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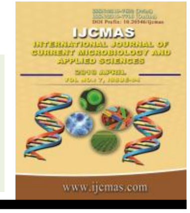


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# Application of DSSAT Crop Simulation Model to Estimate Rice Yield in Keonjhar District of Odisha (India) under Changing Climatic Conditions

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**A B S T R A C T**

Changes of climate will be one of the deciding factors that affect for future food production in the world because crop growth is highly sensitive to any changes of climatic conditions. As the rice is staple food of Odisha, it is essential to identify the impacts of climate changes on State's rice production. This study was conducted to identify the yield and growth changes of the popular rice variety (Swarna) cultivated in Keonjhar district at *kharif* season. Effects of change in weather conditions on the yields of Swarna variety was assessed through sensitivity analysis using the Ceres rice model v 4.6 of the DSSAT modeling system. The model was validated using rice growth and development data during the 2015 cropping season. To simulate the rice yield DSSAT requires data sets of crop growth and management, daily weather data and soil data. Daily maximum and minimum temperatures and precipitation were collected from the weather station while daily solar radiation was generated using weatherman in the DSSAT shell. Crop management data were obtained from an experiment which was conducted in Keonjhar. The study revealed that increase in both maximum and minimum temperatures affects the grain yield. The results of the study therefore show that weather conditions in Keonjhar affect rice yield and should be taken into consideration to improve food security.

## Introduction

Impacts of climate change on Agriculture will be one of the major deciding factors influencing the future food security of mankind on earth. Since rice is the staple food of India, it is essential to identify the impacts of climate change on rice yield to increase the country's rice production. Climatic factors such as temperature, rainfall, atmospheric $CO_2$ and solar radiation are important parameters to rice production (Nyangau *et al.*, 2014). The average daily maximum temperature and rainfall pattern will be changed as a result of increasing concentrations of $CO_2$ and other greenhouse gases in atmosphere. These changes have become the most important considerations for rice production (Dharmarathna *et al.*, 2011).

Increasing trend of daily maximum temperature may decrease the rice spikelet fertility, which affects for reduction of the yield while the increasing trend of atmospheric $CO_2$ concentration could increase the rice yield (Dharmarathna *et al.*, 2012).

Keonjhar district is one of the rice cultivation districts in Odisha and have a good potential for rice cultivation. Most of the farmers in this area cultivate improved rice varieties but their yield is always lower than the potential yield due to the different level of management practices and the variation of climatic conditions. Yield gap can be increased in the future due to climate change especially if current agricultural practices are continued (Basak *et al.,* 2012). Understanding rice production in relation to weather changes is of great importance to boost food productivity Conducting the field experiments for identify impacts of climate change on rice cultivation will take long time period.

DSSAT is a popular crop model that is used worldwide for modeling growth and yield of 30 different crops including rice under given soil and daily weather conditions. For future yield prediction it is required to calibrate and validate the DSSAT model with adjusting the cultivar genetic coefficients. Validated DSSAT model can be used to predict the future rice yields with future weather conditions and find the suitable adaptation measures for increase the yield (Jones *et al.,* 2013). These tools can reduce the need for expensive and time-consuming field trials and could be used to analyze yield gaps in various crops including rice (Pathak *et al.,* 2005). Therefore this study was conducted to identify the changes of rice yield and growth in Keonjhar district under changing climate using DSSAT model.

## Materials and Methods

### Plant material

Swarna rice variety was used in this study. This is because this variety is commonly grown variety in Keonjhar. The rice profile and management practices from nursery till harvest were monitored.

### Management practices

**Adopted and data collected:** The crop management data (i.e., agronomic data) required by the model include planting date, planting density, row spacing, planting depth, fertilizer application dates, and amounts was recorded. The major crop management input data used in the model for simulations is shown in Table 1.

The following data were collected:

**Daily weather data:** Maximum and minimum air temperature, precipitation, and solar radiation.

Soil data: involved collection of set of input data on soil characteristics at 5 cm and 25 cm depths before and during the cropping season on soil classes, bulk density, organic carbon (%), sand silt clay (%), soil texture, pH of soil in water, organic carbon, cation exchange capacity, total nitrogen, potassium, and phosphorus,

**Management practices:** plant density, planting date, irrigation, weeding, row spacing, sowing depth, and nitrogen fertilization,

**Plant profile data:** data related to date of sowing, date of emergence, date of floral initiation, date of synthesis, date of physiological maturity, panicle initiation date (when 50% of the crop had reached those stages) plant population, plant height, grain weight, and grain yield per area of production, Latitude of production area to evaluate day length during the cropping season.

The following six input files were created to run the model:

Weather file with annual daily solar radiation, maximum air temperature, minimum air

temperature, and precipitation,
Soil file with soil properties under study,

Rice management file

Experimental data file with measured data,

**Genetic coefficients file:** The cultivar coefficient was determined with thermal time from emergence to the end of juvenile stage (P1), rate of photo induction (P2R), optimum photoperiod (P2), thermal time for grain filling (P5), conversion efficiency from sunlight to assimilates (G1), tillering rate (TR), and grain size (G2).

## Data analysis

The CERES rice model version 4.6 of the DSSAT modeling system which is an advanced physiologically based rice crop growth simulation model was used to predict rice (Swarna) growth, development, and response to various climatic conditions. This was through determination of duration of growth stages, dry matter production and partitioning, root system dynamics, effect of soil water and soil nitrogen contents on photosynthesis, carbon balance, and water balance (Ritchie *et al.*, 1986), followed by sensitivity analysis to assess the effects of change in weather conditions on Swarna grain yield.

## Model calibration and validation

The model was calibrated experimental data for Swarna variety of rice for the main cropping season 2015 as reported by Ndiiri *et al.*, 2012. The model was validated using the rice growth and development data, during the cropping season July to Nov 2015. This was done by comparing the observed results with simulated yield. In this study, combination of graphical, tabular, and statistical analysis was applied. Model performance evaluation was presented by the absolute Root Mean Square Error (RMSE) This characteristic is common tools to test the goodness of fit of simulation models. The RMSE between the simulated and observed values for a data set with measured points is defined as

$$\mathrm{RMSE} = \left[\sum_{i=1}^{n} \frac{(\mathrm{Si} - \mathrm{Ob})^2}{n}\ )\right]^{0.5} \qquad (1)$$

$$\mathrm{RMSE}_n = 100\frac{\left[\sum_{i=1}^{n} (\mathrm{Si} - \mathrm{Ob})^2/n\ )\right]^{0.5}}{\mathrm{Ob}_{avg}}, \qquad (2)$$

Where Si = simulated value, Ob = observed value, and = number of observations.

The observed data points may be from one treatment or multiple treatments (Ma and Selim, 2005). Goodness was evaluated visually and by computing index of agreement. The index of agreement is defined by Ahiya *et al.*, (2002) as shown in (3).

The computed values of RMSE and value determine the degree of agreement between the predicted values with their respective observed values, and a low RMSE value and a value that approaches 1 are desirable.

$$D = 1 - \frac{\sum_{i=1}^{n} (\mathrm{Si} - \mathrm{Ob})^2}{\sum_{i=1}^{n} \left(\left|\mathrm{Si} - \mathrm{Ob}_{avg}\right| \left|\mathrm{Obi} - \mathrm{Ob}_{avg}\right|\right)^2}. \qquad (3)$$

Normalized RMSE (RMSEn) was used to give a measure (%) of the relative difference of simulated versus observed data. The simulation was considered excellent with a normalized RMSE less than 10%, good if the normalized RMSE was greater than 10 and less than 20%, fair if the normalized RMSE was greater than 20% and less than 30%, and poor if the normalized RMSE was greater than 30% (Loague and Green., 1991).

## Results and Discussion

### Weather conditions during the cropping season

According to Hay and Walker, 1989 the primary atmospheric variables that impact on crop growth are solar radiation, air temperature, humidity, and precipitation. They mentioned that extreme weather at critical periods of a crop's development can have large effects on its productivity and yield.

The climate of Keonjhar is governed by seasonal monsoon rainfall patterns. During 2015, maximum and minimum temperatures, rainfall, and solar radiation varied as shown in Figure 1. During the cropping season, the mean maximum temperature ($_{max}$) and minimum temperature ($_{min}$) were 31.6°C and 19.4°C, respectively. Mean solar radiation was 18.7 MJ/m$^2$ while total precipitation was 1183.9 mm.

*B. Genetic Coefficients* The value for the cultivar coefficients that determine vegetative (P1, P5, P2O, and P2R) and reproductive (G1, G2, G3, and G4) growth and development for Swarna variety of rice is presented in Table 2. The cultivar coefficient P1 defines the time from seedling emergence to the end of juvenile phase (GDD). The coefficient P2O is the extent at which the development occurs at a maximum rate. The coefficient P2R is the extent to which phasic development from vegetative to panicle initiation was delayed for each hour increase in photoperiod above P2O. The coefficient P5 is the time from grain filling to physical maturity. The coefficient. G1 defines the maximum spikelet number coefficient. The cultivar coefficient G2 is the maximum possible single grain size under stress free conditions. The coefficient G3 defines the scalar vegetative growth coefficient for tillering. The cultivar coefficient G4 defines the temperature tolerance scalar coefficient. Genetic coefficients are sets of parameters that describe the genotype and environmental interactions (IBSNAT, 1993). They summarize quantitatively how a particular cultivar responds to environmental factors.

### Main growth and development variables

Table 3 shows the mean simulated and observed main growth and development variables.

### Model validation

The model was validated using observed growth and phenological data collected during the 2015 cropping season. A good match was obtained between observed and simulated grain yield with a RMSE of 0.817 t/ha and a normalized RMSE (RMSEn) of 14.943%. An index of agreement for grain yield closer to 1 (0.869) also revealed that the model performed well in predicting the yield. The regression analysis gave a coefficient of determination ($R^2$) value of 0.778. In general, the results from the model validation indicate that CERES rice version 4.6 was able to predict growth and development for Swarna variety in a good manner and therefore can be applied as a study tool.

The -stat of a "good" model should approach unity and the RMSE approach zero. The RMSE is considered as the "best" overall measure of model performance as it summarizes the mean difference in the units of observed and predicted values (Willmot, 1982 and Toit and Toit, 2003).

### Sensitivity analysis on climatic adaptations

Temperature regime greatly influences not only the growth duration but also the growth pattern of the rice plant.

**Table.1** Crop management data used in the model

| Serial/number | Simulation parameter | |
|---|---|---|
| 1 | Planting method | Nursery |
| 2 | Transplanting date | August 20, 2015 |
| 3 | Planting distribution | Hill |
| 4 | Row spacing | 20 cm by 10 cm |
| 5 | Planting depth | 2 cm |
| 6 | Transplanting age | 21days |
| 7 | Plant per hill | 1 |
| 8 | Plants per $m^2$ | 16 |
| 9 | Fertilizer application | |
| | Basal | 20kg/ha |
| | 21 DAP | 40kg/ha |
| | 45 DAP | 20kg/ha |

**Table.2** Genetic coefficients for Swarna

| P1($^0$C-days) | P2R($^0$C-days) | P5($^0$C-days) | P2O(h) | G1(no.) | G2(g) | G3 | G4 |
|---|---|---|---|---|---|---|---|
| 620 | 180 | 490 | 11.8 | 70 | 0.02 | 1 | 1 |

Satapathy *et al., 2014*

**Table.3** Main growth and development variables

| Variable | Simulated | Observed |
|---|---|---|
| Anthesis | 77 | 79 |
| Physiological maturity (dap) | 115 | 111 |
| Yield at harvest maturity (t/ha) | 6.131 | 6.022 |
| Unit weight at maturity (g) | 0.025 | 0.024 |

**Table.4** Effects of plus maximum and minimum temperatures on simulated Swarna yield grain

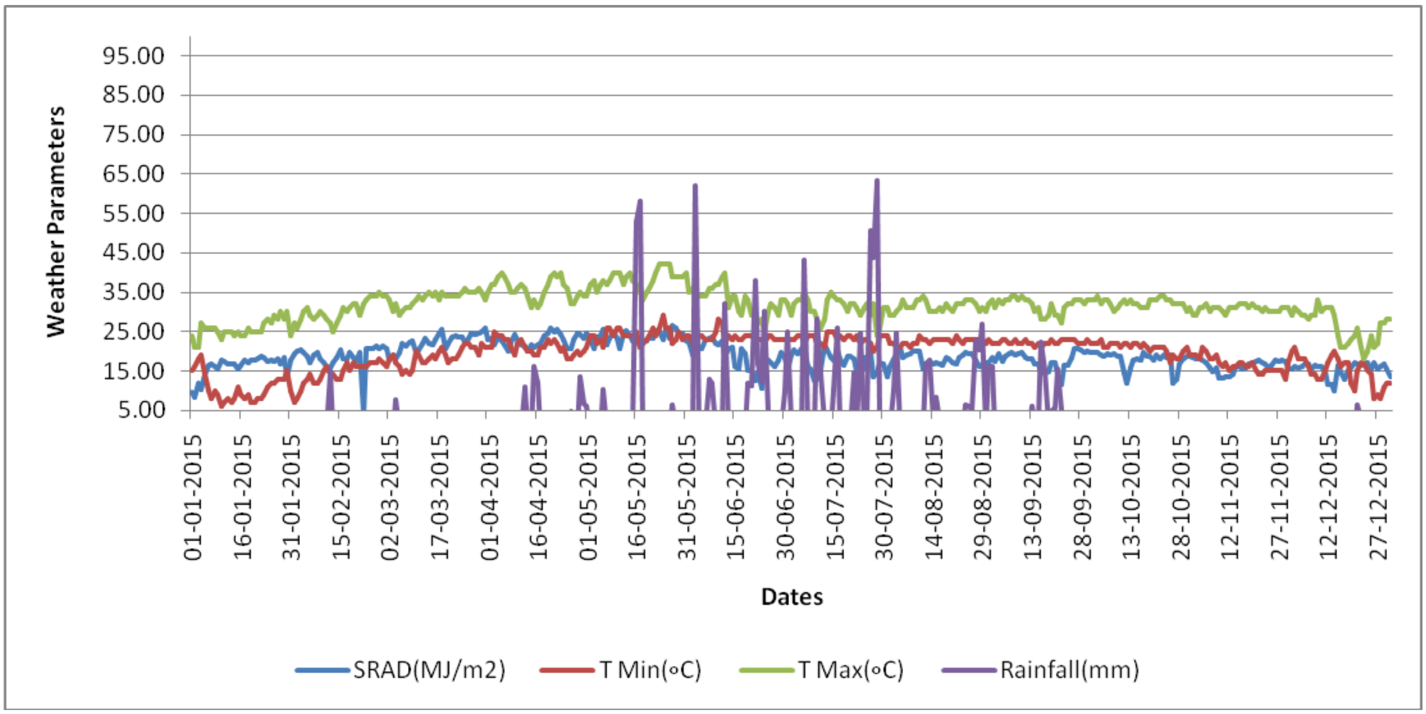
| Plus temperature($^0$C) | Grain yield at maximum temperature (t/ha) | Grain yield at minimum temperature (t/ha) |
|---|---|---|
| +1 | 5.712 | 5.621 |
| +2 | 5.168 | 5.163 |
| +3 | 4.837 | 4.385 |
| +4 | 4.056 | — |
| +5 | 3.711 | — |

**Table.5** Critical temperatures for the development of rice plant at different growth stages

| Growth stages | Critical temperature ($^0$C) | | |
|---|---|---|---|
| | Low | High | Optimum |
| Germination | 16-19 | 45 | 18-40 |
| Seedling emergence | 12 | 35 | 25–30 |
| Rooting | 16 | 35 | 25–28 |
| Leaf elongation | 7-12 | 45 | 31 |
| Tillering | 9-16 | 33 | 25–31 |
| Initiation of panicle primordial | 15 | — | — |
| Panicle differentiation | 15-20 | 30 | — |
| Anthesis | 22 | 35-36 | 33 |
| Ripening | 12-18 | >30 | 20-29 |

Source: Yoshida, 1978

**Fig.1** Keonjhar weather for 2015




During the growing season, the mean temperature, the maximum and minimum temperature, rainfall distribution pattern, and diurnal changes, or a combination of these, may be highly correlated with grain yields (Mooman and Vergara., 1965). Effects of increase in temperature on Swarna rice grain yield was assessed by increasing the maximum and minimum temperatures by +1, +2, +3, +4, and +5 followed by subsequent simulations.

The simulated results in Table 4 shows that increase in both maximum and minimum temperature led to a decrease in grain yield. As compared to maximum temperature, increase in minimum temperature had more pronounced negative impacts on Swarna yield. This more pronounced negative impact of minimum temperature on rice yield could be explained by increased respiration losses during the vegetative phase (Peng *et al.*, 2004) and reduced grain-filling duration and endosperm cell size during the ripening phase (Morita *et al.*, 2005).

Temperature regimes greatly influence not only the growth duration, but also the growth pattern and the productivity of rice crops. The critical temperatures for the development of the rice plant at different growth phases are highlighted by Yoshida (1978) as shown in Table 5.

Other studies on rice productivity under global warming also suggest that the productivity of rice and other tropical crops will decrease as global temperature increases. Mohandrass *et al.*, (1995), using the Hadley-coupled model, predicted a yield decrease of 14.5 percent for summer rice crops across nine experiment stations in India in 2005. Peng *et al.*, (2004) reported that the yield of dry-season rice crops in the Philippines decreased by as much as 15 percent for each 1°C increase in the growing season mean temperature. In Bangladesh, the impact of climate change on high yield rice varieties was studied by Karim *et al.*, (1994) using the CERES rice model and several scenarios and sensitivity analysis. They found that high temperatures reduced rice yields in all seasons in most arid locations.

Temperature is considered to be one of the dominant factors that affect the growth and yield of rice. Each phase has its low and high temperature thresholds. The effect of temperature on vegetative growth of rice plants was reviewed in relation to germination, early growth, rooting, tillering, and the critical temperature common for different physiological plant properties that were 0–3°C, 15–18°C, 30–33°C, and 45–48°C, respectively (Nishiyama., 1976). Low temperature in early growth stages retards the development of seedling and dry matter production (Yoshida, 1978). In tropical regions, the temperature increase due to the climate change is probably near or above the optimum temperature range for the physiological activities of rice (Hogan *et al.*, 1991). Such warming will thus reduce rice growth. In addition, higher temperatures will cause spikelet sterility owing to heat injury during panicle emergence (Satake and Yoshida., 1978).

Changes in mean temperatures can shorten the time to maturity of a crop, thus reducing yield. Hardacre and Turnbull, 1986 state that temperature affects the duration of crop growth and consequently the time during which incident radiation can be intercepted and transformed to dry matter. Temperature also affects final leaf number (Stevenson and Goodman., 1972) and leaf canopy development (Tollenaar *et al.,* 1979; Thiagarajah and Hunt., 1982). Which defined crop leaf area index, thereby determining the proportion of the incident radiation intercepted (Muchon and Carberry, 1993) by the crop and accumulation of dry matter. At the same time, while using ORYZA1 and INFOCROP rice simulation models at the current $CO_2$ levels studies have also shown that even a few days of temperature above a threshold value, if coincident with anthesis, can significantly reduce yield, through affecting subsequent reproductive processes (Wheeler *et al.*, 2000). Generally, the effect of increasing temperature above the tolerance limit on rice potential production is generally negative. Temperature beyond the optimum level reduces the photosynthesis, increase the respiration and shorten the vegetation and grain-filling periods. Rice yield is negatively correlated with high (>35 $^0$C) temperature during the reproductive phase (Satake and Yoshida, 1978).

Weather changes affect Swarna yield in Keonjhar. Increase in maximum and minimum temperatures beyond optimum temperatures for rice production led to a decrease in yield and minimum temperature changes had more profound negative impacts as compared to maximum temperature changes. Therefore to improve rice production in Keonjhar, proper understanding of the prevailing weather conditions and regular monitoring is necessary.

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