *et al.* (1989) to simulate the changes in photosynthesis and evapotranspiration caused by higher concentrations of CO_2. For the daily canopy photosynthetic rate predictions, a multiplier was developed as a function of CO_2 concentration based on experimental data collected by Allen *et al.* (1987). The multiplier was used to adjust daily biomass growth rate depending on CO_2 level. The Peart *et al.* (1989) estimated the ratio which is applied to the calculation of transpiration rates in the model to account for stomatal closure under higher CO_2 concentrations.

2.4. *Climate model*

The climate change scenarios considered in the present study is based on the results of the numerical experiments performed (Lal, *et al*, 1995) with the European Community HAMburg (ECHAM version 3) atmospheric model coupled to a large scale geostrophic (LSG) ocean model. ECHAM3 is extensively used for global climate modelling in Germany (DKRZ, 1994).

2.5. *Design of experiments for climate change impacts on rice yield*

2.5.1. *Control experiments*

The CERES-Rice V3. model was run with the base line climate data of the selected locations, designated as control experiments for comparison of the crop performance of the climate changed scenarios with climate unchanged scenarios. The CO_2 concentration considered in the model simulation for control run is 330 ppm.

2.5.2. *Climate change scenario for the Indian subcontinent*

Lal *et al.* (1995) examined the response of a transient increase of green house gases and sulphate aerosols in the earth's atmosphere on the monsoon climate using the data generated in a coupled atmosphere-ocean model experiment performed recently at Deutsches

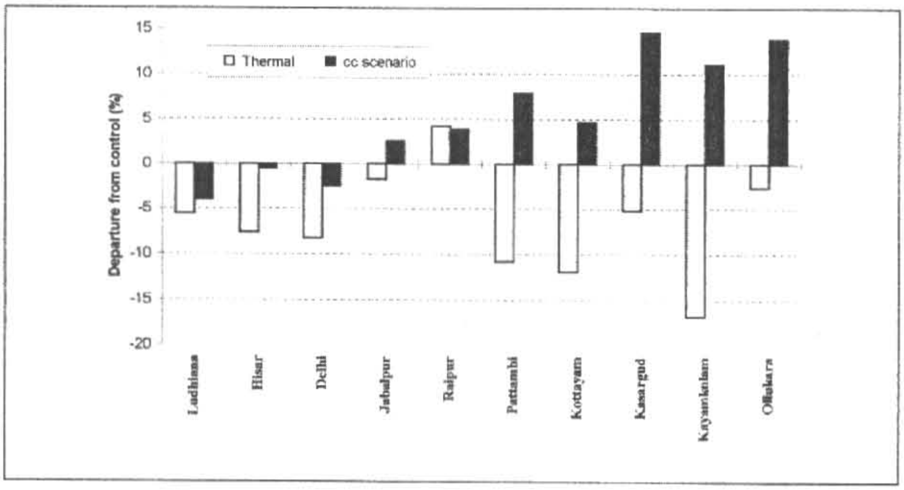

Fig. 3. Comparison between average rice yields at different locations in India under climate change scenario and temperature elevations over the control (baseline climate)

Klimarechenzentrum, Germany. The ECHAM version 3 Deutsches Klimarechenzentrum, 1994) atmospheric model coupled to a Large Scale Geostrophic ocean model was used for the experiments. The study presented the plausible climate change scenario for the Indian subcontinent as expected by the middle of the twenty first century taking into account the projected emission of green house gases and sulphate aerosols. The results show an increase in monsoon seasonal mean surface temperature of the order of about 1.5°C over the south India and 1°C over northwest and central India in the decade 2040-49 with respect to the 1980s and an increase in rainfall of the order of 2 mm per day over south India while the simulated decrease of the order about -1 mm and -1.5 mm over northwest and central India respectively. These anomalies in surface air temperature and rainfall were imposed over the observed base line climate data of selected stations as explained in the next paragraph. The resulted climatic data series were adopted for the rice crop simulation in the changed climate scenario. The CO_2 concentration considered for the model simulation is based on the Business-as-usual scenario of IPCC (IPCC, 1994) with a 1.3% per year compound increase of CO_2, yielding an average equivalent CO_2 concentration of about 660 ppm for the 2040-49 decade. This equivalent concentration represents CO_2 and other green house gases. As such, the actual plant usable CO_2 concentration is only about 460 ppm (Sinha, 1993). Hence, the value of 460 ppm of CO_2 concentration has been used in the crop simulations.

Temperature anomaly projected under climate change scenario at a station was added to the daily values of maximum and minimum temperature in the baseline climate data of the station. Rainfall anomalies were applied only to the rainfall values on rainy days. If one apply a certain increment in rainfall to all days of the season, all the days would turn out to be rainy. As such the amount of anomaly to be added on rainy day based on a certain increment in rainfall was calculated by working out a multiplication factor based on number of actual rainy days in the baseline climate data for the corresponding season in the following way:

From the baseline climate data, find out the ratio of the observed rainfall amount on a particular rainy day to the south west monsoon seasonal total rainfall amount. Then multiply this ratio with the seasonal rainfall anomaly (seasonal rainfall anomaly = daily rainfall anomaly *x* number of days in the season) to find out the fraction to be added to the rainfall on a rainy day in the baseline climate data series. The baseline climate data series thus created is further used as input to the crop models.

3. Crop growth model sensitivity

3.1. *Model sensitivity to CO_2*

The response of rice to increasing atmospheric CO_2 has been examined under a wide range of conditions in phytotron, glass house and SPAR unit studies (Imai *et al.*,

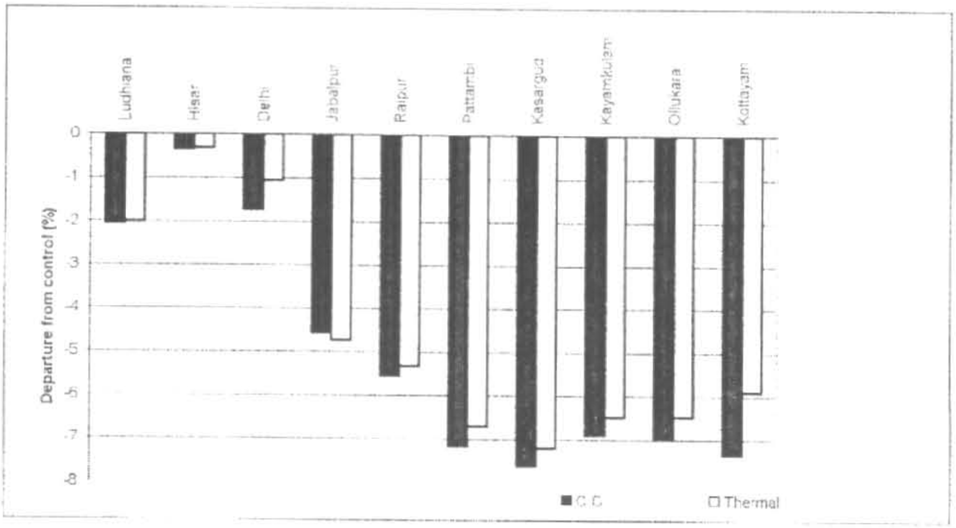

Fig. 4. Comparison between rice crop duration from transplanting to maturity at different locations in India under climate change scenario and temperature elevation over control (baseline climate)

1985, Baker *et al.* 1990). In the field grown tropical rice during 1994 wet (August - November) and 1995 dry (January - April) seasons, Ziska *et al.* (1997) analysed that increases in CO_2 concentration alone (+200 ppmv, +300 ppmv) resulted in a significant increse in total plant biomass (+31%, +40%) and crop yield (+15%, +27%) compared with the ambient control during two seasons respectively. In a sensitivity study on yield, simulated by CERES Rice model, to CO_2 concentration ranging from 150 to 1200 ppmv, Lal *et al.* (1998) found that under irrigated cultivation in NW India the increase in rice yield was quite pronounced for CO_2 concentration from 150 ppmv to about 350 ppmv and slow increase for CO_2 levels between 350 ppmv and 950 ppmv, further no significant increase. Their results also indicate 15% increase in simulated rice yield for doubling of atmospheric CO_2 from the present day level of 330 ppmv. In another experiment in south India under rainfed cultivation, similar response of CERES Rice yield to CO_2 concentrations was reported by Saseendran *et al.* (1999). With a doubling of CO_2 the yield is found to increase by 10% under rainfed cultural practices for cultivation of rice crop. These sensitivity results are consistent with those reported elsewhere suggesting that a doubling of atmospheric CO_2 concentration from 330 ppmv to 660 ppmv might cause a 10 to 50% increase in growth and yield of C3 crops such as wheat, rice and soyabean (Warrick *et al.*, 1986; Gifford, 1988). Adams *et al.* (1988; 1990) reported an increase in dry matter of 10- 50% with doubling of CO_2 in most species of crops when all other factors remain constant.

The increased CO_2 has an important effect on stomatal regulation also. The response of the model simulated evapotranspiration (ET) to an increase in CO_2 in tropical environment is also discussed. The results by Saseendran *et al.* (1999) for rainfed rice indicate a decline in the crop ET with increase in ambient CO_2 level. Model simulations by Lal *et al.* (1998) for the prevailing environmental conditions under irrigated field in NW India suggest 4% reduction in ET in rice and 11% reduction in wheat crop for a doubling of CO_2 from 330 ppmv. A lowering in the ET of the crop results in a reduced water requirement of the crop, which may be attributed to stomatal regulation by CO_2 concentration in the ambient atmosphere. Morison (1987) and Cure and Acock (1986) have also reported about 40% decrease in stomatal aperture resulting in reduced transpiration by 23-46% after doubling of the CO_2 concentration. Hence it may be concluded that an increase in CO_2 concentration leads to yield increase due to CO_2 fertilisation and also enhance the water use efficiency of the paddy.

3.2. *Model sensitivity to temperature*

Biomass yield of a crop can be taken as the product of the rate of biomass accumulation times the duration of growth. The rate of biomass accumulation is determined by the photosynthetic rate minus the respiration rate. Higher temperature shortens the rice growth period, consequently reduce the period available to the plant for photosynthetic accumulation. Highest potential yield of a particular annual crop is therefore obtained in regions where the crop duration is characterised by relatively low temperatures unless the radiation levels are also low (Ritchie, 1993). This is due to the fact that, at low temperature levels the crop gets more days to mature and hence accumulate more biomass. Hence, there will be a reduction in the grain weight of crop plants with increase in temperature. Also, in rice, high temperature conditions after heading was reported to result in both smaller kernels and kernel damage at maturity leading to reduction in grain yield (Yoshida and Hara 1977; Tashiro, 1991). Based on CERES-Rice simulation studies, Zhiqing *et al.* (1994) reported that an increase in temperature alone would decrease rice yield but that enhanced photosynthesis caused by increased CO_2 can compensate for this effect. In a similar study in the Philippines, a 2°C rise in temperature caused yield decrease of 15 - 27% at different locations but the increase in CO_2 concentration to 555 ppm nullified this effect (Crisanto and Leandro, 1994). Rice yields simulated by the CERES-Rice models for a 1° C rise in temperature and 100 mm increase in precipitation in South China showed an increase of 10% in grain yield (Zhang, 1989). The sensitivity of the CERES Rice model to changes in atmospheric temperature in Indian environment has been studied by Lal *et al.* (1998) in NW India for irrigated rice and Saseendran *et al.* (1999) in south India for rainfed rice. Their findings suggest that the maximum average yield, indicating 8% (21%) increment over present level, is obtained at a surface temperature 1°C (3°C) below the baseline climate for ambient CO_2 level in NW (south) India. The yields are found to decline more significantly for a rise in temperature than for a fall in temperature with respect to present day climate. In another experiment by them it was observed that the physiological effect of ambient CO_2 concentration at 660 ppm in NW India (425 ppm in south India) almost compensated for the yield losses due to increase in temperature up to 2°C in both regions. It is unequivocal from these findings that, in the event of a rise in temperature associated with the build-up of green house gases in the atmosphere, there is going to be a decrease in the rice crop yield.

4. Results & Discussion

4.1. *Impact of climate change on rice yield*

The impact of increase in temperature (thermal effect) as well as climate change scenario on rice yield over the control run for the sites under study are presented in Fig. 3. The results of the model simulation indicate a clear evidence for a decrease of rice yield at all the locations except at Raipur when these simulations were carried out accounting only for the projected temperature scenario by keeping rainfall and CO_2 concentration at the current level. This decrease is of the order of 5-8% in NW India, 3-17% in south India. In central India the decrease in the yield is 2% while increase at Raipur is 4%. Simulation results (not given in figure) with only increased CO_2 concentration at 460 ppm in the model increases the yield over control run by 7-9% in NW India, 6% in central India and 8-20% in south India as a result of increased photosynthesis due to higher CO_2. Under climate change scenario our findings suggest the decrease of 0-4% in yield in NW India and increase of the order of 3-5% and 5-17% in central and south India respectively. As such, it is clear from these results that the negative impacts on rice yield associated with increase in temperature is reversed by the fertilisation effect of CO_2 at 460 ppm concentration in central India with negative rainfall anomaly and south India with positive rainfall anomaly. This reversing trend is not seen in NW India under irrigated rice cultivation as the fertilisation effect of CO_2 is partially offsetted by negative rainfall anomaly.

4.2. *Impact of climate change on crop growth period*

The impact of the climate change on time to crop maturity period for the sites under study are presented in Fig. 4. Fig 4 shows the impact of increase in temperature (thermal effect) as well as climate change scenario on rice crop duration in respect of time for maturity, over the time for maturity of a control run. It is clear from the figure that in the case of the thermal effect, the crop maturity period gets reduced by an order of about 0-2% in NW India, 4-5% in central India and 6-8% in south India over the control runs. These reductions in crop maturity period is slightly magnified under climate change scenarios. This indicates that changes in climatic parameters other than surface temperature do not significantly affect the maturity period. Obviously this should lead to reductions in crop grain yields in general, as these yields basically depends on the time available to the crop for accumulating the biomass out of photosynthesis before reaching crop maturity.

5. Limitations of the study

The present day GCMs with coarse resolution are well accepted for global climate change scenario projections. But, they are still inadequate in predicting the regional climate in relation to agriculture (Sinha, 1991). The crop model used is not calibrated for all locations in the state. Only one rice crop variety, namely, Jaya could be subjected to the impact analysis. The primary thrust of the CERES models used in the impact analysis was to analyze how weather and genetic characteristics affect potential yield given a specified management scheme. The factors currently given attention to are limited to plant water supply and plant nitrogen supply, temperature and CO_2. The nutrient factors representing phosphorus, potassium, and other essential plant nutrients are assumed to be in abundant supply in the soil so as not to cause any extent of stress to the plant, hence excluded. The pest problems, weeds, diseases, and toxicities of the soil as well as soil salinity and soil erosion problems are also not covered by the model.

Increased shading associated with enhanced cloudiness lead to spikelet sterility in rice (Sinha,1993). It has been reported that for a decrease in radiation by 25%, the reduction in yield could be more than 30 %. Therefore, in the event of an increase of temperature in the atmosphere consequent to build up of greenhouse gases, enhanced cloudiness is expected with more heat induced evaporation. Even though the enhanced level of CO_2 concentration in the atmosphere lead to increased biomass production, it may not proportionately enhance the grain yield (Sinha, 1993). The crop models currently available are not capable of simulating these interactive mechanisms affecting yield. Results of the study presented above should be viewed in the light of these limitations.

6. Conclusions

The impact of climate changes as simulated by atmosphere ocean coupled GCM on the rice crop productivity in the country was analysed using CERES-Rice crop simulation model. From the study, the following broad conclusions can be made :

By the middle of the next century in central and south India, an increase in rice yield is possible under the projected climate change scenario adopted for the study. In NW India a decrease in yield under irrigated conditions may take place as a result of significant decrease in rainfall during the monsoon season under climate change scenario. Also, reduction in crop duration may occur at all the locations in the country due to increase in temperature associated with the build-up of greenhouse gases in the atmosphere. The results of the study should be viewed only within the constraints of the limitations of the tools adopted for the analysis.

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