MAUSAM, **65**, 4 (October 2014), 529-538

631.15 : 633.18 (540.29)

Crop yield prediction using CERES-Rice *vs* 4.5 model for the climate variability of different agroclimatic zone of south and north-west plane zone of Bihar (India)

P. K. SINGH, K. K. SINGH, A. K. BAXLA, B. KUMAR*, S. C. BHAN and L. S. RATHORE

India Meteorological Department, Lodi Road, New Delhi, India

**Department of Agronomy, BAU, Sabour, Bhagalpur, Bihar, India*

(*Received 1 April 2013, Modified 13 September 2013*)

e mail : pksingh66@gmail.com

सार – विश्व में CERES धान निदर्शों को प्रमाणिक माना गया और इनका परीक्षण किया गया तथा कृषि प्रौद्योगिकी अंतरण में इसका व्यापक रूप से उपयोग किया गया। फसलों के संवर्धन और उपज बढ़ाने के लिए फसल संवर्धन मॉडल को प्रमुख उपकरणों के रूप में देखा गया है। अत: भारत के बिहार राज्य में धान के उत्पादन को सुदृढ़ करने के लिए DSSAT बनाम 4.5/CERES धान (कृषि प्रौद्योगिकी अंतरण के लिए निर्णय समर्थन प्रणाली/संसाधन और पर्यावरण सिंथेसिस के माध्यम से फसल आकलन) का अनुप्रयोग किया गया है। बिहार के दक्षिणी और उत्तरी पूर्वी कछार के मैदानी भागों के दीर्घावधि ऐतिहासिक मौसम आँकड़ों (1980-2011) और (1985-2011) का उपयोग फसल की पैदावार का विश्लेषण करने के लिए किया गया। CERES- धान बनाम 4.5 निदर्श के संचालन के लिए उत्पत्ति मूलक गुणांक प्राप्त किए गए और इन दो कृषि जलवायविक क्षेत्रों द्वारा अनुभव जनित जलवायु की विविधता की स्थितियों के अन्तर्गत निदर्श के निष्पादन की जाँच की गई। प्रबंधन संयोजन अनुकरण में वर्षा वाली स्थितियों के अंतर्गत धान कृषिजोपजाति रमनसूरी की पौध लगाने की तीन तारीखें (1, 15 और 30 जुलाई) हैं।

परिणामों से पता चला है कि बुआई की पहली और बाद की दोनों तारीखों में 15 जुलाई की अनुकूलतम बुआई की तारीख की तुलना में कम पैदावार हुई है। अनुकरित ऋतुजैविकी और पैदावार प्रेक्षित आँकड़ों के अनुरूप पाई गई जिससे बिहार के इन दो क्षेत्रों में फसल की पैदावार का आकलन करने के लिए अंशाकन निदर्श का प्रचालनात्मक रूप से दैनिक प्रेक्षित मृदा, फसल प्रबंधन और मौसम प्राचलों के साथ उपयोग किया गया।

इस विश्लेषण से यह भी पता चला है कि इस विषय के अध्ययन की अवधि में विभव और वर्षा वाली स्थितियों के अन्तर्गत फसल की भिन्नताएं आर्द्र क्षेत्रों के साथ-साथ तापीय, विकिरण क्षेत्र से भी प्रभावित थी। इनसे प्राप्त हुए परिणामों से यह पता चला है कि धान की फसल में दाना पड़ने के समय गुच्छे बनने की ऋतुजैविकी अवस्था, जल और नाइट्रोजन की उपलब्धता के प्रति संवेदनशील रही। धान ऋतुजैविकी का पूर्वानुमान करने के लिए भी यह निदर्श संतोषजनक है। प्राप्त हुए परिणामों से यह पता चला है कि CERES धान बनाम 4.5 पर्याप्त सटीकता के साथ बिहार की जलवायु संबंधी स्थितियों में धान ऋतुजैविकी रमनसूरी फसल वृद्धि की अवस्थाओं और अनाज की पैदावार का आकलन करने के लिए सक्षम है और इससे यह पता चलता है कि बिहार राज्य में कृषि योजना से संबंधित विभिन्न नीतिगत और युक्तियुक्त निर्णयों को लेने के लिए इसमें एक उपकरण के रूप में उपयोग करने की क्षमता है।

ABSTRACT. CERES-rice models are being validated and tested across the world and vigorously used in agrotechnology transfer. Crop growth models have been considered as potential tools for simulating growth and yield of crops. Hence, DSSAT v 4.5/ CERES-Rice (Decision Support System for Agro-technology Transfer / Crop Estimation through Resource and Environment Synthesis) was applied to validate the Rice productivity from Bihar State in India. Long term historical weather data (1980-2011) and (1985-2011) from South and North West Alluvial plane zones of Bihar was used for yield analysis. Genetic coefficients required for running the CERES-Rice *vs* 4.5 model were derived and the performance of the model was tested under the climate variability conditions experienced by these two agroclimatic zones. Management combinations simulated were three transplanting dates (1^{st}, 15^{th} & 30^{th} July) for rice cultivar Rmansuri under rainfed conditions.

The results indicated that both the early and late sowing dates result in lower yields as compared to optimum sowing date of 15^{th} July. The simulated phenology and yield were found to be in agreement with observed data suggesting that the calibrated model may be operationally used with routinely observed soil, crop management and weather parameters for Rice yield estimation from these two regions of Bihar.

The analysis also brought out that the yield differences under potential and rainfed condition during the study period , was influenced by variations in thermal, radiation regime as well as moisture regimes. The results showed that phenological stage of panicle initiation to grain filling is sensitive to water and Nitrogen availability status in the Rice Crop. This model is also satisfactory in predicting the Rice phenology. These results indicate that the CERES rice *vs* 4.5 models is capable of estimating growth stages and grain yield of rice cultivar Rmansuri in climatic conditions of Bihar with reasonable accuracy and hence show potential for its use as a tool in making various strategic and tactical decisions related to Agriculture planning in the state of Bihar.

Key words – CERES-rice model, Yield gap, Genetic coefficients, Soil and weather.

1. Introduction

In India, about 65% of gross cropped area corresponds to the summer monsoon season (about 70% of the total annual rainfall in India occurs during June to September). In this season, Rice is the most important cereal crop in India which occupies nearly 35% of the total area under food grains under kharif acreage and is mostly grown in areas receiving 1000 mm and above, indicating its heavy dependence on monsoon rainfall. Fluctuation in the total seasonal rainfall and intra seasonal distribution has strong link to rice productivity. Moisture stress due to prolonged dry spells or thermal stress due to heat wave conditions significantly affect the rice productivity when they occur in critical life stages of the crop. Similarly wet spells promote the spread of pest and diseases, thus leading to significant loss in crop yield, unless the preventive measures are adopted. In contrast, the yields of about 6 tones per hectare have been achieved in Uttar Pradesh, Punjab and Haryana due to favorable environmental conditions and better management techniques in these states. There have been few studies both in India and elsewhere aimed at understanding the nature and magnitude of gains and /or losses in yield of particular crops at selected sites under climate variability and change (Sinha & Swaminathan, 1991; Abrol *et al*., 1991; Aggarwal & Sinha, 1993; Aggarwal & Karla, 1994; Gangadhar Rao & Sinha, 1994; Gangadhar Rao *et l*.,1995; Mearns *et al*., 1996; Riha *et al*., 1996; Lal *et al*., 1999; Lal *et al*., 1998a, Lal *et al*., 1998b, Singh *et al*., 2009-2010 and Singh *et al*., 2010). Studies also suggest a marked reduction in crop yields in the arid and sub humid tropical regions in recent decades due to global warming (IPCC, 1996).

The traditional rice growing states of Eastern India constitute Assam, Bihar, Jharkhand, Orissa, West Bengal, Chhattisgarh and eastern parts of Uttar Pradesh, which account for 61% of the total rice area and 51% of total rice production in the country. Rice as staple food crop plays an important role in the Indian economy. Rice is the main crop of Bihar. There are three crop growing seasons, *i.e*., autumn, winter and garma (summer) and as such rice is grown throughout the year. As the state has been bifurcated into Bihar and Jharkhand, the area under rice in Bihar is seen relatively to have been decreased, but there is significant increase in production and productivity of rice from Bihar, during each plan period.

Average rice productivity of the state is 1272 kg/ha and it is categorized under low productivity group. About 89% of rice area in Bihar is concentrated in medium to low productivity group which, however, contributes 80% of the total production of the state. Across the State, Buxar district is having the highest productivity of 2585 kg/ha and Samstipur is having the lowest productivity of 539 kg/ha (Diwakar, 2009).

The gap between the state average productivity and potential is thus very high owing to environmental conditions, technology adoption and inputs. Therefore, bridging the existing yield gaps by making adequate availability of quality seeds and other technical inputs to farmers would be the first and foremost requirement for improvement of crop productivity. Crop specific and zone specific strategies should be adopted at farmer level to derive maximum benefit. Bihar needs specific development strategies suitable for North and South region of the State (Diwakar, 2009).

Bihar, as other eastern states of India, is characterized by good soil, adequate rainfall, favorable hydrological profile, water resources, and congenial temperature regime, indicating has high agricultural production potential. In fact, this state represents the heart of the great Indo-Gangetic Plains-one of the most fertile plains of the world. But, enigmatically, this plain continues to be “rich State inhabited by poor people”. Though agriculture is the backbone of Bihar’s economy, employing 81% of the workforce and generating nearly 42% of the State Domestic Product, it has not improved the livelihood security of the poor farmers because of the lack of adequate technological support by the state. The State with geographical area of about 94.2 thousand sq. km. has the natural endowment of fertile soil, good rainfall, plenty of water resources and agro-climatic conditions suitable for growing three crops a year and almost all types of crops.

About 71 per cent of the variations in the agricultural output in the state were explained by variations in rainfall, irrigation and farm harvest prices. Since variability in the rainfall and farm harvest prices is high, the production process remains quite risky. There is thus an urgent need to understand the crop phenology weather interactions to assess the means to address the instability in production and to enhance and achieve a sustainable higher productivity from this state through scientific interactions.

In this paper, the ability of the CERES (Crop Estimation through Resource and Environment Synthesis) rice crop simulation model to simulate practically the variations in productivity and identify the critical phenological stages and establish optimum plant weather interactions for improved rice production has been attempted using weather data from South and North West Alluvial plane zones of Bihar.

2. Data and methodology

Bihar Agricultural College, Sabour (Bihar) is situated in the Gangetic alluvial plains of South Alluvial Plane zone district in Bihar. It is located north of the river Ganga at 25.23° N Latitude, 87.07° E Longitude at an altitude of 37 meters above mean sea level. The soil type at the farm is sandy loam and an average depth of 70cm was considered for rice growth. This region is characterized by hot desiccating summer, cold winter and moderate rainfall. May is the hottest month with an average maximum temperature of 42 °C. January is the coldest month with an average minimum temperature of 5 to 10 °C. The average annual rainfall is 1150 mm, precipitating mostly between mid June to mid October.

College of Agriculture, Pusa (Bihar) is situated in North Gangetic plains of Samstipur district in Bihar. It is located south of the river Ganga at 25.98° N Latitude, 85.67° E Longitude at an altitude of 52 meters above mean sea level. The soil type at the farm is silty clay and an average depth of 70 cm is considered for rice crop. This region is also characterized by hot desiccating summer, cold winter and moderate rainfall. May is the hottest month with an average maximum temperature of 44 °C. January is the coldest month with an average minimum temperature of 3 to 4 °C. The average annual rainfall is 1235 mm, precipitating mostly between mid June to mid October.

2.1. *Model description*

Crop models which share a common input and output data format have been developed and embedded in a software package called Decision Support System for Agrotechnology Transfer (DSSAT) by the IBSNAT group. The DSSAT itself (Godwin *et al*., 1990; Jones, 1993; IBSNAT, 1994; Ritchie *et al*., 1998 and 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 analyze their outputs. The models running under DSSAT include the CERES models for rice, maize, wheat, sorghum, pearl millet and barely; the CROPGRO models for bean, peanut, soybean etc.

The CERES-Rice model (Tsuji *et al*., 1994; Alocilja & Ritchie, 1988 and Godwin & Singh, 1998) is a process–oriented crop growth simulation model that simulates soil water balance and nitrogen balance on daily incremental basis during the crop life cycle. The model simulates the transformation of seeds, water and fertilizers into grain and straw through the use of land, energy (solar, chemical and biological) and management practices, subject to environmental factors such as solar radiation, maximum/minimum temperature, precipitation, day length variation, soil properties and soil water conditions. Phenological stages are simulated in the model using the concept of thermal time or degree days and photoperiod as defined as by the genetic characteristics of the crop.

Crop growth is simulated employing a carbon balance approach in a source-sink system. Photosynthetic process is initially assured to be controlled only by solar radiation and temperature and later modified by the effect of stresses due to temperature, water and fertilizer. The analytical relationship of the soil water balance and nitrogen balance and nitrogen transformation and uptake leading to the quantification of these stress factors in this model, are taken from Jones & Kiniry (1986).

2.2. *Input data*

The input data required for running the model include daily weather data, soil albedo, soil water 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 data include chemical and physical description of the soil profile with separate information for each horizon, initial organic matter in the soil, initial soil water content, nitrogen concentration and pH for each layer of the soil profile, dates and amount of irrigation, dates, amount and types of fertilizer, planting date and depth, row and plant spacing and other information for crop management, cultivar specific characteristic (genetic coefficients).

The long term observed daily weather data on maximum and minimum temperatures, solar radiation (derived from sunshine hour data) and rainfall along with the data on the soil parameters (as described above) for the selected station, namely, South Alluvial plane zone and North West Plane zone of Bihar has been used in this study. Optimum dates of sowing are chosen as per the current field practices at the selected sites, are given in

TABLE 1

Genetic coefficients used in the CERES –Rice simulation model for genotype(Rmansuri), in the two agroclimatic zones of Bihar, India

Name	Description	Genetic coefficient
	Development aspects	
P1 (Juvenile Phase)	Time period (expressed as growing degree days [GDD] in °C above a base temperature of 9°C) from seedling emergence during which the rice plant is not responsive to changes in photoperiod. This period is also referred to as the basic vegetative phase of the plant	710.0
P2R (Photoperiodism Coefficient)	Extent to which phasic development leading to panicle initiation is delayed (expressed as GDD in øC) for each hour increase in photoperiod above P2O	170.0
P5 (Grain filling duration coefficient)	Time period in GDD °C) from beginning of grain filling (3 to 4 days after flowering) to physiological maturity with a base temperature of 9°C	320.0
P2O (Critical Photoperiod)	Critical photoperiod or the longest day length (in hours) at which the development occurs at a maximum rate. At values higher than P2O developmental rate is slowed, hence there is delay due to longer day lengths	11.2
	Growth aspects	
G1 (Spikelet number coefficient)	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	40.0
G2 (Single grain weight)	Single grain weight (g) under ideal growing conditions, *i.e*., nonlimiting light, water, nutrients, and absence of pests and diseases	0.0240
G3 (Tillering coefficient)	Tillering coefficient (scaler value) relative to IR64 cultivar under ideal conditions. A higher tillering cultivar would have coefficient greater than 1.0	1.00
G4 (Temperature tolerance coefficient)	Temperature tolerance coefficient. Usually 1.0 for varieties grown in normal environments. G4 for japonica type rice growing in a warmer environment would be 1.0 or greater. Likewise, the G4 value for indica type rice in very cool environments or season would be less than 1.0	1.00

Table 1. The terms- lower limit and drained upper limit corresponds to the permanent wilting point and field capacity, respectively (Ritchie *et al*., 1998).

Crop genetic input data, which explain how the life cycle of a particular rice cultivar responds to its environment, are not usually available and therefore these were derived iteratively following Hunt's method (Hunt *et al*., 1993). This involved determining values of the phenology coefficient and then values of the coefficients describing growth and grain development. Minimum data sets required for these calculations included dates of emergence, anthesis, and maturity, grain yield, above ground biomass, grain density and single grain weight. In this study, the cultivar specific data were obtained from recent field experiments at South Alluvial Plane zone and North West Alluvial Plane zone of Bihar. The model was run initially with genetic coefficients derived elsewhere for cultivar Rmansuri and then re-run, using a range of values of each coefficient, to obtain the desired level of agreement between simulated values of development and growth and to determine the genetic coefficients.

In this study the CERES – Rice model with the new genetic coefficients was used to estimate the potential yields of rice during a period of 32 years (1980-2011) and 27 years (1985 to 2011) from South Alluvial plane zone and North West Alluvial Plane zone of Bihar respectively. Further, attempts were made to work out quantitatively the effect of water stress (rainfed conditions), on biomass productivity and grain yield of rice as compared to irrigated conditions under both these growing environments of Bihar.

2.2.1. *Weather data*

Daily weather data (Tmax & Tmin, Rainfall and Bright Sunshine) for 32 years (1981-2011) and 27 years (1985 to 2011) respectively ,from weather stations in South and North West Alluvial plane zones of Bihar, was collected from IMD, New Delhi.

Preparation of weather files for model

For simulation, the model requires weather data to be stored in the format, which is compatible to the model. Weather data pertaining to these locations were arranged in the specific format of DSSAT 4.5 and were given the file extension of WTH.

Global radiation has been computed from sunshine hours using the following Angstrom (1924) formula:

$$R_S = \left[\mathrm{a} + \mathrm{b}\,\frac{n}{N} \right] R_a$$

where,

R_S = Global solar radiation at the surface (MJ/m^2/ day)

Ra = Extra- terrestrial radiation (MJ/m^2/ day)

n = Actual duration of sunshine (Hours)

N = Maximum possible duration of sunshine (Hours)

a and b = Constant (0.25 and 0.5)

2.2.2. *Soil data*

Soil input files include physical and chemical description of the soil profile with separate information for each horizon, soil reflection coefficient, Stage1 soil evaporation coefficient, soil water drainage constant, USDA SCS Runoff curve number, thickness of soil layer, Lower limit of extract table soil water for soil layer, Drained upper limit of extractable soil water for layer, Saturated water content for soil layer, pH for each layer of the soil profile, Root distribution weighing factor for soil layer and Initial soil water content for soil layer. These files are developed for each important soil type for use as default values. For the study area the appropriate values were chosen. Total extractable soil water is function of soil physical characteristics as well as rooting depth (Ritchie, 1991).

2.2.3. *Crop data/ cultivar file*

Crop cultivars considered in the study are dominant medium duration varieties (varying from 115-140 days) grown by the farmers of the region. Water and nitrogen management parameters considered in the model were as per agronomical recommendations widely accepted in these two agroclimatic zones. Three dates of sowing, *i.e.*, 1 July, 15 July and 30 July respectively for this zone were take-up for the study. The management practices considered for this study are plant population 90-plants/m^2, row spacing 20 cm and planting depth 5 cm.

2.2.4. *Genetic coefficients*

Crop genetic input data, which explains how the life cycle of a rice cultivar respond to its environment, has been developed for cultivar Rmansuri and is presented in Table 1.

3. Result and discussion

Crop growth models have been considered as potential tools for simulating growth and yield of crops and assess crop performance under varying climatic conditions. Hence, DSSATv4.5/ CERES-Rice model was applied to the data recorded from rice crop (var. Rmansuri) transplanted on three dates of sowing, *viz*., 1 July, 15 July and 30 July in the two different agroclimatic (South and North West Alluvial plane) zones of Bihar state. Weather data (Max and Min temperature, Rainfall and Bright Sunshine Hours) of thirty two years (1980-2011) and twenty seven years (1985-2011) respectively from South and North West Alluvial plane zones of Bihar was used in the analysis.

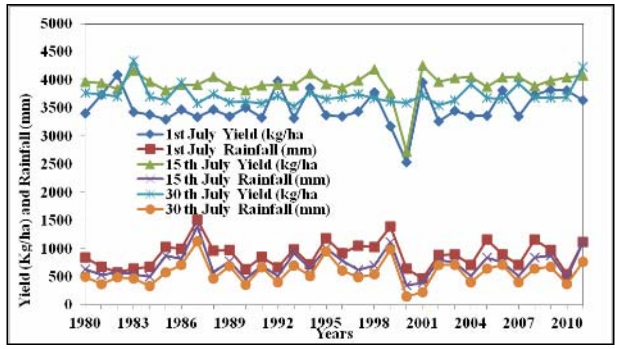

Fig. 1(a). Relation between yield (kg/ha) and rainfall (mm) under rainfed conditions in the South Alluvial plane zone of Bihar (1980-2011)

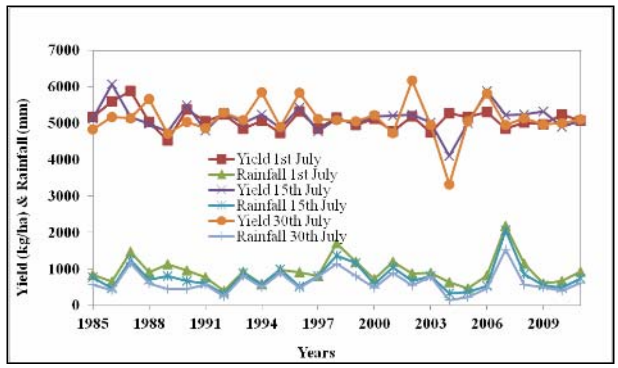

Fig. 1(b). Relation between yield (kg/ha) and rainfall (mm) under rainfed conditions in the North-West Alluvial plane zone of Bihar (1985-2011)

The result indicated that the early and late sowing dates gave lower yield as compared to optimum sowing date of 15th July. The attainable yield was estimated by imposing the management constraint of delayed sowing of 15 days from the optimum time (15 July) of sowing. The simulated phenology and yield were found in agreement with observed data suggesting that calibrated model can be operationally used satisfactorily with routinely observed soil, crop management and weather parameters.

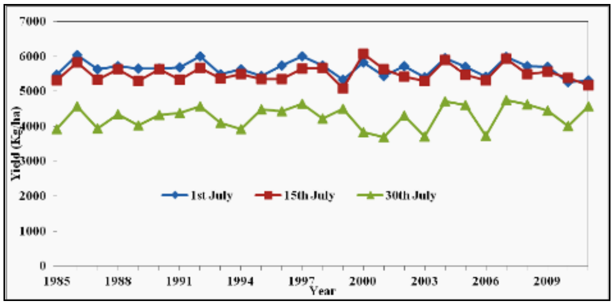

Fig. 2(a). Potential yield (kg/ha) under different sowing dates in the South Alluvial plane zone of Bihar (1985-2011)

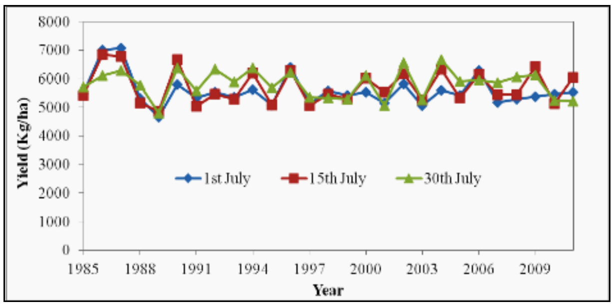

Fig. 2(b). Potential yield (kg/ha) under different sowing dates in the north-west Alluvial plane zone of Bihar (1985-2011)

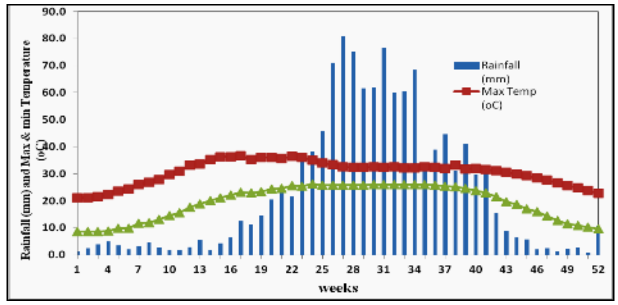

Fig. 3(a). Mean weekly rainfall and max & min temp in South Alluvial plain zone of Bihar (1970-2012)

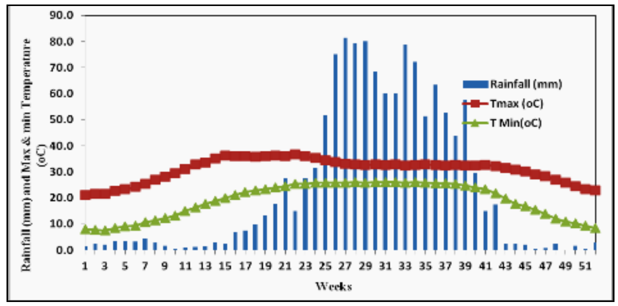

Fig. 3(b). Mean weekly rainfall and max & min temp in North-West Alluvial plain zone of Bihar (1970-2012)

The rainfall conditions and the yield under rainfed conditions from South Alluvial Plane zone of Bihar are depicted in Fig. 1(a). These rainfed crop yields ranged from 2539 to 4086 kg/ha, 2721 to 4257 kg/ha and 3527 to 4341 kg/ha under the different sowing dates of 1st July, 15th July and 30^{th} July. The highest yield of rice was generally recorded under 2^{nd} sowing date as compared to 1st and 3rd sowing dates. Similar analysis for the North West Alluvial plane zone of Bihar indicated that the yield reduction due to water stress under rainfed conditions in this zone ranged from 4528 to 5881 kg/ha, 4110 to 6078 kg/ha and 3321 to 6171 kg/ha respectively under the three different sowing dates (1^{st} July, 15^{th} July and 30^{th} July), as shown in Fig.1(b). The highest yield of rice in this zone was also recorded under 2^{nd} sowing date as compared to 1^{st} and 3^{rd} sowing dates.

The results presented in Figs. 2(a&b) shows the yields of rice under potential (un-stressed) conditions, in these two zones. It can be seen that the potential yields varied from 5256 to 6035 kg/ha for 1^{st} July; 5186 to 6076 kg/ha for 15 July and 3685 to 4746 kg/ha for 30 July sowings in the South Alluvial plane zone of Bihar [Fig. 2(a)]. However, they varied from 4528 to 5881 kg/ha for 1^{st} July; 4110 to 6078 kg/ha for 15^{th} July and 4233 to 5667 kg/ha under 30^{th} July sowings in the North West Alluvial plane zone of Bihar [Fig. 2(b)], indicating lower potential in this zone under early to normal sowing conditions, while poor conditions prevail under late sown situation in the South Alluvial plain zone. The reasons for this can be seen from the Normal rainfall pattern in these two zones [Figs. 3(a&b)] as rainfall during 33 to 39 standard weeks is lower in the SAP Zone (Bhagalpur) compared to NWAP Zone (Pusa) exerting environmental stress conditions limiting the yield potential.

The impact of the severe drought year on rice yield under different sowing dates is presented in Figs. 4(a&b). The year 2000 happened to be the severe drought year under the period of study, in South Alluvial plane zone of Bihar with an amount of 642 mm of rainfall as against the average of 890 mm under first sowing date and a rainfall of 349 mm as against the average of 716 mm under 2nd sowing date. The yield and rainfall deviations (%) under these two sowing dates were -28 & -28; -31 & -51 and -30 & -74 respectively [Fig. 4(a)]. Similar Deviations (%) were observed under 1^{st} and 2^{nd} sowing dates (+4 & -32; - 20 & -56) in the North West Alluvial plane zone of Bihar also [Fig. 4(b)]. While the rainfall deviation had been large (74 & 77%) under the 3^{rd} date of sowing in these two regions, resulting from the prevailing drought conditions during these respective years, the yield variation, however, had been smaller (- 4%) in the South alluvial plain zone while it was higher (-35%) in the North West alluvial plain zone, even though the quantum of rainfall had been similar (148 and 144 mm). These results indicate that not only the quantum but distribution pattern of rainfall is an important parameter and moisture stress

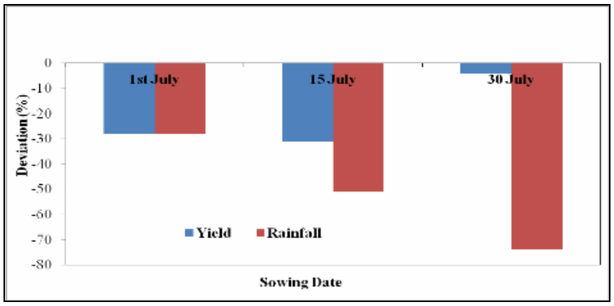

Fig. 4(a). Deviation (%) of rice crop yield and rainfall (under rainfed condition) for the three sowing dates (1st, 15th and 30th July, 2000), as affected by Drought in South Alluvial plane zone of Bihar

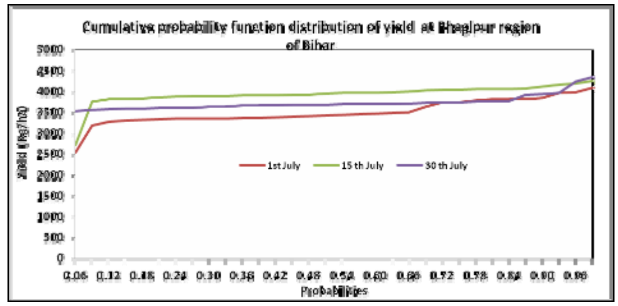

Fig. 5(a). Cumulative probability function distribution of yield under different sowing dates (1st, 15th and 30th July) in South Alluvial plain zone of Bihar

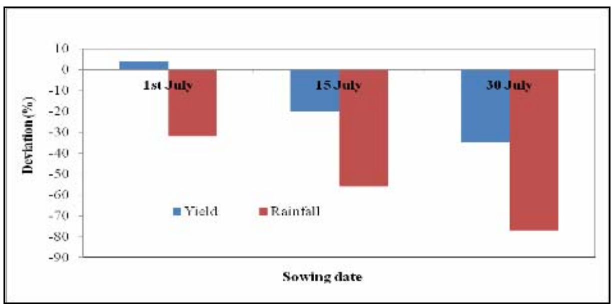

Fig.4(b). Deviation (%) of rice crop yield and rainfall (under rainfed condition) for the three sowing dates (1st, 15th and 30th July, 2004), as affected by Drought in North-west alluvial plain zone of Bihar

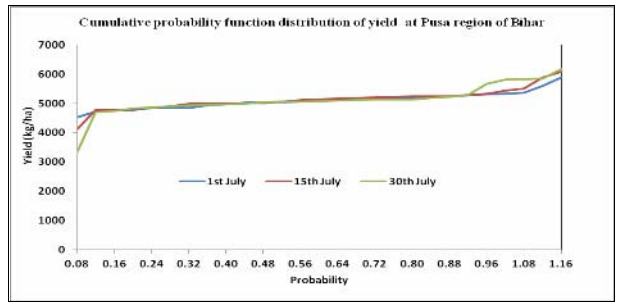

Fig. 5(b). Cumulative probability function distribution of yield under different sowing dates (1st, 15th and 30th July) in North-West Alluvial plain zone of Bihar

during the phenological stage of panicle initiation to grain filling is critical in determining the final yield of rice in both the Alluvial plain zones of Bihar.

The average rice yield under rainfed conditions in respect of the three different sowing dates is 3721 kg/ha, with a CV of 5.1 % and SD (standard deviation) of 190.5 mm (Table 2). In contrast the average potential (unstressed) yield of the three different sowing dates is 5105 kg/ha, with a CV of 3.9% and SD of 201.0 mm in the South Alluvial plane zone of Bihar. The Comparative values for the North West Alluvial Plain Zone of Bihar were 5113 kg/ha, 5.9% and 299.6 mm respectively under rainfed condition and 5703 kg/ha, 8.3 % and 475.6mm respectively under potential yield conditions. The variation in rainfed yield under individual sowing dates indicate that it was 8.5% in 1st sowing date, 6.3 % under 2nd sowing date and 4.8% under 3rd sowing date, with a respective standard deviation of 294.8mm, 248.6mm and 178.8mm. The results also show that variation of potential yield under the three sowing dates is of the order of 3.7 %, 4.2 % and 7.3 % with a corresponding standard deviation of 208.1mm, 229.1mm and 313.3 mm, respectively, in the South Alluvial plane zone of Bihar (Table 2). However, in respect of North West Alluvial plane zone of Bihar, the results indicate that the variation between the yield, under potential and under rainfed conditions is very small as can be seen in Table 2.

A comparison of the average rice yield (kg/ha) across the two agroclimatic zones indicates that the average yield under both the situations (Potential and Rainfed) is higher in North West Alluvial plane zone of Bihar compared to the South Alluvial plane zone. The differences are more conspicuous under rainfed conditions as rice crop experiences better moisture regime in the North West Alluvial Plain zone compared to the South Alluvial plain zone of Bihar (Table 2).

The cumulative probability function distributions of yields, simulated for rice were plotted for the three different sowing dates. The curves [Figs. 5(a&b)] indicate that probabilities are almost the same, up to 50-70%, for the both South and North West Alluvial plane zones of Bihar. It means that rice yield level simulated against the 3 dates of sowing does not vary in 50-70% of the years. Further variation in grain yield (P>0.70) signifies different weather conditions, realized during the crop season in remaining years. For probability >0.70, simulated yield of

TABLE 2

Analysis of potential and rainfed yield (kg/ha) under different climatic conditions of Bihar (India)

Station	Potential yield (kg/ha) Sowing date (July)				Rainfed yield (kg/ha) Sowing date (July)			
South Alluvial plane zone of Bihar								
	1^{st}	15^{th}	30^{th}	Average	1^{st}	15^{th}	30^{th}	Average
Average	5659	5501	4290	5150	3505	3931	3728	3721
SD ±	208.1	229.1	313.3	201.0	294.8	248.6	178.8	190.5
CV (%)	3.7	4.2	7.3	3.9	8.5	6.3	4.8	5.1
North-West Alluvial plane zone of Bihar								
Average	5575	5712	5821	5703	5094	5131	5115	5113
SD ±	539.2	583.2	487.1	475.6	275.6	356.6	502.6	299.6
CV (%)	9.7	10.2	8.4	8.3	5.4	6.9	9.8	5.9

rice sown on 15^{th} July was higher than that on 1^{st} and 30^{th} July under rainfed conditions of South Alluvial Plain Zone [Fig. 5(a)]. Under rainfed condition yield scenario of North West Alluvial plane zone of Bihar also, the curve [Fig. 5(b)], indicates that probabilities of crop yield for the three different sowing dates for cultivar Rmansuri are almost same up to 50-70 % and for probabilities > 0.70 yield of crop sown on 15^{th} July is distinctly higher than the two other (1^{st} and 30^{th} July) sowing dates.

The temperature regime of South and North West Alluvial plane zones of Bihar [Figs. 3(a&b)] clearly indicate that day temperature during hot season is around 35.6oC and it starts decreasing from the first week of June. As far as the risk associated with the rainfall distribution under the different dates of sowing, during 26-31^{th} weeks indicate that the risk associated with early sowing during 25^{th} June to first week of July is high, more so in the South alluvial plain zone, as rain water often is not sufficient from the pre monsoon rain to meet water requirement of the crop in the initial stage [Fig. 3(a)] and also the crop may suffer during juvenile stage, encountered by higher day temperatures. For the dates of sowing 24^{th} July onwards, besides recording low yield as the crop gets caught in moisture stress during flowering to grain filling stage, the crop gets harvested by the end of October or beginning of November, which does not provide the lead -time for sowing of the rabi (second) crops. This problem of lower yield plateau under delayed sowing is more specific to the South alluvial plain zone, than the North West plain alluvial zone, while time gap for sowing rabi crops is a common problem in both regions. The date of 15^{th} July thus can be considered as most suitable for sowing of rice under rainfed conditions in both these agroclimatic zones of Bihar.

The simulated results revealed that the average anthesis and maturity dates to be 115, 114, 73 and 145, 153 and 103 respectively under the different sowing dates, *i.e.*, 1^{st} July, 15^{th} July and 30^{th} July. Since any increase in photoperiod may delay the flowering, longer vegetative phase results into higher dry production being converted into higher grain yield. The simulated values across the years indicate that the maximum period of anthesis and maturity dates observed were 121, 121, 76 and 152, 162 and 109 days respectively. The minimum duration of anthesis and maturity dates have been 108, 109, 69 and 137, 137 and 94 respectively across the different sowing dates in the South Alluvial plane zone of Bihar. The simulations also showed that the average duration of anthesis and maturity dates to be 104, 102, 102 and 131, 132 and 140 respectively across the different sowing dates, *i.e.*, 1 July, 15 July and 30 July for the North West Alluvial plane zone of Bihar, indicating that these durations are shorter under first two sowing dates and longer under 3^{rd} sowing date in this zone.

Potential yield is defined as the maximum yield of a variety restricted only by the seasonal specific climatic conditions. This assumes that other inputs (nutrient, water, pests, etc.) are not limiting and cultural management is optimal. Thus the potential yield of a crop is dependent upon temporal variation in solar radiation and maximum and minimum temperatures during the crop season, and physiological characteristics of the variety. Mechanistic crop growth models are routinely used for estimation of potential yield and determination of yield gaps and assessing yields with the impacts of climate change.

The model simulations indicate that in the South Alluvial plain zone, potential yield under 1st sowing date is better than other two sowing dates, but the biomass of 2^{nd} sowing is better than that recorded under 1st and 3rd sowing dates. The grain number is also higher under 1st sowing date, than under the other sowing dates. In contrast, in the North West Alluvial plain zone, the potential yield increased to be highest under 3^{rd} date of

TABLE 3

Estimation of rice yield gap (difference between potential and rainfed yield) in the North-West and South alluvial agroclimatic zones of Bihar (India)

Station/ statistical method	Attainable yield gap (Potential - Rainfed yield) (kg/ha)			Attainable average yield gap (kg/ha)
	1st July	15th	30th July	
South Alluvial plain zone of Bihar				
Mean	2153.4	1570.2	561.9	1429
SD ±	387.9	377.8	298.4	276.8
CV (%)	18.0	24.1	53.1	19.4
North-West Alluvial plain zone of Bihar				
Mean	481.3	581.5	706.8	589.9
SD ±	308.6	506.1	637.6	384.4
CV (%)	64.1	87.0	90.2	65.2

sowing, indicating that climatic conditions (thermal and radiation) are more favourable in this period of crop growth. However, in both the zones under rainfed conditions, the 2nd date of sowing indicated to be optimum (Table 2).

The analysis of yield gap between potential and under rainfed condition of yield (Table 3), is less under 3rd sowing than under 1st and 2nd sowing dates in the South Alluvial plain zone. The average yield gap was 2153, 1570 and 562 kg/ha, with CV of 18.0, 24.1 and 53.1 % and SD of 387.9, 377.8 and 298.4 mm for the three different sowing dates respectively. The result showed that the average total yield gap is higher (1429 kg/ha) with CV of 19.4 and SD of 276.8 mm for South Alluvial plane zone of Bihar (Table 3). In case of the North west Alluvial plain zone, the average yield gap is 481, 582 and 707 kg/ha with CV of 64.1, 87.0 and 90.2 % and SD of 308.6, 506.1 and 637.6 mm for the three different sowing dates (Table 3). The result also show that the average total yield gap in this zone is relatively small (590 kg/ha) with a CV of 65% and SD of 384 mm.

The analysis clearly brings out that the gap between the state average productivity and potential rice yield in the South Alluvial plain zone is very high owing to poor technology adoption and lack of sufficient inputs. Therefore, bridging the existing yield gaps by making adequate availability of quality seeds and other technical inputs to farmers would be the first and foremost requirement for improvement of crop productivity from this potential rice zone. Crop specific and zone specific strategies therefore, should be adopted at farmer level to derive maximum benefit. Bihar thus needs specific development strategies for North and South regions of the State. These can include suitable technological interventions like selection of suitable variety, quality seed, optimum sowing/planting time, optimum inputs by quality, quantity and time of application etc. The biomass production and its portioning efficiency are important components that can help to assess the effect of drought or stress on plant performance. In fact under South and North West Alluvial plain zones of Bihar state, the water stress conditions occur mainly during heading to maturity stages. Therefore, attempts are to be made to work out strategies for appropriate rain water harvesting and recycling strategies to meet water shortages to rice crop during such critical phenophases. Such strategies have been developed successfully in Chhattisgarh area under NATP program of ICAR (Dabris) and can be adopted in these regions also.

It is seen from the model analysis that the biomass production gets affected mainly from the panicle initiation stage during drought years while under excess and normal rainfall conditions, there is no difference in biomass production till milking stage and the difference becomes considerably higher from milking to maturity stages.

These models thus have the potential suitable for use in defining areas and landscape conditions suitable for raising the rice crop as well as multiple cropping. Uncertainly about the accuracy of solar radiation, extractable soil water and nitrogen status in soil are some of the frequency encountered problems in crop model validity and calibration. Also, many of the models currently available, lack demonstrated strengths in assessing risk related to pests, diseases, tillage and nutrients other than nitrogen. Improvements in this direction can make these models as good Decision Support Tools for efficient Crop management.

4. Conclusions

Climatic conditions experienced in the South alluvial plain and North West Alluvial plain Zones of Bihar indicate that they influence the growth of Rice crop in these regions differently. While the optimum sowing date for rice in both the regions has been 15th July, the yield gap between the potential and rainfed yields is larger in the South Alluvial plain zone compared to the other zone. Under potential growth conditions it was seen that yields decrease with delay in sowing in the south alluvial plain zone while in the North west plain zone the potential yields are higher under 30th July sowings. The present study has clearly showed the robustness of the DSSAT model of rice crop, to be valuable tool for predicting rice yield and identifying the critical phenophases which influence crop performance under varying climatic conditions. Therefore, the validated DSSAT model can be used for various applications such as prediction of crop growth, phenology, potential and actual yield, performance of rice under climate change conditions etc.

The model may also to be used to improve and evaluate the current practices of rice crop growth management and in suggesting ways to enhance rice crop production, in any agroclimatic zone.

References

Abrol, Y. P., Bagga, A. K., Chakravarty, N. V. K. and Wattal, P. N., 1991, "Impact of rice in temperature on the productivity of wheat in India", In: Aborl, Y. P., Wattal, P. N., Gnaman, A., Goyindjee, Ort D. R. and Teramuka, A. H., (Eds) Impact of global climate changes on photosynthesis and plant productivity, Oxford and IBH publishing, New Delhi, 777-789.

Aggarwal, P. K. and Kalra, N., 1994, "Analyzing the limitation set by climatic factors, genotype and water and nitrogen availability on productivity of wheat II, Climatic potential yield and management strategies", *Field Crops Res*., **38**, 93-103.

Aggarwal, P. K. and Sinha, S. K., 1993, "Effect of probable increase in carbon dioxide and temperature on productivity of wheat in India", *J. Agric. Meteorol*., **48**, 811-814.

Alocilja, E. C. and Ritchie, J. T., 1988, "Upland rice simulation and its use in multicriteria optimization", IBSNAT Research Project Series 01, IBSNAT.

Angstrom, A., 1924, "Solar and terrestrial radiation", *Q. J. Roy Meteorol. Soc*., **50**, 121-126.

Diwakar, M. C., 2009, "Rice India during 10th Plan", Directorate of Rice Development, Patna; prepared and Edited by M. C. Diwakar, Patna.

Gangadhar Rao, D., J. C. Katyal, S. K. Sinha and K. Srinivas. 1995, Climate Change and Agriculture: Analysis of Potential International Impact, ASA Special publication No. **59**, 325-337, ASA, Madison, WI.

Gangadhar Rao, D. and Sinha, S. K., 1994, "Impact of climate change on simulated wheat production in India", In C. Rosenzweig and I. Iglesias (Eds.), Implications of climate change for international agriculture: Crop modelling study, USEPA230-B-94-003, USEPA, Washigton, DC, 1-17.

Godwin, D. C. and Singh, U., 1998, "Nitrogen balance and crop response to nitrogen in upland and lowland cropping systems", In: Understanding Options for Agricultural Production. Systems Approaches for Sustainable Agricultural Development, Tsuji, G. Y., Hoogenboom, G. and Thornton, P. K. (eds), Kluwer Academic Publ., *Dordrecht*, *The Netherlands*, 41-54.

Godwin, D. C., Thornton, P. K., Jones, J. W., Singh, U., Jagtap, S. S. and Ritchse, J. C., 1990, "Using IBSNAT, DSSAT in strategy evaluation", In Proc. IBSNAT, DSSAT, Las Vegas, NV, 16-18 Oct, 1989, Part I: Sym Proce., Deptt. of Agronomy and Soil Sciences, College of Tropical Agric. and Human Resources, Honolulu.

Hunt, L. A., Pararajasingham, S., Jones, J. W., Hoogenboom, G., Imamura, D. T. and Ogoshi, R. M., 1993, "GENCALC-software to facilitate the use of crop models for analysis field experiments", *Agronomy. J*., **85**, 1090-1094.

IBSNAT, 1994, "Decision Support Systems for Agrotechnology Version 3.0 (DSSAT V3.0)", International Benchmark Sites Network for Agrotechnology Transfer Project, Honolulu, Hawaii: University of Hawaii, College of Tropical Agriculture and Human Resources, Deptt. of Agronomy and Soil Science.

IPCC, 1996, Houghton, J. T., Meria Filho, L. G., Callander, B. A., Harris, N., Kattenberg, A., Maskella, K. (eds), "Climate change 1995: the science of climate change", Cambridge University Press, Cambridge, p572.

Jones, C. A. and Kiniry, J. R., 1986, "CERES-Maize: A simulation model of maize growth and development", Texas A & M University press, College Station, Texas, USA, p194.

Jones, J. W., 1993, "Decision support systems for agricultural development", In: Penning de Vries, F., Teng, P., Metselaar, K. (Eds.), Systems Approaches for Agricultural Development, Kluwer Academic Press, Boston, 459-471.

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

Lal, M., Singh, K. K., Rathore, L. S., Srinivasan, G. and Saseendran, S. A., 1998a, "Vulnerability of rice and wheat yields in NW India to future changes in climate", *Agric. For. Meteorol.*, **89**, 1-13.

Lal, M., Whettori, P. H., Pittodi, A. B. and Chakraborty, B., 1998b, "The greenhouse gas induced climate change over the Indian sub-continent as projected by GCM model experiments, Terrestrial", *Atmospheric and Oceanic Sciences*, TAO, **9** (iv), 663-669.

Mearns, L. O., Rosenzweig, C. and Goldberg, R., 1996, "The effect of changes in daily and interannual climatic variability on CERES-wheat: A sensitivity study", *Clim. Change*, **32**, 257-292.

Riha, S. J., Wilks, D. S. and Simoens, P., 1996, "Impact of temperature and precipitation variability on crop model predictions", *Climatic Change*, **32**, 293-311.

Ritchie, J. T., Singh, U., Godwin, D. and Bowen, W. T., 1998, "Cereal Growth Development and Yield", In: Understanding Options for Agricultural Production, Tsuji, G. Y., Hoogenboom, G. and. Thornton, P. K. (Eds.), Kluwer Academic Publishers, *Dordrecht, The Netherlands*, 79-97.

Ritchie, J. T., 1991, "Wheat phasic development", In: J. Hanks and J. T. Ritchie (eds), Modelling plant and soil system, Agron. Mongr. 31, ASA, CSSA, Medison, WI, USA.

Singh, K. K., Baxla, A. K., Mall, R. K., Singh, P. K., Balasubramanian, R. and Garg, Shikha, 2009-2010, "Wheat yields prediction using CERES-Wheat model for decision support in agro-advisory", *Journal of Vayu Mandal*, Vol. No 35 & 36 (1-4), 97-109.

Singh, P. K., Rathore, L. S., Singh, K. K., Baxla, A. K. and Mall, R. K. 2010, "Modeling the effect of planting date on Maize (Zea mays L.) crop in Sabour region of Bihar using DSSATv3.5 crop simulation model", *Mausam*, **61,** 1, 75-80.

Sinha, S. K. and Swaminathan, M. S., 1991, "Deformation, Climate change and sustainable nutrition security", *Climate Change*, **16**, 33-45.

Tsuji, G. Y., Uehara, G. and Balas, S., 1994, "DSSAT v3", Vol. **2,** University of Hawaii, Honolulu, Hawaii, p284.