# EFFECT OF $CO_2$ ENRICHMENT AND CLIMATE CHANGE ON RICE CROP THROUGH FIELD AND SIMULATION STUDY

**Ph. D. THESIS**

*by*

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**FEBRUARY, 2016**

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**A THESIS**

***Submitted in partial fulfilment of the requirements for the award of the degree***

***of***

**DOCTOR OF PHILOSOPHY**

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# INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
# ROORKEE

## CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **"EFFECT OF $CO_2$ ENRICHMENT AND CLIMATE CHANGE ON RICE CROP THROUGH FIELD AND SIMULATION STUDY"**, in partial fulfilment of the requirements for the award of the Degree of Doctor of Philosophy and submitted in the Department of Water Resources Development and Management of the Indian Institute of Technology Roorkee, Roorkee is an authentic record of my own work carried out during a period from February, 2011 to February, 2016 under the supervision of Dr. S.K.Tripathi, Professor, Department of Water Resources Development and Management of Indian Institute of Technology Roorkee, Roorkee, India.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other Institute.

**(G. Pranuthi)**

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

(S.K.Tripathi)
Supervisor

**Dated: September, 2016**

The Ph. D. Viva-Voce Examination of **Ms. G. Pranuthi**, Research Scholar, has been held on……………………………

Chairman, SRC                    Signature of External Examiner

This to certify that the student has made all the corrections in the thesis.

Signature of Supervisor                    Head of the Department

# ABSTRACT

This study is directed to identify the probable effect of increased atmospheric $CO_2$ concentrations and changing climate on rice crop yields in Haridwar Uttarakhand. Fine rice particularly the Basmati contributes substantially into the economy of the state. Rice in Haridwar district is grown in 12300 ha with a low recording productivity of only 2227 kgs/ha which requires improvement under the changing climate.

Keeping the aforesaid points in view the study entitled "**Effect of $CO_2$ Enrichment and Climate Change on Rice Crop through Field and Simulation Study"** has been undertaken with the under mentioned objectives:

1. To conduct field experiment with periodical enrichment of $CO_2$ on rice crop for recording its effect on growth, development, yield and quality.
2. To calibrate DSSAT-CERES Rice model using data recorded from the field experiment.
3. To simulate rice yield under different $CO_2$ treatments using DSSAT CERES –Rice model.
4. To assess climate change pattern of Haridwar district upto 2090 using PRECIS RCM data.
5. To study the impact of climate change and $CO_2$ enrichment on rice yields for the future scenario.
6. To suggest ways and means to improve rice productivity for $CO_2$ enriched crops.

Field experiment with different $CO_2$ treatments was conducted at Demonstration Farm, Water Resources Development and Management Department, Indian Institute of Technology Roorkee, Uttarakhand during the year 2011 and 2012. Plants were enriched with $CO_2$ through use of $CO_2$ cylinders that were used for fire extinguishing. Data recorded from field experiment were statistically analyzed using ANOVA analysis along with Tukey Kramer's PostHoc test.

For calibrating DSSAT CERES Rice model field experiment with four dates of planting (on 7th July, 2013 ; 15th July, 2013 ; 22nd July, 2013 and 31st July, 2013) with recommended package of practices was conducted during *Kharif* season 2013–14. Data recorded was used for calibrating the CERES rice model. To validate the CERES Rice model the crop data from the

2011 and 2012 experiments was used. Genetic coefficient generated in the calibration process was used to run the model. The effect of $CO_2$ enrichment on the growth, development and yield parameters was simulated. The simulated values were compared with the observed values by employing statistical evaluation measures such as FB (fractional bias), NMSE (Normalized Root Mean Squared Error), percent deviation and index of agreement (d).

The future rice yield predictions were done using A2 and B2 IPCC scenarios and PRECIS climate data of rainfall, maximum temperature and minimum temperature for Haridwar district for the period 2020 – 2090. PRECIS RCM was collected from IITM, Pune. The data pertaining to maximum temperature, minimum temperature and rainfall was extracted, bias corrected and validated for its use in crop simulation. Mann Kendall Trend test was applied to study the trend of climatic parameters for the coming years. PRECIS RCM corrected data was used to simulate grain yield of rice crop *cv Sharbhati* for the forthcoming decades 2020 – 2090.

$CO_2$ enrichment effect in rice crop can be improved by adjusting sowing dates, irrigation management, nutrient management and adopting high yielding heat resistant cultivars. Therefore yields were simulated under three different planting dates, three different plant spacing's and three different levels of nitrogen fertilizer along with $CO_2$ enrichment treatments for the future (2020 – 2090).

- In general plant growth was improved with $CO_2$ enrichment treatments recording increased tillers/hill, leaves/hill, plant height, leaf length and width, plant dry matter/hill and Leaf Area Index. Yield attributes viz. panicles/m2, filled grains/$m^2$, grain weight as well as grain length and width were improved with periodical enrichment of $CO_2$. Negative impact of $CO_2$ enrichment was recorded with increased broken grain and chalkiness percentage.
- Calibration and validation of DSSAT model using the experimental data showed that the deviation percentage of observed and simulated values was within the acceptable range of +/- 15%.
- Trend analysis of the period showed that the annual rainfall would increase @ 5.8 mm/yr but Kharif rainfall would increase @ 11.6 mm/yr. The annual maximum and minimum temperature would increase @ 0.0460C/yr and 0.0390C/yr.

- DSSAT CERES rice simulations under A2 and B2 scenarios showed that the yields will decline with the advancing climate change but $CO_2$ intervention will compensate the loss in yield occurred due to higher temperatures and erratic rainfall pattern (climate change).
- The DSSAT was used to develop adaptation strategies for the future under the climate change and higher $CO_2$ scenarios. The results showed that the better yields can be obtained by transplanting the crop in the second week of July, adapting the spacing of 20 cm * 15 cm and nitrogen fertilizer application of 90 kgs N/ha.

## ACKNOWLEDGEMENTS

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February, 2016 (G. Pranuthi)

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# LIST OF ACRONYMS (STANDARD)

| S.No | Abbreviation | Expansion |
|---|---|---|
| 1 | ANOVA | Analysis of Variance |
| 2 | AR5 | Assessment Report 5 |
| 3 | AWS | Automatic Weather Station |
| 4 | CAM | Crassulacean acid metabolism |
| 5 | CDIAC | Carbon Dioxide Information Analysis Center |
| 6 | CERES | Crop Estimation through Resource and Environment Synthesis |
| 7 | CMIP3 | Coupled Model Intercomparison Project Phase 3 |
| 8 | CSM | Crop Simulation Model |
| 9 | DSSAT | Decision Support System for Agrotechnology Transfer |
| 10 | ESRL | Earth System Research Laboratory |
| 11 | FACE | Free Air Carbon Dioxide Enrichment |
| 12 | FATI | Free Air Temperature Increased |
| 13 | GCM | Global Climate Model |
| 14 | IARI | Indian Agricultural Research Institute |
| 15 | ICASA | International Consortium for Agricultural Systems Applications |
| 16 | IHBT | Institute of Himalayan Bioresource Technology |
| 17 | IITM | Indian Institute of Tropical Meteorology |
| 18 | IMD | India Meteorological Department |
| 19 | IPCC | Intergovernmental Panel on Climate Change |
| 20 | MBE | Mean Bias Error |
| 21 | NIH | National Institute of Hydrology |
| 22 | NMSE | Normalized Mean Square Error |
| 23 | NOAA | National Oceanic and Atmospheric Administration |
| 24 | ORNL | Oak Ridge National Laboratory |
| 25 | OTC | Open Top Chambers |
| 26 | P-677 | Pusa - 677 |
| 27 | PB-1 | Pusa Basmati - 1 |
| 28 | PRECIS | Providing REgional Climates for Impacts Studies |
| 29 | PRH-10 | Pusa Rice Hybrid 10 |
| 30 | PS-2 | Pusa Sugandh - 2 |
| 31 | PS-II | Photosystem-II |
| 32 | RBD | Randomized Block Design |
| 33 | RCM | Regional Climate Model |
| 34 | RICAM | rice growth calendar model |
| 35 | RuBP | Ribulose Biphosphate |
| 36 | SIMRIW | Simulation Model for Rice-Weather Relations |
| 37 | SPAR | Soil Plant Atmosphere Research |
| 38 | SPS | Sucrose -P- Synthase |
| 39 | TRYM | The Rice Yield Model |
| 40 | USDA | United States Department of Agriculture |
| 41 | WGEN | Weather Generator |
| 42 | WOFOST | WOrld FOod STudies |

## LIST OF ACRONYMS (DSSAT)

| S.No | Abbreviation | Expansion |
|---|---|---|
| 1 | Alb | Albedo Fraction |
| 2 | BD | Bulk Density |
| 3 | Beg Gr Fil | Beginning Grain Filling |
| 4 | CEC | Cation Exchange Capacity |
| 5 | DR | Drainage Rate |
| 6 | EL | Evaporation Limit |
| 7 | End Juveni | End of Juvenile Stage |
| 8 | End Ti Fil | End of all tillers fil |
| 9 | ET | Evapotranspiration |
| 10 | FC | Field Capacity |
| 11 | G1 | Spikelet Number Coefficient |
| 12 | G2 | Single Grain Weight |
| 13 | G3 | Tillering Coefficient |
| 14 | G4 | Temperature Tolerance Coefficient |
| 15 | GDD | Growing Degree Days |
| 16 | OC | Organic Carbon |
| 17 | P1 | Juvenile Phase Coefficient |
| 18 | P2O | Critical Photoperiod |
| 19 | P2R | Photoperiodism Coefficient |
| 20 | P5 | Grain Filling Duration Coefficient |
| 21 | Pan Init | Panicle Initiation Stage |
| 22 | PAR | Photosynthetically Active Radiation |
| 23 | pH | Concentration of Hydrogen Ion |
| 24 | PWP | Permanent Wilting Point |
| 25 | RO | Runoff Curve Number |
| 26 | RUE | Radiation Use Efficiency |
| 27 | SCS | Soil Conservation Service |
| 28 | SP | Saturation Point |
| 29 | Transplant | Transplanting stage |

# LIST OF ACRONYMS (PRESENT STUDY)

| S.No | Abbreviation | Expansion |
|---|---|---|
| 1 | A | Hits |
| 2 | B | False alarms |
| 3 | BG% | Broken Grain percentage |
| 4 | C | Misses |
| 5 | CD | Critical Difference |
| 6 | CK% | Chalkiness percentage |
| 7 | D | Correct rejects |
| 8 | D1 | First date of planting |
| 9 | D2 | Second date of planting |
| 10 | D3 | Third date of planting |
| 11 | D4 | Fourth date of planting |
| 12 | DF | Degrees of Freedom |
| 13 | FA | Forecast Accuracy |
| 14 | FG | Filled Grains |
| 15 | GB | Grain Breadth |
| 16 | GL | Grain Length |
| 17 | HI | Harvest Index |
| 18 | KB | Kernel Breadth |
| 19 | KL | Kernel Length |
| 20 | LAI | LAI |
| 21 | MKTT | Mann Kendall Trend Test |
| 22 | MS | Mean sum of Squares |
| 23 | MSE | Mean Square Error |
| 24 | NN | No No |
| 25 | NUE | Nitrogen Use Efficiency |
| 26 | NY | No Yes |
| 27 | Obs | Observed |
| 28 | P corr | Corrected Parameter |
| 29 | P meancorr | Mean corrected parameter |
| 30 | PI | Panicle Initiation |
| 31 | PM | Physiological Maturity |
| 32 | PN | Panicle number |
| 33 | Pobs | Observed parameter |
| 34 | Prcm | Regional Climate modelled parameter |
| 35 | PSDcorr | Standard Deviation corrected parameter |
| 36 | SGW | Single grain weight |
| 37 | Sim | Simulated |
| 38 | SKW | Single kernel Weight |
| 39 | SRAD | Solar Radiation |
| 40 | SS | Sum of Squares |
| 41 | Tmax | Maximum Temperature |
| 42 | Tmin | Minimum Temperature |
| 43 | ToS | Test of Significance |
| 44 | UFG | Unfilled Grains |
| 45 | WUE | Water Use Efficiency |
| 46 | YN | Yes No |
| 47 | YY | Yes Yes |

## LIST OF UNITS

| S.No | Unit | Denotes |
|---|---|---|
| 1 | $^0C$ | Degrees Celsius |
| 2 | cm | centimeter |
| 3 | cmol/kg | Centi mol units of energy per kilogram of soil |
| 4 | $g/cm^2$ | gram per square centimeter |
| 5 | gm/hill | gram per hill |
| 6 | kgs | kilogram |
| 7 | kgs(dm)/ha | kilograms of dry matter per hectare |
| 8 | kgs/ha | kilogram per hectare |
| 9 | $km^2$ | Square kilometer |
| 10 | m | meter |
| 11 | Mha | Million Hectares |
| 12 | $MJ/m^2/day$ | MegaJoules per square meter per day |
| 13 | mm | millimeter |
| 14 | Mt | Million Tonnes |
| 15 | no./hill | number per hill |
| 16 | $no./m^2$ | number per square meter |
| 17 | ppm | Parts per million |
| 18 | q/ha | quintal per hectare |
| 19 | t/ha | Tonnes per Hectare |
| 20 | Kgs N/ha | Kilograms of nitrogen per hectare |
| 21 | GtC/yr | Gigatonnes carbon per year |

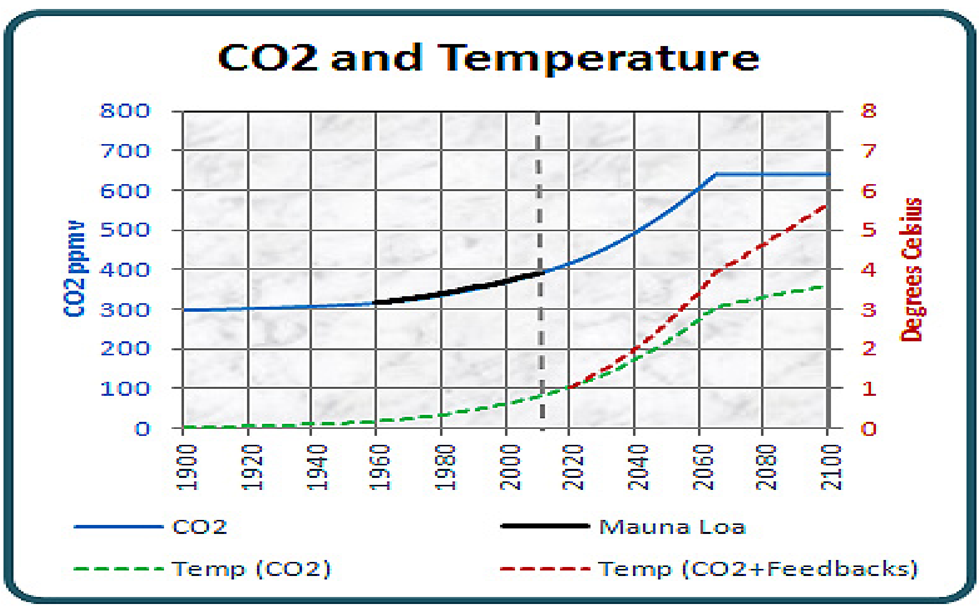
## LIST OF EQUATIONS

# CHAPTER I

# INTRODUCTION

## 1.1 General Background

There is a steady increase in emission of carbon dioxide ($CO_2$) since the beginning of industrialization, as a result its concentration has increased from 270 ppm to 404 ppm in 2015 (Laboratory and Division, 2015). Carbon dioxide is the major greenhouse gas which results from anthropogenic activities and is known to increase global temperature and alter precipitation patterns causing many events such as flood, drought, sea level rise, river level, forest fire etc. The atmospheric $CO_2$ concentration is expected to rise to 550 ppm and air temperature by $2^0$C, respectively by 2050 and 600-700 ppm, $6^0$C temperature by 2100 (Figure 1.1)due to ongoing anthropogenic activities and industrialization.




*Source: CDIAC ORNL, 2009(Boden et al., 2009)*

**Figure 1.1: Global Temperature and $CO_2$ concentrations during the period 1900 - 2100**

According to, (Ziska and Bunce, 2006) both natural and cultivated plants will be affected by different components of global climate change, including elevated $CO_2$ and high temperature. It was observed that elevated atmospheric $CO_2$ has positive effects on crop growth and productivity, both in terms of quantity and quality, by increasing photosynthesis and water use efficiency and decreasing transpiration through reducing stomatal conductance (Long et al., 2004) which is termed as “**Carbon Dioxide Fertilization Effect”**. It is defined as “The enhancement of the growth of plants as a result of increased atmospheric $CO_2$ concentration”. Carbon dioxide is the prime substrate for photosynthesis. Majority of plants, including rice, fix $CO_2$ via C3 pathway. At elevated $CO_2$ the caboxylation rate increases which will increase photosynthesis of C3 plants. Rice (Oryza sativa L.) is the staple food for more than 50% of the world's population, and it is grown on almost 155 Mha of the world's surface. The response of rice crop to the inevitable rise of atmospheric $CO_2$ and temperature is one of the major concerns in the modern world. Meanwhile, an average annual increase in grain production of 44 Mt is required to meet the food demands of the world by 2050 (Tester and Langridge, 2010).

## 1.2 Importance of Rice crop

More than half of the world’s population have rice as their basic diet and the crop is cultivated in more than hundred countries. The total area occupied in the world for rice cultivation is 158 Mha producing more than 470 Mt of milled rice of which 90% is produced in Asian countries(Wasim, 2002). The world’s largest rice producers by far are China and India. After China and India, the next largest rice producers are Indonesia, Bangladesh, Vietnam, Myanmar, and Thailand(Ray et al., 2013). Rice production in Asian countries is increasing but not at par with the population growth. The mismatch in growth rate of population and rice production is widening the gap in supply and demand.

### 1.2.1 Rice cultivation in India

Rice is the most important cereal food grain crop of India occupying about 24% of gross cropped area and contributing about 43% of the total food grain production of the country. Within India, the northern region comprising the states of Punjab, Haryana, Himachal Pradesh, Jammu & Kashmir, Uttar Pradesh and Uttarakhand contribute significantly to India’s rice production due to higher productivity. These states together contribute about 27% to the total rice production and 22 % of the total area occupied for rice cultivation in the country.

In India rice is grown under widely varying physiographic and climatic conditions. The 329 Mha geographic area of the country spread from temperate to tropical zone and semi-arid to humid zone as well as from plain to mountains and rice is grown in all parts of the country. In eastern and southern regions, the mean temperature is high and found to be favorable for rice cultivation throughout the year therefore 2-3 crops of rice are grown. In northern and western parts of the country, where monsoon rainfall is good and winter temperature is fairly low, only one crop of rice is grown during June to October/November.

Rice is a water intensive crop requiring 1500-2500 mm irrigation water to produce a potential yield of 4500 kg $ha^{-1}$, but the productivity ranged from 800 - 3700 kg $ha^{-1}$ only. The low productivity problem in India can be attributed to several factors viz. uneven distribution of rainfall, poor soil fertility, inadequate fertilizer use, shortage of irrigation facility, insect, pest and disease problem, low genetic potential, smaller size of holdings and above all the changing climatic conditions.

### 1.2.2 Rice Cultivation in Uttarakhand

Uttarakhand is the state where river Ganges has its origin and the state is blessed with fertile soils, abundant water resources and favorable climate for rice cultivation. The total geographical area of the Uttarakhand state is 53,204 $km^2$ comprising of 4 plain districts (Haridwar, Udham Singh Nagar, Nainital and Dehradun) and 9 mountainous districts (Tehri Garhwal, Pauri Garhwal, Uttarkashi, Chamoli, Rudraprayag, Almora, Bageshwar, Pithoragarh and Champawat). The general land use pattern of the state consists of 14% area under cultivation, 62% under forest and rest under other uses. Rice is the major cereal crop of *Kharif* season in the state and occupies about 54% of the total cultivated area under cereals. The annual rice production of the state is around 0.55 Mt from an area of about 0.28 Mha. The rice area of Uttarakhand is distributed both in plains and mountains sharing equally, but the total rice production of the plains is twice the total production of the hills and mountains.

Rice is cultivated in all the 13 districts of the state but Udham Singh Nagar, Nainital, Haridwar and Dehradun districts share about 57% of total area and 73% of total production. From productivity point of view these districts are classified in the high (Udham Singh Nagar & Nainital) to medium (Haridwar and Dehradun) category whereas the rest of the nine districts are classified in the low productivity category (Mani, 2013). Uttarakhand, in spite of being endowed with the favorable weather, soils and water resources observes a declining trend in area, production and productivity (http://agriculture.uk.gov.in/files/Index_of_Statistics_GOs.pdf). This has become a matter of concern to farmers, planners and administrators of the state to undertake field studies on rice from different aspects including the climate change to reverse the declining trend and make the state self-reliant in rice production.

The total cost of rice cultivation in plain districts is high due to increased cost of the labor, fertilizers and plant protection chemicals. Farmers prefer to grow a rice variety that has got *Basmati* in its parentage. There are number of such varieties developed by agricultural Institutes and Universities. *Sharbati* is one of the very popular high yielding rice variety in Hardwar district with *Basmati* parentage developed by Indian Agriculture Research Institute New Delhi. Due to higher productivity, net return is also high. Farmers engaged in seed production of this variety of rice make very good profit.

Studies with rice have indicated that elevated $CO_2$ generally increases tiller number, photosynthesis, biomass and grain yield as well as plant nitrogen (N) uptake and biological N fixation(Kim et al., 2001). Factors that have been acknowledged to influence the response of rice crop growth to elevated $CO_2$ include phenological stage, cultivar, season, air temperature and nutrient supply. However, our understanding of these factors still cannot satisfactorily explain the large variations of results obtained in different high $CO_2$ studies. Elevated $CO_2$ accelerated rice development by increasing leaf photosynthesis by 30–70% and crop biomass yield by 15–30%, depending on genotype and environment. Elevated $CO_2$ had a minor effect on rice nitrogen (N) uptake, which appeared to be associated with the relatively insensitive response of leaf area growth to $CO_2$. Those rice responses to $CO_2$ resulted in a substantial increase in grain yield and at nearly optimum temperature conditions. The anticipated changes in temperature and $CO_2$ have been modeled to have opposite effects on the production. Increasing temperatures shortened the growing season leading to decreased yields, while elevated $CO_2$ increased the yields (Erda et al., 2005).

When C3 plants, such as rice, are exposed to high $CO_2$ concentration, the net photosynthesis rate of the leaves is accelerated due to both enrichment of substrate $CO_2$ and inhibition of photorespiration by high $CO_2$ concentration (Long et al., 2004). However, the stimulatory effect of high $CO_2$ concentration decrease gradually as the time of the exposure is prolonged (Chen et al., 2005).

Rice production can be dramatically affected by temperature. Traditionally, cool temperatures have been more limiting for rice production than warm temperatures. In this regard, production areas could expand with increasing temperature. However, rice plants also respond to high temperatures. Thus, for tropical areas, increased temperature by itself could lead to reduction in grain yield. High temperature boosts plant growth rate and could reduce growth duration leading to shorter grain filling period which varies from 25 days in the tropics to 35 days in the temperate zone (Swaminathan, 1984). Spikelet sterility induced by higher temperature (Yoshida and Parao, 1976) which becomes very severe near 40°C resulting in complete loss of crop production. Possible effects on rice have been described, but further studies are needed to evaluate the potential impact of precipitation and temperature changes on the major farming systems of each agro-climate zone. In India 15 major agro-climate zones have been recognized (Sinha and Swaminathan, 1991).

### 1.3 $CO_2$ Enrichment Studies

Laboratory and controlled condition studies on rice have reported that the elevated $CO_2$ level increased the number of tillers, biomass production and grain yield along with the increased and uptake of soil nitrogen (N) (Kim et al., 2003; Kim et al., 2001). $CO_2$ enrichment improved the leaf photosynthesis by 30–70% and crop biomass and grain yield by 15–30%, depending on their genotype and working environment. The elevated temperature regime of crop shortened the growing period of rice that lead to decreased yields whereas the elevated $CO_2$ increased the yields (Baker and Allen Jr, 1993; Baker et al., 1992a; Baker et al., 1992b).

Laboratory experiments, undertaken world over by the scientists in controlled conditions of FACE (Free Air Carbon Dioxide Enrichment) and OTC (Open Top chambers) maintaining a constant level of elevated $CO_2$ has demonstrated a positive response on growth and development of rice (Madan et al., 2012; Roy et al., 2012; Satapathy et al., 2014; Sujatha et al., 2008; Uprety et al., 2002; Uprety et al., 2003; Uprety et al., 2006). $CO_2$ is an important component of photosynthetic process therefore it helps improving the growth and development of plants (Stitt, 1991). This technology needs to be transferred to the famer's field for drawing the benefits of $CO_2$ fertilization of crops. Therefore conducting field experiments with $CO_2$ enrichment on rice crop was felt.

### 1.4 Crop Simulation Models (CSM): tools for Climate Change Studies

New agricultural research is needed to supply information to agronomists, farmers, policy makers, and also for other decision makers, how to accomplish sustainable agriculture over the wide variations of climate, soil, environments, political, social and economic conditions around the world. CSM can be used to create virtual "experiments" to simulate, on computers, outcome of complex interaction between crop growth and various agricultural practices, soil and weather conditions and to suggest appropriate solutions to site specific problems (Jones et al., 1998; Tsuji et al., 1994; Uehara and Tsuji, 1998). This system relies heavily on simulation models to predict the performance of crops for making a wide range of decisions.

With the ever increasing $CO_2$ concentrations in the atmosphere and changing climates it has become important to study their effect on rice crop in Uttarakhand. Fine rice particularly the Basmati contributes substantially into the economy of the state. Rice in Haridwar district is grown in 12300 ha with a low recording productivity of only 2227 kgs/ha which requires improvement under the changing climate.

Keeping the aforesaid points in view the study entitled "**Effect of $CO_2$ Enrichment and Climate Change on Rice Crop through Field and Simulation Study"** has been undertaken with the under mentioned objectives:

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6. To suggest ways and means to improve rice productivity for $CO_2$ enriched crops.

# CHAPTER II

# REVIEW OF LITERATURE

## 2.1 Global $CO_2$ concentrations

NOAA's (National Oceanic & Atmospheric Administration) Earth System Research Laboratory – Global Monitoring Division (http://www.esrl.noaa.gov/gmd/ccgg/trends/#mlo_data) is continuously monitoring the global atmospheric gases especially atmospheric $CO_2$ concentrations from 1960 onwards and more than 50 sites of network has reported that global $CO_2$ concentrations are increasing (Laboratory and Division, 2015). The current annual rise in atmospheric $CO_2$ concentration recorded at Mauna Loa observatory, Canada shows that the $CO_2$ concentration is increasing @ 2.11ppm /yr (http://CO2now.org/Current-CO2/CO2-Trend/).

## 2.2 $CO_2$ concentrations at National and Regional Level

In India, industrialization is increasing, lifestyle is changing and the use of fossil fuel is increasing therefore $CO_2$ concentration in the atmosphere is increasing. The emission of $CO_2$ during 2007 was estimated to be 475 Mt which increased by 8.1% during 2008 (Boden et al., 2009). From 1950 to 2008, India experienced dramatic growth in fossil-fuel consumption and $CO_2$ emission @ 5.7% per year and became the world's third largest fossil-fuel $CO_2$-emitting country (Andres et al., 2009). The emissions of $CO_2$ from fossil-fuel consumption and cement production in India have doubled since 1994 (Boden et al., 2009; Marland et al., 2003; Raupach et al., 2007).

## 2.3 Carbon response of crops and their behavior

Crop species are directly affected by increased atmospheric $CO_2$, which changes the plant physical structures (growth and development), photosynthesis, respiration, stomatal conductance, biomass accumulation and carbon: nitrogen ratio as shown in Figure 2.1, and in turn affects crop growth and yield, water use efficiency (Ritchie and Otter, 1985) and susceptibility to insect pests and diseases (Mitchell et al., 2003; PaHerson, 1993). Responses of crops to climate change are closely related to the local climate variability rather than to the global climate patterns and, therefore, crop response to climate change vary with agro climatic region and plant species (Stocker et al., 2013).

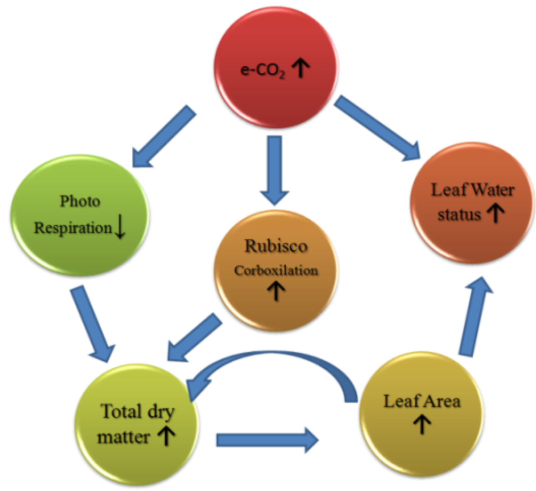



**Figure 2.1: Impact of elevated $CO_2$ on physiological processes of Rice crop**

## 2.4 Crop Responses to $CO_2$ enrichment

There are three different types of plants in which they undergo photosynthesis or take carbon dioxide from the air. The C3 plants are most common and efficient in photosynthesis in cool, wet climates. C4 plants are efficient in photosynthesis in hot, sunny climates. The CAM plants are adapted to avoid water loss during photosynthesis so they are best in deserts.

The increased economic yield of C3 and C4 crops have been reported due to $CO_2$ enrichment (Reddy and Hodges, 2000; White et al., 2011). $CO_2$ enrichment resulted into increased grain yield by 20 -35% in C3 crops and 10 – 15% in C4 crops (Reddy et al., 2010). Although the grain yield increased but the protein content deteriorated in rice, wheat and maize crops (Taub et al., 2008). The yield of crops grown under limited water and nutrient supply conditions, was increased with $CO_2$ enrichment (Jalota et al., 2013; Zhang et al., 2013) The drought tolerance in crops is increased through partial closure of stomata that reduces water vapor conductance by doubling the $CO_2$ concentration above the ambient level (Ainsworth and Rogers, 2007; Leakey et al., 2009).

## 2.5 Carbon Cycle in rice

Rice synthesizes carbohydrates through C3 or Calvin photosynthetic pathway. This pathway is mediated by an enzyme known as RuBP carboxylase and oxygenase which fixes Carbon into a three carbon compound known as 3 – Phospho Glyceric Acid due to which this cycle is named as C3 cycle. Almost 80 – 85% plant communities are C3 plants (http://hyperphysics.phy-astr.gsu.edu/hbase/biology/phoc.html). Cereals which have C3 photosynthetic pathway are rice, wheat, oats, barley etc.

RuBP can bind with both oxygen and carbon, when the $CO_2$ concentration is higher RuBP binds with $CO_2$ leading to increased photosynthesis, When oxygen concentration in the air is higher RuBP binds with oxygen leading to increased respiration (Bowes, 1993; Teramura et al., 1990; Vu et al., 1997).

## 2.6 Chamber studies

Numerous studies on the impact of enhanced level of $CO_2$ and temperature on crop(s) under controlled conditions were undertaken in India and abroad since the start of era of climate change (Long et al., 2004. Though the objective and principle behind the experiments was similar but the approach of the experiments has changed over the years and improved since then. Initially, leaf cuvettes were used to study the exchange of $CO_2$ between atmosphere and leaf. Leaf cuvettes were soon replaced by the use of SPAR (Soil, Plant and Atmospheric Research) chambers in order to provide a controlled environment. Later on, OTC (Open Top Chamber) was developed where the use of $CO_2$ concentrations is controlled but the natural growth of the crop plants is disturbed due to the chamber effect. In order to avoid the effect of chamber on crop growth and development, the concept of FACE (Free Air Carbon Dioxide) was developed and put into practice at Arizona which was called as Maricopa FACE. This was modified to suite the crops of South Asian Climatic conditions and was called as FACE. Studies focused on evaluating the response of different crop species to elevated $CO_2$ and temperature in FACE chamber are being undertaken in different parts of the country (Uprety et al., 2002; Uprety et al., 2006). The FACE chambers were further modified with added provision of controlling $CO_2$ application and regulating the temperature and was named as FATE (Free Air Temperature

Elevation). This technology is being used by IHBT, Palampur and IARI, New Delhi (Jagadish and Pal, 2009; Krishnan et al., 2007; Madan et al., 2012; Sujatha et al., 2008).

## 2.7 Effect of Elevated $CO_2$ on Rice crop

A comprehensive literature survey was conducted using peer-reviewed research articles related to impact of elevated $CO_2$ on growth, development and yield of rice. The effect of $CO_2$ enrichment on phenology, plant height, leaf area, number of tiller per plant, number of leaves per plant, leaf length, leaf width, yield, and number of panicles per plant, number of grain per panicle, grain weight, and harvest index of rice crop were reviewed.

Studies with $CO_2$ enrichment were conducted in isolation or combination with other variables such as nitrogen, phosphorous, temperature etc. were reviewed. Results were compared by calculating deviation percentage (Eqn 2.1) between the crop parametric values obtained under elevated $CO_2$ and ambient $CO_2$ conditions.

$$Dev\% = \frac{E - A}{A} * 100 \tag{2.1}$$

Where E = Crop parameter at $CO_2$ enriched conditions

A = Crop parameter at ambient $CO_2$ concentrations

The specific objective of this review is to evaluate the recent studies on rice crop response to $CO_2$ enrichment in terms of growth, development, yield and quality.

### 2.7.1 Effect of Elevated $CO_2$ on Rice Growth and Development

The review on effect of elevated $CO_2$ on rice growth and development is given in Table 2.1. The growth and development parameters that are reviewed in this section are phenology, plant height, leaf area, tiller number, biomass and its partitioning.

The effect of elevated $CO_2$ on phenology of rice crop is not uniform and insignificant as the response of different genotypes behaved differently (Liu et al., 2008). Some studies have reported that $CO_2$ enrichment shortens the crop growth period while in some studies the crop growth period was prolonged by 1-3 days (Adachi et al., 2014; Manalo et al., 1994). Some studies also reported that $CO_2$ has no role to play in phenological development of rice crop (Kim, 1996). The differential response of rice phenology of different genotypes to $CO_2$ enrichment is probably due to their difference in physiological and biochemical character (Vanuytrecht et al., 2012). The phenology of rice crop is majorly influenced by temperatures and photoperiod rather than $CO_2$ (Meehl et al., 2005; Nakagawa and Horie, 2000). Rice crop is although adaptable to a variety of climatic conditions, but the lower temperatures are less adaptable than higher temperatures. Low temperature during the flowering period has been reported to induce spikelet sterility (Gunawardena et al., 2003; Shimono et al., 2005). Increased temperature during the growing period reduces the maturity and grain setting period (Peng et al., 2004).

Very few studies have focused on the $CO_2$ enrichment response on plant height of rice. In one such experiment the plant height increased by 7-17% under elevated $CO_2$ condition (Manalo et al., 1994). Increased plant height under higher $CO_2$ concentrations for *Pusa Basmati -1* and *Pusa – 677* of about 7.8 and 16.4 % respectively for each cultivar has been reported (Uprety et al., 2003)

Rice crop grown under elevated $CO_2$ condition without any stress of weather, soil physical condition, water and nutrients recorded increased effective tillers ranging from 4 – 50% (Liu et al., 2008; Yang et al., 2006; Yang et al., 2009). The experiment conducted with the treatments of elevated $CO_2$ and varying nitrogen levels on rice crop significantly increased the tiller number.(Aben et al., 1999). The response of $CO_2$ enrichment was found to be higher at lower nitrogen treatments. The temperature and $CO_2$ enrichment effect was found to be significant in a study done by (Cheng et al., 2008) which shows that the low night temperature (3.8%) was found to be more detrimental than high night temperature (5%). Different varieties respond differently to $CO_2$ enrichment which has been proved in studies done by (Shimono et al., 2009) with variability ranging from 4.3 – 23.6 %. Crops exposed to higher $CO_2$ generally grow larger (Bowes, 1993). Crops such as rice and wheat grown under $CO_2$ enriched conditions recorded increased tiller number, which leads to greater yield because of the greater number of seed and heads per plant (Baker et al., 1992).

The $CO_2$ concentration around plant canopy affects photosynthetic process. The increase in the leaf area is due to the increase in size of leaves and tiller count. The significantly increased leaf area under $CO_2$ enriched conditions has been reported by (Aben et al., 1999; Uprety et al., 2003). The leaf number increased by 11-16%, leaf area increased by 9-25% and leaf dry matter increased by 9-51% in the rice cv *Pusa Basmati-1*, *Pusa-677* has been reported. Maximum Leaf Area Index increased by 35% under elevated $CO_2$ conditions compared to that of the ambient $CO_2$ conditions (Roy et al., 2012). The $CO_2$ enrichment in rice and soybean increased size of leaves and leaf thickness (Ainsworth et al., 2002).

Increased root biomass is probably due to increased translocation of photosynthate to root zone in $CO_2$ treated rice plant which has been reported by (Kim et al., 2003). The interacting response biomass production was found to be significant in rice crop grown under low, medium and high nitrogen levels with enriched $CO_2$ treatments (Kim et al., 2001). The rice crop grown under enriched $CO_2$ condition recorded significantly increased biomass of leaf (5-50%), stem (15-21%) and panicle (12-17%) over the ambient $CO_2$ concentrations (Seneweera, 2011).

### 2.7.2 Effect of Elevated $CO_2$ on Rice yield and yield attributes

The effect of elevated $CO_2$ on rice grain yield and yield attributes is reviewed in Table 2.2. The yield and yield attributes reviewed were grain yield, straw yield, panicle number, grain number, and single grain weight and harvest index.

The rice crop grown with enriched $CO_2$ recorded 4 – 71% increased grain yield in comparison with the crop grown under ambient $CO_2$ (Bhattacharyya et al., 2012; De Costa et al., 2007; Hasegawa et al., 2013; Shimono and Okada, 2013; Uprety et al., 2003). Interacting response of $CO_2$ and nitrogen on grain yield was found to be significant (Kim et al., 2003; Kim et al., 2011; Kim et al., 2001; Zhang et al., 2013). The grain yield in rice crop with individual treatments of $CO_2$ and phosphorous enrichment was remarkably increased between 25 – 50% but the interacting response was not significant (Conroy et al., 1994; Seneweera and Conroy, 1997). The grain yield was reduced with increasing temperature and increased with increasing $CO_2$ concentrations. (Baker et al., 1992; Baker et al., 1992b; Cheng et al., 2008; Cheng et al., 2009). Grain yield increase did not increase in proportion to the increase in assimilation of photosynthate (Moya et al., 1998; Ziska et al., 1997). The rice crop yield responded positively to increasing $CO_2$ level even at the higher range of temperature regime (Moya et al., 1998). The increase in the straw yield under $CO_2$ enriched conditions is more evident than the grain yield as $CO_2$ directly impacts the photosynthate accumulation (Lawlor and Mitchell, 2000; Ziska et al., 2004). From the survey of literature it is noted that the straw yield recorded 6 – 46% increase under $CO_2$ enrichment (Baker et al., 1992a; Baker, 2004; Teramura et al., 1990). According to (Ainsworth and Rogers, 2007; Long et al., 2004) higher $CO_2$ levels could serve the purpose of increasing global rice yields for feeding the future generations.

The panicle no./$m^2$ increased by 8-10% due to increase in tiller number under $CO_2$ enriched condition but productive tiller ratio did not change much (Baker and Allen Jr, 1993b; Baker, 2004; Cheng et al., 2008; Cheng et al., 2009; Conroy et al., 1994; Hasegawa et al., 2013; Seneweera, 2011) (Kim et al., 2003; Kim et al., 2001; Roy et al., 2012; Zhang et al., 2013). The grain numbers/panicle increased by 24 -39 % in rice grown under elevated $CO_2$ condition (Baker, 2004; Hasegawa et al., 2013; Roy et al., 2012). However decreased grain number/panicle under $CO_2$ enrichment has also been reported by some of the researchers ((Baker and Allen Jr, 1993b; Baker, 2004; Cheng et al., 2008; Cheng et al., 2009; Conroy et al., 1994; Hasegawa et al., 2013; Seneweera, 2011). The effect of elevated $CO_2$ on single grain weight is not significant and marginal variation can be attributed to even other factors.

The increase in grain yield due to $CO_2$ enrichment could be attributed largely to increased grain number per plant and marginally due to grain weight (Seneweera, 2011). Researchers have reported that the elevated $CO_2$ concentration increased the harvest index of rice crop (Kim et al., 2003; Kim et al., 2001; Lin and Wang, 1998); while others reported decrease harvest index with increasing $CO_2$ concentrations (Cheng et al., 2008; Cheng et al., 2009; Seneweera and Conroy, 1997).

### 2.7.3 Effect of Elevated $CO_2$ on physiological processes of rice crop

It is well documented that the crops with C3 photosynthetic pathway like rice respond more to elevated $CO_2$ rather than crops with C4 pathway. The major physiological processes that are likely to be affected by higher $CO_2$ concentrations in rice are photosynthesis, respiration and transpiration and water uptake. $CO_2$ increased rice leaf photosynthesis by 30–70%, leading to more biomass accumulation which in turn lead to increased leaf area (Shimono and Okada, 2013).

Basmati rice cultivars viz. PRH-10 (*Pusa rice hybrid-10*) and PS-2 (Pusa Sugandh-2) grown under two different day/night temperature regimes (31/24°C, 35/28°C) at elevated (550 ppm) $CO_2$ concentrations recorded 17 – 39% increase in photosynthetic rate in comparison with the crop grown at ambient (370 ppm) $CO_2$ concentrations (Sujatha et al., 2008). Elevated temperature decreased the photosynthetic rates both under ambient and elevated $CO_2$ conditions (Ziska et al., 1996; Ziska et al., 1997). The respiration of rice crop grown under high $CO_2$ was decreased by 12 – 13% whereas it increased by 13 – 35% in crop grown under high temperatures regime (Cheng et al., 2008; Cheng et al., 2009). Stomatal conductance of rice crop grown under high $CO_2$ concentrations decreased by 30 – 65% (Uprety et al., 2002). Research studies under controlled condition demonstrated that water use efficiency (WUE) of rice crop under high $CO_2$ concentrations is improved due to increased photosynthesis and reduced transpiration (Jianlin et al., 2008).

In a research study done by (Chen et al., 2014) a particular cultivar Takanari was identified to show higher rate of photosynthesis and stomatal conductance under both ambient and FACE growth conditions over 2 years than Koshihikari variety. Even ribulose-1,5-bisphosphate carboxylation, mesophyll conductance, chlorophyll content and electron transport rates were higher for Takanari at the mid-grain filling stage in both years. These results indicated that Takanari maintains its superiority over Koshihikari when grown in elevated $CO_2$ and it may be a valuable resource for rice breeding programs which seek to increase crop productivity under current and future $CO_2$.

### 2.7.4 Effect of Elevated $CO_2$ on Rice grain quality

Elevated $CO_2$ affects physiological and biochemical processes (photosynthesis, translocation, nutrient and water uptake, enzyme activity and gene expression etc.) in the rice plant thereby changes the chemical and physical characteristics of rice grains (Wang et al., 2011). The characteristics of rice grain quality viz, processing, appearance, cooking and nutritional quality are studied for impact analysis of $CO_2$ enrichment. Elevated $CO_2$ seriously deteriorated the processing quality; head rice percentage was significantly decreased (Dong et al., 2002; Myers et al., 2014; Usui et al., 2016; Yang et al., 2007; Zhang et al., 2015). In most cases, elevated $CO_2$ increased chalkiness of rice grains by 3 -28% (Xu et al., 2008). The evaluation of physicochemical characteristics of kernel together with starch content indicated no significant change in cooking and eating quality of rice grown under elevated $CO_2$ (Terao et al., 2005). Although the rice crop yields are reported to increase under $CO_2$ enriched conditions but the susceptibility of crop varieties to lodging have been reported by (Shimono et al., 2007; Zhu et al., 2013).

## 2.8 Global Climate Change

Climate change is the most sought after topic in climate related research studies. Intergovernmental Panel on Climate Change (IPCC) is an international organization which mainly deals with climate change, global warming and their impacts on various sectors of the community. Climate change in terms of global warming of the climate has been reported since 1950s (Pachauri et al., 2014). The global average annual temperature of 2014 was 14.9 °C which is 0.69°C warmer than the normal temperature. The year 2014 was reported to be the warmest year across the globe since 1880 (https://www.ncdc.noaa.gov/sotc/global/201413).

Annual precipitation measured at land-based stations around the globe during 2014 was 1033.5 mm which is closer to the normal global rainfall (http://data.worldbank.org/indicator/AG.LND.PRCP.MM). However, precipitation varied greatly from region to region (Rajeevan et al., 2008). Climatic conditions upto 2035 AD were projected using Coupled Model Inter Comparison Project third generation (CMIP3) and presented in Fifth Assessment Report (AR5) of IPCC which reports that the global annual air surface temperature would increase by 0.3 – $2^0$C by the end of 2035 AD (Pachauri et al., 2014; Stocker et al., 2013). It also predicted warmer days and nights in a year, temporal and spatial changes in precipitation amounts and increase in heavy rainfall events (Stocker et al., 2014). All the organizations concerned with the climatological studies have shown that the earth is continuously warming since 1880 and abrupt increase has occurred after 1970 (Stocker et al., 2014).

**Table 2.1: Literature Review - Effect of Elevated $CO_2$ on Growth and Developmental Parameters of Rice Crop (%) increase or decrease in the growth and developmental parameters of rice crop grown under elevated $CO_2$ concentrations in comparison with the crop grown at ambient $CO_2$ concentrations).**

| S.No. | Author | Place of Study | Study Year | Species | Tech. used | Elevated $CO_2$ levels (ppm) | Other treatments | No. of Tiller | Plant height | Leaf Area | Above ground biomass (Dry weight) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Leaf | Stem | Root | Ear | Plant |
| | | | | | | | | % Increase or decrease above ambient $CO_2$ level | | | | | | | |
| 1 | (Aben et al., 1999) | Yanco, Australia | 1999 | *Jarrah* | Hydrophonics | 350700 | N - 5 mg/l | 60 | - | 30 | - | - | - | - | - |
| | | | | | | | N - 20 mg/l | 17 | - | 2 | - | - | - | - | - |
| | | | | | | | N - 40 mg/l | 29 | - | 15 | - | - | - | - | - |
| | | | | | | | N - 60 mg/l | 39 | - | 2 | - | - | - | - | - |
| | | | | | | | N - 100 mg/l | 30 | - | 22 | - | - | - | - | - |
| 2 | (Kim et al., 2003) | Northern Japan | 19,981,999 | *Akitakomachi* | FACE | 370+200 | 4 $gN/m^2$ | - | - | - | - | - | 30.8 | - | 11.8 |
| | | | | | | | 8 $gN/m^2$ | - | - | - | - | - | 25.6 | - | 15.3 |
| | | | | | | | 12 $gN/m^2$ | - | - | - | - | - | 14.3 | - | 19.2 |
| 3 | (Uprety et al., 2003) | New Delhi, India | 1998 | *Pusa Basmati - 1* | OTC | 600 | Pusa Basmati - 1 | 23.6 | 7.8 | 25.5 | 50.0 | 43.6 | - | - | |
| | | | | *Pusa - 677* | | | Pusa - 677 | 14.2 | 16.4 | 9.5 | 9.5 | 12.6 | - | - | |
| 4 | (Cheng et al., 2008) | Tsukuba, Japan | | *IR72* | Climatrons | 680 | High Night Temperature | 5 | - | | 5 | 9 | 2 | 13 | 5 |
| | | | | | | | Low Night temperature | 3.8 | - | - | 6 | 21 | 9 | 21 | 18 |
| 5 | (Shimono et al., 2009) | Tohoku Region, Japan | 2003, 2004 | *Kirara397* | FACE | 600 | - | 21.8 | - | - | - | - | - | - | 16 |
| | | | | *Kakehashi* | | | - | 4.3 | - | - | - | - | - | - | 8.4 |
| | | | | *Akitakomachi* | | | - | 9.9 | - | - | - | - | - | - | 11 |
| | | | | *Hitomebore* | | | - | 17.6 | - | - | - | - | - | - | 13.2 |
| 6 | (Seneweera, 2011) | Victoria, Australia | - | *Jarrah* | Hydrophonic Growth chambers | 720 | - | 50 | - | - | -11 | - | 86 | - | - |
| 7 | (Bhattacharyya et al., 2012) | Central Rice Research Institute, Cuttack, India | 2009,2010& 2011 | *Naveen* | OTC | 500 | 2009 | 34.0 | - | - | - | - | | - | 16.9 |
| | | | | | | | 2010 | 29.0 | - | - | - | - | | - | 26.1 |
| | | | | | | | 2011 | 24.0 | - | - | - | - | | - | 20.3 |
| 8 | (De Costa et al., 2007; De Costa et al., 2003; De Costa et al., 2006) | Srilanka | 2000 - 2002 | *BG 300* | OTC | 350, 570 | Yala | | | | | | | 17.2 | 23 |
| | | | | | | | Maha | | | | | | | 34.4 | 37 |

**Table 2.2: Literature Review - Effect of Elevated $CO_2$ on Yield and Yield Associated Parameters of Rice Crop (% increase or decrease in the Yield and Yield Associated Parameters of rice crop grown under elevated $CO_2$ concentrations in comparison with the crop grown at ambient $CO_2$ concentrations).**

| S.No. | Author | Study area | Study Year | Cultivars | Tech. used | $CO_2$ level (ppm) | Interaction with other factor | Seed Yield | Straw yield | Panicle No | Grain No | SGW | HI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | % Increase or decrease above ambient $CO_2$ level | | | | | | |
| 1 | (Teramura et al., 1990) | Durham, North Carolina | 1988 | *IR-36* | $CO_2$ injection system | 350 & 650 | $CO_2$ | 18 | 11 | - | - | - | - |
| | | | | | | | $CO_2$ +UV-B | 10 | 6 | - | - | - | - |
| 2 | (Ziska et al., 1997) | IRRI, Philippines | 1994, 1995 | *IR72* | OTC | 500 | | 15 | 31 | | | | |
| | | | | | | 600 | | 27 | 40 | | | | |
| 3 | (Baker and Allen Jr, 1993) | University of Florida at Gainesville Florida, USA | 1987 | | | 330 & 660 | 24.2$^0$C | 6 | 8 | -2 | 9 | 3 | -2 |
| | | | | | | | 25.1$^0$C | 58 | 37 | 8 | 47 | 5 | 14 |
| | | | | | | | 25.1$^0$C | 26 | 15 | 10 | 14 | 3 | 9 |
| | | | | | | | 31$^0$C$^0$C | 31 | 36 | 17 | 9 | 1 | -5 |
| | | | | | | | 31$^0$C | 49 | 29 | 11 | 31 | 3 | 12 |
| | | | | | | | 30.2$^0$C | 14 | 13 | -16 | 22 | 3 | -26 |
| | | | | | | | 36.2$^0$C | - | - | - | - | - | - |
| 4 | (Conroy et al., 1994) | Srilanka | 1994 | *Jarah* | | 350 & 700 | P-30 | - | - | 75.0 | 28.4 | 8.7 | - |
| | | | | | | | P-120 | - | - | 32.3 | 19.3 | 20.8 | - |
| | | | | | | | P-480 | - | - | 16.7 | -3.0 | 0.0 | - |
| 5 | (Seneweera and Conroy, 1997) | Yanco, Australia | 1994 | *Jarrah* | Pot treatments in chambers | 350 & 700 | P - 0 | 29 | - | 133 | 38 | 14 | 0 |
| | | | | | | | P - 30 | 50 | - | 75 | -28 | 9 | 11 |
| | | | | | | | P - 60 | 38 | - | 0 | 32 | 22 | 20 |
| | | | | | | | P - 120 | 50 | - | 32 | 19 | 21 | 63 |
| | | | | | | | P - 240 | 41 | - | 18 | 19 | 8 | 44 |
| | | | | | | | P - 480 | 25 | - | 49 | -3 | 8 | 44 |
| 6 | (Lin and Wang, 1998) | Beijing, China | 1997 | *Jindao 1187* | OTC | 350 & 650 | - | - | - | 21 | - | - | -31 |
| 7 | (Kim et al., 2001) | Shizukuishi, Japan | 1998, 1999 | *Akitakomachi* | FACE | 365 & 565 | 4 g N /$m^2$ | 4 | 9 | 3 | -2 | 2 | -4 |
| | | | | | | | 8 - 9g N/$m^2$ | 13 | 16 | 9 | -2 | 4 | -2 |
| | | | | | | | 12 - 15 g N/$m^2$ | 11 | 14 | 7 | 8 | -5 | -2 |
| 8 | (Kim et al., 2003) | Shizukuishi, Japan | 1998, 1999, 2000 | *Akitakomachi* | FACE | 365 & 565 | 4 g N /$m^2$ | 7.4 | - | 5.5 | -0.2 | 2.2 | -4.4 |
| | | | | | | | 8 - 9g N/$m^2$ | 14.6 | - | 10.2 | 1.5 | 1.7 | -1.4 |
| | | | | | | | 12 - 15 g N/$m^2$ | 15.2 | | 10.1 | 4.0 | -0.2 | -1.4 |
| 9 | (Uprety et al., 2003) | New Delhi, India | 1998 | *Pusa Basmati - 1* | OTC | 360 & 600 | Pusa Basmati - 1 | 40.7 | | | 22.3 | 7.2 | |
| | | | | *Pusa - 677* | | | Pusa - 677 | 24.3 | | | 26.8 | 0.8 | |
| 10 | (Baker, 2004) | Beltsville, Florida | 2000, 2002 | *Cocodrie, Cypress, Jefferson* | SPAR | - | - | 46 – 71 | 35 - 46 | 6 - 23 | 16 - 41 | | |
| 11 | (De Costa et al., 2007; De Costa et al., | Srilanka | 2000 | *BG300* | OTC | 370 & 570 | Maha Season | 24 | 23 | - | 11 | 2 | 4 |
| | | | | | | | Yala Season | 39 | 37 | - | 36 | -4 | 2 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2003; De Costa et al., 2006) | | | | | | | | | | | | |
| 12 | (Cheng et al., 2008) | Tsukuba, Japan | | *IR72* | Climatrons | 680 & 380 | High Night Temperature | 8.5 | - | 5 | -0.1 | 5.1 | 4.2 |
| | | | | | | | Low Night temperature | 26.9 | - | 3.8 | 14.1 | 5.3 | 8.5 |
| 13 | (Cheng et al., 2009) | National Institute forAgro-Environmental Sciences, Tsukuba, Japan | 2006 | *IR72* | Climatrons | 380 & 680 | High night temperature - 320C | 8.5 | - | 5 | -1 | 5.1 | 4.2 |
| | | | | | | | Low night temperature - 220C | 26.9 | - | 3.8 | -2.6 | 5.3 | 8.5 |
| 14 | (Bhattacharyya et al., 2012) | Central Rice Research Institute, Cuttack, India | 2009,2010& 2011 | *Cv. Naveen* | OTC | 380 & 500 | 2009 | - | - | 25.2 | 25.4 | 2.5 | - |
| | | | | | | | 2010 | - | - | 19.9 | 19.1 | 1.9 | - |
| | | | | | | | 2011 | - | - | 21.8 | 22.5 | 2.5 | - |
| 15 | (Shimono and Okada, 2013) | Tohoku Region, | 2005 | *24 cultivars* | Pot culture in Temperature - $CO_2$ gradient chambers | 370 &560 | - | 22.8 | - | - | - | - | - |
| | | | | | | | | 18.1 | - | - | - | - | - |
| 16 | (Zhang and Tao, 2013) | Tsukuba FACE, Japan | 2010 & 2011 | *Koshihikari* | FACE | 386 & 560 | 0gm/m2 - N | 10.2 | | 6.3 | 7.4 | 1.1 | - 4.0 |
| | | | | | | | 8gm/m2 - N | 16.0 | | 12.7 | -2.9 | -3.4 | 0.4 |
| 17 | (Hasegawa et al., 2013) | Shizukuishi and Tsukuba, Japan | 2007,2008 &2010 | *Akihikari* | FACE | 350 & 550 | - | 2.8 | | 1.4 | 3.4 | 1.3 | - |
| | | | | *Akitakomachi* | | | - | 4.1 | | - 11.2 | 23.0 | -0.9 | - |
| | | | | *Akita 63* | | | - | 19.8 | | 4.1 | 7.3 | -1.7 | - |
| | | | | *Aikoku* | | | - | 26.5 | | 11.0 | 0.0 | -0.9 | - |
| | | | | *Koshihikari* | | | - | 16.3 | | 9.3 | 2.2 | 0.5 | - |
| | | | | *Takanari* | | | - | 21.2 | | 7.6 | 6.8 | 2.6 | - |
| | | | | *Akidawara* | | | - | 26.1 | | 3.9 | | -4.1 | - |

### 2.8.1 Climate Change at National and Regional Level

Data obtained from India Meteorological Department (IMD) was analyzed and reported that all India mean annual temperature has increased by $0.5^0$C and mean monsoon temperature by $0.4^0$C in a span of 100 years (Arora et al., 2005; Jain and Kumar, 2012). Trend analysis of annual and monsoon rainfall of 135 years (1871–2005) over India indicated no definite trend but varied regionally (Jain and Kumar, 2012; Kumar et al., 2010). It has been observed that the changes in temperature in India over last century are broadly matched with global trend of increase in temperature. IMD has also reported the increase in occurrence of extreme events such as floods, droughts, cyclones, heat waves etc. (De et al., 2005; Goswami et al., 2006; Parthasarathy et al., 1987). Trend analysis of rainfall over Haridwar district indicated the increase @ 6.4 mm/yr (Pranuthi et al., 2014; Yadav et al., 2014). The rise in temperature @ 0.017 $^0$C/yr for Haridwar district has also been reported (Tripathi et al., 2008).

### 2.8.2 Climate Change Assessment

Numerical models predicting physical processes of the atmosphere are the most advanced tools currently available for simulating the future climatic conditions. These numerical models are available with different spatial resolutions. Global Climate Models (GCM) is a coarse resolution and it needs to be down scaled for the specific location. Regional Climate Model (RCM) is a high resolution data (20 km* 20 km) and downscaling is not required (De Sales and Xue, 2011; Di Luca et al., 2012; Di Luca et al., 2013; Feser et al., 2011; McGregor, 1997; Prommel et al., 2010; Seth et al., 2007). RCMs provide high resolution unbiased scenarios (Less than 20 km). There are large number of studies that use RCMs for climate change assessment and also for climate change impact studies up to the end of the 21$^{st}$ century (Giorgi et al., 2004; Giorgi and Lionello, 2008; Moberg and Jones, 2004; Räisänen et al., 2004; Rao et al., 2014).

Providing Regional Climates for Impact Studies (PRECIS) RCM (Gordon et al., 2000) developed by UK Hadley Met Office was used to simulate climate change projections of various regions such as South America (Alves and Marengo, 2009; Alves and Marengo, 2010; Marengo et al., 2009), Pakistan (Islam et al., 2009; Ul Islam et al., 2009), Eastern Mediterranean region (Bloom et al., 2008; Kotroni et al., 2008), Bangladesh (Islam et al., 2011; Islam, 2009; Islam et al., 2008) and proved to be a good tool for climate change assessment. PRECIS RCM predicted that all India annual mean temperatures would increase by 3.5 – 4.3$^0$C, annual precipitation would increase by 9 – 16% by the end of this century (Akhtar et al., 2009; Gosain et al., 2011; Rupa Kumar et al., 2006).

#### 2.8.2.1 Bias correction and evaluation methods of climate modeled data

Although RCMs provide a better picture of the future climate scenario than GCMs still there is a mismatch between the actual and the forecasted values (Fowler et al., 2007; Grotch and MacCracken, 1991; Maraun et al., 2010; Parry, 2007). So, this problem has led to the development of various bias correction methods such as linear correction method (Lenderink et al., 2007) Non-Linear Correction method (Leander and Buishand, 2007), $\gamma$ - distribution correction method (Hay et al., 2002; Piani et al., 2010), Empirical distribution correction method (Ashfaq et al., 2010; Wood et al., 2002) and many more. Each bias correction method has its own merits and demerits but the linear bias correction method was found to be easier in calculation and suitable under various conditions as reported by (Ines and Hansen, 2006; Zheng, 2002).

#### 2.8.2.2 Trend Detection in Climatic parameters

There are number of parametric and non-parametric statistical test available to examine the trend of hydro meteorological parameters (Chen and Gao, 2007). Parametric tests requiring independent and normally distributed data series are reliable whereas non-parametric tests requiring independent data have the ability to remove outliers and is easy to use. Mann Kendal Trend Test (MKTT) (Kendall, 1962; Mann, 1945) which is a non-parametric test is frequently used for trend analysis of climatic parameters.

The macro scale rainfall trend analysis of the country indicated that the monsoon rainfall is decreasing. No definite trend was observed in annual rainfall but rainfall of peninsular region of India showed declining trend. (Guhathakurta and Rajeevan, 2008; Joshi and Pandey, 2011; Pal and Al-Tabbaa, 2009). Mann Kendall trend test was used to analyze the rainfall trend for several regions of India and reported that there is no clear trend of increase or decrease in average annual rainfall (Duhan and Pandey, 2013; Mooley and Parthasarathy, 1984; Rajeevan et al., 2008; Thapliyal and Kulshrestha, 1991).

### 2.8.3 Rice Crop Models

A number of crop models are available to simulate rice yields under varying climatic and management conditions. Some of the popular rice crop models are DSSAT (Decision Support System for Agrotechnology Transfer) (Jones et al., 2003), ORYZA (Bouman, 2001; Kropff et al., 1994; Wopereis et al., 1996), InfoCrop (Aggarwal et al., 2004; Aggarwal et al., 2006), SIMRIW (Horie, 1995; Horie et al., 1996), RICE GROW (Tang et al., 2009), WARM (Confalonieri et al., 2005), WOFOST (Boogaard et al., 1998; Diepen et al., 1989; Supit et al., 1994), Aqua Crop (Raes et al., 2009; Steduto et al., 2009), TRYM (The Rice Yield model) (Williams et al., 1994) and RICAM (Yin and Kropff, 1998; Yin and Qi, 1994). Each model works with its own assumptions and calculations required to simulate growth, development and yield of rice crop. The most widely used rice crop models is CERES Rice.

#### 2.8.3.1 Calibration and Validation of crop models

Crop models are simple representation of a crop and effective tools for decision making especially under the extreme and contingent situations (Boote et al., 1996; Murthy, 2004) but they are required to be calibrated for improving their reliability (White et al., 2011). Any discrepancy in evaluating the crop model will lead to a great deal of errors (van Oijen, 2002). The processes in nature are very complex and impossible to fully accommodate them into crop model (Tremblay and Wallach, 2004; Wallach et al., 2001). The gap between model and nature can never be removed completely but it can be reduced. CERES-Rice model v 4.5 has been calibrated for climate change impact studies (Amiri et al., 2014; Hoogenboom et al., 2012). CERES-Rice model was developed evaluated under elevated $CO_2$ environment with four rice cultivars (IR 36, Swarna, Swarna sub1, and Badshabhog) grown in Open Top chambers at Kharagpur, India (Satapathy et al., 2014; Swain and Thomas, 2010; Swain et al., 2007).

The combination of FACE studies with modelling study to identify the impact of climate change on rice crop yields is done by (Hasegawa et al., 2015) in which it is reported that there is linear decrease in the yield enhancement by 2.1% per 1°C increase above 20°C during a 30-d period after heading due to climate change. This method of study also increased the reliability of crop models for studying effect of climate change under elevated atmospheric $CO_2$ conditions.

#### 2.8.3.2 Climate Change Impact Assessment using Crop Growth Simulation Models

Numerous simulation studies have reported increased yields under higher atmospheric $CO_2$ concentrations and decreased yields under increased temperatures (Aggarwal and Mall, 2002; Mall and Aggarwal, 2002; Saseendran et al., 2000; Swain and Thomas, 2010).

Felkner evaluated DSSAT model under various climate change scenarios for rice crop and observed that the yields decreased under increased temperatures (Felkner et al., 2009). Models of DSSAT model along with PRECIS RCM weather data was used to predict rice, wheat and maize yields of China (Erda et al., 2005; Yao et al., 2007). The study showed that the climate change without carbon dioxide ($CO_2$) fertilization could reduce the rice, maize and wheat yields up to 37% in the next 20–80 years. Effect of elevated $CO_2$ on yield of two varieties of *boro* rice has been assessed using CERES-Rice model and reported that the increase in $CO_2$ concentration increases the rice yield offsetting the adverse effects of other climatic parameters on rice yield in Thailand (Babel et al., 2011). The CERES-Rice model used for simulating rice yields under different climate change scenarios in Ghana results showed that with an increase in $CO_2$ concentration by 100 ppm above 330 ppm, led to an increase in rice yield by 33% (Basak et al., 2010). During the last fifty years a 70 ppm the $CO_2$ level increased by 70 ppm and showed that this has contributed to about 8.7% increase in China's rice production (Xiong et al., 2012).

ORYZA and Infocrop model studies showed that the yield of rice cv IR36 would decrease by 6.2% and 7.2% with increase of every$1^0$C temperature and would increase by 30.7% and 56.4% with 700 ppm $CO_2$ elevation respectively in Eastern India (Krishnan et al., 2007). Infocrop model simulation study for India showed that by 2080 the atmospheric temperature would rise by $2^0$C and rice crop yield would decrease by 10% (Jalota et al., 2013).

The CERES rice model was used to simulate rice yields of Ganga basin for future upto 2040 which showed 43% decrease in yields with increasing temperatures (Mishra et al., 2013).

CERES-Rice model was used for assessing the impact of climate change on rice yields of Tamil Nadu which showed that with the increase of temperature of $1^0$C & $5^0$C the yields would decrease by 4% & 56 % respectively (Bhuvaneswari et al., 2014). In India, several other studies have also demonstrated the utility of DSSAT for climatic change impact studies (Aggarwal and Mall, 2002; Dharmarathna et al., 2014; Mall and Aggarwal, 2002; Saseendran et al., 2000).

#### 2.8.3.3 Generating Strategic Management Options using DSSAT CSM

CERES –Rice model was used for strategic management manipulating the crop management climatic options for Pakistan (Ahmad et al., 2013). CERES Rice model was used to evaluate the adaptation of rice cultivar to elevated $CO_2$ and temperature in sub-tropical and tropical agro climatic regions of India (Saseendran et al., 2000).

# CHAPTER III

# 3 EFFECT OF $CO_2$ ENRICHMENT ON RICE CROP – FIELD STUDY

## 3.1 Introduction

This chapter describes the methods and material used and the observations recorded from the field experiment to study the effect of periodical $CO_2$ enrichment on growth, development, yield and quality during *Kharif* 2011 and 2012.

## 3.2 Field Experiment

### 3.2.1 Description of Experimental site

The field experiments were conducted at Demonstration Farm, Water Resources Development and Management Department, Indian Institute of Technology Roorkee, Uttarakhand India located at $29^0$ 50' 7" N latitude, $77^0$ 55' 18" E longitude and 262 m altitude.

### 3.2.2 Soil sample collection, preparation and analysis

Soil samples from different parts of the experimental field were collected from the depths of 0-15 cm, 15-30 cm, 30- 60 cm, 60-90 cm and 90-120 cm with the help of a 2 m long soil auger before the start of the crop season. Composite soil sample of each layer was prepared. Soil samples were air & oven dried, powdered and passed through 2 mm sieve. This sample was stored for physical and chemical analysis of soil.

Sand (<0.02 mm) and silt (0.02-0.002 mm) content was analyzed by hydrometer method (Bouyoucos, 1962). Bulk density (BD) was estimated by core method. Field Capacity (FC) and Permanent Wilting Point (PWP) were estimated using pressure plate apparatus. Soil color was determined using Munsell soil color chart (Colour, 1991). Organic carbon (OC) by Potassium Dichromate method, total nitrogen by Kjheldhal method (Bremner, 1960), Cation Exchange Capacity (CEC) by acetone extraction method and soil pH was determined using hand held pH meter. Land information on degree of slope, soil depth, and drainage condition and infiltration behavior were also collected.

### 3.2.3 Weather Data Collection

Weather data on daily rainfall, maximum & minimum temperatures as well as the sun shine hours were collected from the AWS (Automated Weather Station) installed at the experimental site for the years 2011 - 2013 (Figure 3.2 - Figure 3.4).

### 3.2.4 Experimental Design and layout plan

The experiment was laid out in Randomized Block Design (RBD) with 4 treatments of periodical $CO_2$ application (T0, T1, T2, and T3) and 3 replication (R1, R2, R3) during *Kharif* season (June-October) in 2011 & 2012 (Figure 3.1). Treatment details are mentioned below:

$T_0$ = Control

$T_1$ = $CO_2$ (700 ± 50 ppm) one application /Week (Monday)

$T_2$ = $CO_2$ (700 ± 50 ppm) two applications /Week (Monday & Wednesday)

$T_3$ = $CO_2$ (700 ± 50 ppm) three application / Week (Monday, Wednesday & Friday)

### 3.2.5 $CO_2$ Enrichment and temperature measurements

Plots were enriched with $CO_2$ through the use of $CO_2$ cylinders that were used for fire extinguishing. The CO2 gas of 99.6 % purity which is colour & odour less; soluble in water, alcohol and acetone; melting point of -55.6 $^0$C; boiling point of -78.5 $^0$C; density of 1.977 g/m$^3$. It produces $H_2CO_3$ reacting with water; produces $HCO_3$ reacting with alkali was used in the experiment.

The Intergovernmental Panel on Climate Change (IPCC) reported that the global atmospheric $CO_2$ concentrations would reach to the level of 550 ppm by 2050 and 750 – 1000 ppm by 2100 (Stocker et al., 2014; Stocker et al., 2013). These projections were used as a guideline to study the effect of $CO_2$ enrichment on rice crop.

Enclosure of 1.5 m height using polythene sheet and iron rod was erected around the treatment plots to avoid the escape of CO2 gas from the plot (Plate 4). The CO2 was applied to the concentration of 750 ± 50 ppm in the respective treatment plots. CO2 gas application set up is shown in Fig 3.1.

The $CO_2$ concentration in the plots was measured using $CO_2$ gas analyzer Model KM302 with a measuring range of 0 to 9999 ppm and resolution of 1ppm (Plate 7 & 8). This instrument is hand held, portable and capable of measuring $CO_2$ gas in the range of 0 to 9999 ppm with the precision of 1ppm. $CO_2$ enrichment in the experimental plots started in the 3$^{rd}$ week after transplanting and stopped in the 12$^{th}$ week after transplanting (to avoid any problem to pollinating insects).

The $CO_2$ concentrations were measured within 15 min after the application within the canopy before and after $CO_2$ enrichment (Plate 5 & 6). Temperatures were recorded within and above canopy using hand held thermometer and leaf temperatures were measured using infrared thermometer before and after $CO_2$ enrichment (Plate 9).

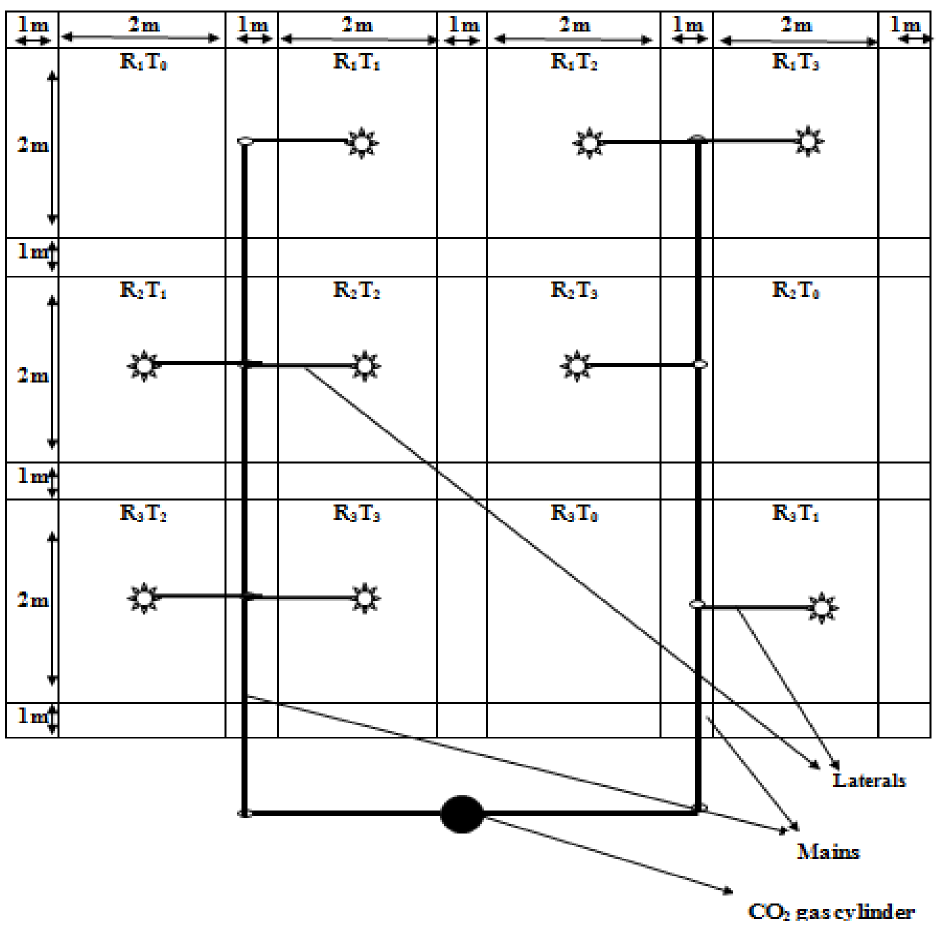



**Figure 3.1: Layout plan of the experimental field**

### 3.2.6 Crop Management Practices

Crop was managed at two levels, firstly at the nursery for about one month and secondly at the field for about 4 months. Certified seeds of rice cv *Sharbati* a popular cultivar of Haridwar district were procured from the market. Nursery of 2 x 2 sqm was prepared and puddled in the standing water to improve water retention, weed control, germination and crop growth. Seeds were broadcasted in the nursey and irrigated regularly as and when required. Due care was given against bird and weed damage.

#### 3.2.6.1 Field Preparation, Nursery and Management

The experimental plots were ploughed twice, harrowed and puddled to obtain lowland paddy conditions (Plate.1). Plots were prepared as sunken beds with earthen walls around them to maintain standing water.

#### 3.2.6.2 Transplanting

Nursery was sown $8^{th}$ June 2011 (Plate 2) and 29 days old seedlings were transplanted on $7^{th}$ July (Plate 3), 2011 in the *Kharif* season. Two seedlings/hill were planted at 20 x 15 cm spacing. Standing water was maintained at a level of 2 cm during the vegetative phase of the crop (i.e. up to 40 days after transplanting) to control weeds. Thereafter, the plots were maintained at field capacity but without standing water (Plate 4). All plots were given similar levels of fertilizer application. At transplanting, a basal fertilizer application of 10 kgs N/ha and 40 kgs P/ha was given. Top dressings of 20 kgs N /ha were given on 21 DAP and 20 kgs N/ha on 35 DAP. Weeds were removed manually at every 25 days interval.

Interactions with the local farmers and agricultural officers (Plate 25 & 26) of this region revealed that the *Sharbati* cultivar is popularly grown in this region. So, *Sharbati* is selected for field trials during *Kharif* 2011and 2012 experimental trials. *Sharbati* is the most popular variety among the farmers and is grown widely in the plains of Haridwar district where drought and flooding are persistent phenomena during crop growth stages. This cultivar is tolerant to both drought and flooding. *Sharbati* is a short duration and high yielding cultivar with long grains. It is a tall statured plant and is resistance to major pests and diseases of rice crop such as leaf folder, leaf hoppers, leaf and node blast etc.

### 3.2.7 Observations Recorded

#### 3.2.7.1 Growth and Development

Observations were recorded on plant height (cm), tiller numbers (no/$m^2$), leaf numbers/plant, leaf length (cm), leaf breadth (cm) in at 20 days interval from transplanting to harvesting stage. Leaf Area Index (LAI) was calculated employing the formula (total leaves per hill* leaf length (cm) per hill* leaf breadth (cm) * leaf shape factor/300). Leaf shape factor was determined at all the crop growth stages (measured area of one leaf/ length*breadth of the same leaf). Plant samples collected (Plate 12), were dried in shade initially for 3-4 days for removal excess moisture and further dried in the electric oven at 80$^o$C till the weight became constant and plant dry weight (kgs/ha) was recorded (Plate 10).

Observations were also recorded on days taken to establishment (Plate 13), panicle initiation (PI) (Plate 14), days taken to ear emergence (Plate 15) and days taken to express physiological maturity (Plate 16) conducting survey of 50% plant population of each experimental plots (Plate 11).

#### 3.2.7.2 Yield Attributes and Yield

Before the harvest of the crop panicle density (no/$m^2$) from the standing crop was recorded. From the standing crop panicle samples were also collected (to record average number of filled grains (no./$m^2$) and average number of unfilled grains/panicle (unfilled spikes/total spikes).

Crop was harvested from 1 $m^2$ area of each experimental plot and were allowed to dry for about 10 days in the sun separately (Plate 17 & 18). When samples were dried to about 14% moisture then the total biomass weight (kgs) was recorded. Samples were threshed, grains removed from straw, cleaned and weighed to recorded grain and straw yield (kgs/ha). Grain and biomass yield was recorded (kgs/ha). Harvest Index was also calculated (grain yield/biomass yield).

#### 3.2.7.3 Grain and Kernel Quality

Grain length (mm), grain breadth (mm) and test weight or 1000 grain weight (g) was recorded. Husk was removed from grain and kernel was weighed to determine hulling % (kernel weight/ grain weight). Kernel length (mm), kernel breadth (mm) and test weight or 100 kernel weight (g) was recorded. Head rice (%), broken rice (%) was determined (total rice-head rice)/total rice) and chalkiness (%) was also determined (chalky rice/ total rice).

**Table 3.1: Schedule of field operations during *Kharif* 2011 and 2012.**

| **Particulars** | **Crop** | |
|---|---|---|
| | **2011-12** | **2012-13** |
| **Rice Variety** | *Sharbati* | |
| **Nursery** | | |
| **Field Preparation (Puddling)** | 7.06.2011 | 5.06.2012 |
| **Sowing (broadcasting)** | 8.06.2011 | 7.06.2012 |
| **Nursery Fertilizer (**40:0:0) | 7.06.2011 | 5.06.2012 |
| **Irrigation** | As and when required | |
| **Weeding** | As and when required | |
| **Crop Management** | | |
| **Experimental Design** | RBD | |
| **Treatments** | 4 | |
| **Replications** | 3 | |
| **Total number of plots** | 12 | |
| **Plot size** | 2m*2m | |
| **Spacing (Row to Row)** | 20 cm | |
| **Spacing (Plant to Plant)** | 15 cm | |
| **Transplanting Depth** | 2 cm | |
| **Method of Sowing** | Transplanting | |
| 1st ploughing | 25.05.2011 | 25.05.2012 |
| Levelling | 27.06.2011 | 28.06.2012 |
| Soil Sample Collection | 30.06.2011 | 28.06.2012 |
| 2nd ploughing | 05.07.2011 | 30.06.2012 |
| Pre Transplanting irrigation | 07.07.2011 | 1.07.2012 |
| **Transplanting** | **07.07.2011** | **09.07.2012** |
| **Irrigation** | | |
| Method of Application | Flooding | |
| 1st irrigation (50 mm) | 07.07.2011 | 09.07.2012 |
| 2nd irrigation (50 mm) | 27.07.2011 | 12.07.2012 |
| 3rd irrigation (50 mm) | 07.08.2011 | 21.07.2012 |
| 4th irrigation (50 mm) | 29.08.2011 | 27.07.2012 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 5th irrigation (50 mm) | 07.09.2011 | | | | 05.08.2012 | | | |
| 6th irrigation (50 mm) | 12.09.2011 | | | | | | | |
| 7th irrigation (50 mm) | 21.09.2011 | | | | - | | | |
| **Fertilizer application** | | | | | | | | |
| Basal dressing (10:40:40) | 09.07.2011 | | | | 07.07.2012 | | | |
| 1st top dressing (20:0:0) | 22.07.2011 | | | | 17.07.2012 | | | |
| 2nd top dressing (20:0:0) | 25.07.2011 | | | | 3.08.2012 | | | |
| 3rd top dressing (20:0:0) | 17.08.2011 | | | | | | | |
| **$CO_2$ Application Schedule** | **T0** | **T1** | **T2** | **T3** | **T0** | **T1** | **T2** | **T3** |
| 1st Application | - | - | - | 27/7 | - | - | - | 27/7 |
| 2nd Application | - | - | 1/8 | 1/8 | - | - | 1/8 | 1/8 |
| 3rd Application | - | 3/8 | 3/8 | 3/8 | - | 3/8 | 3/8 | 3/8 |
| 4th Application | - | - | - | 5/8 | - | - | - | 5/8 |
| 5th Application | - | - | 8/8 | 8/8 | - | - | 8/8 | 8/8 |
| 6th Application | - | 10/8 | 10/8 | 10/8 | - | 10/8 | 10/8 | 10/8 |
| 7th Application | - | - | - | 12/8 | - | - | - | 12/8 |
| 8th Application | - | - | 14/8 | 14/8 | - | - | 14/8 | 14/8 |
| 9th Application | - | 17/8 | 17/8 | 17/08 | - | 17/8 | 17/8 | 17/08 |
| 10th Application | - | - | - | 19/08 | - | - | - | 19/08 |
| 11th Application | - | - | 21/8 | 21/08 | - | - | 21/8 | 21/08 |
| 12th Application | - | 24/8 | 24/8 | 24/08 | - | 24/8 | 24/8 | 24/08 |
| 13th Application | - | - | - | 29/08 | - | - | - | 29/08 |
| 14th Application | - | - | 31/8 | 31/08 | - | - | 31/8 | 31/08 |
| 15th Application | - | 2/9 | 2/9 | 2/9 | - | 2/9 | 2/9 | 2/9 |
| 16th Application | - | - | - | 5/9 | - | - | - | 5/9 |
| 17th Application | - | - | 7/9 | 7/9 | - | - | 7/9 | 7/9 |
| 18th Application | - | 9/9 | 9/9 | 9/9 | - | 9/9 | 9/9 | 9/9 |
| 19th Application | - | - | - | 12/9 | - | - | - | 12/9 |
| 20th Application | - | - | 14/9 | 14/9 | - | - | 14/9 | 14/9 |
| 21st Application | - | 23/9 | 23/9 | 23/9 | - | 23/9 | 23/9 | 23/9 |
| **Plant protection measures** | | | | | | | | |
| 1st weeding | 28.7.2011 | | | | 18.7.2012 | | | |
| 2nd weeding | 14.08.2011 | | | | 30.07.2012 | | | |
| 3rd weeding | - | | | | 10.08.2012 | | | |
| Termite treatment | 09.09.2011 | | | | - | | | |
| **Harvesting** | 07.10.2011 | | | | 10.10.2012 | | | |
| **Threshing** | 17.10.2011 | | | | 20.10.2012 | | | |

Data recorded from field experiment were statistically analyzed using ANOVA analysis along with Tukey Kramer's PostHoc test.

### 3.2.8 ANOVA Analysis with PostHoc Test

ANOVA (Fisher, 1926) test is performed on the observed values to check the significance of periodical $CO_2$ enrichment on the rice crop growth, development, yield, and yield attributes and grain quality. This method has the advantage of testing whether there are any differences between the groups with a single probability associated with the test. The fundamental technique is the partitioning of the total sum of squares (SS) into components related to the effects used in the model.

$$SS_{Total} = SS_{Treatments} + SS_{Error} \tag{3.1}$$

The number of degrees of freedom DF can be partitioned in a similar way:

$$DF_{Total} = DF_{Treatments} + DF_{Error} \tag{3.2}$$

Mean Sum of squares (MS) for treatments, error and total are calculated by using the formula. Similarly MS is calculated for treatments and error.

$$MS_{Total} = \frac{SS_{Total}}{DF_{Total}} \tag{3.3}$$

Then F value is calculated to compare the deviations of two means. It is calculated using formula

$$F_{calc} = \frac{MS_{Treatments}}{MS_{Error}} \tag{3.4}$$

Tukey’s multiple comparison method is one efficient procedure designed to identify the specific differences that exist among mean responses to several treatments, after the ANOVA has concluded such differences do exist. This result might be useful in supporting decision making.

Test whether there is sufficient evidence at least one of the mean values is different. If so, calculate a critical difference value (CD) between every two means using the formula.

$$CD = q\alpha\,(c, N - c)\sqrt{\frac{MSE}{N}} \tag{3.5}$$

Where ‘q’ is taken from the “Studentized Range” Table and is determined by alpha, c (the number of treatments), and N (the total number of observations); n is the sample size of the treatments compared; and MSE is taken from the ANOVA output.

## 3.3 Results and Discussion

### 3.3.1 Weather Data

The weather condition during the growing season ($1^{st}$ June - $31^{st}$ October) of 2011 and 2012 are recorded as 1158 and 647 mm rainfall (RF), $34.1^{0}$C and $32.0^{0}$C average maximum temperature (Tmax), $24.7^{0}$C and $23.2^{0}$C average minimum temperature (Tmin) 22.4 $MJm^{-2}day^{-1}$ and 19.8 $MJm^{-2}day^{-1}$ average solar radiation (SRAD) respectively (Figure 3.2 - Figure 3.4). Daily record of weather data of 1.1.2011 -31.12.2013 was used to develop weather file using weatherman in DSSAT.

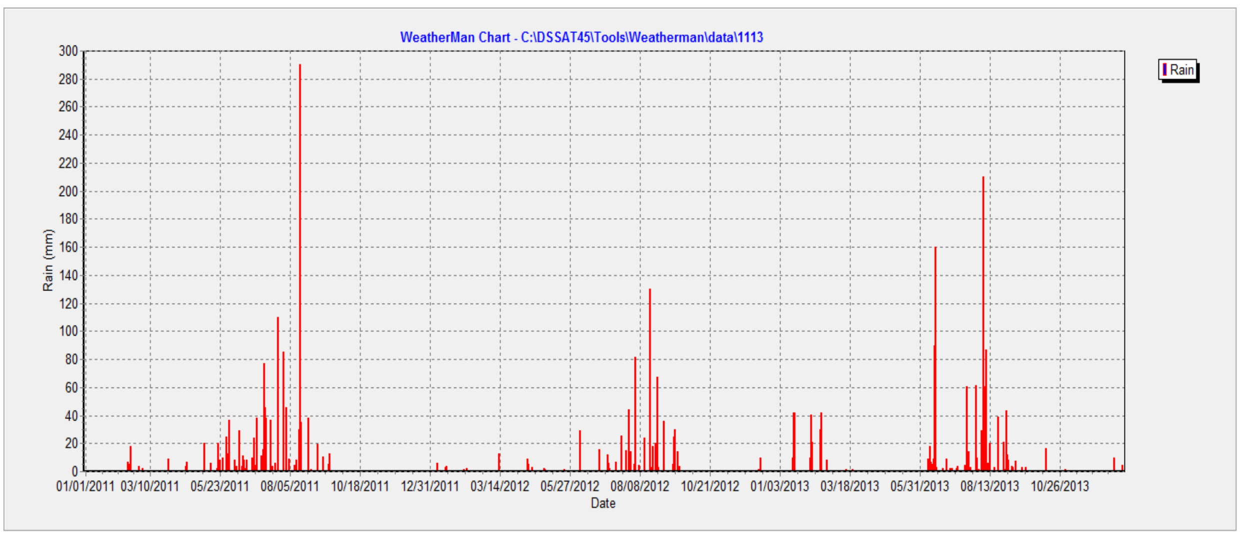



**Figure 3.2: Daily rainfall (mm) from 1.1.2011 – 31.12.2013.**

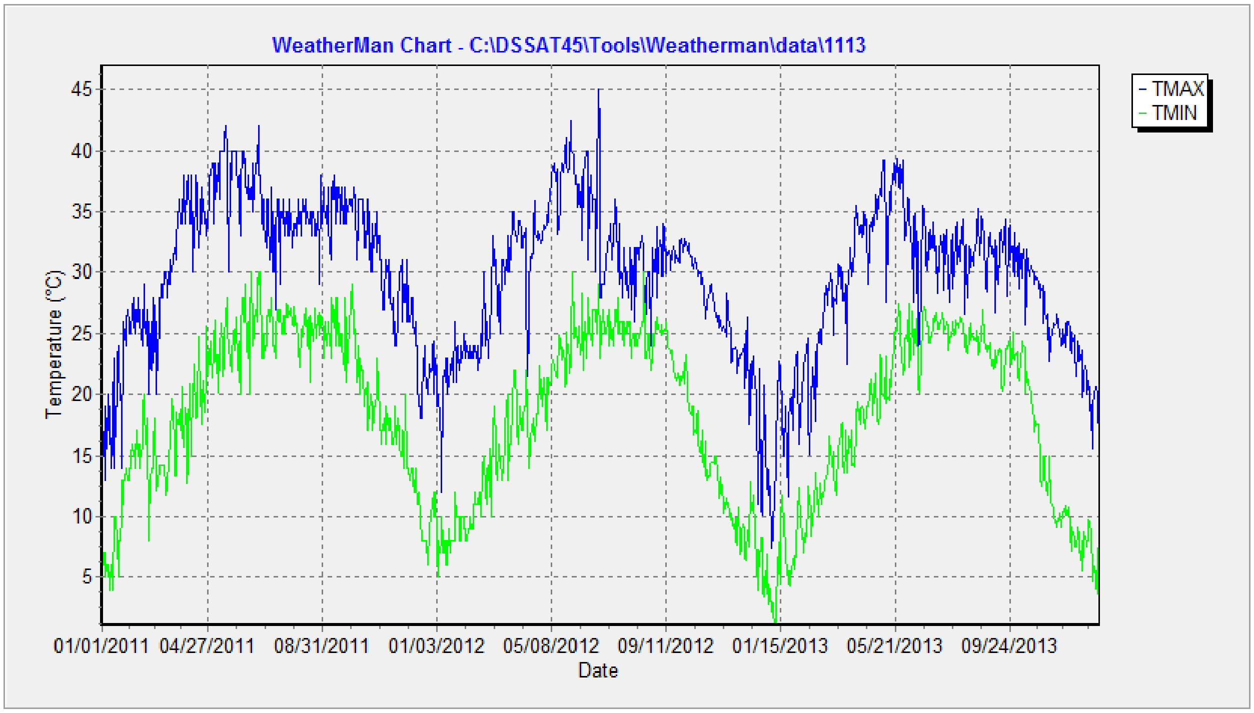



**Figure 3.3: Daily maximum and minimum temperature ($^0$C) from 1.1.2011 – 31.12.2013.**

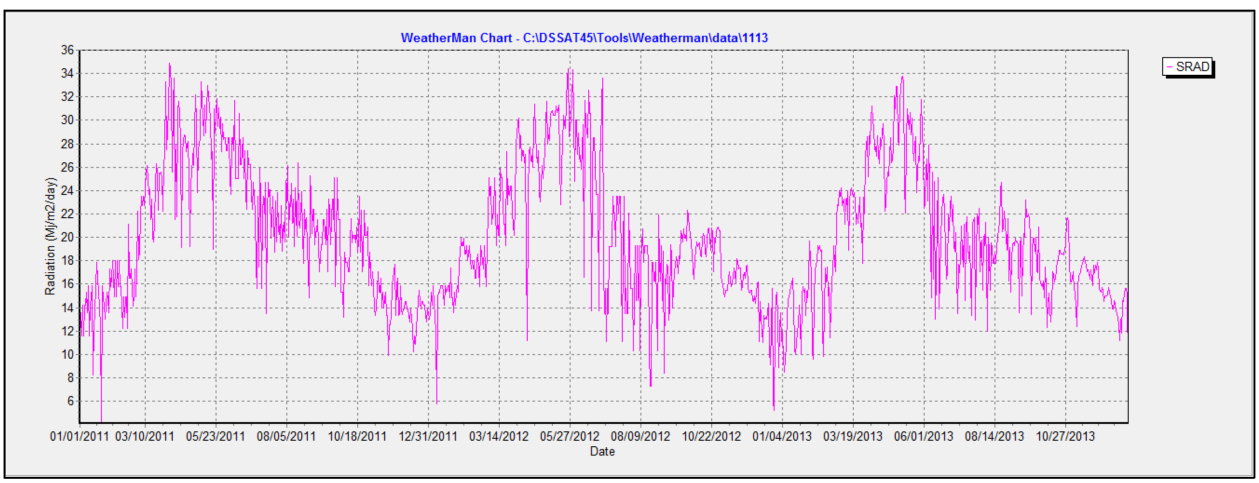



**Figure 3.4: Daily Solar radiation (MJm$^{-2}$day$^{-1}$) from 1.1.2011 – 31.12.2013.**

### 3.3.2 Effect of periodical $CO_2$ enrichment on leaf and canopy temperatures

The effect of periodical application of $CO_2$ on leaf temperature, canopy and above canopy temperatures recorded during the rice crop growth period of 2011 and 2012, 15 -20 minutes before and after enrichment which are presented in Table 3.2.

The average $CO_2$ concentrations in the air before $CO_2$ application ranged between 290 – 310 ppm. The $CO_2$ concentration within the canopy on an average increased to the level of 715.3 ppm, 726 ppm and 729.8 ppm during the year 2011 and to the level of 708.4 ppm, 722.4 ppm and 730.2 ppm during 2012 in T1, T2 and T3 treatments respectively after $CO_2$ application.

The average leaf temperature before $CO_2$ application ranged between 25.8$^0$C – 26.6$^0$C. The leaf temperature on an average increased to the level of 30.7$^0$C, 30.8$^0$C and 31.0$^0$C during the year 2011 and increased to the level of 30.9$^0$C, 30.8$^0$C and 31.4$^0$C during 2012 in T1, T2 and T3 treatments respectively after the $CO_2$ application. Increase in leaf temperature by 1 – 2$^0$C under doubled $CO_2$ concentrations have been reported by (Allen Jr and Prasad, 2004) which is due to decreased evaporative cooling.

The average canopy air temperature before $CO_2$ application ranged between 27.5$^0$C – 27.6$^0$C. The canopy temperature increased to the level of 28.1$^0$C, 27.9$^0$C and 27.8$^0$C during the year 2011 and to the level of 34.5$^0$C, 34.3$^0$C and 34.0$^0$C during 2012 in T1, T2 and T3 treatments respectively after $CO_2$ application. Air temperature within canopy has been reported to increase by 0.2 – 1$^0$C due to $CO_2$ enrichment in rice (Yoshimoto et al., 2005).

The average above canopy air temperature before $CO_2$ application ranged between 29.0$^0$C – 29.1$^0$C. The above canopy air temperature increased to the level of 29.1$^0$C, 29.3$^0$C and 29.4$^0$C during the year 2011 and to the level of 34.7$^0$C, 34.1$^0$C and 33.8$^0$C during 2012 in T1, T2 and T3 treatments respectively after $CO_2$ application. Air temperature within canopy has been reported to increase by 0.6 – 1$^0$C due to $CO_2$ enrichment upto 550 ppm in wheat (Pinter et al., 2000).

**Table 3.2: Average ambient $CO_2$ level within canopy, leaf temperature ($^0C$), above canopy temperature ($^0C$) and canopy temperature ($^0C$) of Rice cv *Sharbati* as affected by $CO_2$ applications.**

| Treatments | Ambient $CO_2$ Level (ppm) within canopy | | | Leaf Temperature ($^0C$) | | | Canopy air Temperature ($^0C$) | | | Above Canopy air temperature ($^0C$) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **2011** | **2012** | **Mean** | **2011** | **2012** | **Mean** | **2011** | **2012** | **Mean** | **2011** | **2012** | **Mean** |
| | **Before $CO_2$ Application** | | | | | | | | | | | |
| **T0** | 296.1 | 301.9 | **299.0** | 26.2 | 30.9 | **28.6** | 27.5 | 33.7 | **30.6** | 29.1 | 33.8 | **31.5** |
| **T1** | 297.4 | 294.6 | **296.0** | 25.8 | 30.7 | **28.3** | 27.6 | 33.6 | **30.6** | 29.1 | 33.7 | **31.4** |
| **T2** | 297 | 296.6 | **296.8** | 26.2 | 30.8 | **28.5** | 27.5 | 33.7 | **30.6** | 29.1 | 33.8 | **31.5** |
| **T3** | 299.3 | 294.2 | **296.8** | 26.2 | 31 | **28.6** | 27.7 | 33.7 | **30.7** | 29.0 | 33.8 | **31.4** |
| **Mean** | **297.4** | **296.8** | **297.1** | **26.1** | **30.8** | **28.5** | **27.6** | **33.7** | **30.7** | **29.1** | **33.8** | **31.5** |
| | **After $CO_2$ Application** | | | | | | | | | | | |
| **T0** | 300.7 | 306.5 | **303.6** | 26.2 | 30.9 | **28.6** | 27.5 | 33.7 | **30.6** | 29.1 | 33.8 | **31.5** |
| **T1** | 715.3 | 708.4 | **711.9** | 26 | 30.9 | **28.5** | 28.1 | 34.5 | **31.3** | 29.1 | 34.7 | **31.9** |
| **T2** | 726 | 722.4 | **724.2** | 26 | 30.8 | **28.4** | 27.9 | 34.3 | **31.1** | 29.3 | 34.1 | **31.7** |
| **T3** | 729.8 | 730.2 | **730.0** | 26.6 | 31.4 | **29.0** | 27.8 | 34 | **30.9** | 29.4 | 33.8 | **31.6** |
| **Mean** | **618** | **617** | **617.5** | **26.2** | **31** | **28.6** | **27.8** | **34.1** | **31.0** | **29.2** | **34.1** | **31.7** |

### 3.3.3 Effect of $CO_2$ enrichment on rice crop growth and development

The results obtained from the experimental study on growth and development parameters such as plant height (cm), tiller number (no./$m^2$), dry matter (kgs/ha), phenology (DAP), leaf number (no./plant), leaf length (cm), leaf width (cm) and LAI are presented in this section.

#### 3.3.3.1 Plant Height

Data of plant height (cm) as affected by different $CO_2$ treatments in rice *cv Sharbati* are presented in Table 3.3. Significant difference in plant height between the treatments at 40, 60 and 80 days after transplanting was recorded only during 2011. But in 2012 no such difference in plant height at either of the growth stages was recorded. Though insignificant; plant height recorded is maximum in T3 (140 cm) and T2 treatments (121.7 cm) at 80 DAP during *Kharif 2011 and Kharif 2012* respectively. In general the plant height increased with advancing age and was recorded as 66.0 cm, 86.7 cm, 130.1 cm and 132.4 cm at 20, 40, 60 and 80 DAP respectively. The effect of higher $CO_2$ concentrations on plant height could not be ascertained due to inconsistency in the experimental results observed in the two years. Increase in plant height of rice crop by 7 – 17% due to $CO_2$ enrichment has been reported by (Manalo et al., 1994; Uprety et al., 2003).

#### 3.3.3.2 Tiller Number

$CO_2$ enrichment effect was observed to significantly affect the tiller number (no./$m^2$) of rice crop at 40 DAP, 60 DAP and 80 DAP during 2011 and 60 DAP and 80 DAP during the year 2012 (Table 3.3). Average number of tillers of the two year experiment was recorded as 209.1 no./$m^2$ 368.8 no./$m^2$, 338.3 no./$m^2$, and 312.7 no./$m^2$ at 20, 40, 60 and 80 DAP respectively. The highest tiller number was recorded at 40 DAP in T3 (491.7 no./$m^2$) treatment during 2011. But the highest tiller number was recorded at 60 DAP in T2 (343.3 no./$m^2$) treatment during 2012. From the Tukey PostHoc CD value of 85.8 no./$m^2$, 52.5 no./$m^2$ and 57.7 no./$m^2$ for 40, 60 and 80 DAP respectively during *Kharif* 2011 suggest that T3 treatment significantly differs from the T0 treatment, at 60 DAP. At 80 DAP T1, T2 and T3 significantly differ from T0 treatment. CD values for 2012 experiment at 40 DAP, 60 DAP and 80 DAP are 52.1 no./$m^2$, 48.2 no./$m^2$ and 52.8 no./$m^2$ respectively. For 2012 experiment at 40 DAP T1 and T2 treatments significantly differ from T0, at 60 DAP T2 treatment significantly differed from T0 and at 80 DAP T3 treatment is found to be significantly different from control treatment.

Percentage increase or decrease in rice tiller number due to $CO_2$ application over the ambient concentrations is presented in Figure 3.5. The results showed that tiller number was higher in $CO_2$ enriched treatments with one or two exceptions which are very insignificant. The $CO_2$ enrichment effect was highest in T3 treatment at 60 DAP (42.2%) during the year 2011. Similarly it was maximum in T2 treatment at 40 DAP (30.4%) in 2012 experiment. The results obtained for tiller number in this study are in agreement with the study of many researchers around the world (Kim et al., 2003; Kim et al., 2001; Nam et al., 2013; Uprety et al., 2003).

#### 3.3.3.3 Crop biomass

Biomass of rice crop significantly increased by increasing the frequency of $CO_2$ enrichments at 40, 60 and 80 DAP during the years 2011 and 2012 which is given in Table 3.3. The maximum biomass of rice crop was recorded at 80 DAP (17729 kgs/ha) on an average for both the years. The overall average biomass of the two year experiment was recorded as 1095 kgs/ha, 5450 kgs/ha, 13329 kgs/ha and 17729 kgs/ha at 20, 40, 60 and 80 DAP respectively. The biomass accumulation in rice crop is highest at 80 DAP for T2 treatment for the year 2011 (18333 kgs/ha) and 2012 (11567 kgs/ha) respectively. CD value of 657 kgs/ha, 1550 kgs/ha and 2190 kgs/ha at 40 DAP, 60 DAP and 80 DAP during 2011 and 500 kgs/ha, 1123 kgs/ha and 2437 kgs/ha at 40 DAP, 60 DAP and 80 DAP during 2012 was estimated by Tukey PostHoc method which suggests that T2 treatment significantly differed from control treatment at 60 and 80 DAP during 2011 and 2012 experiments.

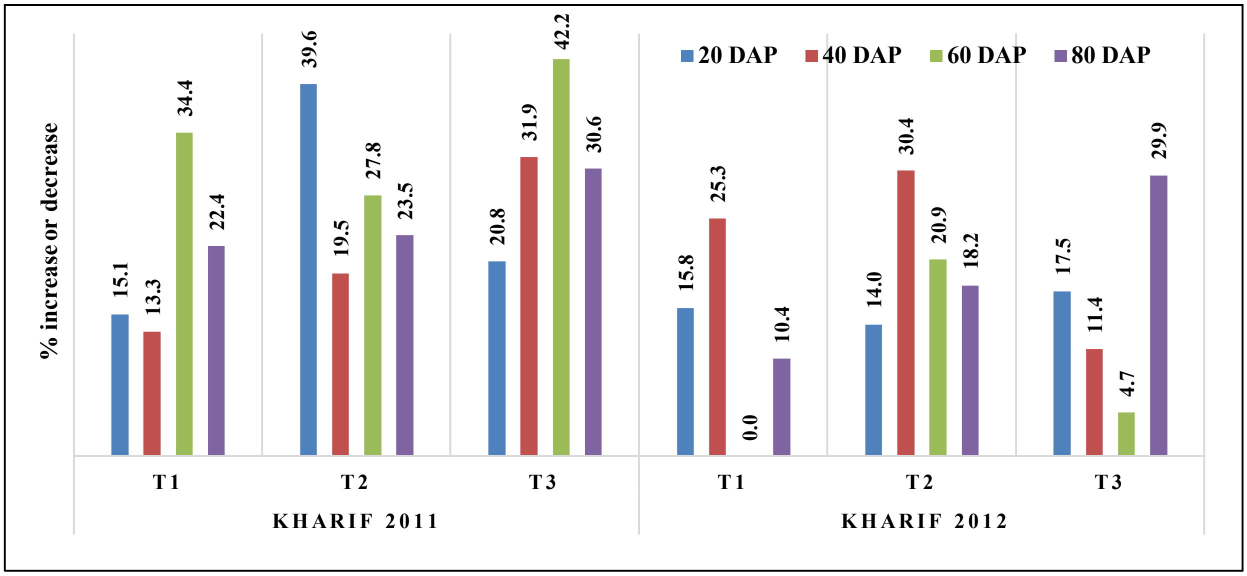



**Figure 3.5: % increase or decrease in tiller count as affected by periodical $CO_2$ enrichment in T1, T2 and T3 in comparison with the tiller count in T0 treatment of rice crop grown during *Kharif* 2011 and 2012.**

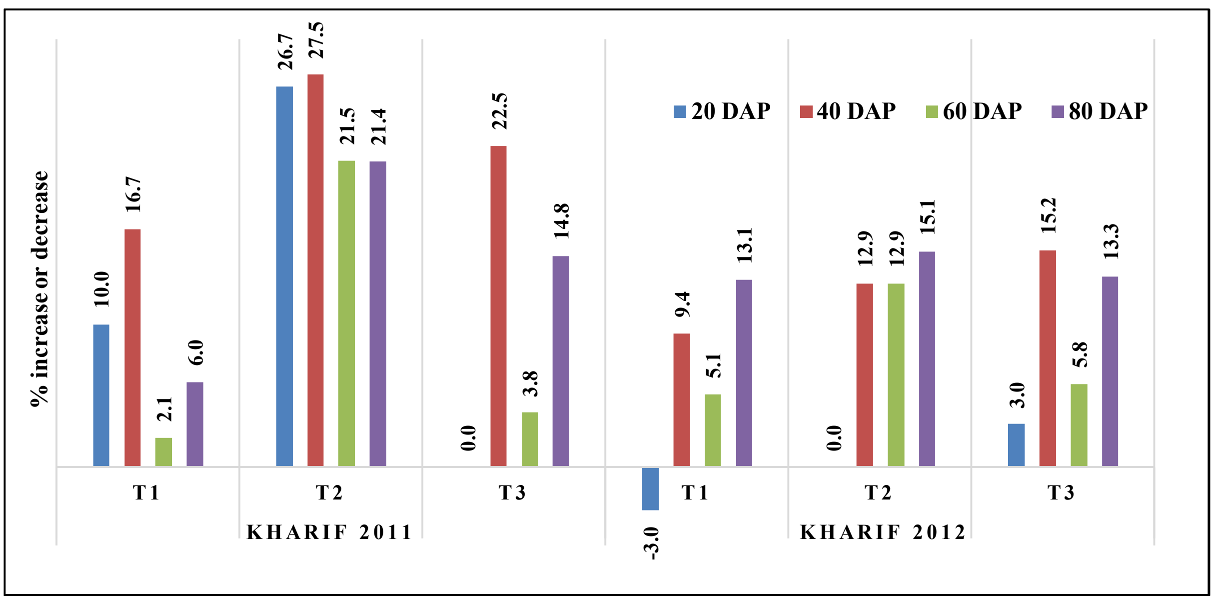



**Figure 3.6: % increase or decrease in biomass accumulation as affected by periodical $CO_2$ enrichment in T1, T2 and T3 in comparison with the biomass in T0 treatments of rice crop grown during *Kharif* 2011 and 2012.**

From Figure 3.6 it is observed that the response of rice crop to $CO_2$ applications for biomass accumulation is more during *Kharif* 2011 in comparison with *Kharif* 2012. The biomass accumulation is maximum at 40 DAP. The percent increase in biomass of rice crop as effected by $CO_2$ applications when compared with control (T0) is maximum in T2 treatment during *Kharif* 2011 (27.5%) and maximum in T3 treatment during *Kharif* 2012 (15.2%) experiments. The direct impact of $CO_2$ is on photosynthetic processes which invariably effects biomass accumulation which has been observed in many of the experiments done previously (Baker et al., 1995; Shimono and Okada, 2013; Ziska and Teramura, 1992).

#### 3.3.3.4 Phenology

The results on phenological observations obtained during the 2011 and 2012 $CO_2$ enrichment experiments are presented in Table 3.3. The $CO_2$ enrichment effect on phenology of rice crop was not significant. On an average for all treatments the juvenile, PI, anthesis and maturity stage was attained at 25 DAP, 32 DAP, 63 DAP and 93 DAP respectively during 2011. Similarly the juvenile, PI, anthesis and maturity stage was attained at 22 DAP, 29 DAP, 61 DAP and 91 DAP respectively during 2012.

#### 3.3.3.5 Leaf Number

From Table 3.4 it is evident that the effect of $CO_2$ enrichment on leaf number is significant at 60 and 80 DAP. It cannot be ascertained that the increase in leaf number at 20 and 40 DAP is due to $CO_2$ concentrations during *Kharif* 2011 & 2012. The average leaf number is highest at 60 DAP (47.9 plant$^{-1}$ during 2011 and 27.5 plant$^{-1}$ during 2012). The CD value estimated by Tukey PostHoc method at 60 and 80 DAP is 7.1 plant$^{-1}$ and 6.37 no./plant during 2011; 4.38 plant$^{-1}$ and 3.26 plant$^{-1}$ during 2012. From the PostHoc tests it is observed that T3 treatment significantly differs from T0 at 80 DAP during 2011 and 2012 experiments.

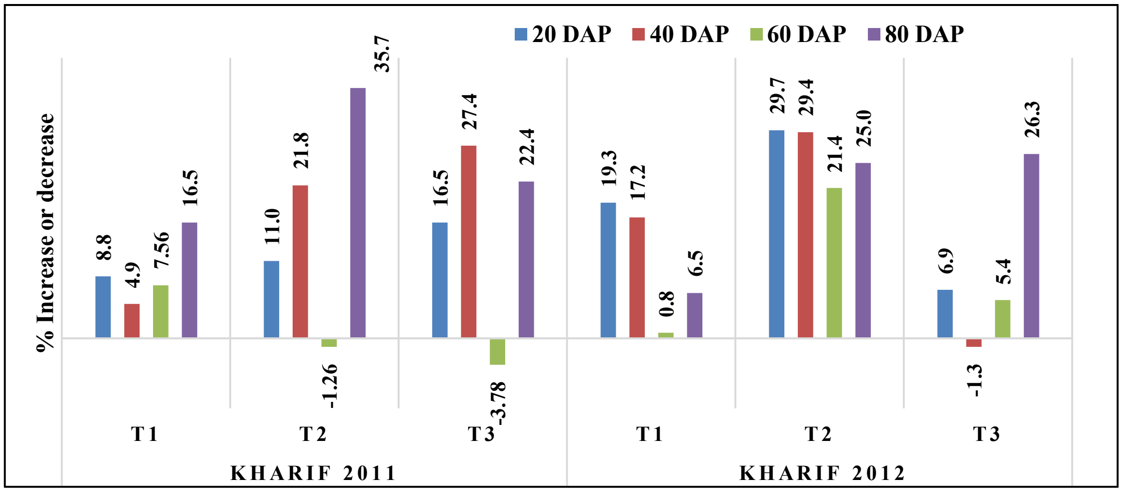



**Figure 3.7: % increase or decrease in leaf number as affected by periodical $CO_2$ enrichment in T1, T2 and T3 in comparison with the leaf number in T0 treatment of rice crop grown during Kharif 2011 and 2012.**

Percentage increase or decrease in rice leaf number due to $CO_2$ application over the ambient concentrations is presented in Figure 3.7. The results showed that average leaf number was higher in $CO_2$ enriched treatments with one or two exceptions which are very insignificant. The $CO_2$ enrichment effect was highest in T2 treatment at 80 DAP (35.7%) during the year 2011. Similarly it was maximum in T2 treatment at 20 DAP (29.7%) in 2012 experiment. The results obtained for tiller number in this study are in agreement with the study of many researchers around the world (Kim et al., 2003; Kim et al., 2001; Nam et al., 2013; Uprety et al., 2003).

### 3.3.3.6 Leaf length and width

Observations recorded on leaf length and width are presented in Table 3.4. The effect of $CO_2$ enrichment was significant during the *Kharif* 2011 experiment whereas no significant difference in treatment was recorded during second year (*Kharif* 2012) of experiment. In general the leaf length increased with advancing age and was recorded as 27.7 cm, 50.4 cm, 49.0 cm and 47.8 cm at 20, 40, 60 and 80 DAP respectively. The effect of higher $CO_2$ concentrations on leaf length is not clear due to inconsistency in the experimental results observed across two seasons. Leaf width of rice crop at 20, 40, 60 and 80 DAP was not affected by $CO_2$ enrichment. The average leaf width observed for *Sharbati* cultivar during *Kharif* 2011 and 2012 at 20, 40, 60 and 80 DAP is 0.7 cm, 1.2 cm, 1.4 cm and 1.3cm respectively.

**Table 3.3: Effect of periodical $CO_2$ enrichment on plant height, tiller number, biomass, phenology at 20, 40, 60 and 80 DAP during *Kharif* 2011 and 2012 in rice crop cv *Sharbati*.**

| Treatments | Plant Height (cm) | | | | Tiller (no./m²) | | | | Biomass (kgs/ha) | | | | Phenological expression (DAP) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 20 | 40 | 60 | 80 | 20 | 40 | 60 | 80 | 20 | 40 | 60 | 80 | Juvenile stage | PI Stage | Anthesis Stage | Maturity Stage |
| | DAP | | | | DAP | | | | DAP | | | | | | | |
| | | | | | | | | ***Kharif* 2011** | | | | | | | | |
| **T0** | 41.7 | 82.7 | 128.3 | 131.7 | 174.9 | 372.9 | 297 | 280.5 | 1000 | 4000 | 11333 | 15100 | 24 | 31 | 62 | 92 |
| **T1** | 43.0 | 84.7 | 131.7 | 130.0 | 201.3 | 422.4 | 399.3 | 343.2 | 1100 | 4667 | 11567 | 16000 | 25 | 32 | 63 | 93 |
| **T2** | 43.3 | 88.0 | 133.3 | 135.0 | 244.2 | 445.5 | 379.5 | 346.5 | 1267 | 5100 | 13767 | 18333 | 25 | 32 | 63 | 93 |
| **T3** | 44.0 | 82.3 | 137.3 | 140.0 | 211.2 | 491.7 | 422.4 | 366.3 | 1000 | 4900 | 11767 | 17333 | 26 | 33 | 63 | 93 |
| **Mean** | **43.0** | **84.4** | **132.7** | **134.2** | **207.9** | **433.1** | **374.6** | **334.1** | **1092** | **4667** | **12108** | **16692** | **25** | **32** | **63** | **93** |
| **ToS** | **NS** | **sig*** | **sig*** | **sig*** | **NS** | **sig*** | **sig*** | **sig*** | **NS** | **sig*** | **sig*** | **sig*** | **NS** | **NS** | **NS** | **NS** |
| **CD (0.05)** | | **3.9** | **5.6** | **6.4** | | **85.8** | **52.47** | **57.75** | | **657** | **1550** | **2190** | | | | |
| | | | | | | | | ***Kharif* 2012** | | | | | | | | |
| **T0** | 50.0 | 86.7 | 128.3 | 116.7 | 188.1 | 260.7 | 283.8 | 254.1 | 1100 | 5700 | 6184 | 9000 | 21 | 29 | 60 | 90 |
| **T1** | 52.8 | 86.7 | 128.3 | 116.7 | 217.8 | 326.7 | 283.8 | 280.5 | 1067 | 6233 | 6946 | 11233 | 22 | 29 | 61 | 91 |
| **T2** | 52.5 | 95.0 | 131.7 | 121.7 | 214.5 | 339.9 | 343.2 | 300.3 | 1100 | 6433 | 7036 | 11567 | 22 | 29 | 61 | 91 |
| **T3** | 51.2 | 90.0 | 121.7 | 116.7 | 221.1 | 290.4 | 297.0 | 330.0 | 1133 | 6567 | 7269 | 11267 | 22 | 30 | 62 | 91 |
| **Mean** | **88.9** | **88.9** | **127.5** | **130.5** | **210.4** | **304.4** | **302.0** | **291.2** | **1100** | **6233** | **14550** | **18767** | **21.8** | **29.3** | **61** | **90.8** |
| **ToS** | **NS** | **NS** | **NS** | **NS** | **NS** | **sig*** | **sig*** | **sig*** | **NS** | **sig*** | **sig*** | **sig*** | **NS** | **NS** | **NS** | **NS** |
| **CD (0.05)** | | | | | | **52.1** | **48.2** | **52.8** | | **500** | **1123** | **2437** | | | | |
| **C Mean** | **66** | **86.7** | **130.1** | **132.4** | **209** | **369** | **338** | **313** | **1096** | **5450** | **13329** | **17729** | **23.4** | **30.6** | **61.9** | **91.8** |

### 3.3.3.7 Leaf Area Index (LAI)

From Table 3.4 it is evident that the effect of $CO_2$ application on LAI is evident at 60 and 80 DAP with CD value of 1.4 and 0.37 during 2011 and 1.13 and 0.79 during 2012. It cannot be said that $CO_2$ has any effect on LAI at 20 and 40 DAP as there is no consistency in the results obtained in *Kharif* 2011 and *Kharif* 2012 experiments. Generally LAI variation during the crop growth is 1.3, 4.4, 5.9 and 4.9 at 20, 40, 60 and 80 DAP respectively. The LAI is highest at 60 DAP during both the years (6.5 – 2011 & 5.2 – 2012). Increased LAI due to $CO_2$ enrichment can be attributed to increased leaf number and not due to increased leaf length or width. Among all the treatments T2 treatment significantly differed from T0 at 60 and 80 DAP.

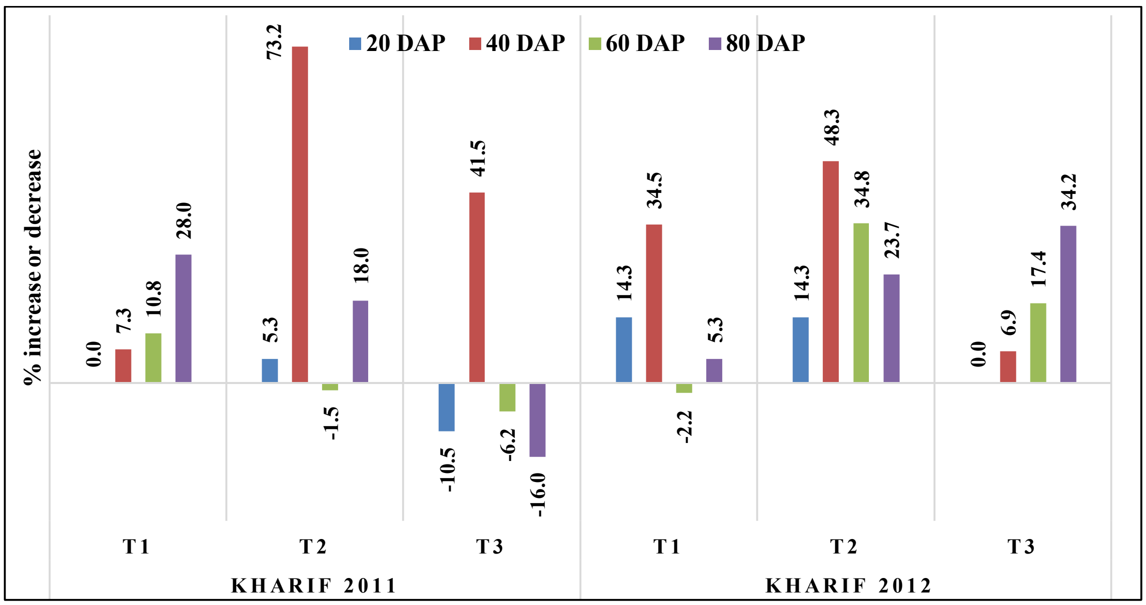



**Figure 3.8: % increase or decrease in LAI as affected by periodical $CO_2$ enrichment in T1, T2 and T3 in comparison with the LAI in T0 treatment of rice crop grown during Kharif 2011 and 2012.**

It has been observed that the LAI significantly decreased with increasing $CO_2$ enrichment treatments especially at higher $CO_2$ concentrations T2 and T3 during the 2011 experiment but in 2012 experiment it is observed that the $CO_2$ enrichment had a positive effect on LAI of rice crop (Figure 3.8). This complex response of LAI to $CO_2$ enrichment has been explained by (Ewert, 2004) as LAI of rice crop depends on substrate allocation, leaf area development and senescence, and the role of LAI in controlling plant adaptation to environmental changes. Further investigation is required in this regard to state the probable reason for such response of LAI.

**Table 3.4: Effect of periodical $CO_2$ enrichment on leaf number (plant$^{-1}$), leaf length (cm), leaf width (cm), Leaf Area Index during *Kharif* 2011 and 2012 in rice crop cv *Sharbati*.**

| Treatments | Leaf Numbers (plant$^{-1}$) DAP | | | | Leaf length (cm) DAP | | | | Leaf width (cm) DAP | | | | Leaf Area Index DAP | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 20 | 40 | 60 | 80 | 20 | 40 | 60 | 80 | 20 | 40 | 60 | 80 | 20 | 40 | 60 | 80 |
| | DAP | | | | | | | | | | | | | | | |
| ***Kharif* 2011** | | | | | | | | | | | | | | | | |
| **T0** | 27.3 | 39.0 | 47.6 | 25.5 | 23.4 | 45.9 | 43.5 | 34.9 | 0.6 | 1.1 | 1.4 | 1.3 | 1.9 | 4.1 | 6.5 | 5 |
| **T1** | 29.7 | 40.9 | 51.2 | 29.7 | 24.5 | 49.1 | 44.0 | 41.2 | 0.6 | 1.1 | 1.5 | 1.5 | 1.9 | 4.4 | 7.2 | 6.4 |
| **T2** | 30.3 | 47.5 | 47.0 | 34.6 | 29.9 | 64.9 | 47.0 | 44.1 | 0.6 | 1.3 | 1.5 | 1.4 | 2 | 7.1 | 6.4 | 5.9 |
| **T3** | 31.8 | 49.7 | 45.8 | 31.2 | 26.9 | 51.6 | 48.2 | 45.6 | 0.6 | 1.1 | 1.5 | 1.3 | 1.7 | 5.8 | 6.1 | 4.2 |
| **Mean** | **29.8** | **44.3** | **47.9** | **30.3** | **26.2** | **52.9** | **45.7** | **41.4** | **0.6** | **1.1** | **1.5** | **1.4** | **1.9** | **5.3** | **6.5** | **5.4** |
| **ToS** | **NS** | **sig*** | **sig*** | **sig*** | **NS** | **sig*** | **NS** | **sig*** | **NS** | **NS** | **NS** | **NS** | **NS** | **sig*** | **sig*** | **sig*** |
| **CD (0.05)** | | **7.34** | 7.1 | **6.37** | | **9.63** | | **5.29** | | | | | | **0.34** | **1.4** | **1.37** |
| ***Kharif* 2012** | | | | | | | | | | | | | | | | |
| **T0** | 14.5 | 23.8 | 25.7 | 23.2 | 29.8 | 47.3 | 50.8 | 52.7 | 0.8 | 1.1 | 1.3 | 1.1 | 0.7 | 2.9 | 4.6 | 3.8 |
| **T1** | 17.3 | 27.9 | 25.9 | 24.7 | 30.5 | 46.7 | 51.2 | 53.7 | 0.8 | 1.2 | 1.3 | 1.1 | 0.8 | 3.9 | 4.5 | 4 |
| **T2** | 18.8 | 30.8 | 31.2 | 29.0 | 28.8 | 50.1 | 54.8 | 54.7 | 0.8 | 1.3 | 1.4 | 1.2 | 0.8 | 4.3 | 6.2 | 4.7 |
| **T3** | 15.5 | 23.5 | 27.1 | 29.3 | 28.1 | 47.2 | 52.3 | 55.7 | 0.8 | 1.2 | 1.4 | 1.2 | 0.7 | 3.1 | 5.4 | 5.1 |
| **Mean** | **16.5** | **26.5** | **27.5** | **26.6** | **29.3** | **47.8** | **52.3** | **54.2** | **0.8** | **1.2** | **1.3** | **1.1** | **0.8** | **3.5** | **5.2** | **4.4** |
| **ToS** | **sig*** | **NS** | **sig*** | **sig*** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **sig*** | **sig*** |
| **CD (0.05)** | **3.27** | | **4.38** | **3.26** | | | | | | | | | | | **1.13** | **0.79** |
| **C Mean** | **23.2** | **35.4** | **37.7** | **28.4** | **27.7** | **50.4** | **49** | **47.8** | **0.7** | **1.2** | **1.4** | **1.3** | **1.3** | **4.4** | **5.9** | **4.9** |

### 3.3.4 Effect of $CO_2$ enrichment on rice crop yield and yield attributes

The results obtained from the experimental study on growth and development parameters such as panicle number (no./$m^2$), filled and unfilled grains (no./$m^2$), grain length (mm), grain breadth (mm), single grain weight (g), kernel length (mm), kernel width (mm), single kernel weight (g), hulling %, broken grain percentage (%), chalkiness percentage (%), grain yield (kgs/ha), straw yield (kgs/ha) and HI are presented in this section.

#### 3.3.4.1 Panicle Character

The panicle number in rice crop is significantly affected by the elevated $CO_2$ concentrations (Table 3.5). The average number of panicles during *Kharif* 2011 (323 no./$m^2$) is higher compared to *Kharif* 2012 (253 no./$m^2$). *Sharbati* cultivar on an average has a panicle density of 288 panicles (no./$m^2$). Results obtained during 2011 and 2012 indicated a higher panicle density of 353 no./$m^2$ and 284 no./$m^2$ respectively for T2 treatment during 2011 and 2012 $CO_2$ experiments. Tukey PostHoc CD calculated for panicle no./$m^2$ during 2011 and 2012 is 57.8 no./$m^2$ and 52.2 no./$m^2$. From this test it is observed that all the three treatments (T1, T2 and T3) significantly differ from T0 during 2011and T2 and T3 treatments significantly differed from T0 during 2012. Percent increase in panicle density per sqm in response to $CO_2$ enrichment is highest in T2 treatment during the 2011 (30.7%) and 2012 (34.3%) experiments respectively in comparison with T0 treatment (Figure 3.9).

The filled grains number (no./$m^2$) was significantly affected by $CO_2$ enrichment treatments as presented in Table 3.5. The two year average number of filled grains was 24883.8 no./$m^2$, 35058.05 no./$m^2$, 42587.7 no./$m^2$ and 37159.05 no./$m^2$ in T0, T1, T2 and T3 respectively. The average grain number (no./$m^2$) is higher during *Kharif* 2011(44847 no./$m^2$) compared to *Kharif* 2012 (24997 no./$m^2$) experiment. Tukey PostHoc CD calculated for filled grain number (no./$m^2$) during 2011 and 2012 is 6303.8 no./$m^2$ and 5435.6 no./$m^2$. From this it is observed that all the three treatments (T1, T2 and T3) significantly differ from T0 during 2011 and 2012 experiments. The number of unfilled grains (no./$m^2$) also decreased with the increase in $CO_2$ concentration resulting in increase in the grain yield. Percent increase in filled grain number per sqm in response to $CO_2$ enrichment is highest in T2 treatment during the 2011 (37.0%) and 2012 (17.8%) experiments respectively in comparison with T0 treatment (Figure 3.9). The number of unfilled grains also decreased with the increase in $CO_2$ concentration. The controlled-environment experiments have shown that elevated $CO_2$ increases tiller and panicle numbers in rice (Baker et al., 1992a; Kim et al., 2011; Moya et al., 1998; Yang et al., 2006; Yang et al., 2009a; Yang et al., 2009b; Ziska et al., 1997).

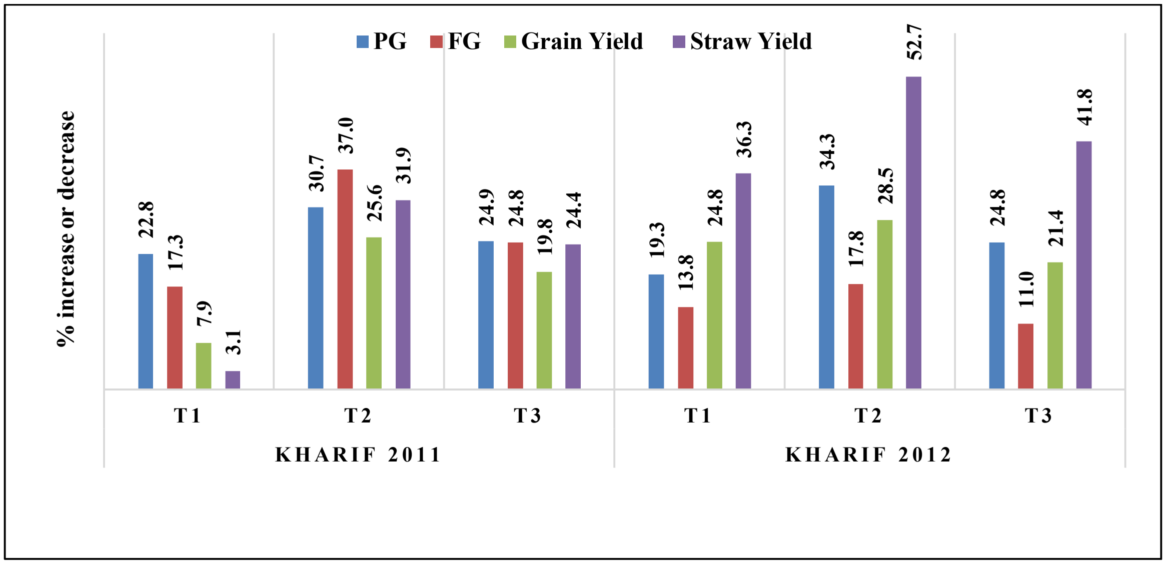



**Figure 3.9: % increase or decrease in panicle number, filled grain number, grain yield and straw yield as affected by periodical $CO_2$ enrichment in T1, T2 and T3 in comparison with the panicle number, filled grain number, grain yield and straw yield in T0 treatment of rice crop grown during Kharif 2011 and 2012.**

**Table 3.5: Effect of periodical $CO_2$ enrichment on panicle number, filled grain number (FG), unfilled grain number (UFG), single grain weight (SGW), grain length (GL), grain width (GW) and hulling % during *Kharif* 2011 and 2012 in rice cv *Sharbati*.**

| Treatments | Panicle | | | Grains | | | Hulling |
|---|---|---|---|---|---|---|---|
| | PN (no./$m^2$) | FG (no./$m^2$) | UFG (no./$m^2$) | SGW (g) | GL (mm) | GW(mm) | % |
| | | | ***Kharif* 2011** | | | | |
| **T0** | 270.2 | 30991.9 | 4620.4 | 0.022 | 10 | 2 | 74.3 |
| **T1** | 331.7 | 44613.7 | 3980.4 | 0.022 | 10 | 2 | 70.3 |
| **T2** | 353.1 | 55472 | 3566.3 | 0.025 | 11 | 2 | 85.5 |
| **T3** | 337.6 | 48310.6 | 3342.2 | 0.023 | 10 | 2 | 77.1 |
| **Mean** | **323.2** | **44847** | **3877** | **0.023** | **10.2** | **2** | **76.8** |
| **ToS** | **sig*** | **sig*** | **sig*** | **NS** | **NS** | **NS** | **sig*** |
| **CD (0.05)** | **57.8** | **6303.8** | **1760** | **-** | - | **-** | **9.9** |
| | | | ***Kharif* 2012** | | | | |
| **T0** | 211.2 | 18775.7 | 4984.3 | 0.023 | 10 | 2 | 77.3 |
| **T1** | 252 | 25502.4 | 7938 | 0.024 | 10 | 3 | 73.5 |
| **T2** | 283.7 | 29703.4 | 6723.7 | 0.022 | 10 | 2 | 86.5 |
| **T3** | 263.5 | 26007.5 | 4848.4 | 0.022 | 11 | 3 | 76.8 |
| **Mean** | **252.6** | **24997** | **6124** | **0.023** | **10.2** | **2.5** | **78.5** |
| **ToS** | **sig*** | **sig*** | **NS** | **NS** | **NS** | **NS** | **NS** |
| **CD (0.05)** | **52.2** | **5435.6** | **-** | **-** | **-** | **-** | **-** |
| **C Mean** | **288** | **34922** | **5000** | **0.023** | **10.3** | **2.3** | **77.7** |

### 3.3.4.2 Grain Characters

It is observed that the SGW of rice crop is unaffected under elevated $CO_2$ conditions. Generally *Sharbati* is a long-slender grained cultivar. The impact of elevated $CO_2$ on grain length (GL) and grain width (GW) parameter is not significant. The length of the grain generally varied between 1.0-1.1 mm and with a width ranging between 0.2 - 0.3 mm (Table 3.5). The hulling (%) was affected inconsistently by increasing the frequency of $CO_2$ application. The two year average hulling (%) was 75.8, 71.9, 86.0 and 77.0 in T0, T1, T2 and T3 respectively. The overall average hulling (%) recorded was 76.8 and 78.5 during 2011 and 2012 respectively (Table 3.5).

### 3.3.4.3 Kernel Characters

Kernel is the economic part of rice crop which is used for consumption purpose. Therefore the kernel characters both quality and quantity are of prime importance to get good returns. Effect of any treatment on kernel characteristics should be checked as it can affect the market value at large. The average single kernel weight (SKW), kernel length (KL) and kernel width (KW) as observed from experimental study are 0.018 gm, 9.8 mm and 1.9 mm respectively (Table 3.6).

**Table 3.6: Effect of $CO_2$ enrichment on single kernel weight (SKW) (g), kernel length (KL) (mm), Kernel breadth (KB) (mm), Broken grain percentage (BG%), chalkiness percentage (CK%), grain Yield (kgs/ha), straw yield (kgs/ha) and HI *Kharif* 2011 and 2012 in rice cv *Sharbati*.**

| Treatments | Kernels | | | | | Yield (kgs/ha) | | HI |
|---|---|---|---|---|---|---|---|---|
| | SKW (g) | KL (mm) | KTW (mm) | BG (%) | CK (%) | Grain | Straw | |
| ***Kharif* 2011** | | | | | | | | |
| **T0** | 0.017 | 9.7 | 1.8 | 9.3 | 12.3 | 6610 | 15057 | 0.45 |
| **T1** | 0.018 | 9.6 | 1.7 | 10.9 | 17.1 | 7133 | 15533 | 0.46 |
| **T2** | 0.018 | 10 | 1.9 | 10.9 | 20.6 | 8303 | 19863 | 0.42 |
| **T3** | 0.018 | 9.8 | 1.9 | 12.8 | 22.8 | 7923 | 18743 | 0.44 |
| **Mean** | **0.0176** | **9.775** | **1.825** | **11** | **18.2** | **7492** | **17299** | **0.44** |
| **ToS** | **sig*** | **sig*** | **NS** | **sig*** | **sig*** | **sig*** | **sig*** | **NS** |
| **CD (0.05)** | **0.003** | **0.2** | **-** | **1.09** | **2.8** | **767** | **3930** | **-** |
| ***Kharif* 2012** | | | | | | | | |
| **T0** | 0.017 | 9.6 | 1.8 | 13.3 | 15.4 | 4670 | 11170 | 0.49 |
| **T1** | 0.018 | 9.8 | 1.7 | 14.9 | 23.1 | 5830 | 12530 | 0.51 |
| **T2** | 0.019 | 9.9 | 1.9 | 12.1 | 20.7 | 6000 | 15352 | 0.44 |
| **T3** | 0.018 | 9.7 | 1.9 | 16.2 | 24.3 | 5670 | 14330 | 0.44 |
| **Mean** | **0.018** | **9.8** | **1.8** | 14.1 | 20.9 | **5543** | **13346** | **0.47** |
| **ToS** | **NS** | **sig*** | **NS** | **sig*** | **sig*** | **sig*** | **sig*** | **NS** |
| **CD (0.05)** | **-** | **0.47** | **-** | **2.6** | **4.6** | **1038** | **2940** | **-** |
| **C Mean** | **0.018** | **9.8** | **1.8** | **11.9** | **19.6** | **6517** | **15322** | **0.5** |

From the experimental results (Table 3.6) the effect of $CO_2$ application on KTW cannot be attributed to $CO_2$ alone as there is no proper consistency in the results observed during *Kharif* 2011 and *Kharif* 2012. It is clear from the tabulated results that $CO_2$ has very minute or insignificant effect on KL and KW. During both the years the KL and KW are maximum in T2 treatments.

Significant effect of $CO_2$ applications is seen on broken grain percentage (BG) and chalkiness (CK) in both the years (Table 3.6). It is clearly observed that the BG% and CK% increases with increasing $CO_2$ applications. Average BG% and CK% during the study is observed to be 11.9% and 19.6 % respectively. The BG is maximum in T3 treatments during *Kharif* 2011 (12.8%) and *Kharif* 2012 (16.2%). CK was observed to be maximum in T3 (22.8%) treatment and T2 (24.3%) treatment during 2011 and 2012 experiments respectively.

It has been observed that the BG% and CK% increased with increasing $CO_2$ enrichment treatments leading to quality deterioration of kernel. The BG% increased by 2 – 3% and CK% increased by 5 – 10% in the $CO_2$ enriched treatments (T1, T2, T3) in comparison with the control treatment (T0). Similar findings on BG% and CK% were reported by (Liu et al., 2008; Wang et al., 2011; Yang et al., 2007).

#### 3.3.4.4 Grain Yield and straw yield

The observations taken on yield and straw yield (Table 3.6) shows that there is significant difference in $CO_2$ treatment across two seasons *Kharif* 2011 and *Kharif* 2012. The average yield observed during *Kharif* 2011 and 2012 are 7492 kgs/ha and 5543 kgs/ha respectively. The yield recorded is higher in *Kharif* 2011 compared to *Kharif* 2012. This difference in yields across two seasons can be attributed to weather conditions. The rainfall during *Kharif* 2011 was timely and adequate whereas 2012 had a comparatively less rainfall with improper temporal distribution. Grain yield of T2 and T3 treatments differed significantly from T0 treatment during 2011; grain yield of T1 and T2 differed significantly from T0 during 2012.

The maximum yield during *Kharif* 2011 is observed for T2 (8303 kgs/ha) and lowest for control treatment T0 (6610 kgs/ha). Similarly, maximum yield during *Kharif* 2012 was recorded for T2 treatment (6000 kgs/ha) and lowest for control treatment T0 (4670 kgs/ha). CD value estimated for grain yield were 767 kgs/ha and 1038 kgs/ha for 2011 and 2012 experiments respectively which indicated that T2 and T3 treatment significantly differed from T0 treatment during 2011; while T1 and T2 treatments significantly differed from T0 treatment during 2012 experiment.

The percentage increase in grain yield due to $CO_2$ enrichment treatments is maximum in T2 treatments for *Kharif* 2011 (25.6%) and *Kharif* 2012 (28.6%) experiments over the control plots (Figure 3.9). These results indicated that the T2 treatment was found to have good impact on grain yield of rice cv *Sharbati*. Rice yield is determined by panicle number per land area, spikelet number per panicle, filled spikelet percentage and individual grain weight. Yield increases caused by elevated $CO_2$ are related most strongly to larger productive panicle number per area and larger spikelet number per panicle (Cheng et al., 2009; Kim et al., 2003; Madan et al., 2012; Nam et al., 2013; Yang et al., 2009b). The findings by (Kim et al., 2011) indicated that elevated atmospheric $CO_2$ concentration, in a certain range, promotes rice grain yield but high dose of $CO_2$ beyond the range has little effect on yield improvement.

The overall average straw yield of *Sharbati* cultivar is 15332 kgs/ha, it was found to be higher in T2 treatment for *Kharif* 2011 (19863 kgs/ha) and *Kharif* 2012 (15352 kgs/ha) and lower for control treatments during both the years (15057 kgs/ha during 2011 and 11170 kgs/ha during 2012). Effect of $CO_2$ applications did not show any significant effect on harvest index of rice crop. CD value estimated for straw yield were 3930 kgs/ha and 2940 kgs/ha for 2011 and 2012 experiments respectively which indicated that T2 treatment significantly differed from T0 treatment during 2011; while T2 and T3 treatments significantly differed from T0 treatment during 2012 experiment. Percentage increase in straw yield in response to $CO_2$ enrichment is highest in T2 treatment during the 2011 (31.9%) and 2012 (52.7%) experiments respectively in comparison with T0 treatment (Figure 3.9). The increase in the straw yield due to higher $CO_2$ concentrations has been reported by several scientists and researchers (Baker et al., 1992a; Baker et al., 1992b; Vu et al., 1997; Widodo et al., 2003; Ziska and Teramura, 1992).

## 3.4 Conclusion

In general plant growth was improved with $CO_2$ enrichment treatments recording increased tillers/hill, leaves/hill, plant height, leaf length and width, plant dry matter/hill and Leaf Area Index. Yield attributes viz. panicles/$m^2$, filled grains/$m^2$, grain weight as well as grain length and width were improved with periodical enrichment of $CO_2$. Negative impact of $CO_2$ enrichment was recorded with increased broken grain and chalkiness percentage.

# CHAPTER IV

# CERES RICE CALIBRATION AND VALIDATION

## 4.1 Introduction

DSSAT models have been used to simulate crop yields under climate change and $CO_2$ enriched conditions. From field experiments it is evident that biomass and grain yield of C3 crops increases under $CO_2$ enriched conditions. Experimental data input and treatments actually matched with field experiment. Results obtained were used to validate this model.

### 4.1.1 DSSAT Model Description

In this study crop simulation model DSSAT v 4.5 software (Hoogenboom et al., 2010) (Hoogenboom et al., 2010) was used, which is assembled and distributed by International Consortium for Agricultural Systems Analysis (ICASA). It simulates growth, development and yield of a crop growing on a uniform area of land under different soil, water, carbon, and fertility conditions that take place under the cropping system over time (Jones et al., 2003). DSSAT was designed to allow user to (1) input, organize, and store data on crops, soil, and weather, (2) retrieve, analyze and display data, (3) calibrate and evaluate crop growth models and (4) evaluate different management practices at a site (Jones et al., 1998; Tsuji et al., 1994; Uehara and Tsuji, 1998).

DSSAT crop models are process oriented, and are designed to have global applications; i.e., to be independent of location, season, and management system. The models simulate effects of weather, soil water, cultivar, and nitrogen dynamics in the soil and crop, on crop growth and yield for well drained soils. DSSAT allows creating different management strategies and simulating performance of the crop (Basak et al., 2010).

### 4.1.2 CERES Rice Model Description

DSSAT comprises of multiple crop models including CERES-Rice. The CERES-Rice model simulate rice plant growth, development, yield attributes and yield considering the effects of weather condition, management practice, genetic character, soil water regime, Carbon and

Nitrogen applications (Timsina and Humphreys, 2006). The phenology of rice crop is simulated by CERES Rice model based on the growing degree days (GDD) and was modified to suite under all growing conditions (Alocilja and Ritchie, 1991). The germination of the rice seed is achieved when the GDD reaches to $45^0$C with a base temperature of $8^0$C (Livingston and Haasis, 1933). Biomass or dry matter production is a function of Photo synthetically Active Radiation (PAR) and Radiation Use Efficiency (RUE) of crop. The model predict daily photosynthesis using radiation-use efficiency approach as a function of daily irradiance for a full canopy, which is then multiplied by a factors ranging from 0 to 1 for light interception, temperature, leaf nitrogen and water status. CERES Rice model adapts Beer's Law to simulate the amount of light absorbed by the crop during the process of photosynthesis (Yoshida, 1981).

This model computes daily changes in root zone soil water content requires data of soil infiltration rate, drainage coefficient and Evapo transpiration (ET) of crop etc. (Ritchie and Otter, 1985). The water balance subroutine calculates run-off by modified United States Department of Agriculture (USDA)-Soil and Conservation Service (SCS) curve number method (Williams et al., 1991). The CERES model uses various weather data (temperature, humidity, sunshine hours, wind speed) to calculate ET by Penman-Montieth method (Jensen et al., 1990), uses temperature and solar radiation data by Ritchie's method (Allen et al., 1998).

DSSAT (Decision Support System for Agrotechnology Transfer) have also been widely used for yield gap analysis, decision making and planning, strategic and tactical management decisions, climate change impact studies etc. In India, several studies have demonstrated the utility of DSSAT for impact assessment of climatic change (Saseendran et al., 2000) (Aggarwal and Mall, 2002; Dharmarathna et al., 2014; Mall and Aggarwal, 2002; Saseendran et al., 2000). DSSAT has different sub modules to generate various files viz. weatherman for weather files, S Build for soil files, X Build for crop management and AT for genetic coefficient. The schematic flow chart of DSSAT model is presented in Figure 4.1.

### 4.1.3 DSSAT file Generation

#### 4.1.3.1 Soil file

Soil module S Build is used to generate soil files entering layer wise soil data into the model. The minimum input datasets required for generating soil files are the location details, soil color, slope etc. and layer wise details of silt (%) and clay (%), and nitrogen , soil pH, organic carbon (OC) and cation exchange capacity (CEC) etc. The data generated in the soil file using S Build is bulk density (BD), saturation point (SP), field capacity (FC), permanent wilting point (PWP), runoff curve number (RO), albedo fraction (Alb), Evaporation limit (EL) and Drainage rate (DR) etc.

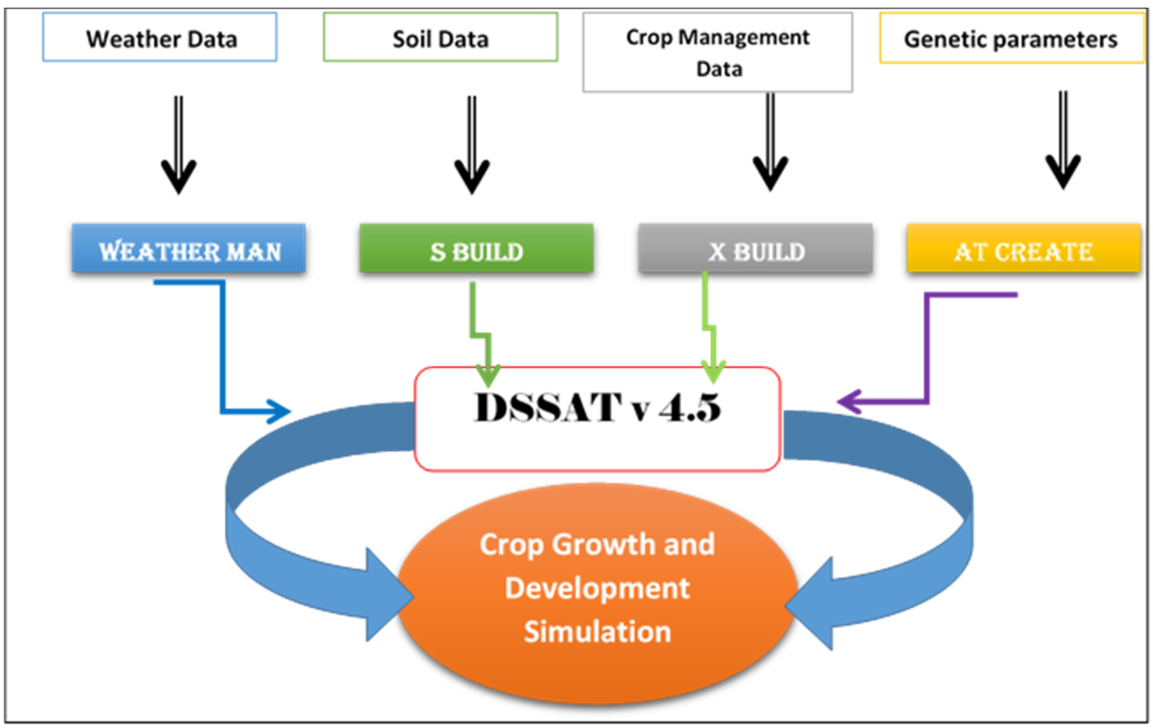



**Figure 4.1: Schematic diagram showing the flow of data in the DSSAT model.**

Roorkee soils were sandy loam soils which are brown in color with an albedo fraction of 0.13. The drainage rate of soils was 0.4 mm/day with the 73 runoff curve number. The soils were classified into order Inceptisols. Roorkee soils were characterized by 12-16% clay content, 24-40% silt with 0.6% OC in the topsoil, and therefore they were classified into sandy loam type of soils. PWP ranged between 0.097 – 0.121 $cm^3$ $cm^{-3}$, FC ranged between 0.2 -0.224 $cm^3$ $cm^{-3}$ and

Saturation point (SP) 0.3 – 0.4 $cm^3$ $cm^{-3}$. BD of the soil ranged between 1.54 g $cm^{-3}$ in the top layers to 1.42 $gcm^{-3}$ in the subsoil layers. CEC also ranged between 13-15 cmol $kg^{-1}$ in various layers of the soil.

**Table 4.1: DSSAT Generated Hydrological, Physical and Chemical properties of soil.**

| Order – Inceptisols<br>DR (mm/day) – 0.4 | | Color – Brown<br>RO - 73 | | | | | Alb– 0.13 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S No. | Layer | Depth | OC | Clay | Silt | N | PWP | FC | SP | BD | pH | CEC |
| | | (cm) | (%) | | | | ($cm^3/cm^3$) | | | ($g/cm^3$) | | (cmol $kg^{-1}$) |
| 1 | A | 30 | 0.6 | 16 | 24 | 0.02 | 0.121 | 0.224 | 0.414 | 1.54 | 7.8 | 13 |
| 2 | $B_0$ | 60 | 0.2 | 15 | 30 | 0.01 | 0.104 | 0.208 | 0.406 | 1.50 | 7.3 | 14 |
| 3 | $B_1$ | 90 | 0.1 | 14 | 32 | 0.01 | 0.097 | 0.201 | 0.407 | 1.49 | 7.3 | 15 |
| 4 | C | 120 | 0.01 | 12 | 40 | 0.01 | 0.082 | 0.195 | 0.319 | 1.42 | 6.8 | 15 |

#### 4.1.3.2 Weather file

Weatherman module of DSSAT generates weather files using daily weather data. The minimum datasets required by the weatherman are latitude and longitude of the weather station, daily values of incoming solar radiation ($MJ/m^2/day$), maximum (Tmax) and minimum (Tmin) air temperature (ºC), and rainfall (mm). WGEN sub module of weatherman generates daily data from monthly or weekly data.

#### 4.1.3.3 Genetic Coefficient file

Genetic coefficients were generated using AT Create module of DSSAT. In this process the observed data for at least six crop growth and development parameters with four dates of sowing is required to calibrate the coefficient. Genetic coefficients of any cultivar whose growth pattern resembles to that of the selected cultivar, which preexists within the model was selected for modification running DSSAT model using actual soil, weather and crop management data and make it usable by adjusting various coefficients through iterative process till the observed and simulated crop parameter data matched for rice cv *Sharbati*. The RICER045.CUL file was opened and the genetic coefficients of rice cv *Sharbati* was incorporated into the DSSAT model.

The DSSAT requires scalar values of genetic coefficients which are crop and cultivar specific for calculating the physiological values (Ritchie, 1993). The values of genetic coefficient of selected rice cultivar is given in Table 4.3. These coefficients determine the phenology and grain yield components of a particular variety as affected by other parameters such as weather, soil etc

(Iglesias, 2006). There are eight parameters of genetic coefficient that need to be adjusted to calibrate the model for each variety (Table 4.2).

**Table 4.2: Parameters of genetic coefficients in CERES Rice model.**

| **Name of the Coefficient** | **Description** |
|---|---|
| **Juvenile phase coefficient (P1)** | Time period (expressed as growing degree days [GDD] in $^0$C over a base temperature of 9 $^0$C) from seeding 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. |
| **Critical photoperiod (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 delay owing to longer day lengths. |
| **Photoperiod coefficient (P2R)** | Extent to which phasic development leading to panicle initiation is delayed (expressed as GDD in $^0$C) for each hour increase in photoperiod above P2O. |
| **Grain filling duration coefficient (P5)** | Time period in GDD ($^0$C) from beginning of grain filling (3–4 days after flowering) to physiological maturity with a base temperature of 9 $^0$C. |
| **Spikelet number coefficient (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. |
| **Single grain weight (G2)** | Single grain weight (g) under ideal growing conditions, i.e. non-limiting light, water, nutrients, and in the absence of pests and diseases. |
| **Tillering coefficient (G3)** | Tillering coefficient (scalar value) relative to IR64 cultivar under ideal conditions. A higher tillering cultivar would have a coefficient greater than 1.0. |
| **Temperature tolerance coefficient (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. Likewise, the G4 value for indica-type rice in very cool environments or season would be less than 1.0. |

Genetic coefficients of *Sharbati* rice cultivar were generated by running the model iteratively until the simulated values were closer to the observed values. Simulated values were close to the observed values and within permissible limits. Therefore, the genetic coefficient values applicable to all the dates of sowing was accepted and adopted for further model run. The genetic coefficient developed is presented in Table 4.3.

**Table 4.3: DSSAT generated Genetic coefficient for rice cv *Sharbati*.**

| Rice Cultivar | Genetic Coefficients | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | P1 | P2R | P5 | P2O | G1 | G2 | G3 | G4 |
| *Sharbati* | 780 | 80 | 350 | 15.4 | 50 | 0.022 | 0.60 | 0.70 |

#### 4.1.3.4 Crop Management File

The X build module of DSSAT generates crop management file. This module requires data of field operations (planting, harvesting, irrigation, fertilizer application etc.) as specified by the users. The minimum data sets required for X build are planting date; planting density, row spacing, planting depth, irrigation, and fertilizer applications etc.

#### 4.1.3.5 Experimental details

In order to calibrate and develop genetic coefficient of rice cv *Sharbati*, field experiment with four dates of transplanting [7$^{th}$ July (D1); 15$^{th}$ July (D2); 22$^{nd}$ July (D3) and 31$^{st}$ July (D4)] with recommended package of practices was conducted at the Demonstration Farm of Indian Institute of Technology Roorkee during *Kharif* 2013 (Plate 19 -24). Data on growth, development, yield attributes and yield were recorded. CERES rice model was run using actual crop management, soil, weather data and genetic coefficient of rice cv. *Sharbati*. Model run for each dates of sowing was iterated altering genetic coefficient parameters till the values of simulated yield and other parameters became apparently closure to the actually observed values. The schedule of field operations taken up during the 2013 experiment are given in Table 4.4.

#### 4.1.3.6 Statistical Analysis using DSSAT Easy Grapher and others

Easy Grapher (EG) is an inbuilt software package designed by Agriculture and Agri-Food, Canada for graphical presentation and statistical analysis of DSSAT v 4.5 outputs (Yang et al.;

Yang and Huffman, 2004). This is compatible to Microsoft excel. It estimates NMSE, index of agreement etc. between simulated and observed values. This module of DSSAT helps to visualize data in graphical format.

**Table 4.4: Schedule of field operations during *Kharif* 2013.**

| S.No. | Field Operations | D1 | D2 | D3 | D4 |
|---|---|---|---|---|---|
| **Nursery Management** | | | | | |
| **1** | **Field Preparation (Puddling)** | 6.06.2013 | 15.06.2013 | 21.06.2013 | 31.06.2013 |
| **2** | **Sowing (broadcasting)** | 12.06.2013 | 20.06.2013 | 26.06.2013 | 05.07.2013 |
| **3** | **Nursery Fertilizer** (40:0:0) | 12.06.2013 | 20.06.2013 | 26.06.2013 | 05.07.2013 |
| **4** | **Irrigation** | As and when required | | | |
| **5** | **Weeding** | As and when required | | | |
| **Crop Management in Main field** | | | | | |
| **6** | **Experimental Design** | Split plot | | | |
| **7** | **Replications** | 3 | | | |
| **8** | **Plot size** | 2m*2m | | | |
| **9** | **Spacing (Row to Row)** | 20 cm | | | |
| **10** | **Spacing (Plant to Plant)** | 15 cm | | | |
| **11** | **Transplanting Depth** | 2 cm | | | |
| **12** | **Method of Sowing** | Transplanting | | | |
| **13** | 1st ploughing | 28.06.2013 | 10.07.2013 | 18.07.2013 | 25.07.2013 |
| **14** | Levelling | 29.06.2013 | 11.07.2013 | 19.07.2013 | 26.07.2013 |
| **15** | 2nd ploughing | 05.07.2013 | 13.07.2013 | 20.07.2013 | 28.07.2013 |
| **16** | Pre Transplanting irrigation | 06.07.2013 | 14.07.2013 | 21.07.2013 | 30.07.2013 |
| **17** | **Transplanting** | **07.07.2013** | **15.07.2013** | **22.07.2013** | **31.07.2013** |
| **Irrigation** | | | | | |
| **18** | Method of Application | Flooding | | | |
| **19** | $1^{st}$ irrigation (50 mm) | 7.07.2013 | 15.07.2013 | 22.07.2013 | 31.07.2013 |
| **20** | $2^{nd}$ irrigation (50 mm) | 13.07.2013 | 20.07.2013 | 27.07.2013 | 5.08.2013 |
| **21** | $3^{rd}$ irrigation (50 mm) | 19.07.2013 | 25.07.2013 | 1.08.2013 | 10.08.2013 |
| **22** | $4^{th}$ irrigation (50 mm) | 23.07.2013 | 30.07.2013 | 16.08.2013 | 15.08.2013 |
| **23** | $5^{th}$ irrigation (50 mm) | 28.07.2013 | 04.08.2013 | 11.08.2013 | 20.08.2013 |
| **24** | $6^{th}$ irrigation (50 mm) | 07.08.2013 | 09.08.2013 | 16.08.2013 | 25.08.2013 |
| **25** | $7^{th}$ irrigation (50 mm) | 17.08.2013 | 19.08.2013 | 26.08.2013 | 04.09.2013 |
| **26** | $8^{th}$ irrigation (50 mm) | 22.08.2013 | 24.08.2013 | 31.08.2013 | 09.09.2013 |
| **27** | $9^{th}$ irrigation (50 mm) | 27.08.2013 | 29.08.2013 | 05.09.2013 | 14.09.2013 |
| **28** | $10^{th}$ irrigation (50 mm) | 01.09.2013 | 3.09.2013 | 10.09.2013 | 19.09.2013 |
| **29** | $11^{th}$ irrigation (50 mm) | 11.09.2013 | 8.09.2013 | 15.09.2013 | 24.09.2013 |
| **30** | $12^{th}$ irrigation (50 mm) | 16.09.2013 | 13.09.2013 | 20.09.2013 | 29.09.2013 |
| **31** | $13^{th}$ irrigation (50 mm) | 26.09.2013 | 18.09.2013 | 25.09.2013 | 14.10.2013 |
| **32** | $14^{th}$ irrigation (50 mm) | 11.09.2013 | 23.09.2013 | 30.09.2013 | |
| **33** | $15^{th}$ irrigation (50 mm) | 11.09.2013 | 28.09.2013 | 05.10.2013 | |

| Fertilizer application | | | | | |
|---|---|---|---|---|---|
| **34** | Basal dressing (10:40:40) | 07.07.2013 | 15.07.2013 | 22.07.2013 | 31.07.2013 |
| **35** | 1st top dressing (20:0:0) | 22.07.2013 | 30.07.2013 | 20.08.2013 | 30.08.2013 |
| **36** | 2nd top dressing (20:0:0) | 04.08.2013 | 15.08.2013 | 31.08.2013 | 10.09.2013 |
| **37** | 3rd top dressing (20:0:0) | 26.08.2013 | 2.09.2013 | 05.09.2013 | 15.09.2013 |
| **38** | 4th top dressing (20:0:0) | 08.09.2013 | | 20.09.2013 | 28.09.2013 |
| **39** | **Weeding** | As and when required | | | |
| **40** | **Harvesting** | 10.10.2013 | 20.10.2013 | 25.10.2013 | 30.10.2013 |
| **41** | **Threshing** | 17.10.2013 | 25.10.2013 | 30.10.2013 | 05.11.2013 |

Simulated and actual values were statistically tested using Fractional Bias (FB) test, percent deviation (Dev) test, Normalized Mean Squared Error (NMSE) test and correlation coefficient test (Willmott, 1982; Willmott et al., 1985).

NMSE emphasizes the scatter in the entire dataset. The normalization by the product assures that the NMSE will not be biased towards models that over predict or under predict. Smaller values of NMSE denote better model performance.

**a. Fractional Bias (FB):**

It is similar to mean bias but it is normalized to make it dimensionless. FB varies between +2 to -2 with an ideal value of zero for an ideal model. Ideal value of Fractional Bias (FB) is zero but is practically not possible therefore acceptable limits are fixed.

$$FB = 2 * \left( \frac{Sim - Obs}{Sim + Obs} \right) \tag{4.1}$$

**b. Percent Deviation (Dev %)**

Deviation is a measure of difference between the observed value and simulated or estimated value of a variable, expressed in terms of percentage. Percent deviation ranges from 0 to 100 and if it is not in percentage it ranges between 0 and 1. An ideal model will have a deviation value of 100 if it is percentage and if is not in percentage the ideal value would be 1.

$$Dev\% = \frac{Sim - Obs}{Obs} * 100 \tag{4.2}$$

If the Dev% is negative it means that the model is overestimating the values of a variable in comparison to the observed values of the same variable. If the Dev % is positive that indicates a condition where the model is underestimating the values of a variable.

c. **Normalized Root Mean Square Error (NMSE):**

The Normalized Root Mean Square Error (NMSE) (Kumar, 2000) is used to estimate the deviation of forecasted value from the observed value. The Normalized Root Mean Square Error is dimensionless and calculated using the following formula.

$$NMSE = \frac{1}{N} \frac{\sum_{i=1}^{n} (Sim - Obs)^2}{\sum_{i}^{n} (Sim * Obs)} \tag{4.3}$$

**d. Index of Agreement**

The index of agreement can detect additive and proportional differences in the observed and simulated means and variances; however, it is overly sensitive to extreme values due to the squared differences (Legates and McCabe, 1999).The Index of Agreement (d) developed by Willmott (1981) as a standardized measure of the degree of model prediction error and varies between 0 and 1. A value of 1 indicates a perfect match, and 0 indicates no agreement at all (Willmott, 1981).

$$d = 1 - \frac{\sum_{i=1}^{n} (Sim_i - Obs_i)^2}{\sum_{i=1}^{n} (|Sim_i - \overline{Obs}| + |Obs_i - \overline{Obs}|)^2} \tag{4.4}$$

Where,

N = number of observations.

Sim = CERES Rice simulated value

Obs = Observed value

### 4.1.4 Model Calibration

For calibration and validation of CERES-Rice model a minimum of 4 experimental datasets of crop grown under variable weather conditions is necessary. Felkner evaluated DSSAT model under various scenarios for rice crop and observed that the yields decreased under increased temperatures (Felkner et al., 2009; Satapathy et al., 2014). Model calibration is the adjustment of parameters so that simulated values compare well with the observed values (Timsina and Humphreys, 2006). The genetic coefficients that influence the occurrence of developmental stages in the CERES models can be derived iteratively by manipulating the relevant coefficients to achieve the best possible match between the simulated and observed number of days to the phenological events. At least four independent data sets generated from different management or climatic conditions are needed for model calibration.

### 4.1.5 Model Calibration Results

Phenology of any crop primarily depends on temperature which is expressed as thermal time. By adjusting P1, P2R and P5 variables the timing of phenological stages of rice crop variety can be adjusted. Final grain yield is the product of plant population, kernels per plant and weight of kernel. The number of kernels per plant is a linear function of stem weight and coefficients that accounts for the variation between genotypes of the number of grains per ear (G1) and spike number (G3). The maximum kernel growth rate is an input coefficient depending on the genotype of rice (G2).

The PI stage was attained at 30, 31, 32 and 33 DAP in experimental study whereas for simulation studied it was reached at 32 DAP irrespective of date of sowing (Table 4.5). The anthesis stage was attained at 66 DAP, 64 DAP, 68 DAP and 69 DAP in D1, D2 D3 D4 experiments respectively. The CERES rice simulated that anthesis would reach at 64 DAP for D1 and 65 DAP for the rest of treatments. Physiological maturity is reached at 89 DAP, 90 DAP, 93 DAP and 95 DAP for D1, D2, D3 and D4 experiments respectively. There was one day difference in simulated values for physiological maturity when compared with the observed data.

Yield of *Sharbati* cultivar was observed to be 4667 kgs/ha, 5200 kgs/ha, 4863 kgs/ha and 3709 kgs/ha for D1, D2, D3 and D4 planting dates (Table 4.5). The simulated results for yield under different dates of planting was found to be 4403 kgs/ha, 5111 kgs/ha, 5094 kgs/ha and 4593 kgs/ha for D1, D2, D3 and D4 treatments respectively. Straw Yield of *Sharbati* cultivar given in Table 4.5 was observed to be 9667 kgs/ha, 10333 kgs/ha, 9500 kgs/ha and 9167 kgs/ha for D1, D2, D3 and D4 planting dates. Straw yield simulated is 10368 kgs/ha, 10946 kgs/ha10643 kgs/ha and 10821 kgs/ha for D1, D2, D3 and D4 treatments respectively. Similarly SGW measured for rice crop grown under variable dates of planting was 0.024 g, 0.023 g, 0.023 g and 0.020 g for D1, D2, D3 and D4 treatments respectively. The simulated results showed that the change in planting has no impact on SGW weight of rice crop with 0.023 g for all the treatments. Harvest Index (HI) observed under field conditions for D1, D2, D3 and D4 dates of planting is 0.48, 0.6, 0.5 and 0.41 respectively. The simulated results for HI are 0.42, 0.47, 0.48 and 0.42 for D1, D2, D3 and D4 dates of planting respectively. GN (no./$m^2$) for rice cultivar *Sharbati* was observed to be 19255 no./$m^2$, 26477 no./$m^2$, 21163 no./$m^2$, and 16013 no./$m^2$, under field conditions and 19060 no./$m^2$, 22121 no./$m^2$, 22052 no./$m^2$ and 19884 no./$m^2$ as simulated by CERES Rice for D1, D2, D3 and D4 planting treatments respectively. PN (no./$m^2$) for rice cultivar *Sharbati* was observed to be 285 no./$m^2$, 278 no./$m^2$, 263 no./$m^2$ and 240 no./$m^2$ under field conditions and 276 no./$m^2$, 327 no./$m^2$, 322 no./$m^2$ and 288 no./$m^2$ as simulated by CERES Rice for D1, D2, D3 and D4 planting treatments respectively.

Fractional bias (FB) is highest for panicle number (0.13) and lowest for grain number (0.0001) (Table 4.5). The percent deviation for all the listed parameters is less than 20% which proves CERES Rice model for its worthiness in crop simulation modelling. It is maximum for straw yield simulation (10.18) and it is minimum for PM stage simulation (0.55). NMSE is maximum for panicle number simulation and minimum for PM stage (0.0004).

**Table 4.5: Observed and CERES Rice model simulated results of rice crop grown under four variable dates of planting during *Kharif* 2013.**

| S.No | Parameter | D1 (7/7/13) | | D2 (15/7/13) | | D3 (22/7/13) | | D4 (31/7/13) | | FB | Dev% | NMSE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Obs | Sim | Obs | Sim | Obs | Sim | Obs | Sim | | | |
| 1 | **PI Stage (DAP)** | 30 | 32 | 31 | 32 | 32 | 32 | 33 | 32 | **0.02** | **1.72** | **0.006** |
| 2 | **Anthesis (DAP)** | 66 | 64 | 64 | 65 | 68 | 65 | 69 | 65 | **-0.03** | **-2.92** | **0.007** |
| 3 | **PM Stage (DAP)** | 89 | 90 | 90 | 91 | 93 | 92 | 95 | 96 | **0.01** | **0.55** | **0.0004** |
| 4 | **Harvest (DAP)** | 93 | 90 | 94 | 91 | 93 | 92 | 100 | 96 | **-0.03** | **-2.87** | **0.004** |
| 5 | **Grain Yield (kgs/ha)** | 4667 | 4403 | 5200 | 5110 | 4863 | 5094 | 3709 | 4593 | **0.04** | **5.30** | **0.041** |
| 6 | **Straw Yield (kgs/ha)** | 9667 | 10365 | 10333 | 10946 | 9500 | 10643 | 9167 | 10821 | **0.10** | **10.81** | **0.047** |
| 7 | **SGW (g)** | 0.024 | 0.023 | 0.023 | 0.023 | 0.023 | 0.023 | 0.02 | 0.023 | **0.02** | **2.71** | **0.019** |
| 8 | **HI** | 0.48 | 0.42 | 0.6 | 0.47 | 0.5 | 0.48 | 0.41 | 0.42 | **-0.11** | **-1.58** | **0.094** |
| 9 | **GN (no./$m^2$)** | 19255 | 19060 | 26477 | 22121 | 21163 | 22052 | 16013 | 19884 | **0.00** | **-8.93** | **0.081** |
| 10 | **PN (no./$m^2$)** | 285 | 276 | 278 | 327 | 263 | 322 | 240 | 288 | **0.13** | **2.73** | **0.102** |
| **Index of Agreement (d)** | | **0.99** | | **0.99** | | **0.99** | | **0.99** | | **0.01** | **-2.17** | **0.037** |

### 4.1.6 Model Validation

The effect of periodical application of $CO_2$ on rice crop growth and development was simulated using CERES-Rice model of DSSAT. Soil condition, weather condition, crop management practices and $CO_2$ applications (schedule and concentration) of the field experiments were used as input data. The effect of $CO_2$ application in rice at periodical interval was recorded on TN, LN, LAI, dry matter, yield through model run. Results obtained were compared with the observed data to test the validity of model.

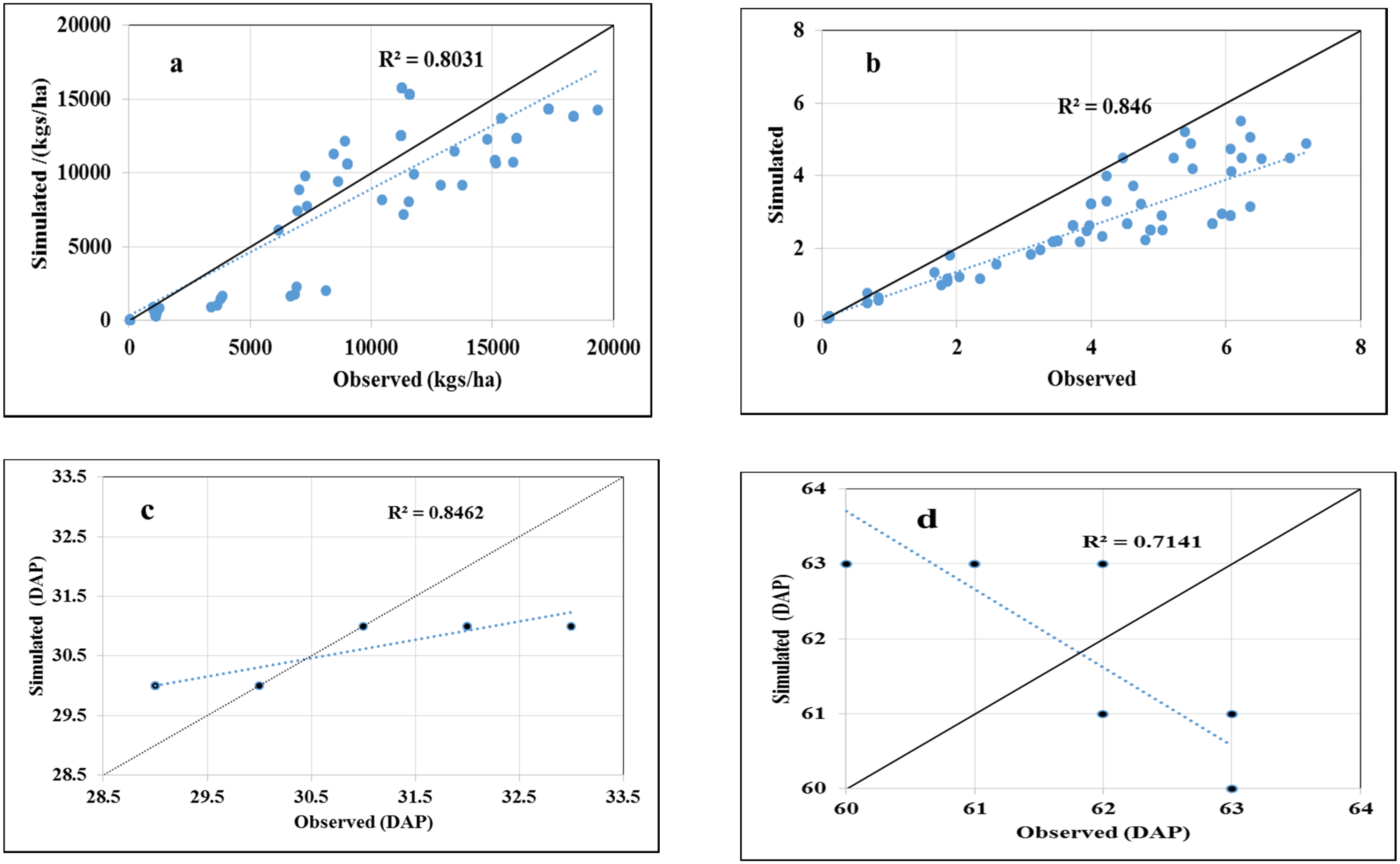
### 4.1.7 Model Validation Results

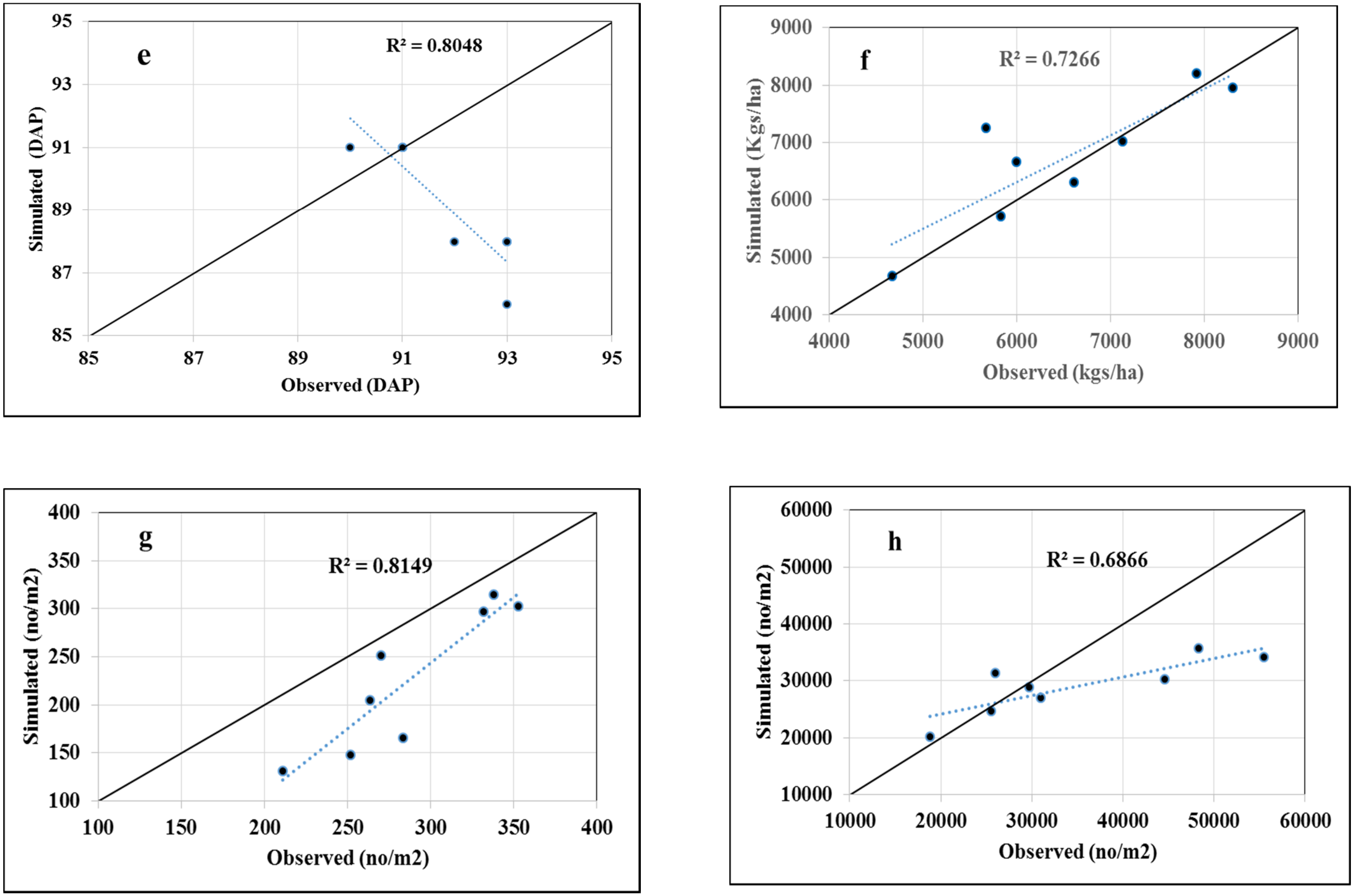
To validate the performance of CERES Rice model for application in $CO_2$ enrichment studies of rice crop cv *Sharbati* NMSE, Index of agreement (d) and $R^2$ were calculated between observed and simulated values which are presented in Table 4.6 - 4.8. The NMSE values estimated between observed and simulated biomass under $CO_2$ enrichment treatments at various crop growth stages during the years 2011 and 2012 are 0.004, 0.382, 1.772, 0.099, 0.072, 0.070, 0.068, 0.068 and 0.068 at end of juvenile stage, panicle initiation, and heading, beginning of grain filling, end of grain filling phase, main, and end of grain filling, tillers, maturity and harvest stages respectively (Table 4.6). The NMSE values estimated between observed and simulated LAI under $CO_2$ enrichment treatments at various crop growth stages during the years 2011 and 2012 are 0.00, 0.19, 0.34, 0.06, 0.09, 0.38, 0.36, 0.36 and 0.36 at end of juvenile stage, panicle initiation, and heading, beginning of grain filling, end of grain filling phase (main plant), and end of grain filling (tillers), maturity and harvest stages respectively (Table 4.7).

The index of agreement for the simulated values was 0.98, 0.96, 0.93 and 0.97 for T0, T1, T2 and T3 treatments respectively for the 2011 experiment. The index of agreement for the simulated values was 0.99, 0.99, 0.99 and 0.98 for T0, T1, T2 and T3 treatments respectively for the 2012 experiment (Table 4.8). The NMSE for simulated values of PI, anthesis, PM, grain yield, SGW, GN, PN, max LAI, HI and LN was 0.0012, 0.0013, 0.0018, 0.0092, 0.0013, 0.1017, 0.3499, 0.063, 0.0157, 0.0527, 0.1759, 0.0426 and 0.3244 respectively (Table 4.8). The 1:1 graph plotted (Figure 4.2) for simulated vs observed values shows that the $R^2$ values for biomass, LAI, PI stage, anthesis stage, physiological maturity, grain yield, SGW, GN, PN, Max LAI, HI and LN are 0.8031, 0.846, 0.8462, 0.7141, 0.8048, 0.7266, 0.00, 0.6866, 0.8149, 0.1065, 0.5631, 0.2125, 0.1158 and 0.2786 respectively.

The simulated results on growth, developmental, yield and yield attributes of rice cv. *Sharbati* under $CO_2$ enrichment treatments during 2011 and 2012 are presented in Table 4.8. Perfect index of agreement (ranging from 0.96-0.99) was observed in both the years of experiments between simulated and observed values of various variables viz. PI stage (DAP), anthesis stage (DAP), PM stage (DAP), grain yield (kgs/ha), SGW (g), GN (no./$m^2$) , PN (no./$m^2$), LAI (maximum), straw yield (kgs/ha), HI and LN (no/plant). The NMSE for simulated values of PI, Anthesis, PM, yield, SGW, straw yield, LAI and HI was less than 0.1 while for PN, GN and LN was more than 0.1. NMSE was found highest for simulation of PN and lowest for simulation of PI stage (Table 4.8). The 1:1graph plotted (Figure 4.2) for simulated vs observed values shows that the $R^2$ is more than 0.5 for PI, anthesis, PM, grain yield, GN, PN and straw yield. The $R^2$ value was found to be less than 0.5 for SGW, LAI, HI and LN.

Treatment effect was remarkably visible on the variables obtained from simulation run viz. grain yield (kgs /ha), SGW (g) GN (no./$m^2$), PN (no./$m^2$), LAI (maximum), (HI) and straw yield (kgs/ha). Use of CERES Rice model for $CO_2$ enrichment studies has been recommended by (Anten et al., 2004; Satapathy et al., 2014).


a
R² = 0.8031
Simulated /(kgs/ha)
Observed (kgs/ha)
0
5000
10000
15000
20000
b
R² = 0.846
Simulated
Observed
0
2
4
6
8
c
R² = 0.8462
Simulated (DAP)
Observed (DAP)
28.5
29.5
30.5
31.5
32.5
33.5
d
R² = 0.7141
Simulated (DAP)
Observed (DAP)
60
61
62
63
64



e
R² = 0.8048
Simulated (DAP)
Observed (DAP)
95
93
91
89
87
85
85
87
89
91
93
95
f
R² = 0.7266
Simulated (Kgs/ha)
Observed (kgs/ha)
9000
8000
7000
6000
5000
4000
4000
5000
6000
7000
8000
9000
g
R² = 0.8149
Simulated (no/m2)
Observed (no/m2)
400
350
300
250
200
150
100
100
150
200
250
300
350
400
h
R² = 0.6866
Simulated (no/m2)
Observed (no/m2)
60000
50000
40000
30000
20000
10000
10000
20000
30000
40000
50000
60000

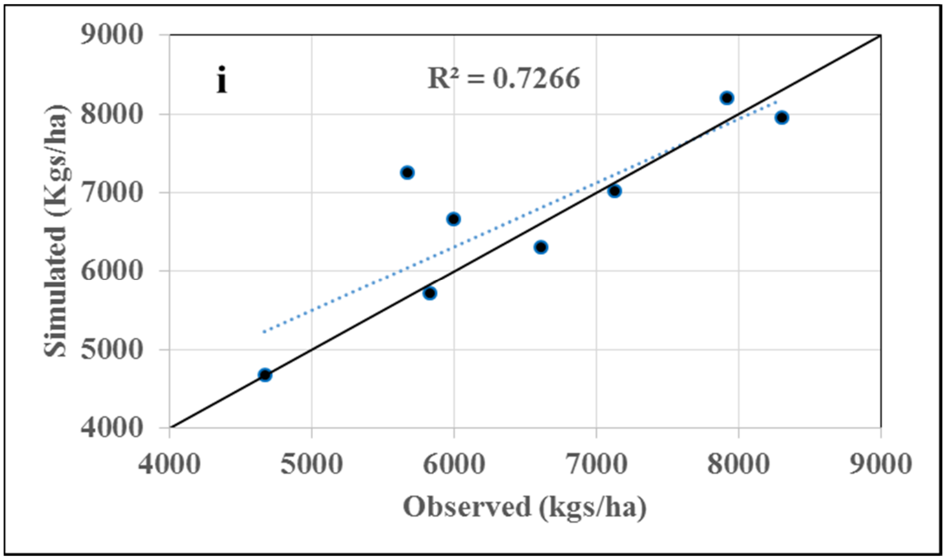



**Figure 4.2: Simulated (CERES Rice) vs. measured values of a) biomass; b) LAI; c) PI stage ; d) Anthesis stage ; e) PM stage ; f) Straw Yield ; g) PN ; h) GN; i) Grain Yield.**

#### 4.1.7.1 Simulated Biomass Production

The effect of $CO_2$ enrichment is significant on biomass of rice crop as simulated by CERES Rice model. The biomass increases with the age but the biomass accumulation remains constant after the start of grain filling stage. In T0 the biomass was simulated to be 758 kgs/ha, 1655 kgs/ha, 7408 kgs/ha, 8189 kgs/ha, 10734 kgs/ha, 10855 kgs/ha and 10855 kgs/ha at end of juvenile stage, panicle initiation, and heading, beginning of grain filling, end of grain filling phase, main, and end of grain filling, tillers, maturity and harvest. The effect of $CO_2$ enrichment is significant on biomass accumulation and maximum in T3 treatment with crop biomass of 946 kgs/ha, 2291 kgs/ha, 10206 kgs/ha, 11503 kgs/ha, 14265 kgs/ha, 14337 kgs/ha and 14337 kgs/ha at end of juvenile stage, panicle initiation, and heading, beginning of grain filling, end of grain filling phase, main, and end of grain filling, tillers, maturity and harvest respectively.

The biomass simulated for 2012 experiment is less than the 2011 experiment and this is probably due to the hot weather that prevailed during the 2012 experiment. In case of T0 the biomass accumulation was 328 kgs/ha, 900 kgs/ha, 6327 kgs/ha, 7743 kgs/ha, 10629 kgs/ha, 10629 kgs/ha and 10629 kgs/ha at end of juvenile stage, panicle initiation, and heading, beginning of grain filling, end of grain filling phase, main, and end of grain filling, tillers, maturity and harvest. The biomass accumulation is maximum in T3 treatment at all crop growth stages with crop biomass of 537 kgs/ha, 1703 kgs/ha, 10097 kgs/ha, 12186 kgs/ha, 15739 kgs/ha, 15739 kgs/ha and 15739 kgs/ha at end of juvenile stage, panicle initiation, and heading, beginning of grain filling, end of grain filling phase, main, and end of grain filling, tillers, maturity and harvest respectively.

**Table 4.6: CERES-Rice simulated biomass production (kgs/ha) in rice cv *Sharbati* under different treatments of $CO_2$ application during *Kharif* 2011 and 2012.**

| Growth Stage | Simulated biomass (kgs/ha) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | T0 | T1 | T2 | T3 | T0 | T1 | T2 | T3 | | |
| | *Kharif* 2011 | | | | *Kharif* 2012 | | | | Mean | NMSE |
| **Transplant** | 53 | 53 | 53 | 53 | 40 | 40 | 40 | 40 | **47** | **0.004** |
| **End Juveni** | 758 | 831 | 873 | 946 | 328 | 381 | 445 | 537 | **637** | **0.382** |
| **Pan Init** | 1655 | 1778 | 2043 | 2291 | 900 | 1065 | 1458 | 1703 | **1612** | **1.772** |
| **Heading** | 7224 | 8067 | 9155 | 9934 | 6327 | 7733 | 9188 | 10097 | **8466** | **0.099** |
| **Beg Gr Fil** | 8189 | 9193 | 10658 | 11503 | 7743 | 9456 | 11289 | 12186 | **10027** | **0.072** |
| **End Mn Fil** | 10734 | 12296 | 13715 | 14265 | 10629 | 12530 | 15352 | 15739 | **13158** | **0.070** |
| **End Ti Fil** | 10855 | 12359 | 13859 | 14337 | 10629 | 12530 | 15352 | 15739 | **13208** | **0.068** |
| **Maturity** | 10855 | 12359 | 13859 | 14337 | 10629 | 12530 | 15352 | 15739 | **13208** | **0.068** |
| **Harvest** | 10855 | 12359 | 13859 | 14337 | 10629 | 12530 | 15352 | 15739 | **13208** | **0.068** |

The biomass of rice cv *Sharbati* increased with the advancement in crop age upto beginning of grain filling stage and declined thereafter. The percentage increase in biomass over the control $CO_2$ application treatment is highest at end of grain filling stage (main plant) for T1 (14.5%) treatment and at beginning of grain filling stage for T2 (30.2%) and T3 (40.5%) during the year 2011(Figure 4.3). The percentage increase in biomass over the control $CO_2$ application treatment is highest at heading stage for T1 (22.2%) treatment and at panicle initiation stage for T2 (62%) and T3 (89%) during the year 2012 (Figure 4.3). The biomass reportedly increased with elevated $CO_2$ by 10 to 70% from previous experiments (Baker, 2004; Bannayan et al., 2005; De Costa et al., 2006; Kim et al., 2003; Kim et al., 2011; Yang et al., 2006). Rice plants grown under elevated $CO_2$ concentration accumulated more biomass before flowering and produced more panicles per plant and more spikelets per panicle (Ainsworth and Rogers, 2007; Baker and Allen Jr, 1993; Baker et al., 1995).

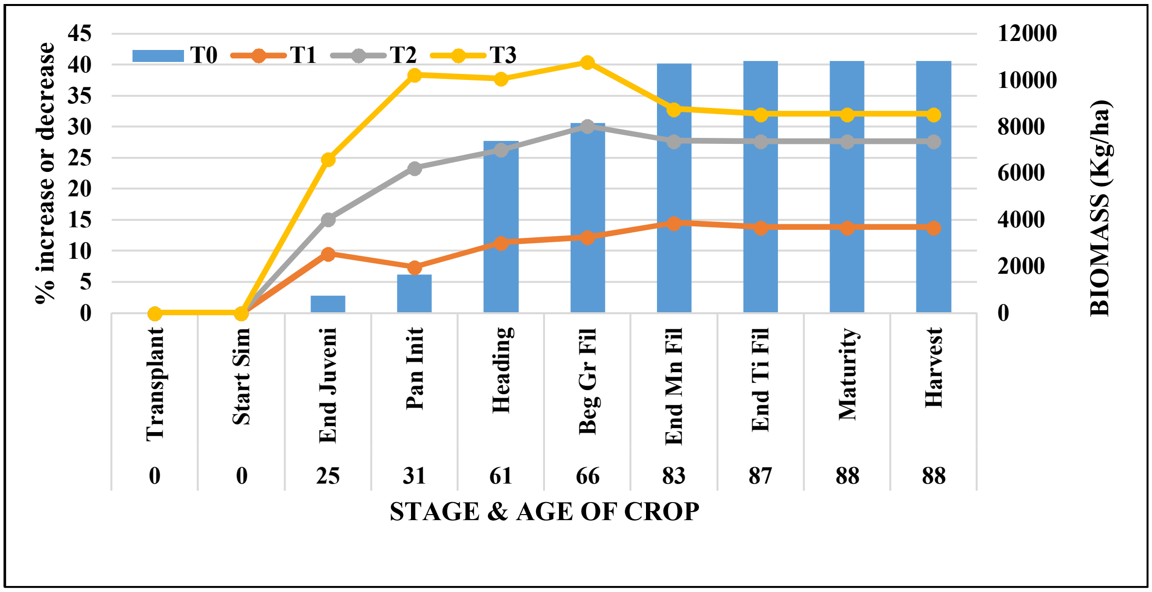



**Figure 4.3: % increase or decrease in CERES Rice simulated biomass production in rice cv *Sharbati* during *Kharif* 2012.**

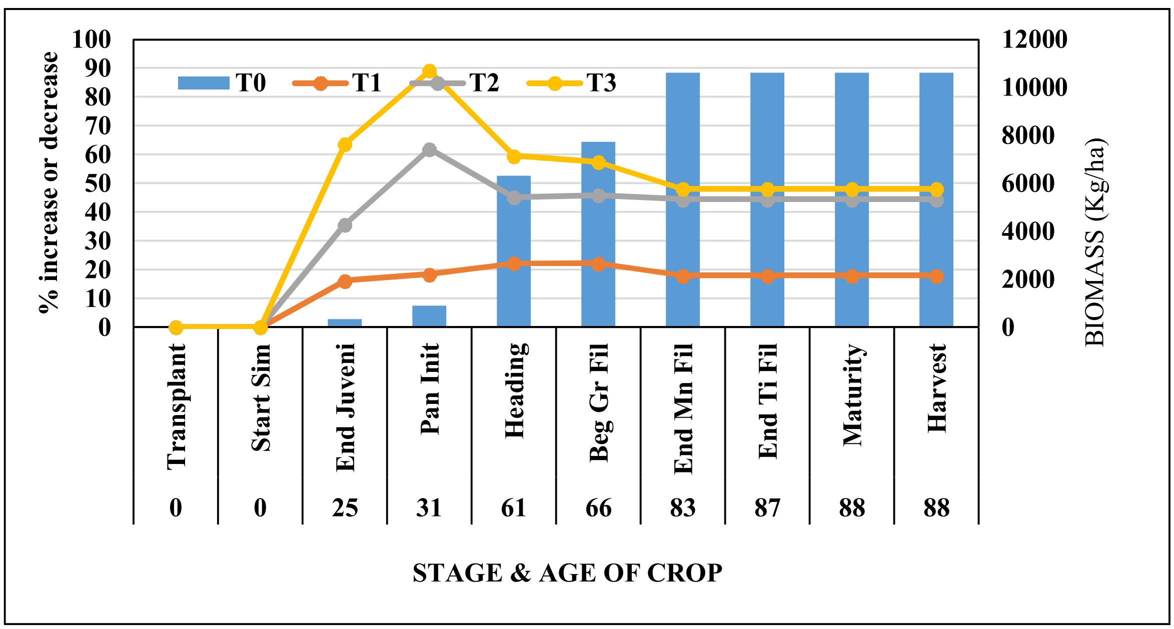



**Figure 4.4: % increase or decrease in CERES Rice simulated biomass production in rice cv *Sharbati* during *Kharif* 2012.**

### 4.1.7.2 Simulated LAI

LAI of rice crop grown under control conditions (T0) is 1.09, 1.84, 4.47, 4.11, 2.89 and 2.68 at end of juvenile stage, panicle initiation, heading, beginning of grain filling, end of grain filling phase (main plant), end of grain filling (tillers) and maturity stages. The effect of $CO_2$

enrichment is significant on LAI. LAI is maximum in T3 treatment which is simulated as 1.33, 2.47, 4.73, 4.19, 2.32, 2.21 and 2.21 at end of juvenile stage, panicle initiation, heading, beginning of grain filling, end of grain filling phase (main plant), end of grain filling (tillers) and maturity stages respectively (Table 4.7). LAI of rice crop grown under control conditions (T0) is 0.49, 0.99, 3.71, 3.3, 2.17 and 2.17 at end of juvenile stage, panicle initiation, and heading, beginning of grain filling, end of grain filling phase, main plant, and end of grain filling, tillers and maturity stages. The effect of $CO_2$ application treatments is significant on LAI and increases with the increasing number of $CO_2$ applications $T0<T3<T1<T2$ LAI in T2 treatment is simulated as 0.65, 1.56, 5.51, 4.89, 3.21, 3.21 and 3.21 at end of juvenile stage, panicle initiation, and heading, beginning of grain filling, end of grain filling phase, main plant, and end of grain filling, tillers and maturity stages respectively.

**Table 4.7: CERES-Rice simulated LAI at various crop growth stages of rice cv Sharabati grown under periodical $CO_2$ enrichment treatments during *Kharif* 2011 and 2012.**

| Growth Stage | Simulated LAI | | | | | | | | Mean | NMSE |
|---|---|---|---|---|---|---|---|---|---|---|
| | **T0** | **T1** | **T2** | **T3** | **T0** | **T1** | **T2** | **T3** | | |
| | ***Kharif* 2011** | | | | ***Kharif* 2012** | | | | | |
| **Transplant** | 0.11 | 0.11 | 0.11 | 0.11 | 0.08 | 0.08 | 0.08 | 0.08 | **0.10** | **0.00** |
| **End Juveni** | 1.09 | 1.16 | 1.22 | 1.33 | 0.49 | 0.56 | 0.65 | 0.77 | **0.91** | **0.19** |
| **Pan Init** | 1.84 | 1.96 | 2.22 | 2.47 | 0.99 | 1.17 | 1.56 | 1.81 | **1.75** | **0.34** |
| **Heading** | 4.47 | 4.89 | 5.05 | 4.73 | 3.71 | 4.48 | 5.51 | 5.2 | **4.76** | **0.06** |
| **Beg Gr Fil** | 4.11 | 4.5 | 4.5 | 4.19 | 3.3 | 3.98 | 4.89 | 4.5 | **4.25** | **0.09** |
| **End Mn Fil** | 2.89 | 3.15 | 2.95 | 2.32 | 2.17 | 2.62 | 3.21 | 2.51 | **2.73** | **0.38** |
| **End Ti Fil** | 2.68 | 2.91 | 2.67 | 2.21 | 2.17 | 2.62 | 3.21 | 2.51 | **2.62** | **0.36** |
| **Maturity** | 2.68 | 2.91 | 2.67 | 2.21 | 2.17 | 2.62 | 3.21 | 2.51 | **2.62** | **0.36** |
| **Harvest** | 2.68 | 2.91 | 2.67 | 2.21 | 2.17 | 2.62 | 3.21 | 2.51 | **2.62** | **0.36** |

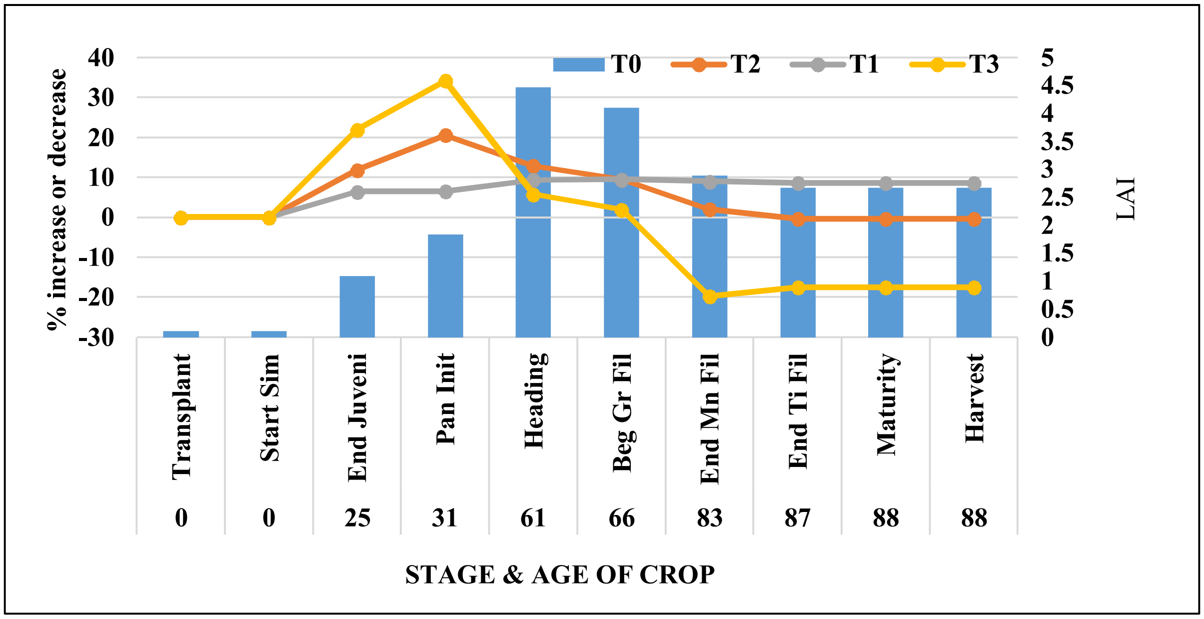



**Figure 4.5: % increase or decrease in CERES Rice simulated LAI in rice cv *Sharbati* during *Kharif* 2011.**

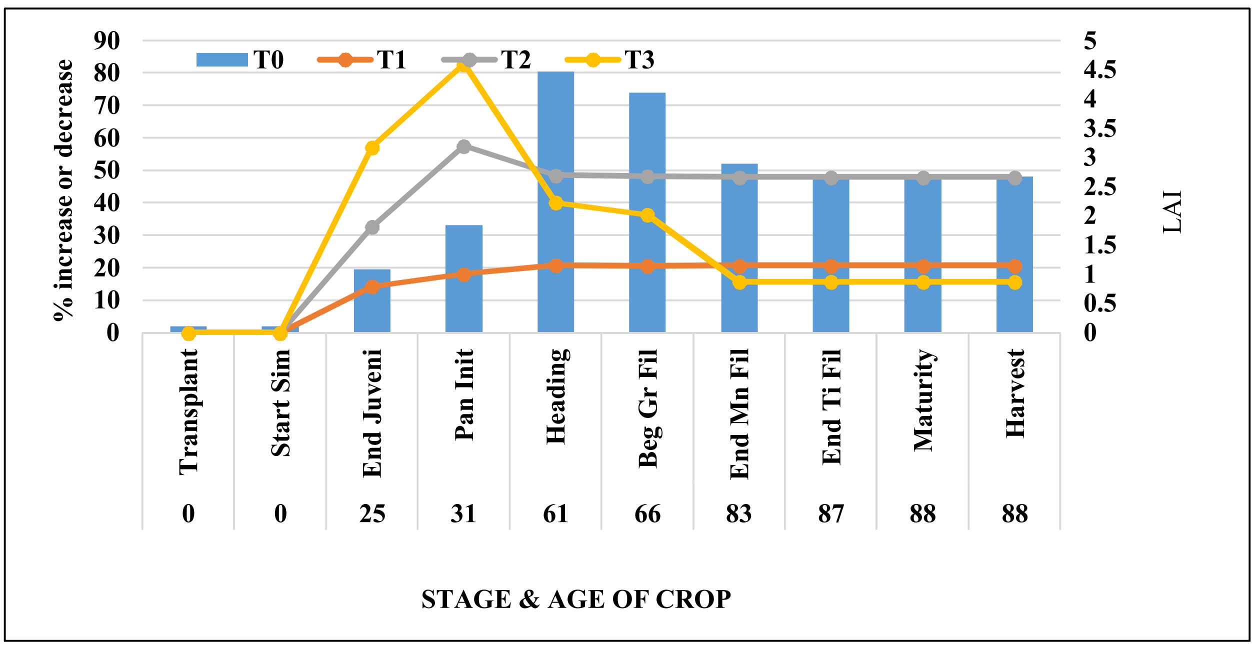



**Figure 4.6: % increase or decrease in CERES Rice simulated LAI in rice cv *Sharbati* during *Kharif* 2012.**

From the experimental study the maximum LAI is observed at heading stage and the same has also been reported by (Sakai et al., 2006). The maximum LAI is simulated by CERES Rice at 31 DAP that is at PI stage but from the experimental data it is observed that the maximum LAI is observed at heading stage. However, the leaf expansion during early stages of growth, when leaves do not shade each other and leaf area development is not limited by the amount of assimilates available, is mainly temperature driven. Even the percentage increase in LAI over the control $CO_2$ application treatment is highest at Panicle initiation stage for T1 (6.52%), T2 (20.6%) and T3 (34.2%) during the year 2011(**Figure 4.5**). The percentage increase in LAI over the control $CO_2$ application treatment is highest at heading stage for T1 (20.7%) treatment and at panicle initiation stage for T2 (57.8%) and T3 (82.8%) during the year 2012(**Figure 4.6**). Failure to simulate response of rice crop LAI to $CO_2$ enrichment by CERES Rice model has been reported by (Ewert, 2004). (Anten et al., 2004) results pertaining to elevated $CO_2$ and rice crop LAI showed that LAI was not influenced by $CO_2$ elevation under field and simulation study.

#### 4.1.7.3 Simulated overview output

The observed and simulated results on growth and developmental variables and comparison of observed and simulated values for the year 2011 and 2012 is given in Table 4.8. The two year simulated average expression of PI, anthesis and PM stages in rice cv. *Sharbati* was obtained at 30.5, 62 and 89.5 days after planting in T0,T1 & T2 treatments whereas at 30.5, 61.5 and 88.5 days after planting in T3 treatment. Simulation model results indicated slight reduction in duration of expression of growth stages. The CERES Rice modeled phenological expressions are reported 3-5 days earlier than the actual (Satapathy et al., 2014).

**Table 4.8: CERES-Rice simulated growth and developmental variables in rice cv *Sharbati* under different treatments of $CO_2$ application during *Kharif* 2011 and 2012.**

| S.No | Growth Variables | T0 | T1 | T2 | T3 | T0 | T1 | T2 | T3 | Mean | NMSE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ***Kharif 2011*** | | | | ***Kharif 2012*** | | | | | |
| 1 | **PI (DAP)** | 31 | 31 | 31 | 31 | 30 | 30 | 30 | 30 | 30.5 | 0.0012 |
| 2 | **Anthesis (DAP)** | 61 | 61 | 61 | 60 | 63 | 63 | 63 | 63 | 61.8 | 0.0013 |
| 3 | **PM (DAP)** | 88 | 88 | 88 | 86 | 91 | 91 | 91 | 91 | 89.3 | 0.0018 |
| 4 | **LN (no/plant)** | 17 | 17 | 17 | 17 | 16 | 16 | 16 | 16 | 16.5 | 0.3244 |
| 5 | **Max LAI** | 4.54 | 4.97 | 5.14 | 5.17 | 3.72 | 4.48 | 5.52 | 5.69 | 4.9 | 0.0630 |
| 6 | **Grain Yield (kgs/ha)** | 6308 | 7017 | 7948 | 8207 | 4685 | 5718 | 6669 | 7260 | 6726.5 | 0.0092 |
| 7 | **Straw Yield (kgs/ha** | 10855 | 12359 | 13859 | 14337 | 10629 | 12530 | 15352 | 15739 | 13207.5 | 0.0527 |
| 8 | **SGW (g)** | 0.023 | 0.023 | 0.023 | 0.023 | 0.023 | 0.023 | 0.023 | 0.023 | 0.023 | 0.0013 |
| 9 | **GN (no./m$^2$)** | 27003 | 30323 | 34220 | 35681 | 20280 | 24753 | 28869 | 31430 | 29069.9 | 0.1017 |
| 10 | **PN (no./m$^2$)** | 303 | 297 | 251 | 190 | 131 | 148 | 166 | 205 | 211.4 | 0.3499 |
| 11 | **HI** | 0.581 | 0.568 | 0.573 | 0.572 | 0.44 | 0.45 | 0.43 | 0.461 | 0.51 | 0.0426 |
| ***Index of Agreement*** | | **0.98** | **0.96** | **0.93** | **0.97** | **0.99** | **0.99** | **0.99** | **0.98** | - | - |

#### 4.1.7.4 Simulated Grain Yield

Yield simulated for rice cv. Sharbhati was 6308 kgs/ha, 7017 kgs/ha, 7948 kgs/ha and 8207 kgs/ha for T0, T1, T2 and T3 treatments respectively for the *Kharif* 2011 (Table 4.8). Similarly yield simulated for rice cv. Sharbhati during the year 2012 was 4685 kgs/ha, 5718 kgs/ha, 6669 kgs/ha and 7260 kgs/ha for T0, T1, T2 and T3 treatments respectively.

The percentage increase in grain yield simulated by DSSAT under the influence of $CO_2$ applications is 11.2%, 26% and 30.1% for T1, T2 and T3 treatments respectively during the year 2011. The percentage deviation in DSSAT simulated grain yield during 2012 is 22%, 42.3% and 55% for T1, T2 and T3 respectively over the control treatment T0 (Figure 4.7). The experimental findings from the growth chamber studies (Baker et al., 1992a; Baker et al., 1992b) showed a 32% increase in rice grain yield due to doubling of the $CO_2$ concentration from 330 to 660 ppm.

#### 4.1.7.5 Simulated grain weight

CERES Rice simulations did not show a significant effect on grain weight due to $CO_2$ applications on rice cv *Sharbati*. The SGW was simulated to be 0.023 through all the treatments for both the years; 2011 & 2012 (Table 4.8).

#### 4.1.7.6 Simulated grain number

Grain number simulated for rice cv. Sharbhati was 20280, 24753, 28869 and 31430 for T0, T1, T2 and T3 treatments respectively. For the year 2012 the GN simulated was 27003, 30323, 34220 and 35681 for T0, T1, T2 and T3 treatments respectively. The percentage increase in GN simulated by DSSAT under the influence of $CO_2$ enrichment is 12.3%, 26.7% and 32.1% for T1, T2 and T3 treatments respectively during the year 2011. The percentage increase in DSSAT simulated GN during 2012 is 22.1%, 42.4% and 55% for T1, T2 and T3 respectively over the control treatment T0. The increased grain yield response with increasing $CO_2$ concentration was attributed to greater tillering and more grain-bearing panicles.

#### 4.1.7.7 Simulated panicle number

Panicle number simulated for rice cv. Sharbhati was 251 no./m$^2$, 297 no./m$^2$, 303 no./m$^2$ and 315 no./m$^2$ for T0, T1, T2 and T3 treatments respectively (Table 4.8). The PN significantly decreased with increasing $CO_2$ applications. PN simulated during the year 2012 was 131 no./m$^2$, 148.7 no./m$^2$, 166 no./m$^2$, and 205 no./m$^2$ for T0, T1, T2 and T3 treatments respectively. The percentage increase in PN simulated by DSSAT under the influence of $CO_2$ applications is 18.3%, 20.7% and 25.5% for T1, T2 and T3 treatments respectively during the year 2011. The percentage increase in DSSAT simulated PN during 2012 is 13.0%, 26.1 % and 56.5 % for T1, T2 and T3 respectively over the control treatment T0. The CERES simulations showed that the increase in rice grain yield is due to increased grain number per panicle and not due to increase in panicle number per plant which is contrary to the observed one. The applicability of CERES rice model for simulating grain and panicle number under variable conditions has been reported by (Wikarmpapraharn and Kositsakulchai, 2010).

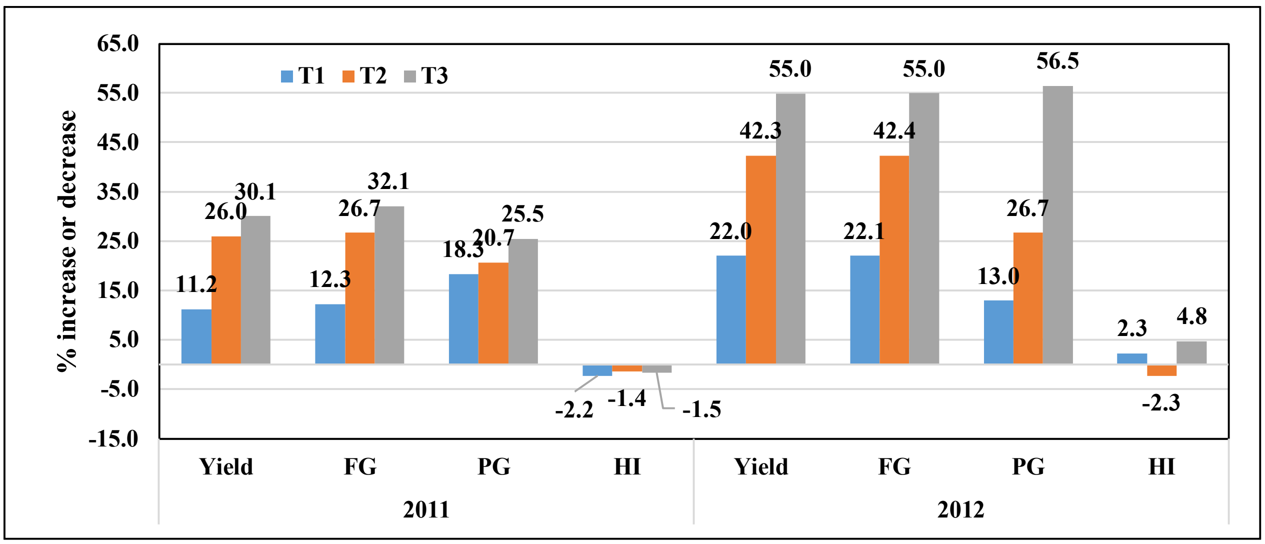



**Figure 4.7: % increase or decrease in CERES Rice simulated grain yield, filled grain number, panicle number and HI in rice cv *Sharbati* during *Kharif* 2011 and 2012.**

#### 4.1.7.8 Simulated Harvest Index

HI simulated for rice cv. Sharbhati was 0.58, 0.57, 0.57 and 0.57 for T0, T1, T2 and T3 treatments respectively. HI increased with increased $CO_2$ applications. HI simulated during 2012 was 0.44, 0.45, 0.43 and 0.46 for T0, T1, T2 and T3 treatments respectively (Table 4.8).

The percentage decrease in harvest index simulated by DSSAT under the influence of $CO_2$ applications is -2.2%, -1.4% and -1.5% for T1, T2 and T3 treatments respectively during the year 2011. The percentage deviation in DSSAT simulated HI during 2012 is 2.3%, 4.8% and -2.3% for T1, T2 and T3 respectively over the control treatment T0.

#### 4.1.7.9 Simulated Crop Nitrogen uptake, content and N Stress

Crop Nitrogen (kgs/ha) of rice crop grown under control conditions (T0) is 24 kgs/ha, 51 kgs/ha, 120 kgs/ha, 126 kgs/ha, 137 kgs/ha, 138 kgs/ha and 138 kgs/ha at end of juvenile stage, panicle initiation, and heading, beginning of grain filling, end of grain filling phase, main, and end of grain filling, tillers and maturity stages respectively. The effect of $CO_2$ application treatments is significant on crop nitrogen and increases with the increasing number of $CO_2$ applications T0<T1<T2<T3. Crop N in T3 treatment is simulated as 31 kgs/ha, 70 kgs/ha, 153 kgs/ha, 156 kgs/ha, 161 kgs/ha, 162 kgs/ha and 162 kgs/ha at the end of juvenile stage, panicle initiation, and heading, beginning of grain filling, end of grain filling phase, main, and end of grain filling, tillers and maturity stages respectively (Table 4.9).

Similarly, crop nitrogen percentage of rice crop grown under control conditions (T0) is 4.6 %, 3.2%, 3.1%, 1.6%, 1.5%, 1.3%, 1.3% and 1.3% at end of juvenile stage, panicle initiation, and heading, beginning of grain filling, end of grain filling phase, main, and end of grain filling, tillers and maturity stages respectively. The percentage of crop nitrogen decreases with the crop age. The effect of $CO_2$ application treatments is significant on crop nitrogen and increases with the increasing number of $CO_2$ applications T0<T1<T2<T3. Crop N in T3 treatment is simulated as 4.6%, 3.2%, 3.1%, 1.5%, 1.4%, 1.1%, 1.1% and 1.1% transplanting, end of juvenile stage, panicle initiation, and heading, beginning of grain filling, end of grain filling phase, main, and end of grain filling, tillers and maturity stages respectively Table 4.9.

**Table 4.9: CERES-Rice simulated crop nitrogen (kgs/ha) and (%) and nitrogen stress at various crop growth stages of rice cv Sharabati grown under different $CO_2$ application treatments during *Kharif* 2011 and 2012.**

| STAGE | Crop N (kgs/ha) | | | | | Crop N (%) | | | | | N Stress (0 - 1) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***Kharif 2011*** | | | | | | | | | | | | | | |
| | T0 | T1 | T2 | T3 | Mean | T0 | T1 | T2 | T3 | Mean | T0 | T1 | T2 | T3 | Mean |
| **Transplant** | 2 | 2 | 2 | 2 | **2** | 4.6 | 4.6 | 4.6 | 4.6 | **4.6** | 0 | 0 | 0 | 0 | **0** |
| **Start Sim** | 2 | 2 | 2 | 2 | **2** | 4.6 | 4.6 | 4.6 | 4.6 | **4.6** | 0 | 0 | 0 | 0 | **0** |
| **End Juveni** | 24 | 27 | 28 | 31 | **27** | 3.2 | 3.2 | 3.2 | 3.2 | **3.2** | 0 | 0 | 0 | 0 | **0** |
| **Pan Init** | 51 | 55 | 63 | 70 | **60** | 3.1 | 3.1 | 3.1 | 3.1 | **3.1** | 0.02 | 0.02 | 0.02 | 0.02 | **0.02** |
| **Heading** | 120 | 133 | 150 | 153 | **139** | 1.6 | 1.6 | 1.6 | 1.5 | **1.575** | 0 | 0.01 | 0.06 | **0.16** | **0.057** |
| **Beg Gr Fil** | 126 | 139 | 152 | 156 | **143** | 1.5 | 1.5 | 1.4 | 1.4 | **1.45** | 0.02 | 0.01 | 0.05 | **0.27** | **0.087** |
| **End Mn Fil** | 137 | 147 | 155 | 161 | **150** | 1.3 | 1.2 | 1.1 | 1.1 | **1.175** | 0 | 0.09 | 0.24 | **0.4** | **0.182** |
| **End Ti Fil** | 138 | 147 | 157 | 162 | **151** | 1.3 | 1.2 | 1.1 | 1.1 | **1.175** | 0.12 | 0.33 | 0.52 | 0.38 | **0.337** |
| **Maturity** | 138 | 147 | 157 | 162 | **151** | 1.3 | 1.2 | 1.1 | 1.1 | **1.175** | 0 | 0 | 0 | 0 | **0** |
| **Harvest** | 138 | 147 | 157 | 162 | **151** | 1.3 | 1.2 | 1.1 | 1.1 | **1.175** | 0 | 0 | 0 | 0 | **0** |
| ***Kharif 2012*** | | | | | | | | | | | | | | | |
| **Transplant** | 2 | 2 | 2 | 2 | **2** | 4.7 | 4.7 | 4.7 | 4.7 | **4.7** | 0 | 0 | 0 | 0 | **0** |
| **Start Sim** | 2 | 2 | 2 | 2 | **2** | 4.7 | 4.7 | 4.7 | 4.7 | **4.7** | 0 | 0 | 0 | 0 | **0** |
| **End Juveni** | 11 | 12 | 14 | 18 | **14** | 3.3 | 3.3 | 3.2 | 3.3 | **3.27** | 0 | 0 | 0 | 0 | **0** |
| **Pan Init** | 28 | 33 | 45 | 52 | **40** | 3.1 | 3.1 | 3.1 | 3.1 | **3.10** | 0.02 | 0.02 | 0.02 | 0.02 | **0.02** |
| **Heading** | 103 | 126 | 142 | 149 | **130** | 1.6 | 1.6 | 1.6 | 1.5 | **1.57** | 0 | 0 | 0 | 0.05 | **0.012** |
| **Beg Gr Fil** | 107 | 132 | 146 | 153 | **134** | 1.4 | 1.4 | 1.3 | 1.3 | **1.35** | 0 | 0 | 0.08 | **0.22** | **0.07** |
| **End Mn Fil** | 120 | 142 | 156 | 162 | **145** | 1.1 | 1.1 | 1 | 1 | **1.05** | 0 | 0 | 0.21 | 0.37 | **0.14** |
| **End Ti Fil** | 120 | 142 | 156 | 162 | **145** | 1.1 | 1.1 | 1 | 1 | **1.05** | 0 | 0 | 0 | 0 | **0** |
| **Maturity** | 120 | 142 | 156 | 162 | **145** | 1.1 | 1.1 | 1 | 1 | **1.05** | 0 | 0 | 0 | 0 | **0** |
| **Harvest** | 120 | 142 | 156 | 162 | **145** | 1.1 | 1.1 | 1 | 1 | **1.05** | 0 | 0 | 0 | 0 | 0 |

Nitrogen stress during various stages of rice crop growth is simulated by CERES Rice which is given in Table 4.9. Nitrogen stress was neglible during panicle initiation (0.02), beginning of grain filling (0.02) and end of grain filling, tillers (0.12) in T0 treatment (Table 4.9). Nitrogen stress increased with the increasing $CO_2$ applications. In T1 the nitrogen was 0.02, 0.01, 0.01, 0.09 and 0.33 at panicle initiation, and heading, beginning of grain filling, end of grain filling phase, main, and end of grain filling, tillers crop stages respectively. In T2 the nitrogen was 0.02, 0.06, 0.05, 0.24 and 0.52 at panicle initiation, and heading, beginning of grain filling, end of grain filling phase, main, and end of grain filling, tillers crop stages respectively. In T3 the nitrogen was 0.02, 0.16, 0.27, 0.4, 0.38 at panicle initiation, and heading, beginning of grain filling, end of grain filling phase, main, and end of grain filling, tillers crop stages respectively. Even photoperiod and temperature stress were not observed for the crop during the year 2011.

The percentage decrease in nitrogen accumulation simulated by CERES Rice in T1, T2 and T3 treatments over T0 treatment during the years 2011 and 2012 at different crop growth stages is given in Figure 4.8 & 4.9. The percentage increase in crop nitrogen over the control $CO_2$ application treatment is highest at end juvenile stage for T1 (12.5%) treatment and at heading stage for T2 (25.0%) and at panicle initiation stage for T3 (37.3%) during the year 2011. The percentage increase in crop nitrogen over the control $CO_2$ application treatment is highest at heading stage for T1 (23.4%) treatment and at panicle initiation stage for T2 (60.7%) and T3 (85.3%) during the year 2012. As a result of greater increase in both biomass and grain yield NUE was higher at higher $CO_2$ concentrations than crop grown at ambient $CO_2$ concentrations (Kim et al., 2001). (Lieffering et al., 2004) has reported that elevated $CO_2$ reduces N in rice grains if N supply is inadequate.

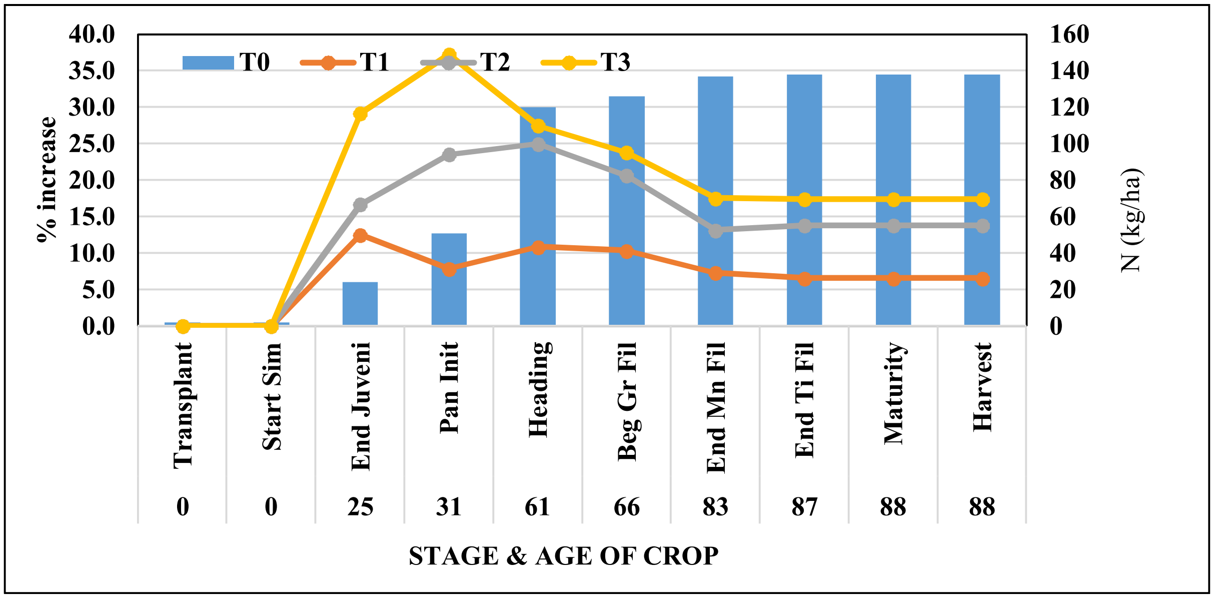



**Figure 4.8: % increase or decrease in CERES Rice simulated crop nitrogen uptake in rice cv *Sharbati* during *Kharif* 2011.**

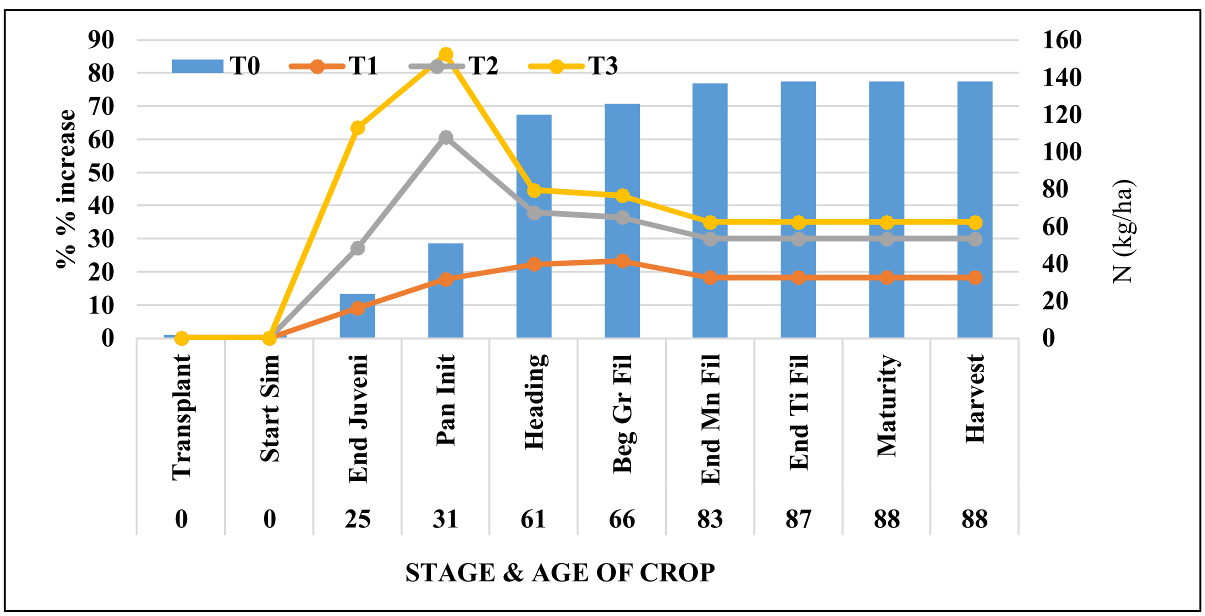



**Figure 4.9: % increase or decrease in CERES Rice simulated crop nitrogen uptake in rice cv *Sharbati* during *Kharif* 2011.**

### 4.1.7.10 Simulated Nitrogen partitioning

The $CO_2$ enrichment positively impacted crop and grain nitrogen but the impact of $CO_2$ was negative on stem nitrogen (Figure 4.10). The percentage deviation in DSSAT simulated crop N at maturity during 2012 is 18.3%, 30% and 35.6% for T1, T2 and T3 respectively over the control treatment T0. The percentage change in crop N at maturity simulated by DSSAT under the influence of $CO_2$ applications is 6.5%, 13.8% and 17.4% for T1, T2 and T3 treatments respectively during the year 2011. The percentage change in stem N at maturity simulated by DSSAT under the influence of $CO_2$ applications is -4.7%, -16.3% and -16.3% for T1, and T2 and T3 treatments respectively during the year 2011. The percentage deviation in DSSAT simulated stem N at maturity during 2012 is 14.6%, 14.6% and 6.3% for T1, T2 and T3 respectively over the control treatment T0. The percentage change in grain N at maturity simulated by DSSAT under the influence of $CO_2$ applications is 11.6%, 27.4% and 31.6% for T1, T2 and T3 treatments respectively during the year 2011. The percentage deviation in DSSAT simulated grain N at maturity during 2012 is 22.5%, 43.7% and 56.3% for T1, T2 and T3 respectively over the control treatment T0. The amount of nitrogen partitioned to grain is higher under $CO_2$ enriched conditions. Stem N is partitioned to grain when N is wanting. Due to this phenomenon the NUE of rice crop increases under elevated $CO_2$ conditions.

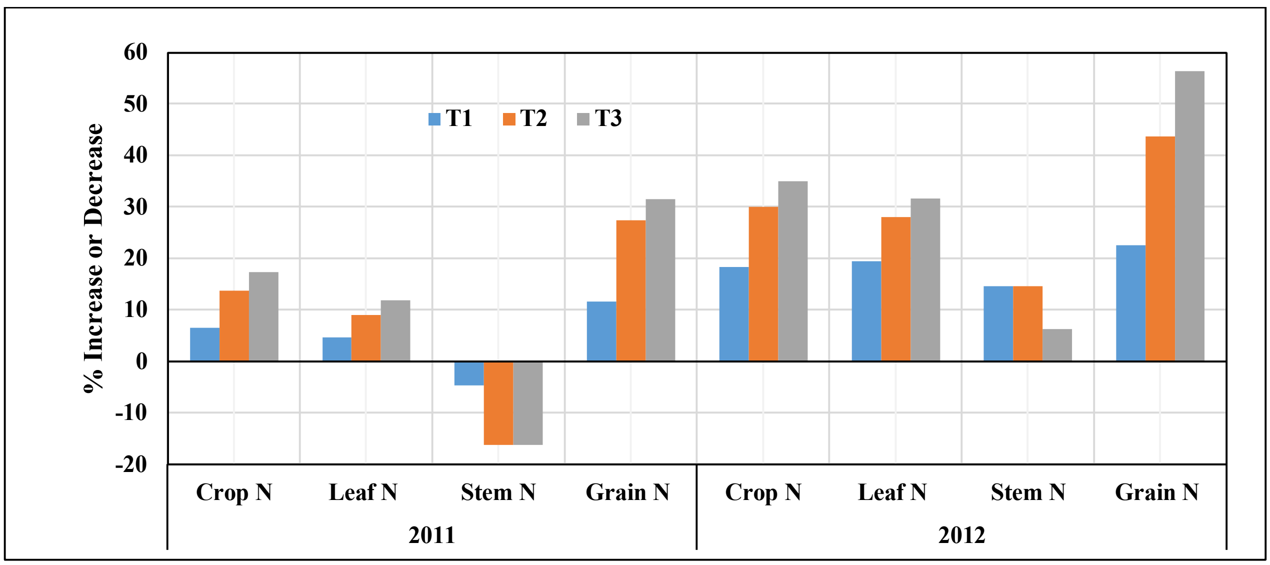



**Figure 4.10: % increase or decrease in simulated crop N, leaf N, stem N and grain N as effected by $CO_2$ application in comparison with the crop grown at ambient concentrations during *Kharif* 2012 experiment**

#### 4.1.7.11 Simulated Nitrogen (NUE) and Water Use Efficiency (WUE)

From the simulated results it is seen that the rainfall and supplemental irrigations provided to the crop were enough to overcome water stress and therefore water stress was not there for all treatments at all crop growth stages. WUE calculated suggests that WUE is higher during 2012

(6.6 kgs/ha/mm) compared to WUE during 2011 (5.7 kgs/ha/mm) (Table 4.10). The highest WUE was simulated for T3 treatment which is 6.3 kgs/ha/mm during 2011 and 7.9 kgs/ha/mm during the year 2012.

NUE calculated suggests that NUE is higher during 2011(73.7 kgs/ha/kg N) compared to NUE during 2012 (60.8 kgs/ha/kg N) (Table 4.10). The highest NUE was simulated for T3 treatment which is 82.1 kgs/ha/ kg N during 2011 and 72.6 kgs/ha/kg N during the year 2012. The RMSE calculated between the observed and simulated values of WUE (0.02) and NUE (0.01) suggest that the CERES Rice model predicts closer values to the observed one.

**Table 4.10: CERES-Rice simulated WUE and NUE of rice cv Sharabati grown under different $CO_2$ application treatments during *Kharif* 2011 and 2012.**

| Treatments | WUE (kgs/ha/mm) | | NUE (kgs/ha/kgN) | |
|---|---|---|---|---|
| | 2011 | 2012 | 2011 | 2012 |
| T0 | 4.8 | 5.1 | 63.1 | 46.9 |
| T1 | 5.4 | 6.2 | 70.2 | 57.2 |
| T2 | 6.1 | 7.2 | 79.5 | 66.7 |
| T3 | 6.3 | 7.9 | 82.1 | 72.6 |
| **Mean** | **5.7** | **6.6** | **73.7** | **60.8** |
| **NMSE** | **0.02** | | **0.01** | |

The CERES models include the capability to simulate the effects of $CO_2$ on photosynthesis and water use. In the models, the daily potential transpiration calculations are modified by the $CO_2$ concentration, based on the effects of $CO_2$ on stomatal conductivity (Peart et al., 1989). The analysis has demonstrated that performance of the CERES model was reasonably good as indicated by close matching between simulated and observed WUE and NUE under varying $CO_2$ enrichment treatments which is in corroboration with the results presented by (Nain and Kersebaum, 2007). Applicability of CERES Rice model for the study of water and nutrient dynamics in rice crop has been suggested by (Jing et al., 2010; Kumar and Goh, 1999; Singh and Ritchie, 1993; Timsina and Humphreys, 2006)

#### 4.1.7.12 Soil Nitrogen Balance

Initial amount of nitrogen present in soil in $NO_3$ and $NH_4$ form is 186.7 kgs N/ha and 21.1 kgs N/ha. The amount of N added through inorganic fertilizers is 100 kgs/ha in $NH_4$ as Urea. N mineralized within the soil is 14.8 kgs/ha, 15.8 kgs/ha, 14.8 kgs/ha and 17.3 kgs/ha for T0, T1, T2 and T3 treatments. The nitrogen lost through denitrification and volatilization is 118 kgs/ha, 118 kgs/ha, 118 kgs/ha and 111 kgs/ha. N uptake from soil indicated the total N used by rice crop. The nitrogen fixed in crop for growth and development is 139 kgs/ha, 135, 139 and 161 kgs/ha for T0, T1, T2 T3 treatments respectively (Table 4.11).

**Table 4.11: CERES Rice Simulated soil nitrogen balance (initial and final) in Rice cv Sharabati grown under various $CO_2$ treatments**

| Treatments | T1 | | T2 | | T3 | | T4 | |
|---|---|---|---|---|---|---|---|---|
| | Initial | Final | Initial | Final | | Initial | Final | Initial |
| ***Kharif* 2011** | | | | | | | | |
| **Soil NO3** | 139.1 | 26 | 139.1 | 21.9 | 139.1 | 15.9 | 139.1 | 13.9 |
| **Soil NH4** | 15.9 | 12.6 | 15.9 | 12.7 | 15.9 | 10.9 | 15.9 | 10.2 |
| **Soil Urea** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Added to / Removed from Soil:** | | | | | | | | |
| **Fertilizer N** | 100 | | 100 | | 100 | | 100 | |
| **Mineralized N** | 22.6 | | 22.7 | | 17.8 | | 15.8 | |
| **Leached NO3** | | 0 | | 0 | | 0 | | 0 |
| **N Denitrified** | | 38.2 | | 35.2 | | 31.9 | | 30 |
| **N Uptake From Soil** | | 154.1 | | 165.6 | | 175.4 | | 178.6 |
| **Ammonia volatilization** | | 44.7 | | 40.3 | | 36.7 | | 36 |
| **N Immobilized** | | 2 | | 2 | | 2 | | 2 |
| ***Total N balance*** | ***277.6*** | ***277.6*** | ***277.7*** | ***277.7*** | ***272.8*** | ***272.8*** | ***270.8*** | ***270.8*** |
| ***Kharif* 2012** | | | | | | | | |
| **Soil NO3** | 186.7 | 41.9 | 186.7 | 47.7 | 186.7 | 41.9 | 186.7 | 29.5 |
| **Soil NH4** | 21.1 | 9 | 21.1 | 8.1 | 21.1 | 9 | 21.1 | 8.5 |
| **Soil Urea** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Added to / Removed from Soil:** | | | | | | | | |
| **Fertilizer N** | 85 | | 85 | | 85 | | 85 | |
| **Mineralized N** | 14.8 | | 15.8 | | 14.8 | | 17.3 | |
| **Leached NO3** | | 0 | | 0 | | 0 | | 0 |
| **N Denitrified** | | 52.3 | | 52.1 | | 52.3 | | 45.9 |
| **N Uptake From Soil** | | 138.7 | | 135 | | 138.7 | | 160.7 |
| **Ammonia volatilization** | | 65.7 | | 65.6 | | 65.7 | | 65.5 |
| **N Immobilized** | | 0.1 | | 0 | | 0.1 | | 0 |
| ***Total N balance*** | ***307.6*** | ***307.6*** | ***308.7*** | ***308.7*** | ***307.6*** | ***307.6*** | ***310.1*** | ***310.1*** |

The initial soil nitrogen and the inorganic nitrogenous fertilizer added to soil are constant for all treatments. The $CO_2$ enrichment modelling using CERES Rice model shows that the nitrogen uptake is increasing and the mineralization and denitrification of soil nitrogen and ammonia volatilization is decreasing leading to increased NUE of rice crop. Therefore, it can be stated that the response of NUE of rice crop under $CO_2$ enrichment can be studied using crop simulations models which also indicates the nitrogen movement in soils and it's partitioning. The use of CERES Rice model to study the soil nitrogen dynamics was satisfactory (Nain and Kersebaum, 2007).

## 4.2 Conclusion

Genetic coefficients developed for *Sharbati* cultivar have been validated which suggests that CERES Rice model can be used with confidence for further studies. During validation of model it has been observed that crop response to $CO_2$ enrichment was positive. The crop phenology, grain yield, biomass, LAI, panicle number, grain number of rice cv *Sharbati* predicted under varying $CO_2$ enrichment conditions are closer to the observed values. The other uncertainities encountered in the simulations is due to failure of crop models to simulate the change in temperature (canopy) due to elevated $CO_2$ concentrations which reduces the grain yield. Similar findings has been reported by (Li et al., 2015) in which it was stated that the elevated $CO_2$ has a varying impact on canopy temperatures depending on the location and crop variety. The increase in temperature due to $CO_2$ elevation is not captured in the CERES rice models which leads to the difference in simulated/predicted results from the experimental results. Therefore, it can be concluded that the CERES Rice model can be used for predicting yields under $CO_2$ enriched conditions even for future scenarios with some exceptions.

# CHAPTER V

# CLIMATE CHANGE ASSESSMENT AND IMPACT ON RICE YIELD

## 5.1 Introduction

Any technology before it is transferred to field it has to be tested for its reliability not only for the present scenario but also for the future. Everywhere there is an emphasis on climate change and $CO_2$ also has a major role to play in such a scenario and therefore it is necessary to evaluate $CO_2$ enrichment for the coming years. With this objective the future weather for Haridwar district was forecasted using PRECIS RCM and given as weather input to CERES Rice model to study the effect of $CO_2$ enrichment on rice grain yield for the period 2014 - 2090 .

## 5.2 PRECIS RCM Data

### 5.2.1 Collection

PRECIS RCM data (Rainfall, Maximum Temperature and Minimum Temperature) was obtained from Indian Institute of Tropical Meteorology (IITM), Pune in binary format. This data is converted into *netcdf* format using FORTRAN program and thereafter the daily data of rainfall, maximum temperature and minimum temperature was extracted for Roorkee location (29$^{o}$ 52' N and 77$^{o}$ 54'S) for the period 01/01/1979-31/12/2090 using Arc GIS 9.3.

### 5.2.2 Extraction

PRECIS RCM daily weather data is available for 360 days/year considering 30 days per month only. Therefore the daily data was adjusted to match the Gregorian calendar days/month taking average of the last five days in the respective months and accounting the same for 31$^{st}$ day. No adjustment was made for the months having only 30 days/month. February is either 28 or 29 days/month therefore one or two days were deleted from the data of 30 days.

Data for the period 1979-2008 was used for calibration; data for the period 2009-2013 was used for validation whereas the data for the period 2014-2090 was bias corrected and used for climate and crop yield forecasting. Steps adopted are described below:

### 5.2.3 Bias correction

**1st Step: Correction for Standard Deviation (Leander and Buishand, 2007)**

$$P_{SDcorr} = \overline{P}_{obs} + \left( \frac{\sigma(P_{obs})}{\sigma(P_{rcm})} \right) \times \left( P_i - \overline{P_{obs}} \right) + \left( \overline{P_{obs}} - \overline{P_{rcm}} \right) \quad (5.1)$$

Where,

$P_{SDcorr}$ = Bias Corrected Precipitation or temperature (Daily/Monthly)

$\overline{P}_{obs}$ = Mean daily observed precipitation or temperature

$\overline{P}_{rcm}$ = Mean daily PRECIS precipitation or temperature

$\sigma(P_{obs})$ = Standard Deviation of the observed precipitation or temperature

$\sigma(P_{rcm})$ = Standard Deviation of the PRECIS precipitation or temperature

$P_i$ = Daily or monthly precipitation or temperature of PRECIS data

**2nd Step: Correction for Mean(Hay et al., 2002)**

$$P_{mean\,corr} = P_{SDcorr} \times \left( \frac{\overline{P_{obs}}}{\overline{P_{rcm}}} \right) \quad (5.2)$$

**3rd Step: Correction for Other biases:**

In the first step there is chance of generating negative values which is not desirable especially in case of precipitation and even in temperatures where it is either abnormally high or low. In order to check such biases the following conditions were employed.

1. The precipitation data of a given day was programmed in such a way that the negative values were automatically replaced with zero.
2. If the bias corrected value of maximum temperature (Tmax $^0$C) exceeds the observed maximum temperature (Tmax $^0$C) value of a given day during the calibration period then the bias corrected value will be replaced by the observed value.
3. If the bias corrected value of minimum temperature (Tmin $^0$C) is lower than the observed minimum temperature (Tmin $^0$C) value for a given day during the calibration period then the bias corrected value will be replaced by the observed value.

### 5.2.4 Statistical evaluation

Calibrated and validated data was evaluated by adopting Normalized Root Mean Square Error (NMSE, Mean Bias Error (MBE) Z-test, Forecast Accuracy (FA), Ratio Score or Hit Score.

Using all the above mentioned evaluation measures the forecast is verified and further climate change assessment is done using Mann-Kendall Trend Test (MKTT). Calibrated and validated data was evaluated by adopting following statistical tests:

#### 5.2.4.1 Normalized Root Mean Square Error (NMSE):

The Normalized Mean Squared Error is calculated between the original RCM data and bias corrected RCM data. This has already been discussed in Chapter 4.

#### 5.2.4.2 Mean Bias Error (MBE):

MBE is simply the difference between the average forecast and average observed values, and therefore expresses the bias of the forecasts. Forecasts values that are higher than the observed values will exhibit MBE >0 and Forecasts values that are lower than the observed values will exhibit MBE < 0.

$$MBE = \frac{1}{N} * \left( \sum \left( P_{corr} - P_{obs} \right) \right) \tag{5.3}$$

Where,

N = number of observations.

SD= Standard Deviation

$P_{corr}$= Bias corrected value

$P_{obs}$= Observed value

#### 5.2.4.3 T-test

It is the most widely used statistic to test the number of standard errors of the forecasted from the observed .The t-statistic was calculated using the formula:

$$t = \frac{(\bar{x}_1 - \bar{x}_2) - (\mu_1 - \mu_2)}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}} \tag{5.4}$$

Where

$\bar{x}_1 \,\&\, \bar{x}_2$ = sample mean of group 1 & 2 respectively

$\mu_1 \,\&\, \mu_1$ = population mean of group 1& 2 respectively

$\sigma_1 \,\&\, \sigma_2$ = Standard Deviation of Group 1 & 2 respectively

$n_1 \,\&\, n_2$ = sample size of group1 and group2

#### 5.2.4.4 F-test

F-statistic/testis also used in ANOVA and regression analysis to determine if the variance of two populations is significantly different. F-test was calculated using the equation

$$F = \frac{S_1^2}{S_2^2} \tag{5.5}$$

**Where**

$S_1 \,\&\, S_2$ = Variance of group1 & group 2 respectively

*Note: Variance is the square of standard deviation.*

Hypothesis for Z – test and F-test

| | |
|---|---|
| Null Hypothesis ($H_0$): | We accept the null hypothesis when the test statistic is less than the tabulated value, which states that there is no significant difference between the two populations. |
| Alternate Hypothesis ($H_1$): | We reject the null hypothesis and accept the alternate hypothesis when the test statistic greater than the tabulated value. This states that the two populations differ significantly from each other. |

#### 5.2.4.5 Correlation Coefficient (CC)

Numerical as well as graphical analyses are involved in the correlation analysis. A value of correlation coefficient (r) close to unity implies good forecast. The numerical result gives a quantitative relation, while graphical analysis gives a qualitative measure of the observed and predicted parameters. In equation form it is represented as:

$$r = \frac{\overline{(P_{obs} - \overline{P}_{obs})(P_{corr} - \overline{P}_{corr})}}{SD_{P_{corr}} * SD_{P_{obs}}} \tag{5.6}$$

#### 5.2.4.6 Forecast Accuracy (FA):

A contingency table (Table 0.1)was prepared for further analysis of rainfall data (bias corrected and observed) using (Wilks, 2006)methodology as described below:

**Table 5.1: Rainfall contingency table**

| | | **Observed** | |
|---|---|---|---|
| | | **Yes** | **No** |
| **Bias Corrected** | **Yes** | A (YY)<br>(Hits) | B (YN)<br>(False alarms) |
| | **No** | C (NY)<br>(Misses) | D (NN)<br>(Correct rejects) |

Where,

i. A (YY) = No. of Hits (predicted and observed).
ii. B (YN)= No. of False Alarms (predicted but not observed)
iii. C (NY)= No. of misses (observed but not predicted), and
iv. D (NN) = No. of correct rejects

It is the ratio of the number of correct forecasts to the total number of forecasts. It varies from 0 to 1. Perfect forecast is indicated as 1.

$$FA = \left( \frac{A + D}{A + B + C + D} \right) * 100 \tag{5.7}$$

Using all the above mentioned forecast evaluation measures the forecast is verified and further climate change assessment is done using Mann-Kendall Trend Test (MKTT).

### 5.2.5 Trend Analysis

To assess future climate change it is necessary to observe the variability and magnitude of change. To assess the trend and its magnitude MKTT(Kendall, 1948) which is one of the widely used non-parametric tests to detect significant trends in time series was used along with Theil Sen's Slope estimator. MKTT, being a function of the ranks of the observations rather than their actual values, is not affected by the actual distribution of the data and is less sensitive to outliers.

#### 5.2.5.1 Mann-Kendall Trend Test

Mann Kendal statistics (*S)* is defined as follows:

$$S=\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\operatorname{sgn}\left(x_j-x_i\right) \tag{5.8}$$

Where *N* is the number of data points. Assuming $(xj - xi) = \theta$, the value of sgn ($\theta$) is computed as follows:

$$\operatorname{sgn}(\theta)=\begin{cases}1 & \text{if } \theta>0\\ 0 & \text{if } \theta=0\\ -1 & \text{if } \theta<0\end{cases} \tag{5.9}$$

It has been documented that when n ≥ 8, the statistic S is normally distributed with the mean.

$$E(S) = 0 \tag{5.10}$$

The variance is written as-

$$\delta(S)=\frac{N(N-1)(2N+5-\sum_{i=1}^{m}(t_i-1)\,(2t_i+5)}{18}. \tag{5.11}$$

Where, Nis the number of ties group and $t_i$the number of data points in the $t_{ih}$ tied group. Then *Z*-statistics computed as:

$$Z=\begin{cases}\dfrac{S-1}{\sqrt{Var\,(S)}} & \text{if } S>0\\ 0 & \text{if } S=0\\ \dfrac{S+1}{\sqrt{Var\,(S)}} & \text{if } S<0\end{cases}. \tag{5.12}$$

Here Z follows standard normal distribution. A positive value of Z indicates upward trend and negative value indicate downward trend.If the *Z value is greater than* $Z_{0.05/2}$, then null hypothesis ($H_0$) is rejected at 0.05 level of significance.

### 5.2.5.2 Theil–Sen's estimator

The slope of n pairs of data points was estimated using the Theil–Sen's estimator(Sen, 1968; Theil, 1992)which is given by the following relation:

$$\beta = Median\ \frac{x_j-x_i}{j-i}\ forall\ i\le j \tag{5.13}$$

In which $1<j<i<n$ and $\beta$ is the robust estimate of the trend magnitude. A positive value of $\beta$ indicates an 'upward trend', while a negative value of $\beta$ indicates a 'downward trend' (Xu et al., 2008)(Xu et al., 2007).

### 5.2.6 IPCC $CO_2$ Emission Scenarios

IPCC has developed four possible $CO_2$ emission scenarios viz. A1, A2, B1 and B2 for every country according to its topographical, economic, technological and social backgrounds. They are described in the forthcoming paragraphs.

The A1 scenario describes a future world of very rapid economic growth; rapid population growth that attains its peaks in mid-century and declines thereafter as well as the rapid introduction of new and efficient technologies for fast increasing the per capita income. This scenario is applicable to developed nations.

The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines. This scenario is applicable to developing nations.

The B1 storyline and scenario family describes a convergent world with the same global population that peaks in midcentury and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. This scenario is applicable to under developed nations.

The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. This scenario is applicable to resource constrained poor nations.

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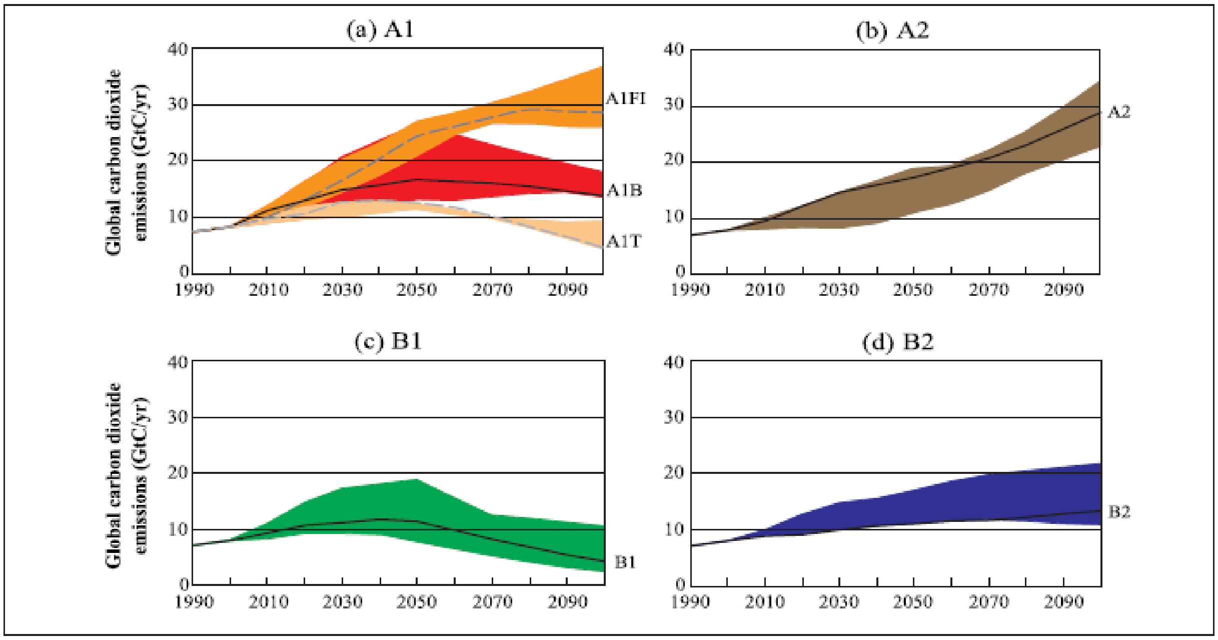


**Figure 5.1: Total global annual $CO_2$ emissions from 1990 to 2100 (GtC/yr) for the 4 IPCC SRES scenarios (A1, A2, B1, and B2). a) A1 b) A2 c) B1 and d) B2.**

High emission scenario of A2 and low emission scenario of B2 were taken under this study. The study of two extreme conditions and their effect on rice grain yields will enable us to prepare for the upcoming future.

### 5.2.7 Data in DSSAT Format

Considering Uttarakhand's technological and socio economical developments A1 and B2 scenarios were selected for this study. Bias corrected PRECIS RCM weather data for the period 2014 – 2090 was arranged in DSSAT format for generating a weather file. Daily Solar Radiation data for the period 01/01/2014- 31/12/2090 using Hargreaves and Samani Method(Pranuthi and Tripathi, 2011). Soil file, genetic coefficient file and crop management files were adopted from Chapter IV.

## 5.3 Climate Change Assessment

### 5.3.1 Bias Correction of Tmax, Tmin and Rainfall data

The PRECIS original data (RCM) was more biased from the observed data which made it unusable for further studies. So, to make it usable the bias correction methods had to be employed for reliable crop yield forecasts. For calibration, weather data from 1979-2009 was selected as training set. The bias corrected data was evaluated using various statistical measures and the evaluation results between observed, RCM predicted and bias corrected RCM data during the calibration period are presented in Table 5.2. The observed, RCM predicted and bias corrected RCM average annual rainfall are 985.2 mm 755.4 mm and 1021.0 mm respectively during the calibration period. The observed, RCM predicted and bias corrected RCM mean maximum temperatures are 30.0$^0$C, 31.1$^0$C and 30.0$^0$C respectively during the period 1979 – 2009. The observed, RCM predicted and bias corrected RCM mean minimum temperatures are 17.4$^0$C, 19.2$^0$C and 17.35$^0$C respectively during the period 1979 – 2009. Standard Deviation of observed, RCM predicted and bias corrected RCM average annual rainfall are 116.5 mm, 89.0 mm and 127.3 mm respectively. Standard Deviation of observed, RCM predicted and bias corrected RCM average annual rainfall are 5.7$^0$C, 8.6$^0$C and 5.8$^0$C respectively. Standard Deviation of observed, RCM predicted and bias corrected RCM average annual rainfall are 7.0$^0$C, 8.9$^0$C and 7.15$^0$C respectively. The MBE of RCM predicted rainfall, maximum and minimum temperatures from the observed values is -19.2 mm, 1.0$^0$C and 1.8$^0$C respectively. The MBE of bias corrected rainfall, maximum and minimum temperatures from the observed values is 2.9 mm, -0.04$^0$C and **-0.03**$^0$C respectively. The NMSE calculated between observed and RCM predicted rainfall, maximum and minimum temperatures is 0.007, 0.15 and 0.08 respectively. The NMSE calculated between observed and bias corrected rainfall, maximum and minimum temperatures is 0.008, 0.1 and 0.05 respectively. t test and F test results showed that the RCM predicted rainfall data is significantly different from the observed data.

During validation period (2010 – 2013) the observed, RCM predicted and bias corrected RCM average annual rainfall are 1249.4 mm, 863.7mm and 1237.5 mm respectively (Table 5.3). The observed, RCM predicted and bias corrected RCM mean maximum temperatures are 29.9$^0$C, 31.7$^0$C and 29.8$^0$C respectively. The observed, RCM predicted and bias corrected RCM mean minimum temperatures are 18.3$^0$C, 19.4$^0$C and 18.4$^0$C respectively. Standard Deviation of observed, RCM predicted and bias corrected RCM average annual rainfall are 168.9 mm, 115.5 mm and 182.9 mm respectively. Standard Deviation of observed, RCM predicted and bias corrected RCM average annual rainfall are 6.0$^0$C, 8.3$^0$C and 6.1$^0$C respectively. Standard Deviation of observed, RCM predicted and bias corrected RCM average annual rainfall for the period 2010 – 2013 are 6.6$^0$C, 8.5$^0$C and 6.7$^0$C respectively.

**Table 5.2: Observed, RCM and bias corrected RCM monthly data of Rainfall, Tmax and Tmin during the period 1/1/1979 – 31/12/2009.**

| | Rainfall (mm) | | | Tmax ($^0$C) | | | Tmin ($^0$C) | | |
|---|---|---|---|---|---|---|---|---|---|
| **Month** | **Obs** | **RCM** | **RCM Corr** | **Obs** | **RCM** | **RCM Corr** | **Obs** | **RCM** | **RCM Corr** |
| **Jan** | 29.0 | 24 | 29.4 | 20.0 | 18.6 | 21.6 | 6.8 | 5.1 | 5.98 |
| **Feb** | 36.9 | 14 | 16.3 | 23.2 | 24.9 | 25.9 | 9.4 | 9.2 | 9.27 |
| **Mar** | 25.8 | 23 | 27.6 | 28.6 | 32.5 | 30.9 | 13.5 | 16.4 | 15.08 |
| **Apr** | 17.9 | 16 | 18.0 | 34.9 | 38.9 | 35.3 | 18.2 | 22.7 | 20.23 |
| **May** | 33.6 | 12 | 13.0 | 37.3 | 45.3 | 39.6 | 22.7 | 29.9 | 26.00 |
| **Jun** | 104.1 | 85 | 115.6 | 36.3 | 42.6 | 37.8 | 25.1 | 31.4 | 27.19 |
| **Jul** | 273.4 | 264 | 373.8 | 33.6 | 32.9 | 31.2 | 25.7 | 26.8 | 23.48 |
| **Aug** | 273.7 | 194 | 272.9 | 32.9 | 31.7 | 30.4 | 25.4 | 25.9 | 22.82 |
| **Sep** | 148.7 | 56 | 73.7 | 32.6 | 32.3 | 30.8 | 23.6 | 24.1 | 21.36 |
| **Oct** | 23.1 | 21 | 26.0 | 31.3 | 30.1 | 29.3 | 18.1 | 19.2 | 17.35 |
| **Nov** | 5.8 | 26 | 32.0 | 27.2 | 24.2 | 25.4 | 12.4 | 12.8 | 12.16 |
| **Dec** | 13.2 | 20 | 22.5 | 22.4 | 18.8 | 21.8 | 7.9 | 6.8 | 7.34 |
| **Total/Avg** | **985.2** | **755.4** | **1021.0** | **30.0** | **31.1** | **30.0** | **17.4** | **19.2** | **17.35** |
| **SD** | **116.5** | **89.0** | **127.3** | **5.7** | **8.6** | **5.8** | **7.0** | **8.9** | **7.15** |
| **MBE** | | **-19.2** | **2.9** | | **1.0** | **-0.04** | | **1.8** | **-0.03** |
| **NMSE** | | **0.007** | **0.008** | | **0.15** | **0.10** | | **0.08** | **0.05** |
| **Z-Test** | | **2.52*** | **-0.33** | | **-1.91** | **0.10** | | **-3.06*** | **0.06** |
| **F-Test** | | **1.71*** | **0.84** | | **0.45** | **0.98** | | **0.63** | **0.96** |

** indicates significance at 0.05 level of significance*

The evaluation of bias corrected PRECIS RCM data for the validation period (2010 – 2013) is presented in Table 5.3.The MBE of RCM predicted rainfall, maximum and minimum temperature from the observed values is -32.1mm, 1.7$^0$C and 1.2$^0$Crespectively. The MBE of bias corrected rainfall, maximum and minimum temperatures from the observed values is -0.9mm, -0.2$^0$C and 0.1$^0$C respectively. The NMSE calculated between observed and RCM predicted rainfall, maximum and minimum temperatures is 0.004, 0.1 and 0.09 respectively. The NMSE calculated between observed and bias corrected rainfall, maximum and minimum temperatures is 0.005, 0.08 and 0.06 respectively. t test results showed that the RCM predicted maximum and minimum temperature data is significantly different from the observed values. F test results indicate that the rainfall predicted by PRECIS RCM is significantly different from the observed values. The t-test and F test values showed that the bias corrected RCM data and observed are not significantly different from each other.

**Table 5.3: Observed, RCM and bias corrected RCM monthly data of Rainfall, Tmax and Tmin during the period 1/1/2010 – 31/12/2013.**

| | Rainfall (mm) | | | Tmax ($^0$C) | | | T min ($^0$C) | | |
|---|---|---|---|---|---|---|---|---|---|
| **Month** | **Obs** | **RCM** | **RCM Corr** | **Obs** | **RCM** | **RCM Corr** | **Obs** | **RCM** | **RCM Corr** |
| **Jan** | 29.7 | 18.3 | 21.8 | 18.2 | 20.2 | 21.3 | 6.7 | 5.6 | 7.39 |
| **Feb** | 59.3 | 28.7 | 28.5 | 23.5 | 24.4 | 24.4 | 12.1 | 10.3 | 11.11 |
| **Mar** | 7.0 | 4.5 | 1.8 | 30.0 | 31.8 | 29.9 | 16.0 | 15.7 | 15.37 |
| **Apr** | 8.0 | 10.9 | 6.7 | 34.6 | 38.1 | 34.5 | 19.5 | 22.4 | 20.72 |
| **May** | 37.6 | 10.5 | 10.2 | 37.7 | 44.6 | 39.3 | 23.3 | 28.8 | 25.83 |
| **Jun** | 135.0 | 35.8 | 43.0 | 35.9 | 44.7 | 39.4 | 25.5 | 31.9 | 28.25 |
| **Jul** | 364.6 | 291.6 | 451.7 | 32.8 | 34.7 | 32.0 | 25.5 | 26.8 | 24.23 |
| **Aug** | 410.5 | 278.9 | 431.1 | 32.4 | 31.9 | 29.9 | 24.8 | 25.9 | 23.49 |
| **Sep** | 170.3 | 122.1 | 178.8 | 33.1 | 32.1 | 30.1 | 24.1 | 23.5 | 21.64 |
| **Oct** | 6.6 | 6.1 | 0.1 | 31.8 | 31.5 | 29.7 | 19.3 | 19.7 | 18.62 |
| **Nov** | 0.5 | 23.9 | 27.9 | 27.7 | 25.2 | 25.0 | 13.7 | 14.1 | 14.14 |
| **Dec** | 20.6 | 32.6 | 36.0 | 21.9 | 21.2 | 22.0 | 8.7 | 8.5 | 9.70 |
| **Total/Avg** | **1249.4** | **863.7** | **1237.5** | **29.9** | **31.7** | **29.8** | **18.3** | **19.4** | **18.4** |
| **SD** | **168.9** | **115.5** | **182.9** | **6.0** | **8.3** | **6.1** | **6.6** | **8.5** | **6.7** |
| **MBE** | | **-32.1** | **-0.9** | | **1.7** | **-0.2** | | **1.2** | **0.1** |
| **NMSE** | | **0.004** | **0.005** | | **0.1** | **0.08** | | **0.09** | **0.06** |
| **t-Test** | | **1.78** | **0.05** | | **-2.59*** | **0.35** | | **-2.21*** | **-0.26** |
| **F-Test** | | **2.14*** | **0.85** | | **0.53** | **0.98** | | **0.61** | **0.96** |

** indicates significance at 0.05 level of significance*

The hit score calculated for RCM predicted and bias corrected RCM rainfall data during calibration and validation are given in Table 5.4. The hit score for RCM predicted rainfall data and bias corrected RCM rainfall data during calibration period is 0.35 and 0.69 respectively. From this score it is evident that there is improvement in the FA in bias corrected RCM (0.74) than the RCM predicted (0.69) rainfall data during validation period.

The bias correction of mean and standard deviation resulted in decreased mean bias error. For maximum temperatures the MBE was brought down from 1.0 to -0.04 and for minimum temperatures it is brought down from 1.8 to 0.03. Even NMSE was reduced to 0.10 from 0.15 and 0.05 from 0.08 in case of maximum and minimum temperatures respectively. But in case of rainfall the NMSE increased from 0.007 to 0.008 but the MBE decreased from -19.2 to 2.9. Even during validation period bias correction decreased the MBE and NMSE of RCM data from 1.2 to 0.1 and 0.09 to 0.06 respectively for minimum temperature. MBE and NMSE for temperatures indicated that the bias correction method applied was good, which can also be applied for the remaining of the data. The applicability of bias correction method to rainfall data cannot be ascertained due to inconsistency in the values of MBE and NMSE.

**Table 5.4: Hit score of RCM and bias corrected RCM monthly rainfall for the period 01/01/1979-31/12/2013.**

| Months | Hit Score of RCM | | Hit Score of Bias corrected RCM | |
|---|---|---|---|---|
| | 1979-2009 | 2010-2013 | 1979-2009 | 2010-2013 |
| **Jan** | 0.33 | 0.63 | 0.67 | 0.73 |
| **Feb** | 0.50 | 0.68 | 0.66 | 0.67 |
| **Mar** | 0.39 | 0.81 | 0.70 | 0.84 |
| **Apr** | 0.38 | 0.72 | 0.77 | 0.81 |
| **May** | 0.57 | 0.77 | 0.71 | 0.79 |
| **Jun** | 0.41 | 0.53 | 0.60 | 0.6 |
| **Jul** | 0.42 | 0.44 | 0.46 | 0.48 |
| **Aug** | 0.47 | 0.45 | 0.51 | 0.52 |
| **Sep** | 0.25 | 0.49 | 0.59 | 0.67 |
| **Oct** | 0.13 | 0.89 | 0.89 | 0.93 |
| **Nov** | 0.15 | 0.74 | 0.91 | 0.93 |
| **Dec** | 0.23 | 0.75 | 0.86 | 0.9 |
| **Annual** | **0.35** | **0.69** | **0.69** | **0.74** |

The monthly hit score shows that bias corrected data FA is better during all the months during calibration period. Even during validation the bias corrected PRECIS forecast showed higher hit rate than the original PRECIS data except for January, February , March and May months but overall FA is higher for bias corrected PRECIS rainfall data.

The bias correction method used in this study is a combination of two methods(Hay et al., 2002) and (Leander and Buishand, 2007). The method suggested by (Hay et al., 2002) was used to bias correct rainfall and (Leander and Buishand, 2007)method was used to bias correct maximum and minimum temperature. The first method is used to correct the mean of precipitation and second method is used to correct coefficient of variation (CV) of maximum and minimum temperatures. These both methods are combined to bias correct the mean and CV of rainfall, maximum and minimum temperature in this study. However the method suggested in this research can be applied to bias correct any climatic parameter as such. The reduction in bias o PRECIS RCM data was reportedly decreased after employing various bias correction methods(Akhtar et al., 2009; Teutschbein and Seibert, 2012).

### 5.3.2 Climate Change Assessment using Mann Kendall Trend Analysis

#### 5.3.2.1 Annual Trend

Trend analysis of future rainfall, maximum and minimum temperatures predicted by PRECIS RCM revealed that increase in annual rainfall and temperatures is significant. Theil Sen's slope estimated for PRECIS weather by 2090 is 5.828mm/yr., $0.046^0$C/yr. and $0.039^0$C/yr. for annual rainfall, maximum and minimum temperatures respectively. After the completion of correction and trend analysis of PRECIS RCM data it can be concluded that the rainfall would increase upto 450 mm and maximum and minimum temperatures by 3.6 $^0$C and $3.0^0$C by the end of 2090.

**Table 5.5: Mann Kendall test and Thiel Sen's slope for rainfall, Tmax and Tmin for the monthly forecasted data (2014 - 2090).**

| Month | Rainfall (2014 - 2090) | | | T max (2014 - 2090) | | | Tmin (2014 - 2090) | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Z** | **Sig** | **Sen's Slope** | **Z** | **Sig** | **Sen's Slope** | **Z** | **Sig** | **Sen's Slope** |
| Jan | -1.05 | | -0.041 | **3.58** | *** | **0.051** | **4.74** | *** | **0.032** |
| Feb | 0.79 | | 0.012 | **3.03** | ** | **0.041** | **5.57** | *** | **0.043** |
| Mar | 0.69 | | 0.019 | **2.23** | * | **0.025** | **4.41** | *** | **0.030** |
| **Apr** | **-1.99** | * | **-0.065** | **5.01** | *** | **0.050** | **4.25** | *** | **0.030** |
| May | 0.05 | | 0.000 | **5.31** | *** | **0.045** | **4.74** | *** | **0.027** |
| Jun | 0.78 | | 0.370 | **2.97** | ** | **0.039** | **4.26** | *** | **0.028** |
| **Jul** | **4.40** | *** | **3.310** | **5.98** | *** | **0.041** | **9.00** | *** | **0.042** |
| **Aug** | **4.68** | *** | **3.161** | **7.20** | *** | **0.045** | **9.43** | *** | **0.038** |
| Sep | -1.23 | | -0.632 | **7.02** | *** | **0.048** | **8.40** | *** | **0.042** |
| **Oct** | **-1.81** | + | **-0.001** | **6.60** | *** | **0.058** | **6.88** | *** | **0.061** |
| Nov | -0.68 | | 0.000 | **4.63** | *** | **0.039** | **5.39** | *** | **0.044** |
| Dec | 0.62 | | 0.004 | **4.15** | *** | **0.050** | **5.99** | *** | **0.040** |
| ***Kharif*** | **3.91** | *** | **6.005** | **7.32** | *** | **0.048** | **8.76** | *** | **0.043** |
| **Annual** | **3.97** | *** | **5.828** | **7.47** | *** | **0.046** | **9.50** | *** | **0.039** |

**** Significant trend at 0.001 level of significance, ** Significant trend at 0.01 level of significance, *Significant trend at 0.05 level of significance, +Significant trend at 0.1 level of significance,*

*Note: Bold values indicate significance of trend at any level of significance*

#### 5.3.2.2 Seasonal Trend

The increase in rainfall (462 mm) during rainy months (*Kharif*) is more prominent and is likely to impact the yields of rice crop. Even the alteration in temperatures would affect the development of rice crop as it is expected that the temperature during the crop growth period (June – October) is likely to increase by 3.7 and $3.3^0$C for maximum and minimum temperatures respectively. The change in the rainfall amounts and temperature would also alter many other weather parameters such as humidity, evaporation wind speed etc. which would in turn directly or indirectly affects the crop growth and development.

For Haridwar district the PRECIS RCM predicted that annual rainfall, maximum and minimum temperatures are likely increase by 2090. Increasing GHG concentrations are the most probable reason that could be attributed to this increase. PRECIS RCM predicted that all India annual mean temperatures would increase by 3.5 – 4.3$^{0}$C by the end of this century. Similarly, all India annual precipitation would increase by 9 – 16% with negative trend towards south and western states according to a study done by (Akhtar et al., 2009; Kumar et al., 2006).

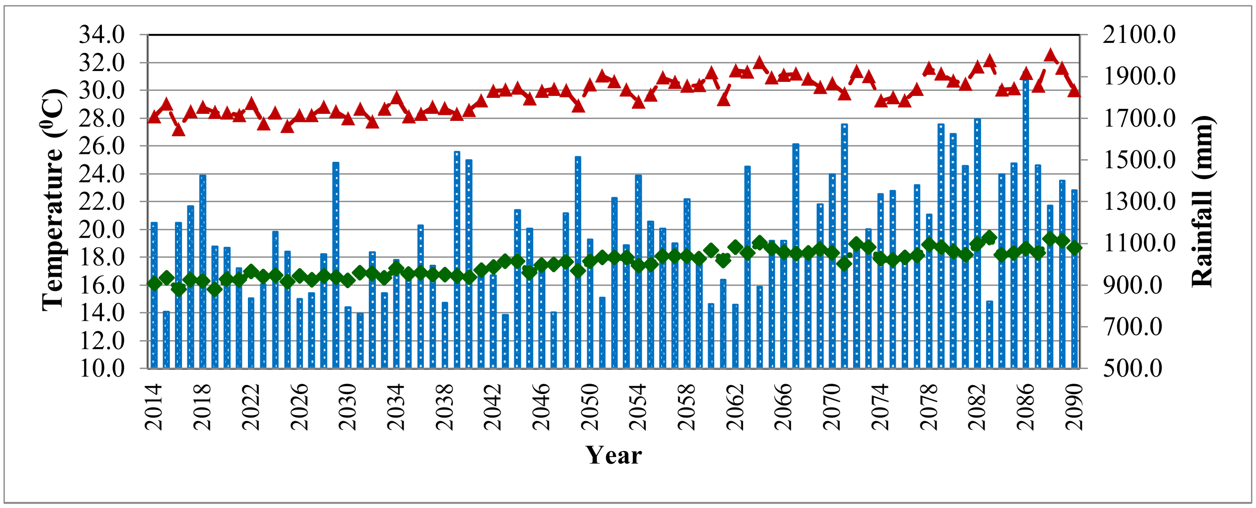


**Figure 5.2: Forecasted annual rainfall and annual average Tmax, Tmin and SRAD for Haridwar district during 2014 – 2090.**

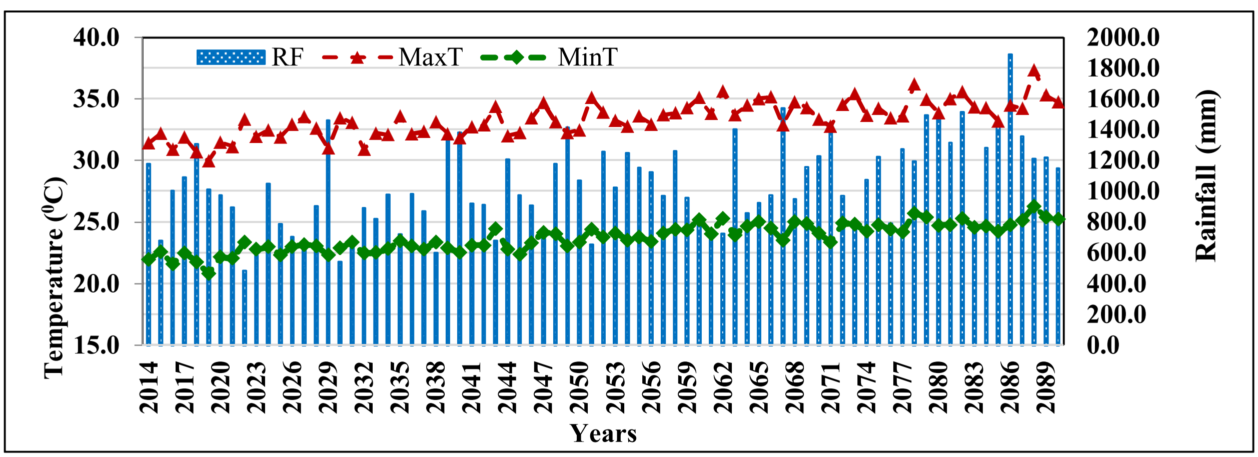


**Figure 5.3: Forecasted *Kharif* rainfall and *Kharif* average Tmax, Tmin and SRAD for Haridwar district during 2014 – 2090**

### 5.3.3 Effect of $CO_2$ enrichment and climate change on crop yield of rice crop for the period 2020 – 2090.

Rice productivity in A2 & B2 scenario presuming no constraint of insect pest and disease, soil fertility, water and management constraint is presented in Table 5.6. Results indicated that rise in $CO_2$ concentration will significantly the rice grain yield. The average grain yield of rice during 2020-2090 under A2 and B2 scenario is 6969 kgs/ha and 6370 kgs/ha respectively. Rice productivity will rise up to 2070 and decline thereafter under both the scenarios probably due to excessive rainfall.

**Table 5.6: Decadal average of yield and weather for that corresponding decade simulated by CERES rice model under A2 and B2 emission scenarios for the period 2020 – 2090 for rice crop cv. Sharbati.**

| Decade | Yield (kgs/ha) | | Tmax ($^0$C) | Tmin ($^0$C) | SRAD (MJ/m$^2$/day) | RF (mm) | ET (mm) | $CO_2$ conc (in ppm) | |
|---|---|---|---|---|---|---|---|---|---|
| | A2 | B2 | | | | | | A2 | B2 |
| 2020 | 6210 | 6163 | 31.2 | 23.6 | 18.3 | 882.2 | 427.3 | 438 | 432 |
| 2030 | 6232 | 6008 | 33.1 | 24.4 | 20 | 496.4 | 444.5 | 506 | 476 |
| 2040 | 6799 | 6143 | 32.2 | 24.2 | 19.1 | 924 | 431.5 | 578 | 520 |
| 2050 | 7422 | 7068 | 32.6 | 25 | 18.5 | 601.1 | 439.4 | 654 | 566 |
| 2060 | 7159 | 6377 | 34.7 | 26.5 | 19.5 | 602.9 | 466.8 | 732 | 606 |
| 2070 | 7509 | 6747 | 33.4 | 26 | 18.5 | 826.8 | 417.8 | 812 | 642 |
| 2080 | 7219 | 6284 | 34.4 | 26.8 | 19.1 | 1104.3 | 408.9 | 900 | 670 |
| 2090 | 7203 | 6170 | 34.8 | 27.2 | 19 | 908.3 | 426.2 | 1000 | 694 |
| Mean | 6969 | 6370 | 33.3 | 25.5 | 19 | 793.3 | 432.8 | 702.5 | 575.8 |
| $CO_2$ – Effect : F calculated: 11.66; F critical: 5.59 CD (Tukey): 492 kgs/ha | | | | | | | | | |
| CC- Effect : F calculated: 22.61; F critical: 3.78 CD (Tukey): 748 kgs/ha | | | | | | | | | |

Grain yield of rice cv Sharbati for the period 2020-2090 was simulated by running DSSAT CERES rice model with PRECIS RCM weather data of Haridwar district and IPCC $CO_2$ scenarios. The simulation result showed that if the crop is grown with the existing soil and crop management conditions, rice productivity of Haridwar in general will decrease @ 16.7 kgs/ha/yr. This could be attributable to the climate change scenario. The simulated rice grain yield was reported to decrease @ 273 kgs/ha with every 1$^0$C increase in minimum temperature (Peng et al., 2004). Decreased rice yields from increased minimum temperature has also been reported (Seshu and Cady, 1984).

## 5.4 Conclusion

The statistical bias correction method adopted to correct PRECIS RCM data was found suitable for bias correction with NMSE less than 0.1. Trend analysis of RCM data for the period 2014 - 2090 showed that the rainfall would increase @ 6.005 mm/yr., maximum temperature @ $0.048^0$C/yr. and minimum temperature @ $0.043^0$C/yr. for *Kharif* season. DSSAT CERES rice simulations under climate change and higher $CO_2$ concentrations showed that the yields will decline with the advancing climate change but $CO_2$ intervention will compensate the loss in yield.

# CHAPTER VI

# STRATEGIC MANAGEMENT OPTIONS

## 6.1 Introduction

DSSAT crop models not only simulate the impact of climate change and $CO_2$ concentrations on crops but can also evaluate various management options under climate change scenario (Doering III, 2002). The impacts of climate change and $CO_2$ concentration on rice crop yield in the future years have been discussed in the earlier sections of the study. (Thornton et al., 2011) hypothesized that to combat with the uncertainty in future, will require quite radical shifts in agriculture systems, rural livelihood strategies and food security strategies and policies. Proactive adaptation will require much more concerted effort at all levels to manage quite radical shifts, for example, the evaluation of successful adaptation becomes more difficult. For crops, changes in management practices and strengthening of seed systems are two key approaches to adapting agricultural systems (Challinor et al., 2007).

Previous research conducted in developing country settings indicates that, in principle, climate change impacts on agriculture can be reduced through human adaptations such as; adjusting sowing dates, irrigation and nutrient management (Winter, 1998) and adopting higher yielding and heat resistant cultivars (Butt et al., 2005).

## 6.2 Effect of planting date on potential yield

Previous studies had suggested that adjusting sowing dates might be a simple and powerful tool for mitigating the effects of a potential global warming (Baker and Allen Jr, 1993). The first step in defining adaptation strategies was to run simulations moving the sowing dates within different time windows, hence exploring the best management practice. According to the agriculture contingency plan developed by the Government of Uttarakhand for Haridwar district suggests the normal planting window varies from 1$^{st}$ week of July to 3$^{rd}$ week of July (delayed). Potential yield was simulated for a range of planting dates (at 7-day intervals from 7$^{th}$ July to 21$^{st}$ July) for 77 years (2014 – 2090) of PRECIS predicted weather data for Haridwar district.

**Table 6.1: Effect of variable planting dates on rice grain yield and weather condition during that respective crop periods.**

| Planting Date | Yield (kgs/ha) | | | | | Crop Period | T max | Tmin | SRAD | RF | ET |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | T0 | T1 | T2 | T3 | Mean | DAP | ($^0$C) | ($^0$C) | (MJm$^{-2}$day$^{-1)}$ | (mm) | |
| 7th July | 6644.7 | 7740.3 | 8775.8 | 9369.7 | 8132.6 | 92.1 | 33.1 | 25.5 | 19.1 | 874.0 | 419.6 |
| 14th July | 6908.6 | 7928.1 | 8992.5 | 9564.4 | 8348.4 | 94.2 | 32.8 | 24.9 | 18.9 | 793.9 | 421.6 |
| 21st July | 7338.2 | 8443.5 | 9529.5 | 10143.0 | 8863.5 | 98.6 | 32.7 | 23.9 | 19.0 | 701.5 | 453.3 |
| $CO_2$ Treatments: F calculated: 211.2; F critical: 2.6 ; | | | | | | | | | | | |
| Planting Date: F calculated: 27.4; F critical: 3.0; | | | | | | | | | | | |
| Interaction: F calculated: 4.8; F critical: 2.4 | | | | | | | | | | | |

It is evident from the probability and F calculated values of ANOVA analysis given in Table 6.1 that the grain yield of rice was significantly affected by both $CO_2$ treatments and variable planting dates. Average weather conditions along with the grain yield during the study period (2014 – 2090) are summarized in the Table 6.1 which showed that growth period is extended under late planting conditions by one week on an average. It is also observed that the amount of rainfall (701.5 mm) received during the crop period in late planted (21$^{st}$ July) crop is less and ET (453 mm) is more. Therefore, in late planted the crop would need more water and also would need more attention due to extended crop period. The Tukey posthoc critical difference of 567 kgs/ha suggests that the yield for planting date 7$^{th}$ July and 14$^{th}$ July were found to be ideal dates if the climate change persists. According to the simulations by CERES rice model the general practice of transplanting rice during the 1$^{st}$ week of July followed by the farmers of the district was found to be a good practice.

## 6.3 Effect of plant spacing on potential yield

The three different populations per square meter i.e. 25, 33 and 44 plants per m$^2$ with row to plant spacing of 20 cm x 20 cm, 20 cm x 15 cm, and 20 cm x 10 cm respectively were kept for simulating the yield and to identify the optimum plant population that could be adapted by the farmers to maximize yields and reduce the ill effects of climate change.

It is evident from the F calculated values of ANOVA analysis that the grain yield of rice was significantly affected by different plant populations and $CO_2$ enrichment treatments (Figure 6.1). The ANOVA results indicate a good interaction between plant spacing and $CO_2$ treatments. The spacing of 20 cm x 15 cm had the highest yield of 9698 kgs/ha under T2 treatment (Figure 6.1) and lowest yield was simulated for the plant spacing of 20 cm x 20 cm (6035 kgs/ha) for T3 treatment. Practically, the closer spacing leads to competition between the plants for sunlight, water and nutrients it also leads difficulty in intercultural operations and increases the susceptibility of plants to pests and diseases. Therefore, it can be concluded that the general practice 20 x 15 spacing (33 hills per $m^2$) adapted by the farmers of the district is ideal even under climate change conditions.

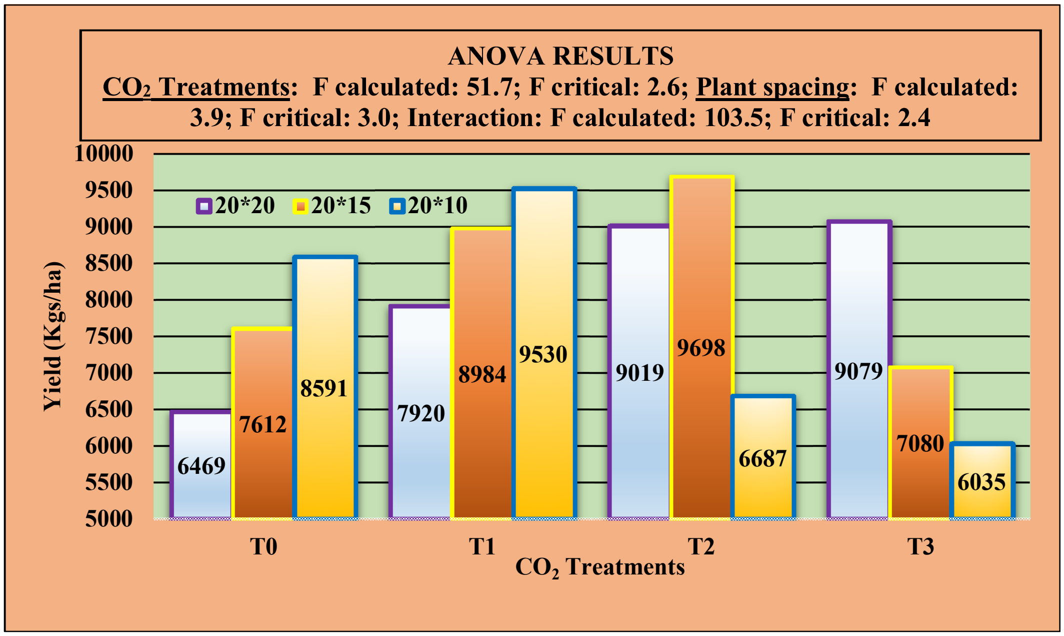


**Figure 6.1: Rice grain yield as effected by variable planting spacing, ANOVA analysis of treatments as simulated by CERES Rice model.**

## 6.4 Effect of Nitrogen Management on potential yield

Variable rates of nitrogen at various stages were given as different nitrogen treatments (Table 6.2) to select the best nitrogen management practice for suggesting to farmers of Haridwar district Uttarakhand. The yield of rice crop cultivar *Sharbati* has been simulated for the coming years with three levels of nitrogen 60kgs N/ha, 90kgs N/ha and 120kgs N/ha for opting best nitrogen management.

The ANOVA analysis of rice yield simulations under varying nitrogen amounts is given in Figure 6.2. The F calculated shows that the effect of nitrogen is significant on rice yield. Highest average yields are simulated under 120 kgs N/ha (9008 kgs/ha) for T3 treatment while the lowest yields are simulated for 60 kgs N/ha (7351 kgs/ha) for T0 treatment for the period 2014 - 2090. Higher the nitrogen levels higher is the yield, but from Tukey critical difference CD of 638 kgs/ha, it is evident that the yield at 60 and 90 kgs nitrogen are significantly different but, 90 kgs N/ha and 120 kgs N/ha are not significantly different therefore the optimum levels of nitrogen that can be applied to the crop for maximizing yields in the event of $CO_2$ enrichment is 90 kgs N/ha.

**Table 6.2: Different levels of nitrogen application given as inputs to CERES Rice model to simulate rice yield for developing adaptation strategies under higher $CO_2$ concentrations.**

| Total Nitrogen amount | Crop growth Stage | Date of application | Kind of Fertilizer | Amt of Fertilizer |
|---|---|---|---|---|
| 60 kgs N/ha | Transplanting | 10-Jul | DAP | 15 |
| | Transplanting | 10-Jul | Urea | 15 |
| | PI Stage | 5-Aug | Urea | 30 |
| 90 kgs N/ha | Transplanting | 10-Jul | DAP | 15 |
| | Transplanting | 10-Jul | Urea | 15 |
| | PI Stage | 5-Aug | Urea | 30 |
| | Anthesis | 25-Aug | Urea | 30 |
| 120 kgs N/ha | Transplanting | 10-Jul | DAP | 15 |
| | Transplanting | 10-Jul | Urea | 15 |
| | PI Stage | 5-Aug | Urea | 30 |
| | Anthesis | 25-Aug | Urea | 30 |
| | Grain filling | 15-Sep | Urea | 30 |

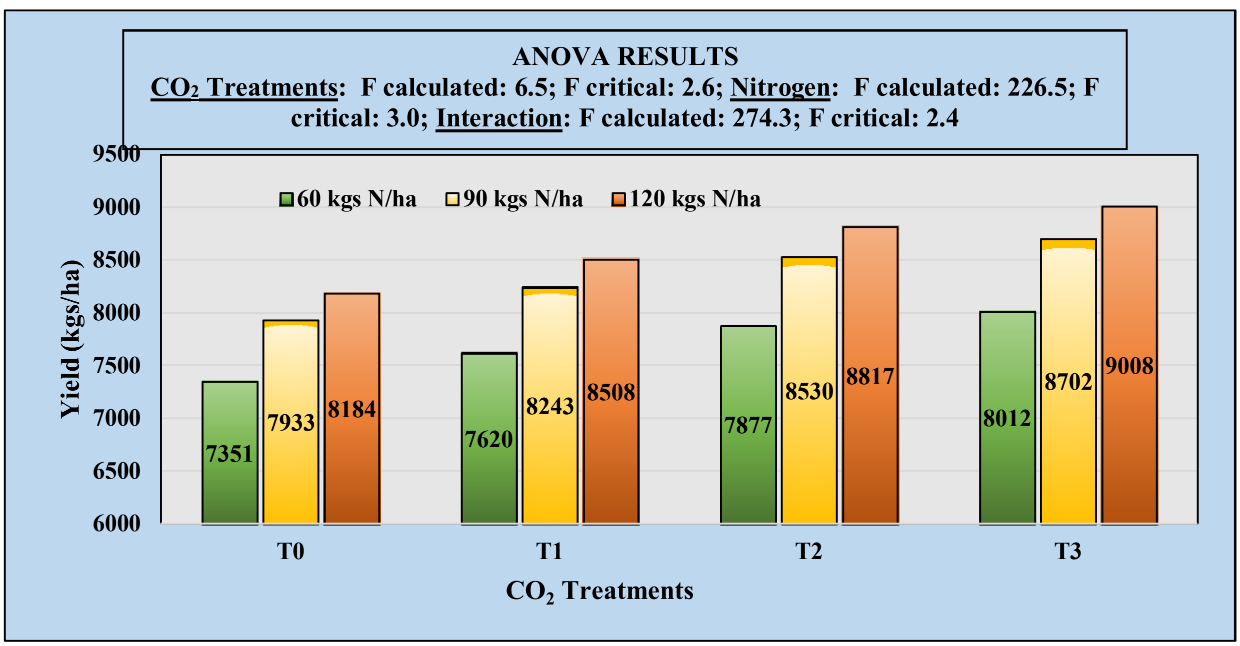


**Figure 6.2: Rice grain yield as effected by variable nitrogen levels, ANOVA analysis of treatments as simulated by CERES Rice model.**

## 6.5 Discussion

Previous studies had suggested that adjusting sowing dates might be a simple and powerful tool for mitigating the effects of a climate change (Baker and Allen Jr, 1993). The planting date under different levels of $CO_2$ concentrations showed that it significantly affects the yield of rice crop. But it is observed that the crop period due to delay in planting (normal planting date recommended is 1st week of July) the crop period is extended by 2 – 40 days. Though the yield is higher for crop planted on 21st July but it requires more attention and more water as the ETc is also higher for late planted. Late planting is beneficial when the rainfall is not timely (delay in monsoon arrival) therefore it is recommended that the planting window for rice crop in Haridwar district is 1st week of July to 2nd week of July. Even Krishnan had done similar kind of study in which he recommended 15th July as best rice planting dates for Cuttack and Jorhat in the event of higher $CO_2$ concentrations (Krishnan et al., 2007) .

The nitrogen treatments and plant spacing along with $CO_2$ application was found to have good interaction which suggests that the $CO_2$ fertilization effect will be affected due to nitrogen application and maintain optimum plant spacing. Many studies have reported that the nitrogen uptake of crop increases with increasing $CO_2$ concentrations (Aben et al., 1999; Dong et al., 2002; Dong et al., 2011; Zhang and Tao, 2013). Therefore, higher nitrogen leads to improved response of crop to $CO_2$ enrichment.

## 6.6 Conclusion

The DSSAT was used to develop adaptation strategies for the future under the climate change and higher $CO_2$ scenarios. Planting date of 14th July, 20 * 15 cm spacing and nitrogen fertilizer application @ 90 kgs N/ha was found suitable for the forth coming decades to improve productivity in $CO_2$ enriched conditions.

# CHAPTER VII

# SUMMARY & CONCLUSION

The study entitled "**Effect of $CO_2$ enrichment and Climate Change on Rice Crop through Field and Simulation Study"** is summarized in this chapter.

The field experiment on rice cv. *Sharbati* were conducted in randomized block design with 4 treatments ($T_0$ = Control, $T_1$ = $CO_2$ (700 ± 50 ppm) one application /Week (Monday), $T_2$ = $CO_2$ (700 ± 50 ppm) two applications /Week (Monday & Wednesday), $T_3$ = $CO_2$ (700 ± 50 ppm) three application / Week (Monday, Wednesday & Friday)) and 3 replications during the Kharif seasons 2011-12 and 2012-13. In general, observations on leaf, within & above canopy temperature after each application of $CO_2$ in the crop recorded a temporal rise of 0.2 – $0.5^0$C. The average yield recorded in the order of merit in different treatments was 7152 kgs/ha in T2, 6797 kgs/ha in T3, 6482 kgs/ha in T1 and 5640 in T0 treatment. In general plant growth was improved with $CO_2$ enrichment treatments recording increased tillers/hill, leaves/hill, plant height, leaf length and width, plant dry matter/hill and Leaf Area Index. Yield attributes viz. panicles/m2, filled grains/$m^2$, grain weight as well as grain length and width were improved with periodical enrichment of $CO_2$. Negative impact of $CO_2$ enrichment was recorded with increased broken grain and chalkiness percentage.

DSSAT model was calibrated using the rice cv. *Sharbati* field experimental data generated with 4 dates of transplanting viz. 7th July, 15th July, 22nd July and 31st July, 2013. The experimental crop was grown adapting good agronomic practices. Data was generated on PI Stage, anthesis stage, physiological maturity stage, harvest stage, grain yield, straw yield, single grain weight, Harvest index, grain number/$m^2$ and panicle number/$m^2$. Genetic coefficients developed for rice cv. *Sharbati* under the soil-climatic conditions of Roorkee by running the model developed are as follows:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| P1 | : 780.0 | P2R | : 90.0 | P5 | : 400.0 | P2O | : 15.4 |
| G1 | : 60.0 | G2 | : 0.0230 | G3 | : 0.70 | G4 | : 0.80 |

DSSAT model was validated for the rice cv. Sharbati using the data generated from field experiments with four periodical $CO_2$ enrichment treatments conducted during the Kharif seasons 2011-12 and 2012-13. Various phenological phases and yield and its attributes viz. to panicle initiation stage, anthesis stage, physiological maturity stage, harvest stage, leaf numbers/hill, Leaf Area Index, grain yield, straw yield, grain numbers/$m^2$, panicle number/$m^2$ and harvest index were validated using DSSAT model. Simulated results statistically matched with the field observed data. Simulated data showed nitrogen stress in treatment T3 from heading to grain filling stage. This shows that in the event of $CO_2$ application to the crop, nitrogen application should also be improved.

Climate change pattern of Haridwar district was assessed was done using PRECIS RCM data rainfall, maximum temperature and minimum temperature for the period 2014 - 2090 obtained from Indian Institute of Tropical Meteorology, Pune. This was bias corrected. Mann Kendall Trend test was applied to study the trend of climate during 2014 - 2090. Trend analysis of the period showed that the annual rainfall would increase @ 5.8 mm/yr but *Kharif* rainfall would increase @ 11.6 mm/yr. The annual maximum and minimum temperature would increase @ $0.046^0$C/yr and $0.039^0$C/yr.

Grain yield of rice cv Sharbati for the period 2020-2090 was simulated by running DSSAT CERES rice model with PRECIS RCM weather data of Haridwar district and IPCC $CO_2$ scenarios. The simulation result showed that if the crop is grown with the existing soil and crop management conditions, rice productivity of Haridwar in general will decrease @ 16.7 kgs/ha/yr. This could be attributable to the climate change scenario. The simulated rice grain yield was reported to decrease @ 273 kgs/ha with every $1^0$C increase in minimum temperature (Peng et al., 2004). Decreased rice yields from increased minimum temperature has also been reported (Seshu and Cady, 1984).

The DSSAT model was also run taking average weather conditions of 2014 – 2090, present soil fertility conditions of Roorkee, rice cv Sharbati to find the best planting dates (7$^{th}$ July, 14$^{th}$ July and 21$^{st}$ July) and plant spacing (20 cm x 20 cm, 20 cm x 15 cm, and 20 cm x 10 cm) as well as the different nitrogen levels (60 kgs N/ha, 90 kgs N/ha and 120 kgs N/ha). The result showed that the highest yield of 9906 kgs/ha was obtained by transplanting the crop on 14$^{th}$ July, adapting the spacing of 20 cm * 15 cm and nitrogen fertilizer application of 90 kg N/ha.

Thus it can be concluded that the response of periodical $CO_2$ enrichment of rice cv *Sharbati* under the soil-climatic conditions of Roorkee (Haridwar, Uttarakhand, India) was positive with respect to increasing the grain yield. However for the best positive response, the crop should be managed properly with nutrients and other agronomic practices.

**Future Scope of Work**

Further studies on the following lines is suggested

1. Physiological, chemical and bio-chemical studies of rice plants grown under $CO_2$ treatments may be initiated.
2. Chemical and bio chemical studies of rice grain produced from $CO_2$ enriched plants may be studied
3. Interaction studies of $CO_2$, water and nitrogen application under controlled climatic condition may be attempted.

# PHOTOGRAPHS OF THE EXPERIMENTAL SETUP 2011 & 2012

**Plate1: Land Preparation**


**Plate2: Nursery Bed**


**Plate 3: Transplanting**

**Plate 4: Irrigating the plots**


**Plates 4 & 5: Construction of Polythene open top chamber**


**Plate 5: $CO_2$ Enrichment of rice crop using $CO_2$ gas fire extinguisher**

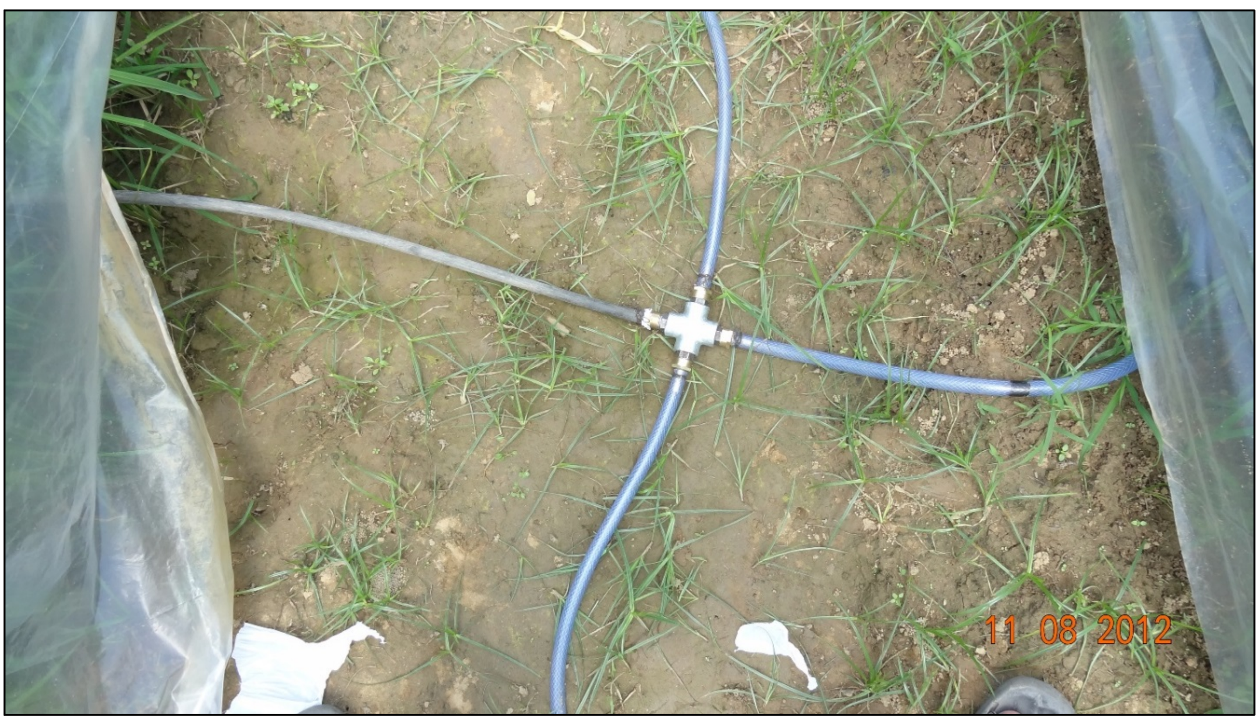


**Plate 6: $CO_2$ supply to plots**


**Plate 7: $CO_2$ Gas Analyser**

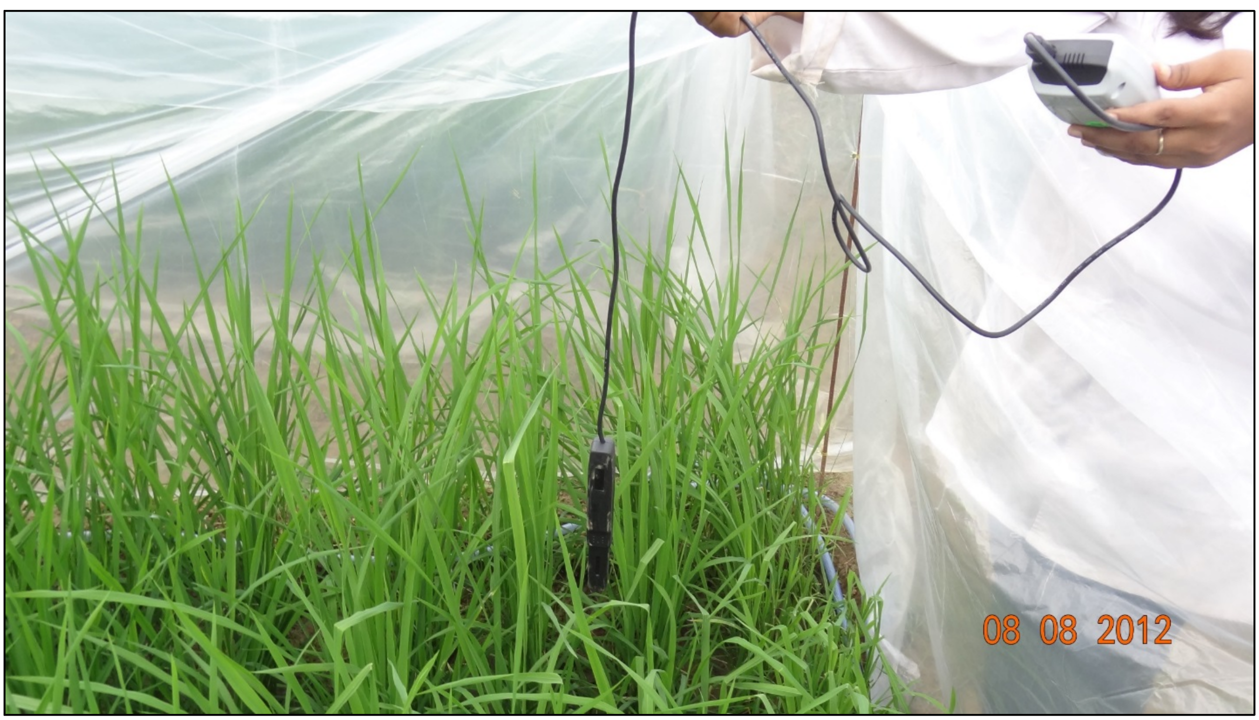


**Plate 8: $CO_2$ measurement within canopy of rice crop**

## PHOTOGRAPHS OF THE EXPERIMENTAL SETUP 2011 & 2012

**Plate 9: Recording Observations on Leaf Temperature, Canopy and Above Canopy Temperature**


**Plate 10: Recording Observations on crop growth parameters**

**Plate 11: Recording Observations on development of rice crop**


**Plate 12: Collection of plant samples**

**Plate 13: Juvenile stage of rice crop**

**Plate 14: Panicle Initiation stage of rice crop**

**Plate 15: Anthesis stage of rice crop**

**Plate 16: Physiological maturity stage of rice crop**


**Plate 17: Recording Observations on yield and yield attributes of rice crop**

**Plate 18: Recording Observations on yield and yield attributes of rice crop**


**Plate 19: Experimental plots of rice crop planted on 7$^{th}$ July 2013**


**Plate 20: Experimental plots of rice crop planted on 7$^{th}$ and 15$^{th}$ July 2013**


**Plate 21: Heading Stage of rice crop planted on 7th July, 2013**

**Plate 22: Physiological maturity stage of rice crop planted on 7th July, 2013**

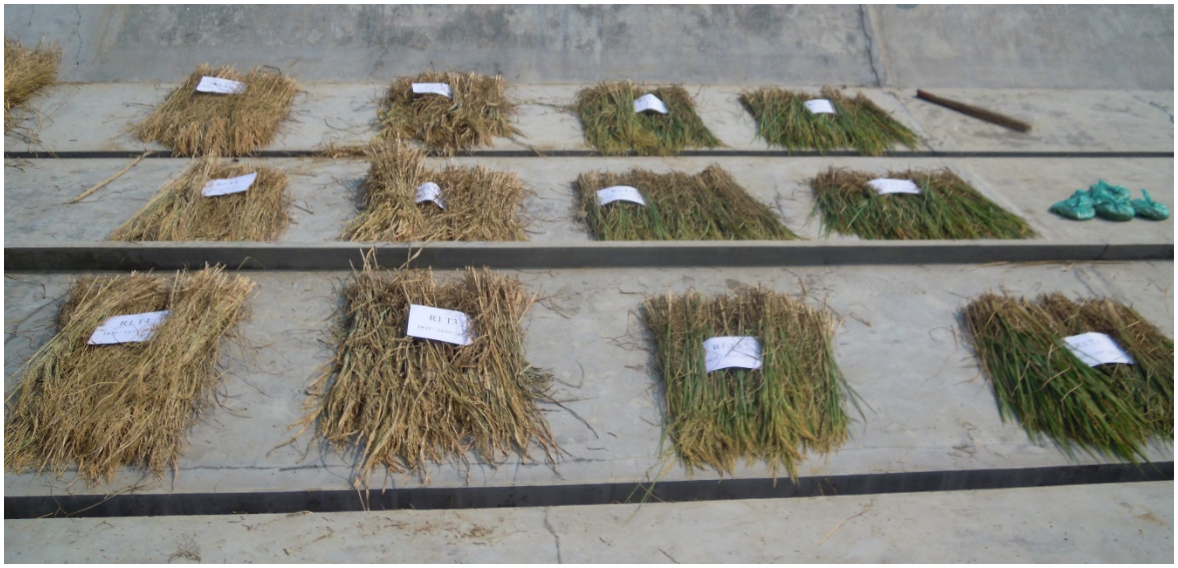

**Plate 23: Harvested rice crop planted on 15$^{th}$, 22$^{nd}$, 31$^{st}$ July, 2013**

**Plate 24: Threshing of rice crop planted on 15$^{th}$, 22$^{nd}$, 31$^{st}$ July, 2013**

## PHOTOGRAPHS OF DATA COLLECTION


**Plate 25: Collection of crop data from farmers of Haridwar district**


**Plate 26: Collection of crop data from farmers of Haridwar district**

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## *APPENDIX I*

**Daily weather data of solar radiation (MJ/m²/day), maximum and minimum temperatures (⁰C) and rainfall for the Kharif season (June – October) during the years 2011, 2012 and 2013.**

| Date | *Kharif* 2011 | | | | *Kharif* 2012 | | | | *Kharif* 2013 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SRAD MJ/m²/day | T Max (⁰C) | T Min (⁰C) | RF mm | SRAD MJ/m²/day | T Max (⁰C) | T Min (⁰C) | RF mm | SRAD MJ/m²/day | T Max (⁰C) | T Min (⁰C) | RF mm |
| 01-Jun | 28.5 | 35 | 22 | 13 | 30.5 | 40.1 | 24.3 | 0 | 22.5 | 32.6 | 24.5 | 0 |
| 02-Jun | 28.5 | 33 | 20 | 37 | 24.8 | 39.8 | 30 | 0 | 22.9 | 33.3 | 24.9 | 0 |
| 03-Jun | 27.4 | 37 | 25 | 0 | 30 | 39.7 | 25.3 | 0 | 25.8 | 35 | 24.4 | 0 |
| 04-Jun | 27.4 | 40 | 28 | 0 | 30 | 39 | 24.6 | 0 | 26.7 | 36.1 | 24.7 | 0 |
| 05-Jun | 28.5 | 39 | 26 | 0 | 27.1 | 37.2 | 25.5 | 0 | 23.1 | 36 | 27.5 | 0 |
| 06-Jun | 28.5 | 40 | 27 | 0 | 28.9 | 37.2 | 23.9 | 0.8 | 27.9 | 34.6 | 22.2 | 0 |
| 07-Jun | 25 | 39 | 29 | 0 | 26.7 | 35.4 | 24 | 29 | 24.9 | 33.2 | 23.3 | 0.8 |
| 08-Jun | 23.7 | 37 | 28 | 8 | 27 | 37.2 | 25.6 | 0 | 19.2 | 31.9 | 26 | 0 |
| 09-Jun | 28.5 | 37 | 24 | 4 | 25.8 | 35.7 | 25.1 | 0 | 14.8 | 30.3 | 26.8 | 9.1 |
| 10-Jun | 28.5 | 36 | 23 | 0.6 | 27.5 | 35.4 | 23.3 | 0 | 25.6 | 34.6 | 24.1 | 0 |
| 11-Jun | 27.4 | 38 | 26 | 0 | 29.6 | 37.8 | 23.8 | 0 | 16.4 | 27.6 | 23.3 | 18.2 |
| 12-Jun | 31.7 | 36 | 20 | 29 | 16.6 | 32.7 | 28.3 | 0 | 24.8 | 34.9 | 25.1 | 6.5 |
| 13-Jun | 25 | 36 | 26 | 0 | 31.7 | 38 | 22 | 0 | 13 | 28.3 | 25.6 | 5.1 |
| 14-Jun | 50 | 70 | 30 | 0 | 29.6 | 38 | 24 | 0 | 21.2 | 33.4 | 26.2 | 0 |
| 15-Jun | 25 | 35 | 25 | 4 | 28.5 | 39 | 26 | 0 | 25.1 | 31.9 | 21.8 | 9.3 |
| 16-Jun | 30.6 | 39 | 24 | 11 | 32.6 | 40 | 23 | 0 | 13.9 | 23.7 | 20.6 | 90 |
| 17-Jun | 26.2 | 36 | 25 | 8.2 | 30.6 | 40 | 25 | 0 | 16.4 | 24.4 | 20.1 | 160.2 |
| 18-Jun | 26.2 | 37 | 26 | 2 | 30.6 | 40 | 25 | 0 | 19.9 | 29.2 | 22.9 | 3 |
| 19-Jun | 27.4 | 39 | 27 | 0 | 13.7 | 31 | 28 | 0 | 22.1 | 31.8 | 24 | 0 |
| 20-Jun | 28.5 | 39 | 26 | 8 | 26.2 | 36 | 25 | 0 | 23.2 | 33.5 | 24.9 | 0 |
| 21-Jun | 25 | 39 | 29 | 0 | 28.5 | 38 | 25 | 0 | 23.7 | 35.5 | 26.5 | 0 |
| 22-Jun | 27.4 | 42 | 30 | 0 | 28.5 | 38 | 25 | 0 | 22.2 | 35.1 | 27.2 | 0 |
| 23-Jun | 23.7 | 38 | 29 | 0 | 26.2 | 35 | 24 | 0 | 18.7 | 32.5 | 26.9 | 0 |
| 24-Jun | 22.4 | 38 | 30 | 0 | 23.7 | 36 | 27 | 0 | 16.4 | 30.8 | 26.5 | 2 |
| 25-Jun | 27.4 | 35 | 23 | 0 | 23.7 | 36 | 27 | 0 | 17 | 30.2 | 25.6 | 0 |
| 26-Jun | 26.2 | 34 | 23 | 10 | 23.7 | 36 | 27 | 0 | 22 | 33.3 | 25.6 | 0 |
| 27-Jun | 26.2 | 36 | 25 | 2 | 13.7 | 30 | 27 | 0 | 20.6 | 31 | 24.2 | 0 |
| 28-Jun | 26.2 | 34 | 23 | 23.6 | 27.4 | 37 | 25 | 16 | 22.8 | 32.5 | 24.2 | 9.1 |
| 29-Jun | 23.7 | 33 | 24 | 4.2 | 27.4 | 37 | 25 | 0 | 23.5 | 33.5 | 24.7 | 0 |
| 30-Jun | 22.4 | 32 | 24 | 3.2 | 31.7 | 45 | 29 | 0 | 21.4 | 32 | 24.7 | 0 |
| 01-Jul | 24.7 | 36 | 26 | 38 | 33.6 | 42 | 24 | 0 | 22.8 | 34.1 | 25.6 | 0 |
| 02-Jul | 23.5 | 36 | 27 | 0 | 17.5 | 28 | 23 | 0 | 19.3 | 32.3 | 26.2 | 2 |
| 03-Jul | 22.1 | 35 | 27 | 0 | 13.5 | 28 | 25 | 0 | 18.8 | 31.8 | 26 | 1.5 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 04-Jul | 17.5 | 31 | 26 | 0 | 15.6 | 29 | 25 | 0 | 20.4 | 33 | 26.2 | 2 |
| 05-Jul | 15.6 | 32 | 28 | 0 | 11.1 | 29 | 27 | 0 | 17 | 31.4 | 26.7 | 0 |
| 06-Jul | 23.5 | 37 | 28 | 11.2 | 15.6 | 29 | 25 | 12 | 13.5 | 28.3 | 25.3 | 0 |
| 07-Jul | 17.5 | 30 | 25 | 6 | 13.5 | 29 | 26 | 6 | 17.7 | 30.4 | 25.3 | 0 |
| 08-Jul | 25.9 | 35 | 24 | 15.4 | 19.2 | 31 | 25 | 2 | 17 | 30 | 25.3 | 0 |
| 09-Jul | 23.5 | 33 | 24 | 77.4 | 19.2 | 31 | 25 | 0 | 18.3 | 31.3 | 25.8 | 2 |
| 10-Jul | 15.6 | 27 | 23 | 45.4 | 19.2 | 32 | 26 | 0 | 21 | 33 | 25.8 | 4.1 |
| 11-Jul | 22.1 | 33 | 25 | 38.2 | 19.2 | 33 | 27 | 0 | 18.7 | 32.2 | 26.5 | 0 |
| 12-Jul | 23.5 | 36 | 27 | 0 | 23.5 | 33 | 24 | 0 | 17.5 | 31.7 | 26.7 | 0 |
| 13-Jul | 22.1 | 35 | 27 | 0 | 22.1 | 33 | 25 | 0 | 21.1 | 33.2 | 25.9 | 0 |
| 14-Jul | 24.7 | 36 | 26 | 0 | 22.1 | 34 | 26 | 0 | 14.6 | 28.6 | 25.1 | 0 |
| 15-Jul | 13.5 | 29 | 26 | 37 | 19.2 | 31 | 25 | 7 | 20.8 | 32.6 | 25.5 | 0 |
| 16-Jul | 22.1 | 35 | 27 | 3 | 23.5 | 33 | 24 | 0 | 21.8 | 33.5 | 25.7 | 0 |
| 17-Jul | 24.7 | 35 | 25 | 4 | 23.5 | 34 | 25 | 0 | 19.2 | 32 | 26 | 0 |
| 18-Jul | 23.5 | 34 | 25 | 0 | 22.1 | 34 | 26 | 0 | 18.2 | 31.1 | 25.7 | 4.5 |
| 19-Jul | 24.1 | 36 | 26.5 | 0 | 23.5 | 36 | 27 | 0 | 19.3 | 29.7 | 23.6 | 1.2 |
| 20-Jul | 19.9 | 33 | 26.5 | 6 | 23.5 | 35 | 26 | 0 | 13.3 | 27.6 | 24.7 | 60.9 |
| 21-Jul | 23.5 | 34 | 25 | 1 | 11.1 | 30 | 28 | 25.1 | 21.3 | 32.1 | 24.7 | 0 |
| 22-Jul | 21.4 | 35 | 27.5 | 0 | 19.2 | 31 | 25 | 0 | 21.4 | 32.3 | 24.8 | 14.2 |
| 23-Jul | 18.7 | 33 | 27.3 | 110 | 23.5 | 34 | 25 | 0 | 21.7 | 33.2 | 25.5 | 0 |
| 24-Jul | 23.1 | 35 | 26.3 | 0 | 13.5 | 29 | 26 | 0 | 12.9 | 28.7 | 26 | 3.1 |
| 25-Jul | 19.6 | 33 | 26.7 | 0 | 15.6 | 30 | 26 | 0 | 18.5 | 30.5 | 24.9 | 0 |
| 26-Jul | 23.8 | 36 | 26.7 | 0 | 13.5 | 29 | 26 | 15.1 | 22 | 32.9 | 25 | 0 |
| 27-Jul | 20.5 | 34 | 27.1 | 1 | 13.5 | 28 | 25 | 0.3 | 21.1 | 33.4 | 26.1 | 0 |
| 28-Jul | 21 | 33 | 25.8 | 0.4 | 22.1 | 32 | 24 | 0 | 22.5 | 34.1 | 25.8 | 0 |
| 29-Jul | 19.5 | 32 | 25.8 | 85 | 19.2 | 32 | 26 | 44 | 17.1 | 30.7 | 25.9 | 61 |
| 30-Jul | 22.7 | 34 | 25.6 | 0 | 15.6 | 29 | 25 | 0 | 19.3 | 31.6 | 25.5 | 10 |
| 31-Jul | 18.8 | 33 | 27.2 | 0 | 15.6 | 30 | 26 | 14.2 | 19.8 | 32.6 | 26.2 | 1.6 |
| 01-Aug | 20.9 | 34 | 25.8 | 46 | 15.6 | 29 | 25 | 0 | 15.5 | 30.9 | 26.4 | 1.2 |
| 02-Aug | 21.3 | 34 | 25.5 | 0 | 10.3 | 28 | 26 | 0 | 20.1 | 33.8 | 26.2 | 0 |
| 03-Aug | 19.6 | 33 | 25.8 | 0 | 14.6 | 30 | 26 | 0 | 19.3 | 33.1 | 26.1 | 0 |
| 04-Aug | 24.9 | 36 | 24.4 | 8.8 | 19.3 | 32 | 25 | 5 | 21.3 | 34.4 | 25.9 | 29 |
| 05-Aug | 23.1 | 34 | 24 | 0 | 14.6 | 27 | 23 | 81.3 | 17.6 | 30 | 24.2 | 0 |
| 06-Aug | 26.1 | 35 | 22.2 | 0 | 19.3 | 31 | 24 | 1.1 | 12 | 26.6 | 23.9 | 210 |
| 07-Aug | 20.1 | 33 | 25.4 | 0 | 14.6 | 29 | 25 | 0 | 20 | 32.3 | 24.8 | 0 |
| 08-Aug | 22.9 | 35 | 25.2 | 0 | 19.3 | 32 | 25 | 4.5 | 18.8 | 30.1 | 23.5 | 60.3 |
| 09-Aug | 22.6 | 35 | 25.4 | 0 | 10.3 | 26 | 24 | 0 | 15.5 | 27.9 | 23.4 | 87 |
| 10-Aug | 24.6 | 36 | 24.7 | 4.4 | 17.9 | 30 | 24 | 0 | 19.5 | 31.8 | 24.7 | 2.5 |
| 11-Aug | 21.2 | 35 | 26.6 | 0 | 19.3 | 32 | 25 | 0 | 19.2 | 32.1 | 25.2 | 6.2 |
| 12-Aug | 23.3 | 36 | 25.8 | 8.2 | 20.7 | 32 | 24 | 0 | 17.8 | 31.8 | 25.9 | 0 |
| 13-Aug | 19.2 | 34 | 27.1 | 0 | 17.9 | 31 | 25 | 0 | 17.8 | 30.4 | 24.5 | 20.2 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14-Aug | 24.2 | 35 | 24 | 0.2 | 19.3 | 32 | 25 | 24.2 | 18.6 | 31.3 | 24.8 | 0 |
| 15-Aug | 21.9 | 35 | 26 | 30 | 19.3 | 32 | 25 | 0 | 17.8 | 30.6 | 24.7 | 0 |
| 16-Aug | 20.1 | 34 | 26.4 | 290 | 19.3 | 32 | 25 | 0 | 19.2 | 31.4 | 24.5 | 0 |
| 17-Aug | 26.4 | 34 | 21 | 35 | 19.3 | 33 | 26 | 0 | 19.9 | 32 | 24.6 | 0 |
| 18-Aug | 21.3 | 35 | 26.5 | 0.1 | 17.9 | 32 | 26 | 0.2 | 20.8 | 32.5 | 24.4 | 3.2 |
| 19-Aug | 20.8 | 33 | 24.9 | 0.4 | 10.3 | 32 | 30 | 0 | 21.2 | 33.6 | 25.2 | 0 |
| 20-Aug | 22 | 35 | 25.9 | 0 | 7.3 | 26 | 25 | 130 | 24.1 | 35.3 | 24.4 | 0 |
| 21-Aug | 23.9 | 35 | 24.3 | 0 | 7.3 | 24 | 23 | 0 | 24.7 | 34.6 | 23.2 | 0 |
| 22-Aug | 20.3 | 34 | 26.3 | 0 | 17.9 | 29 | 23 | 3 | 20.5 | 31.4 | 23.5 | 39 |
| 23-Aug | 17.8 | 33 | 27.1 | 1 | 17.9 | 30 | 24 | 18 | 20.9 | 33.2 | 25 | 0 |
| 24-Aug | 22.4 | 34 | 24.6 | 38 | 16.3 | 30 | 25 | 0 | 22.2 | 34.6 | 25.4 | 0 |
| 25-Aug | 20.7 | 33 | 25 | 0 | 16.3 | 30 | 25 | 0 | 21.1 | 34.3 | 26 | 0 |
| 26-Aug | 21.7 | 35 | 26.2 | 0 | 17.9 | 30 | 24 | 20 | 18.9 | 33.7 | 27 | 0 |
| 27-Aug | 16.8 | 32 | 26.7 | 1.4 | 10.3 | 24 | 22 | 0 | 21.6 | 33.4 | 24.7 | 0 |
| 28-Aug | 14.8 | 29 | 24.9 | 0 | 21.9 | 32 | 23 | 67 | 16.3 | 28.7 | 23.7 | 21 |
| 29-Aug | 25.3 | 38 | 26 | 0 | 17.9 | 31 | 25 | 3 | 19.1 | 30.5 | 23.7 | 1.4 |
| 30-Aug | 23.7 | 37 | 26.5 | 0 | 16.3 | 30 | 25 | 0 | 15.3 | 28.4 | 24 | 43.2 |
| 31-Aug | 20.3 | 34 | 26.3 | 0 | 19.3 | 31 | 24 | 0 | 18.2 | 29.7 | 23.5 | 12.2 |
| 01-Sep | 22.4 | 37 | 25 | 0 | 14.6 | 30 | 26 | 0 | 19.4 | 32.7 | 23.7 | 8.2 |
| 02-Sep | 22.4 | 35 | 23 | 0 | 18.8 | 33.8 | 25.4 | 0 | 19.5 | 33.3 | 24.2 | 0 |
| 03-Sep | 19.4 | 35 | 26 | 19.4 | 8.4 | 28 | 26.3 | 0 | 19.3 | 32.2 | 23.3 | 0 |
| 04-Sep | 20.5 | 35 | 25 | 0 | 16.4 | 31.8 | 25.4 | 36 | 19.9 | 32.2 | 22.7 | 0 |
| 05-Sep | 20.5 | 34 | 24 | 0 | 16 | 31.4 | 25.3 | 0 | 19.6 | 31.8 | 22.6 | 3.5 |
| 06-Sep | 21.5 | 37 | 26 | 0 | 17.7 | 32.7 | 25.2 | 0 | 19.6 | 31.3 | 22.1 | 3.3 |
| 07-Sep | 19.4 | 34 | 25 | 0 | 17.5 | 32.1 | 24.8 | 0 | 19.4 | 32.6 | 23.6 | 0 |
| 08-Sep | 17.1 | 32 | 25 | 0 | 12.9 | 29.7 | 25.7 | 0 | 13.6 | 26.7 | 22.3 | 0 |
| 09-Sep | 18.3 | 31 | 23 | 10.6 | 14 | 29.7 | 25 | 0 | 19.5 | 32 | 22.9 | 7.3 |
| 10-Sep | 19.4 | 37 | 28 | 0 | 19.4 | 34 | 25 | 0 | 19.9 | 32.1 | 22.6 | 0 |
| 11-Sep | 19.4 | 36 | 27 | 0 | 18.6 | 33.6 | 25.3 | 0 | 15 | 29 | 23.6 | 0 |
| 12-Sep | 21.5 | 37 | 26 | 0 | 14 | 29.9 | 25.2 | 1 | 18.3 | 31.7 | 23.7 | 0 |
| 13-Sep | 21.5 | 38 | 27 | 0 | 15.7 | 31.9 | 26 | 5 | 20.3 | 33.3 | 23.5 | 0 |
| 14-Sep | 20.5 | 34 | 24 | 0 | 17 | 31.6 | 24.7 | 25 | 20 | 33.2 | 23.6 | 0 |
| 15-Sep | 19.4 | 37 | 28 | 4.9 | 17.6 | 31.4 | 24 | 30 | 23.2 | 33.5 | 20.6 | 0 |
| 16-Sep | 22.4 | 37 | 25 | 12.9 | 18.3 | 31.8 | 23.8 | 0 | 21.8 | 31.6 | 20.3 | 3 |
| 17-Sep | 17.1 | 35 | 28 | 0 | 18 | 31.3 | 23.6 | 0 | 21.8 | 32.6 | 21.2 | 0 |
| 18-Sep | 23.3 | 37 | 24 | 0 | 16.9 | 30.2 | 23.4 | 14.5 | 22 | 33.2 | 21.6 | 0 |
| 19-Sep | 22.4 | 36 | 24 | 0 | 18.4 | 31.6 | 23.5 | 3 | 21.6 | 34.4 | 23.3 | 0 |
| 20-Sep | 19.4 | 34 | 25 | 0 | 18.2 | 31.5 | 23.6 | 3.8 | 20 | 33.3 | 23.7 | 3.2 |
| 21-Sep | 21.5 | 36 | 25 | 0 | 20.6 | 32.1 | 22 | 0 | 13.4 | 28.1 | 23.8 | 0 |
| 22-Sep | 23.3 | 37 | 24 | 0 | 20.2 | 31.5 | 21.8 | 0 | 19 | 32.9 | 24.3 | 0 |
| 23-Sep | 21.5 | 34 | 23 | 0 | 19.6 | 30.8 | 21.6 | 0 | 19.9 | 33.5 | 24 | 0 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24-Sep | 25.1 | 37 | 22 | 0 | 20.7 | 31.4 | 21.2 | 0 | 19.9 | 33.9 | 24.4 | 0 |
| 25-Sep | 15.8 | 34 | 28 | 0 | 19.9 | 31.2 | 21.7 | 0 | 18.8 | 31.1 | 22.7 | 0 |
| 26-Sep | 19.4 | 34 | 25 | 0 | 20.2 | 31.1 | 21.4 | 0 | 20 | 32.1 | 22.5 | 0 |
| 27-Sep | 25.1 | 36 | 21 | 0 | 19.7 | 30.8 | 21.5 | 0 | 17.1 | 32.1 | 25.1 | 0.2 |
| 28-Sep | 21.5 | 35 | 24 | 0 | 22.3 | 32.7 | 20.8 | 0 | 17 | 30 | 23.1 | 0 |
| 29-Sep | 21.5 | 36 | 25 | 0 | 21.9 | 32.8 | 21.3 | 0 | 20.9 | 33.3 | 22.9 | 0 |
| 30-Sep | 21.5 | 36 | 25 | 0 | 20.8 | 32 | 21.7 | 0 | 16.5 | 29.7 | 23.2 | 0 |
| 01-Oct | 15.3 | 36 | 28 | 0 | 20.3 | 31.7 | 21.9 | 0 | 15.9 | 32 | 23.3 | 0 |
| 02-Oct | 15.3 | 36 | 28 | 0 | 18.6 | 32.8 | 20.9 | 0 | 15.8 | 32.1 | 23.5 | 0 |
| 03-Oct | 13.2 | 35 | 29 | 0 | 17.2 | 32.2 | 22.1 | 0 | 16.3 | 30.6 | 21.5 | 0 |
| 04-Oct | 18.7 | 37 | 25 | 0 | 16.4 | 32.5 | 23.3 | 0 | 14.8 | 28.7 | 21.2 | 0 |
| 05-Oct | 17.9 | 37 | 26 | 0 | 18.2 | 31.9 | 20.6 | 0 | 17.5 | 32.4 | 21.9 | 0 |
| 06-Oct | 17.9 | 36 | 25 | 0 | 18.9 | 31.8 | 19.5 | 0 | 15.7 | 30.9 | 22.4 | 0 |
| 07-Oct | 17.9 | 36 | 25 | 0 | 19.6 | 32.4 | 19.2 | 0 | 12.3 | 29.5 | 24.3 | 0 |
| 08-Oct | 17.1 | 31 | 21 | 0 | 19.2 | 31.6 | 18.9 | 0 | 14.5 | 31.2 | 24 | 0 |
| 09-Oct | 17.1 | 34 | 24 | 0 | 19.4 | 31.3 | 18.4 | 0 | 15.2 | 31.9 | 24 | 0 |
| 10-Oct | 19.5 | 36 | 23 | 0 | 19.5 | 31.3 | 18.3 | 0 | 13.8 | 30.4 | 23.9 | 0 |
| 11-Oct | 21.6 | 36 | 20 | 0 | 18.4 | 30.6 | 19 | 0 | 12.8 | 25.7 | 20.1 | 16.2 |
| 12-Oct | 19.5 | 36 | 23 | 0 | 18.3 | 30.5 | 19 | 0 | 14 | 28.4 | 21.7 | 0 |
| 13-Oct | 20.2 | 36 | 22 | 0 | 19.9 | 30.3 | 16.7 | 0 | 17.1 | 31.9 | 21.9 | 0 |
| 14-Oct | 20.2 | 36 | 22 | 0 | 20.3 | 31.2 | 17.1 | 0 | 16.8 | 30.5 | 20.8 | 0 |
| 15-Oct | 20.2 | 36 | 22 | 0 | 20.1 | 30.7 | 16.8 | 0 | 16.2 | 29.7 | 20.7 | 0 |
| 16-Oct | 19.5 | 32 | 19 | 0 | 18.8 | 30.3 | 18.2 | 0 | 16.5 | 29.9 | 20.6 | 0 |
| 17-Oct | 20.9 | 35 | 20 | 0 | 18.3 | 30.2 | 18.7 | 0 | 17.2 | 30.4 | 20.2 | 0 |
| 18-Oct | 18.7 | 32 | 20 | 0 | 19.8 | 29.7 | 16.2 | 0 | 18 | 30.6 | 19.5 | 0 |
| 19-Oct | 19.5 | 34 | 21 | 0 | 20.7 | 30 | 15.3 | 0 | 18 | 30.1 | 19 | 0 |
| 20-Oct | 23.5 | 36 | 17 | 0 | 20.8 | 30 | 15.2 | 0 | 18.9 | 30 | 17.8 | 0 |
| 21-Oct | 18.7 | 31 | 19 | 0 | 19.9 | 29 | 15.4 | 0 | 18.9 | 29.1 | 16.9 | 0 |
| 22-Oct | 22.3 | 35 | 18 | 0 | 18.9 | 29.3 | 17.1 | 0 | 18.6 | 29.6 | 17.7 | 0 |
| 23-Oct | 17.1 | 30 | 20 | 0 | 20.8 | 29.5 | 14.7 | 0 | 18.6 | 29.7 | 17.8 | 0 |
| 24-Oct | 17.9 | 30 | 19 | 0 | 20.5 | 28.5 | 14.1 | 0 | 18.6 | 29.5 | 17.6 | 0 |
| 25-Oct | 22.3 | 34 | 17 | 0 | 17.1 | 26.2 | 16.2 | 0 | 18.5 | 29.2 | 17.5 | 0 |
| 26-Oct | 20.2 | 32 | 18 | 0 | 19.9 | 26.9 | 13.3 | 0 | 19 | 29.3 | 16.9 | 0 |
| 27-Oct | 20.2 | 33 | 19 | 0 | 19.5 | 26.9 | 13.8 | 0 | 19.4 | 28 | 15.1 | 0 |
| 28-Oct | 20.2 | 33 | 19 | 0 | 20.6 | 27.5 | 13 | 0 | 21.5 | 29 | 13.2 | 0 |
| 29-Oct | 20.9 | 35 | 20 | 0 | 20.8 | 28.2 | 13.3 | 0 | 21.7 | 28.6 | 12.5 | 0 |
| 30-Oct | 15.9 | 31.7 | 23 | 0 | 20.9 | 28.3 | 13.3 | 0 | 21.3 | 28.9 | 13.3 | 0 |
| 31-Oct | 18.7 | 33 | 21 | 0 | 20.6 | 28.8 | 14.2 | 0 | 17.9 | 25.9 | 14.9 | 0 |
| **Total/Avg** | **22.0** | **35.1** | **24.7** | **1158.1** | **19.8** | **32.0** | **23.3** | **647.1** | **19.1** | **31.4** | **23.5** | **1062.7** |

APPENDIX II

OVERVIEW FILE GENERATED FOR VALIDATION OF DSSAT CERES RICE MODEL USING KHARIF 2011 FIELD EXPERIMENT DATA

```
*SIMULATION OVERVIEW FILE

*DSSAT Cropping System Model Ver. 4.5.0.030           SEP 01, 2015; 11:22:36

*RUN   1         : T1
 MODEL           : RICER045 - Rice
 EXPERIMENT      : IITP1101 RI IITP1001RI IITR1001RI IITR, ROORKEE, RICE EXPERIME
 TREATMENT  1    : T1


 CROP            : Rice             CULTIVAR : Sharbati        ECOTYPE :IB0001
 STARTING DATE   : JUL  7 1911
 PLANTING DATE   : JUL  7 1911    PLANTS/m2 : 33.0     ROW SPACING :  20.cm
 WEATHER         : WRDM   1911
 SOIL            : IITR791201     TEXTURE : SL    - Dhanauri
 SOIL INITIAL C  : DEPTH:120cm EXTR. H2O:127.2mm  NO3:139.1kg/ha  NH4: 15.8kg/ha
 WATER BALANCE   : IRRIGATE ON REPORTED DATE(S)
 IRRIGATION      :      250 mm IN    4 APPLICATIONS
 NITROGEN BAL.   : SOIL-N & N-UPTAKE SIMULATION; NO N-FIXATION
 N-FERTILIZER    :       90 kg/ha IN     5 APPLICATIONS
 RESIDUE/MANURE  : INITIAL :   500 kg/ha ;       0 kg/ha IN     1 APPLICATIONS
 ENVIRONM. OPT.  : DAYL= A  0.00  SRAD= A  0.00  TMAX= A  0.00  TMIN= A  0.00
                   RAIN= A  0.00  CO2 = R 352.0  DEW =A  0.00  WIND=A  0.00
 SIMULATION OPT  : WATER   :Y  NITROGEN:Y  N-FIX:N  PHOSPH :N  PESTS  :N
                   PHOTO   :C  ET      :R  INFIL:S  HYDROL :R  SOM    :G
                   CO2     :D  NSWIT   :1  EVAP :R  SOIL   :2
 MANAGEMENT OPT  : PLANTING:R  IRRIG   :R  FERT :R  RESIDUE:R  HARVEST:M
                   WEATHER :M  TILLAGE :N

*SUMMARY OF SOIL AND GENETIC INPUT PARAMETERS
```

| SOIL DEPTH cm | LOWER LIMIT cm3/cm3 | UPPER LIMIT | SAT SW cm3/cm3 | EXTR SW | INIT SW cm3/cm3 | ROOT DIST | BULK DENS g/cm3 | pH | NO3 ugN/g | NH4 ugN/g | ORG C % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0- 5 | 0.121 | 0.224 | 0.414 | 0.103 | 0.115 | 1.00 | 1.47 | 7.80 | 7.90 | 0.90 | 0.60 |
| 5- 15 | 0.121 | 0.224 | 0.414 | 0.103 | 0.115 | 1.00 | 1.47 | 7.80 | 7.90 | 0.90 | 0.60 |
| 15- 30 | 0.121 | 0.224 | 0.414 | 0.103 | 0.120 | 1.00 | 1.47 | 7.80 | 7.90 | 0.90 | 0.60 |
| 30- 45 | 0.104 | 0.208 | 0.406 | 0.104 | 0.120 | 0.41 | 1.49 | 7.80 | 7.90 | 0.90 | 0.20 |
| 45- 60 | 0.104 | 0.208 | 0.406 | 0.104 | 0.107 | 0.41 | 1.49 | 7.80 | 7.90 | 0.90 | 0.20 |
| 60- 90 | 0.097 | 0.201 | 0.407 | 0.104 | 0.101 | 0.22 | 1.49 | 7.80 | 7.90 | 0.90 | 0.10 |
| 90-120 | 0.082 | 0.195 | 0.419 | 0.113 | 0.102 | 0.12 | 1.42 | 7.80 | 7.90 | 0.90 | 0.01 |

```
TOT-120  12.1  24.8  49.4  12.7  13.0  <--cm   -  kg/ha-->  139.1   15.8  40296
SOIL ALBEDO    : 0.13      EVAPORATION LIMIT : 6.00         MIN. FACTOR  : 1.00
RUNOFF CURVE # :73.00      DRAINAGE RATE     : 0.40         FERT. FACTOR : 1.00

 Rice       CULTIVAR :IB0054-Sharbati1         ECOTYPE :IB0001
 P1     : 780.0  P2R    :  90.0  P5     : 400.0  P2O    :  15.4
 G1     :  60.0  G2     :0.0230  G3     :  0.70  G4     :  0.80
*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

 RUN NO.     1     T1
```

| DATE | CROP AGE | GROWTH STAGE | BIOMASS kg/ha | LAI | LEAF NUM | CROP N kg/ha | CROP N % | STRESS H2O | STRESS N | STRESS P1 | STRESS P2 | RSTG |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 JUL | 0 | Transplant | 53 | 0.11 | 5.0 | 2 | 4.6 | 0.00 | 0.00 | 0.00 | 0.00 | 1 |
| 7 JUL | 0 | Start Sim | 53 | 0.11 | 5.0 | 2 | 4.6 | 0.00 | 0.00 | 0.00 | 0.00 | 1 |
| 1 AUG | 25 | End Juveni | 758 | 1.09 | 11.0 | 24 | 3.2 | 0.00 | 0.00 | 0.00 | 0.00 | 2 |
| 7 AUG | 31 | Pan Init | 1655 | 1.84 | 12.0 | 51 | 3.1 | 0.00 | 0.02 | 0.00 | 0.00 | 3 |
| 6 SEP | 61 | Heading | 7408 | 4.47 | 17.0 | 120 | 1.6 | 0.00 | 0.00 | 0.00 | 0.00 | 4 |
| 11 SEP | 66 | Beg Gr Fil | 8189 | 4.11 | 17.0 | 126 | 1.5 | 0.00 | 0.02 | 0.00 | 0.00 | 5 |
| 28 SEP | 83 | End Mn Fil | 10734 | 2.89 | 17.0 | 137 | 1.3 | 0.00 | 0.00 | 0.00 | 0.00 | 5 |
| 2 OCT | 87 | End Ti Fil | 10855 | 2.68 | 17.0 | 138 | 1.3 | 0.00 | 0.12 | 0.00 | 0.00 | 6 |
| 3 OCT | 88 | Maturity | 10855 | 2.68 | 17.0 | 138 | 1.3 | 0.00 | 0.00 | 0.00 | 0.00 | 20 |
| 3 OCT | 88 | Harvest | 10855 | 2.68 | 17.0 | 138 | 1.3 | 0.00 | 0.00 | 0.00 | 0.00 | 20 |

*MAIN GROWTH AND DEVELOPMENT VARIABLES

| @ | VARIABLE | SIMULATED | MEASURED |
|---|---|---|---|
| | Panicle Initiation day (dap) | 31 | -99 |
| | Anthesis day (dap) | 61 | -99 |
| | Physiological maturity day (dap) | 88 | -99 |
| | Yield at harvest maturity (kg [dm]/ha) | 6308 | -99 |
| | Unit wt at maturity (g [dm]/unit) | 0.0234 | -99 |
| | Number at maturity (no/m2) | 27003 | -99 |
| | Pod or panicle number (no/m2) | 251.00 | -99 |
| | Leaf area index, maximum | 4.54 | -99 |
| | Tops weight at anthesis (kg [dm]/ha) | 7224 | -99 |
| | Tops N at anthesis (kg/ha) | 120 | -99 |
| | Tops weight at maturity (kg [dm]/ha) | 10855 | -99 |
| | By-product produced (stalk) at maturity (kg[dm]/ha | 4547 | -99 |
| | Harvest index at maturity | 0.581 | -99 |
| | Leaf number per stem at maturity | 17 | -99 |
| | Grain N at maturity (kg/ha) | 95 | -99 |
| | Tops N at maturity (kg/ha) | 138 | -99 |
| | Stem N at maturity (kg/ha) | 43 | -99 |
| | Grain N at maturity (%) | 1.51 | -99 |

*ENVIRONMENTAL AND STRESS FACTORS

```
 |-----Development
Phase------|-------------Environment--------------|----------------Stress-------
----------|
                              |--------Average-------|---Cumulative--|
(0=Min, 1=Max Stress)         |
                         Time  Temp  Temp Solar Photop         Evapo
|----Water---|--Nitrogen--|--Phosphorus-|
                         Span   Max   Min   Rad  [day]   Rain  Trans  Photo
   Photo          Photo
```

```
                         days    øC    øC MJ/m2     hr     mm     mm  synth
Growth  synth Growth  synth Growth
--------------------------------------------------------------------------------
------------------------------
 Emergence-End Juvenile    25  33.7  26.0  20.3  13.68  441.0  122.2  0.000
0.000  0.000  0.000  0.000  0.000
 End Juvenil-Panicl Init    6  34.0  25.4  20.1  13.39   54.8   33.1  0.000
0.000  0.000  0.021  0.000  0.000
 Panicl Init-End Lf Grow   30  34.5  25.3  21.0  12.93  428.1  165.2  0.000
0.000  0.000  0.000  0.000  0.000
 End Lf Grth-Beg Grn Fil    5  33.6  24.6  15.7  12.42   10.6   19.9  0.000
0.000  0.000  0.000  0.000  0.000
 Grain Filling Phase       21  35.9  25.1  20.0  12.02   17.8  115.2  0.000
0.000  0.000  0.031  0.000  0.000

 Planting to Harvest       88  34.5  25.5  20.1  12.91  952.3  459.3  0.000
0.000  0.000  0.009  0.000  0.000
--------------------------------------------------------------------------------
------------------------------

*Water Productivity
 Growing season length:  88 days

 Precipitation during growth season        952.3 mm[rain]
   Dry Matter Productivity                  1.14 kg[DM]/m3[rain]          =
11.4 kg[DM]/ha per mm[rain]
   Yield Productivity                       0.66 kg[grain yield]/m3[rain] =
6.6 kg[yield]/ha per mm[rain]

 Evapotranspiration during growth season   459.3 mm[ET]
   Dry Matter Productivity                  2.36 kg[DM]/m3[ET]            =
23.6 kg[DM]/ha per mm[ET]
   Yield Productivity                       1.37 kg[grain yield]/m3[ET]   =
13.7 kg[yield]/ha per mm[ET]

 Transpiration during growth season        286.5 mm[EP]
   Dry Matter Productivity                  3.79 kg[DM]/m3[EP]            =
37.9 kg[DM]/ha per mm[EP]
   Yield Productivity                       2.20 kg[grain yield]/m3[EP]   =
22.0 kg[yield]/ha per mm[EP]

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                      Rice YIELD :     6308 kg/ha    [Dry weight]

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*DSSAT Cropping System Model Ver. 4.5.0.030              SEP 01, 2015; 11:22:36

*RUN   2         : T2
 MODEL           : RICER045 - Rice
 EXPERIMENT      : IITP1101 RI IITP1001RI IITR1001RI IITR, ROORKEE, RICE EXPERIME
 TREATMENT  2    : T2


 CROP            : Rice             CULTIVAR : Sharbati1        ECOTYPE :IB0001
 STARTING DATE   : JUL  7 1911
 PLANTING DATE   : JUL  7 1911    PLANTS/m2 : 33.0     ROW SPACING :  20.cm
 WEATHER         : WRDM   1911
 SOIL            : IITR791201     TEXTURE : SL    - Dhanauri
 SOIL INITIAL C  : DEPTH:120cm EXTR. H2O:127.2mm  NO3:139.1kg/ha  NH4: 15.8kg/ha
```

```
 WATER BALANCE   : IRRIGATE ON REPORTED DATE(S)
 IRRIGATION      :      250 mm IN    4 APPLICATIONS
 NITROGEN BAL.   : SOIL-N & N-UPTAKE SIMULATION; NO N-FIXATION
 N-FERTILIZER    :       90 kg/ha IN     5 APPLICATIONS
 RESIDUE/MANURE  : INITIAL :   500 kg/ha ;        0 kg/ha IN     1 APPLICATIONS
 ENVIRONM. OPT.  : DAYL= A  0.00  SRAD= A  0.00  TMAX= A  0.00  TMIN= A  0.00
                   RAIN= A  0.00  CO2 = R 328.0  DEW =A  0.00  WIND=A  0.00
 SIMULATION OPT  : WATER   :Y  NITROGEN:Y  N-FIX:N  PHOSPH :N  PESTS  :N
                   PHOTO   :C  ET      :R  INFIL:S  HYDROL :R  SOM    :G
                   CO2     :D  NSWIT   :1  EVAP :R  SOIL   :2
 MANAGEMENT OPT  : PLANTING:R  IRRIG   :R  FERT :R  RESIDUE:R  HARVEST:M
                   WEATHER :M  TILLAGE :N

*SUMMARY OF SOIL AND GENETIC INPUT PARAMETERS

   SOIL LOWER UPPER   SAT  EXTR  INIT   ROOT   BULK     pH    NO3    NH4    ORG
  DEPTH LIMIT LIMIT    SW    SW    SW   DIST   DENS                          C
   cm   cm3/cm3    cm3/cm3    cm3/cm3          g/cm3         ugN/g  ugN/g     %
--------------------------------------------------------------------------------
  0-  5 0.121 0.224 0.414 0.103 0.115   1.00   1.47   7.80   7.90   0.90   0.60
  5- 15 0.121 0.224 0.414 0.103 0.115   1.00   1.47   7.80   7.90   0.90   0.60
 15- 30 0.121 0.224 0.414 0.103 0.120   1.00   1.47   7.80   7.90   0.90   0.60
 30- 45 0.104 0.208 0.406 0.104 0.120   0.41   1.49   7.80   7.90   0.90   0.20
 45- 60 0.104 0.208 0.406 0.104 0.107   0.41   1.49   7.80   7.90   0.90   0.20
 60- 90 0.097 0.201 0.407 0.104 0.101   0.22   1.49   7.80   7.90   0.90   0.10
 90-120 0.082 0.195 0.419 0.113 0.102   0.12   1.42   7.80   7.90   0.90   0.01

TOT-120  12.1  24.8  49.4  12.7  13.0  <--cm   -  kg/ha-->  139.1   15.8  40296
SOIL ALBEDO    : 0.13      EVAPORATION LIMIT : 6.00          MIN. FACTOR  : 1.00
RUNOFF CURVE # :73.00      DRAINAGE RATE     : 0.40          FERT. FACTOR : 1.00

 Rice        CULTIVAR :IB0054-Sharbati1          ECOTYPE :IB0001
 P1     : 780.0  P2R     :  90.0  P5     : 400.0  P2O     :  15.4
 G1     :  60.0  G2      :0.0230  G3     :  0.70  G4      :  0.80
*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

 RUN NO.     2     T2

       CROP GROWTH     BIOMASS         LEAF   CROP N      STRESS       STRESS

   DATE  AGE STAGE          kg/ha    LAI   NUM  kg/ha  %    H2O     N     P1     P2
RSTG
 ------  --- ----------   -----  -----  ----  ---  ---  ----  ----  ----  ----
----
  7 JUL    0 Transplant      53   0.11   5.0    2  4.6  0.00  0.00  0.00  0.00
  1
  7 JUL    0 Start Sim       53   0.11   5.0    2  4.6  0.00  0.00  0.00  0.00
  1
  1 AUG   25 End Juveni     831   1.16  11.0   27  3.2  0.00  0.00  0.00  0.00
  2
  7 AUG   31 Pan Init      1778   1.96  12.0   55  3.1  0.00  0.02  0.00  0.00
  3
  6 SEP   61 Heading       8248   4.89  17.0  133  1.6  0.00  0.01  0.00  0.00
  4
 11 SEP   66 Beg Gr Fil    9193   4.50  17.0  139  1.5  0.00  0.01  0.00  0.00
  5
 28 SEP   83 End Mn Fil   12296   3.15  17.0  147  1.2  0.00  0.09  0.00  0.00
  5
  2 OCT   87 End Ti Fil   12359   2.91  17.0  147  1.2  0.00  0.33  0.00  0.00
  6
  3 OCT   88 Maturity     12359   2.91  17.0  147  1.2  0.00  0.00  0.00  0.00
 20
  3 OCT   88 Harvest      12359   2.91  17.0  147  1.2  0.00  0.00  0.00  0.00
```

*MAIN GROWTH AND DEVELOPMENT VARIABLES

| @ VARIABLE | SIMULATED | MEASURED |
|---|---|---|
| Panicle Initiation day (dap) | 31 | -99 |
| Anthesis day (dap) | 61 | -99 |
| Physiological maturity day (dap) | 88 | -99 |
| Yield at harvest maturity (kg [dm]/ha) | 7017 | -99 |
| Unit wt at maturity (g [dm]/unit) | 0.0231 | -99 |
| Number at maturity (no/m2) | 30323 | -99 |
| Pod or panicle number (no/m2) | 296.90 | -99 |
| Leaf area index, maximum | 4.97 | -99 |
| Tops weight at anthesis (kg [dm]/ha) | 8067 | -99 |
| Tops N at anthesis (kg/ha) | 134 | -99 |
| Tops weight at maturity (kg [dm]/ha) | 12359 | -99 |
| By-product produced (stalk) at maturity (kg[dm]/ha | 5341 | -99 |
| Harvest index at maturity | 0.568 | -99 |
| Leaf number per stem at maturity | 17 | -99 |
| Grain N at maturity (kg/ha) | 106 | -99 |
| Tops N at maturity (kg/ha) | 147 | -99 |
| Stem N at maturity (kg/ha) | 41 | -99 |
| Grain N at maturity (%) | 1.51 | -99 |

*ENVIRONMENTAL AND STRESS FACTORS

```
 |-----Development
Phase------|-------------Environment--------------|----------------Stress-------
----------|
                                   |--------Average-------|---Cumulative--|
(0=Min, 1=Max Stress)              |
                         Time  Temp  Temp Solar Photop         Evapo
|----Water---|--Nitrogen--|--Phosphorus-|
                         Span   Max   Min   Rad  [day]   Rain  Trans  Photo
   Photo         Photo
                         days    øC    øC MJ/m2     hr     mm     mm  synth
Growth  synth Growth  synth Growth
--------------------------------------------------------------------------------
------------------------------
 Emergence-End Juvenile    25  33.7  26.0  20.3  13.68  441.0  121.9  0.000
0.000  0.000  0.000  0.000  0.000
 End Juvenil-Panicl Init    6  34.0  25.4  20.1  13.39   54.8   32.2  0.000
0.000  0.000  0.018  0.000  0.000
 Panicl Init-End Lf Grow   30  34.5  25.3  21.0  12.93  428.1  163.3  0.000
0.000  0.000  0.005  0.000  0.000
 End Lf Grth-Beg Grn Fil    5  33.6  24.6  15.7  12.42   10.6   19.6  0.000
0.000  0.000  0.000  0.000  0.000
 Grain Filling Phase       21  35.9  25.1  20.0  12.02   17.8  113.5  0.000
0.000  0.078  0.141  0.000  0.000

 Planting to Harvest       88  34.5  25.5  20.1  12.91  952.3  454.3  0.000
0.000  0.019  0.037  0.000  0.000
--------------------------------------------------------------------------------
------------------------------
```

*Water Productivity
 Growing season length:  88 days

 Precipitation during growth season        952.3 mm[rain]
   Dry Matter Productivity                  1.30 kg[DM]/m3[rain]          =

```
13.0 kg[DM]/ha per mm[rain]
   Yield Productivity                      0.74 kg[grain yield]/m3[rain] =
7.4 kg[yield]/ha per mm[rain]

 Evapotranspiration during growth season   454.3 mm[ET]
   Dry Matter Productivity                  2.72 kg[DM]/m3[ET]           =
27.2 kg[DM]/ha per mm[ET]
   Yield Productivity                       1.54 kg[grain yield]/m3[ET]   =
15.4 kg[yield]/ha per mm[ET]

 Transpiration during growth season        289.3 mm[EP]
   Dry Matter Productivity                  4.27 kg[DM]/m3[EP]           =
42.7 kg[DM]/ha per mm[EP]
   Yield Productivity                       2.43 kg[grain yield]/m3[EP]   =
24.3 kg[yield]/ha per mm[EP]

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                      Rice YIELD :     7017 kg/ha    [Dry weight]

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*DSSAT Cropping System Model Ver. 4.5.0.030             SEP 01, 2015; 11:22:36

*RUN   3         : T3
 MODEL           : RICER045 - Rice
 EXPERIMENT      : IITP1101 RI IITP1001RI IITR1001RI IITR, ROORKEE, RICE EXPERIME
 TREATMENT  3    : T3


 CROP            : Rice             CULTIVAR : Sharbati1        ECOTYPE :IB0001
 STARTING DATE   : JUL  7 1911
 PLANTING DATE   : JUL  7 1911    PLANTS/m2 : 33.0     ROW SPACING :  20.cm
 WEATHER         : WRDM   1911
 SOIL            : IITR791201     TEXTURE : SL    - Dhanauri
 SOIL INITIAL C  : DEPTH:120cm EXTR. H2O:127.2mm  NO3:139.1kg/ha  NH4: 15.8kg/ha
 WATER BALANCE   : IRRIGATE ON REPORTED DATE(S)
 IRRIGATION      :      250 mm IN    4 APPLICATIONS
 NITROGEN BAL.   : SOIL-N & N-UPTAKE SIMULATION; NO N-FIXATION
 N-FERTILIZER    :       90 kg/ha IN     5 APPLICATIONS
 RESIDUE/MANURE  : INITIAL :   500 kg/ha ;       0 kg/ha IN     1 APPLICATIONS
 ENVIRONM. OPT.  : DAYL= A  0.00  SRAD= A  0.00  TMAX= A  0.00  TMIN= A  0.00
                   RAIN= A  0.00  CO2 = R 321.0  DEW =A  0.00  WIND=A  0.00
 SIMULATION OPT  : WATER   :Y  NITROGEN:Y  N-FIX:N  PHOSPH :N  PESTS  :N
                   PHOTO   :C  ET      :R  INFIL:S  HYDROL :R  SOM    :G
                   CO2     :D  NSWIT   :1  EVAP :R  SOIL   :2
 MANAGEMENT OPT  : PLANTING:R  IRRIG   :R  FERT :R  RESIDUE:R  HARVEST:M
                   WEATHER :M  TILLAGE :N

*SUMMARY OF SOIL AND GENETIC INPUT PARAMETERS

   SOIL LOWER UPPER   SAT  EXTR  INIT   ROOT   BULK     pH    NO3    NH4    ORG
  DEPTH LIMIT LIMIT    SW    SW    SW   DIST   DENS                          C
   cm   cm3/cm3    cm3/cm3    cm3/cm3          g/cm3          ugN/g  ugN/g     %
-------------------------------------------------------------------------------
   0-   5 0.121 0.224 0.414 0.103 0.115   1.00   1.47   7.80   7.90   0.90   0.60
   5-  15 0.121 0.224 0.414 0.103 0.115   1.00   1.47   7.80   7.90   0.90   0.60
  15-  30 0.121 0.224 0.414 0.103 0.120   1.00   1.47   7.80   7.90   0.90   0.60
  30-  45 0.104 0.208 0.406 0.104 0.120   0.41   1.49   7.80   7.90   0.90   0.20
  45-  60 0.104 0.208 0.406 0.104 0.107   0.41   1.49   7.80   7.90   0.90   0.20
  60-  90 0.097 0.201 0.407 0.104 0.101   0.22   1.49   7.80   7.90   0.90   0.10
```

```
 90-120 0.082 0.195 0.419 0.113 0.102   0.12   1.42   7.80   7.90   0.90   0.01

TOT-120  12.1  24.8  49.4  12.7  13.0  <--cm   -  kg/ha-->  139.1   15.8  40296
SOIL ALBEDO    : 0.13      EVAPORATION LIMIT : 6.00         MIN. FACTOR  : 1.00
RUNOFF CURVE # :73.00      DRAINAGE RATE     : 0.40         FERT. FACTOR : 1.00

 Rice        CULTIVAR :IB0054-Sharbati1          ECOTYPE :IB0001
 P1     : 780.0  P2R    :  90.0  P5     : 400.0  P2O    :  15.4
 G1     :  60.0  G2     :0.0230  G3     :  0.70  G4     :  0.80
```

*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

RUN NO. 3 T3

| DATE | CROP AGE | GROWTH STAGE | BIOMASS kg/ha | LAI | LEAF NUM | CROP N kg/ha | CROP N % | STRESS H2O | STRESS N | STRESS P1 | STRESS P2 | RSTG |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 JUL | 0 | Transplant | 53 | 0.11 | 5.0 | 2 | 4.6 | 0.00 | 0.00 | 0.00 | 0.00 | 1 |
| 7 JUL | 0 | Start Sim | 53 | 0.11 | 5.0 | 2 | 4.6 | 0.00 | 0.00 | 0.00 | 0.00 | 1 |
| 1 AUG | 25 | End Juveni | 873 | 1.22 | 11.0 | 28 | 3.2 | 0.00 | 0.00 | 0.00 | 0.00 | 2 |
| 7 AUG | 31 | Pan Init | 2043 | 2.22 | 12.0 | 63 | 3.1 | 0.00 | 0.02 | 0.00 | 0.00 | 3 |
| 5 SEP | 60 | Heading | 9361 | 5.05 | 17.0 | 150 | 1.6 | 0.00 | 0.06 | 0.00 | 0.00 | 4 |
| 11 SEP | 66 | Beg Gr Fil | 10658 | 4.50 | 17.0 | 152 | 1.4 | 0.00 | 0.05 | 0.00 | 0.00 | 5 |
| 28 SEP | 83 | End Mn Fil | 13715 | 2.95 | 17.0 | 155 | 1.1 | 0.00 | 0.24 | 0.00 | 0.00 | 5 |
| 2 OCT | 87 | End Ti Fil | 13859 | 2.67 | 17.0 | 157 | 1.1 | 0.00 | 0.52 | 0.00 | 0.00 | 6 |
| 3 OCT | 88 | Maturity | 13859 | 2.67 | 17.0 | 157 | 1.1 | 0.00 | 0.00 | 0.00 | 0.00 | 20 |
| 3 OCT | 88 | Harvest | 13859 | 2.67 | 17.0 | 157 | 1.1 | 0.00 | 0.00 | 0.00 | 0.00 | 20 |

*MAIN GROWTH AND DEVELOPMENT VARIABLES

| @ VARIABLE | SIMULATED | MEASURED |
|---|---|---|
| Panicle Initiation day (dap) | 31 | -99 |
| Anthesis day (dap) | 60 | -99 |
| Physiological maturity day (dap) | 88 | -99 |
| Yield at harvest maturity (kg [dm]/ha) | 7948 | -99 |
| Unit wt at maturity (g [dm]/unit) | 0.0232 | -99 |
| Number at maturity (no/m2) | 34220 | -99 |
| Pod or panicle number (no/m2) | 302.79 | -99 |
| Leaf area index, maximum | 5.14 | -99 |
| Tops weight at anthesis (kg [dm]/ha) | 9155 | -99 |
| Tops N at anthesis (kg/ha) | 149 | -99 |
| Tops weight at maturity (kg [dm]/ha) | 13859 | -99 |
| By-product produced (stalk) at maturity (kg[dm]/ha | 5911 | -99 |
| Harvest index at maturity | 0.573 | -99 |
| Leaf number per stem at maturity | 17 | -99 |
| Grain N at maturity (kg/ha) | 121 | -99 |
| Tops N at maturity (kg/ha) | 157 | -99 |
| Stem N at maturity (kg/ha) | 36 | -99 |
| Grain N at maturity (%) | 1.52 | -99 |

```
*ENVIRONMENTAL AND STRESS FACTORS

 |-----Development
Phase------|-------------Environment--------------|----------------Stress-------
----------|
                              |--------Average-------|---Cumulative--|
(0=Min, 1=Max Stress)         |
                         Time  Temp  Temp Solar Photop         Evapo
|----Water---|--Nitrogen--|--Phosphorus-|
                         Span   Max   Min   Rad  [day]   Rain  Trans  Photo
   Photo         Photo
                         days    øC    øC MJ/m2     hr     mm     mm  synth
Growth  synth Growth  synth Growth
--------------------------------------------------------------------------------
------------------------------
 Emergence-End Juvenile    25  33.7  26.0  20.3  13.68  441.0  120.7  0.000
0.000  0.000  0.000  0.000  0.000
 End Juvenil-Panicl Init    6  34.0  25.4  20.1  13.39   54.8   31.5  0.000
0.000  0.000  0.018  0.000  0.000
 Panicl Init-End Lf Grow   29  34.5  25.3  20.9  12.94  428.1  156.4  0.000
0.000  0.000  0.058  0.000  0.000
 End Lf Grth-Beg Grn Fil    6  33.8  24.7  16.8  12.44   10.6   24.0  0.000
0.000  0.000  0.022  0.000  0.000
 Grain Filling Phase       21  35.9  25.1  20.0  12.02   17.8  111.5  0.000
0.000  0.200  0.306  0.000  0.000

 Planting to Harvest       88  34.5  25.5  20.1  12.91  952.3  447.6  0.000
0.000  0.048  0.095  0.000  0.000
--------------------------------------------------------------------------------
------------------------------

*Water Productivity
 Growing season length:  88 days

 Precipitation during growth season        952.3 mm[rain]
   Dry Matter Productivity                  1.46 kg[DM]/m3[rain]          =
14.6 kg[DM]/ha per mm[rain]
   Yield Productivity                       0.83 kg[grain yield]/m3[rain] =
8.3 kg[yield]/ha per mm[rain]

 Evapotranspiration during growth season   447.6 mm[ET]
   Dry Matter Productivity                  3.10 kg[DM]/m3[ET]            =
31.0 kg[DM]/ha per mm[ET]
   Yield Productivity                       1.78 kg[grain yield]/m3[ET]   =
17.8 kg[yield]/ha per mm[ET]

 Transpiration during growth season        288.4 mm[EP]
   Dry Matter Productivity                  4.81 kg[DM]/m3[EP]            =
48.1 kg[DM]/ha per mm[EP]
   Yield Productivity                       2.76 kg[grain yield]/m3[EP]   =
27.6 kg[yield]/ha per mm[EP]

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                      Rice YIELD :     7948 kg/ha    [Dry weight]

********************************************************************************
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*DSSAT Cropping System Model Ver. 4.5.0.030             SEP 01, 2015; 11:22:36
```

```
*RUN   4          : T4
 MODEL            : RICER045 - Rice
 EXPERIMENT       : IITP1101 RI IITP1001RI IITR1001RI IITR, ROORKEE, RICE EXPERIME
 TREATMENT  4     : T4


 CROP             : Rice              CULTIVAR : Sharbati1        ECOTYPE :IB0001
 STARTING DATE    : JUL  7 1911
 PLANTING DATE    : JUL  7 1911    PLANTS/m2 : 33.0     ROW SPACING :  20.cm
 WEATHER          : WRDM   1911
 SOIL             : IITR791201     TEXTURE : SL    - Dhanauri
 SOIL INITIAL C   : DEPTH:120cm EXTR. H2O:127.2mm  NO3:139.1kg/ha  NH4: 15.8kg/ha
 WATER BALANCE    : IRRIGATE ON REPORTED DATE(S)
 IRRIGATION       :      250 mm IN    4 APPLICATIONS
 NITROGEN BAL.    : SOIL-N & N-UPTAKE SIMULATION; NO N-FIXATION
 N-FERTILIZER     :       90 kg/ha IN     5 APPLICATIONS
 RESIDUE/MANURE   : INITIAL :   500 kg/ha ;       0 kg/ha IN     1 APPLICATIONS
 ENVIRONM. OPT.   : DAYL= A  0.00  SRAD= A  0.00  TMAX= A  0.00  TMIN= A  0.00
                    RAIN= A  0.00  CO2 = R 735.0  DEW =A  0.00  WIND=A  0.00
 SIMULATION OPT   : WATER   :Y  NITROGEN:Y  N-FIX:N  PHOSPH :N  PESTS  :N
                    PHOTO   :C  ET      :R  INFIL:S  HYDROL :R  SOM    :G
                    CO2     :D  NSWIT   :1  EVAP :R  SOIL   :2
 MANAGEMENT OPT   : PLANTING:R  IRRIG   :R  FERT :R  RESIDUE:R  HARVEST:M
                    WEATHER :M  TILLAGE :N

*SUMMARY OF SOIL AND GENETIC INPUT PARAMETERS

   SOIL LOWER UPPER   SAT  EXTR  INIT   ROOT   BULK     pH    NO3    NH4    ORG
  DEPTH LIMIT LIMIT    SW    SW    SW   DIST   DENS                           C
   cm   cm3/cm3    cm3/cm3    cm3/cm3          g/cm3         ugN/g  ugN/g     %
--------------------------------------------------------------------------------
  0-  5 0.121 0.224 0.414 0.103 0.115   1.00   1.47   7.80   7.90   0.90   0.60
  5- 15 0.121 0.224 0.414 0.103 0.115   1.00   1.47   7.80   7.90   0.90   0.60
 15- 30 0.121 0.224 0.414 0.103 0.120   1.00   1.47   7.80   7.90   0.90   0.60
 30- 45 0.104 0.208 0.406 0.104 0.120   0.41   1.49   7.80   7.90   0.90   0.20
 45- 60 0.104 0.208 0.406 0.104 0.107   0.41   1.49   7.80   7.90   0.90   0.20
 60- 90 0.097 0.201 0.407 0.104 0.101   0.22   1.49   7.80   7.90   0.90   0.10
 90-120 0.082 0.195 0.419 0.113 0.102   0.12   1.42   7.80   7.90   0.90   0.01

TOT-120  12.1  24.8  49.4  12.7  13.0  <--cm   -  kg/ha-->  139.1   15.8  40296
SOIL ALBEDO    : 0.13      EVAPORATION LIMIT : 6.00         MIN. FACTOR  : 1.00
RUNOFF CURVE # :73.00      DRAINAGE RATE     : 0.40         FERT. FACTOR : 1.00

 Rice       CULTIVAR :IB0054-Sharbati1         ECOTYPE :IB0001
 P1      : 780.0  P2R    :  90.0  P5     : 400.0  P2O    :  15.4
 G1      :  60.0  G2     :0.0230  G3     :  0.70  G4     :  0.80
*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

 RUN NO.     4     T4

        CROP GROWTH     BIOMASS         LEAF   CROP N     STRESS      STRESS

   DATE  AGE STAGE         kg/ha    LAI   NUM  kg/ha  %   H2O    N     P1    P2
RSTG
 ------  --- ----------   -----  -----  ----  ---  ---  ----  ----  ----  ----
----
  7 JUL    0 Transplant      53   0.11   5.0    2  4.6  0.00  0.00  0.00  0.00
  1
  7 JUL    0 Start Sim       53   0.11   5.0    2  4.6  0.00  0.00  0.00  0.00
  1
  1 AUG   25 End Juveni     946   1.33  11.0   31  3.2  0.00  0.00  0.00  0.00
  2
```

```
  7 AUG   31 Pan Init      2291   2.47  12.0   70  3.1  0.00  0.02  0.00  0.00
  3
  5 SEP   60 Heading      10206   4.73  17.0  153  1.5  0.00  0.16  0.00  0.00
  4
 11 SEP   66 Beg Gr Fil   11503   4.19  17.0  156  1.4  0.00  0.27  0.00  0.00
  5
 28 SEP   83 End Mn Fil   14265   2.32  17.0  161  1.1  0.00  0.40  0.00  0.00
  5
 30 SEP   85 End Ti Fil   14337   2.21  17.0  162  1.1  0.00  0.38  0.00  0.00
  6
  1 OCT   86 Maturity     14337   2.21  17.0  162  1.1  0.00  0.00  0.00  0.00
 20
  1 OCT   86 Harvest      14337   2.21  17.0  162  1.1  0.00  0.00  0.00  0.00
 20
```

*MAIN GROWTH AND DEVELOPMENT VARIABLES

```
@     VARIABLE                                          SIMULATED     MEASURED
      --------                                          ---------     --------
      Panicle Initiation day (dap)                             31          -99
      Anthesis day (dap)                                       60          -99
      Physiological maturity day (dap)                         86          -99
      Yield at harvest maturity (kg [dm]/ha)                 8207          -99
      Unit wt at maturity (g [dm]/unit)                    0.0230          -99
      Number at maturity (no/m2)                            35681          -99
      Pod or panicle number (no/m2)                        314.91          -99
      Leaf area index, maximum                               5.17          -99
      Tops weight at anthesis (kg [dm]/ha)                   9934          -99
      Tops N at anthesis (kg/ha)                              153          -99
      Tops weight at maturity (kg [dm]/ha)                  14337          -99
      By-product produced (stalk) at maturity (kg[dm]/ha    6130          -99
      Harvest index at maturity                             0.572          -99
      Leaf number per stem at maturity                         17          -99
      Grain N at maturity (kg/ha)                             125          -99
      Tops N at maturity (kg/ha)                              162          -99
      Stem N at maturity (kg/ha)                               36          -99
      Grain N at maturity (%)                                1.53          -99
```

*ENVIRONMENTAL AND STRESS FACTORS

```
 |-----Development
Phase------|-------------Environment--------------|----------------Stress-------
----------|
                              |--------Average-------|---Cumulative--|
(0=Min, 1=Max Stress)         |
                         Time  Temp  Temp Solar Photop         Evapo
|----Water---|--Nitrogen--|--Phosphorus-|
                         Span   Max   Min   Rad  [day]   Rain  Trans  Photo
   Photo         Photo
                         days    øC    øC MJ/m2     hr     mm     mm  synth
Growth  synth Growth  synth Growth
--------------------------------------------------------------------------------
-----------------------------
 Emergence-End Juvenile    25  33.7  26.0  20.3  13.68  441.0  119.2  0.000
0.000  0.000  0.000  0.000  0.000
 End Juvenil-Panicl Init    6  34.0  25.4  20.1  13.39   54.8   30.6  0.000
0.000  0.000  0.019  0.000  0.000
 Panicl Init-End Lf Grow   29  34.5  25.3  20.9  12.94  428.1  154.9  0.000
0.000  0.033  0.152  0.000  0.000
 End Lf Grth-Beg Grn Fil    6  33.8  24.7  16.8  12.44   10.6   23.7  0.000
0.000  0.000  0.218  0.000  0.000
```

```
 Grain Filling Phase       19  35.8  25.2  20.1  12.05   17.8  102.4  0.000
0.000  0.305  0.424  0.000  0.000

 Planting to Harvest       86  34.5  25.4  20.2  12.94  952.3  435.4  0.000
0.000  0.079  0.161  0.000  0.000
--------------------------------------------------------------------------------
------------------------------

*Water Productivity
 Growing season length:  86 days

 Precipitation during growth season        952.3 mm[rain]
   Dry Matter Productivity                  1.51 kg[DM]/m3[rain]          =
15.1 kg[DM]/ha per mm[rain]
   Yield Productivity                       0.86 kg[grain yield]/m3[rain] =
8.6 kg[yield]/ha per mm[rain]

 Evapotranspiration during growth season   435.4 mm[ET]
   Dry Matter Productivity                  3.29 kg[DM]/m3[ET]            =
32.9 kg[DM]/ha per mm[ET]
   Yield Productivity                       1.88 kg[grain yield]/m3[ET]   =
18.8 kg[yield]/ha per mm[ET]

 Transpiration during growth season        280.5 mm[EP]
   Dry Matter Productivity                  5.11 kg[DM]/m3[EP]            =
51.1 kg[DM]/ha per mm[EP]
   Yield Productivity                       2.93 kg[grain yield]/m3[EP]   =
29.3 kg[yield]/ha per mm[EP]

--------------------------------------------------------------------------------
------------------------------

                      Rice YIELD :     8207 kg/ha    [Dry weight]

********************************************************************************
******************************
```

APPENDIX III
OVERVIEW FILE GENERATED FOR VALIDATION OF DSSAT CERES RICE MODEL USING KHARIF 2012
FIELD EXPERIMENT DATA

```
*DSSAT Cropping System Model Ver. 4.5.0.030          AUG 29, 2015; 03:16:21

*RUN   1         : T0 2012
 MODEL           : RICER045 - Rice
 EXPERIMENT      : IITR7901 RI IITR1001RI IITR, ROORKEE, RICE EXPERIMENT, 2010
 TREATMENT  1    : T0 2012

 CROP            : Rice              CULTIVAR : Sharbati         ECOTYPE :IB0001
 STARTING DATE   : JUL 20 1911
 PLANTING DATE   : JUL 20 1911    PLANTS/m2 : 25.0     ROW SPACING :  20.cm
 WEATHER         : RCM1   1911
 SOIL            : IITR791201     TEXTURE : SL    - Dhanauri
 SOIL INITIAL C  : DEPTH:120cm EXTR. H2O:127.2mm  NO3:186.7kg/ha  NH4: 21.1kg/ha
 WATER BALANCE   : IRRIGATE ON REPORTED DATE(S)
 IRRIGATION      :      350 mm IN     7 APPLICATIONS
 NITROGEN BAL.   : SOIL-N & N-UPTAKE SIMULATION; NO N-FIXATION
 N-FERTILIZER    :       100 kg/ha IN     4 APPLICATIONS

 RESIDUE/MANURE  : INITIAL :    50 kg/ha ;       0 kg/ha IN     1 APPLICATIONS
 ENVIRONM. OPT.  : DAYL= A  0.00  SRAD= A  0.00  TMAX= A  0.00  TMIN= A  0.00
                   RAIN= A  0.00  CO2 = R 352.0  DEW =A  0.00  WIND=A  0.00
 SIMULATION OPT  : WATER   :Y  NITROGEN:Y  N-FIX:N  PHOSPH :N  PESTS  :N
                   PHOTO   :C  ET      :R  INFIL:S  HYDROL :R  SOM    :G
                   CO2     :D  NSWIT   :1  EVAP :R  SOIL   :2
 MANAGEMENT OPT  : PLANTING:R  IRRIG   :R  FERT :R  RESIDUE:R  HARVEST:M
                   WEATHER :M  TILLAGE :N

*SUMMARY OF SOIL AND GENETIC INPUT PARAMETERS

   SOIL LOWER UPPER   SAT  EXTR  INIT   ROOT   BULK     pH    NO3    NH4    ORG
  DEPTH LIMIT LIMIT    SW    SW    SW   DIST   DENS                           C
   cm   cm3/cm3    cm3/cm3    cm3/cm3          g/cm3         ugN/g  ugN/g     %
--------------------------------------------------------------------------------
  0-  5 0.121 0.224 0.414 0.103 0.210   1.00   1.47   7.80  10.60   1.20   0.60
  5- 15 0.121 0.224 0.414 0.103 0.210   1.00   1.47   7.80  10.60   1.20   0.60
 15- 30 0.121 0.224 0.414 0.103 0.206   1.00   1.47   7.80  10.60   1.20   0.60
 30- 45 0.104 0.208 0.406 0.104 0.206   0.41   1.49   7.80  10.60   1.20   0.20
 45- 60 0.104 0.208 0.406 0.104 0.198   0.41   1.49   7.80  10.60   1.20   0.20
 60- 90 0.097 0.201 0.407 0.104 0.197   0.22   1.49   7.80  10.60   1.20   0.10
 90-120 0.082 0.195 0.419 0.113 0.203   0.12   1.42   7.80  10.60   1.20   0.01

TOT-120  12.1  24.8  49.4  12.7  24.3  <--cm   -  kg/ha-->  186.7   21.1  40296
SOIL ALBEDO    : 0.13      EVAPORATION LIMIT : 6.00         MIN. FACTOR  : 1.00
RUNOFF CURVE # :73.00      DRAINAGE RATE     : 0.40         FERT. FACTOR : 1.00

 Rice        CULTIVAR :IB0054-Sharbati1         ECOTYPE :IB0001
 P1     : 780.0  P2R    :  90.0  P5     : 400.0  P2O    :  15.4
 G1     :  60.0  G2     :0.0230  G3     :  0.70  G4     :  0.80

*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

 RUN NO.     2     T0 2012
```

| DATE | CROP AGE | GROWTH STAGE | BIOMASS kg/ha | LAI | LEAF NUM | CROP N kg/ha | CROP N % | STRESS H2O | STRESS N | STRESS P1 | STRESS P2 | RSTG |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19 JUL | 0 | Transplant | 40 | 0.08 | 5.0 | 2 | 4.7 | 0.00 | 0.00 | 0.00 | 0.00 | 1 |
| 19 JUL | 0 | Start Sim | 40 | 0.08 | 5.0 | 2 | 4.7 | 0.00 | 0.00 | 0.00 | 0.00 | 1 |
| 11 AUG | 23 | End Juveni | 328 | 0.49 | 10.0 | 11 | 3.3 | 0.00 | 0.00 | 0.00 | 0.00 | 2 |
| 18 AUG | 30 | Pan Init | 900 | 0.99 | 12.0 | 28 | 3.1 | 0.00 | 0.02 | 0.00 | 0.00 | 3 |
| 20 SEP | 63 | Heading | 6327 | 3.71 | 16.0 | 103 | 1.6 | 0.00 | 0.00 | 0.00 | 0.00 | 4 |
| 27 SEP | 70 | Beg Gr Fil | 7743 | 3.30 | 16.0 | 107 | 1.4 | 0.00 | 0.00 | 0.00 | 0.00 | 5 |
| 16 OCT | 89 | End Mn Fil | 10629 | 2.17 | 16.0 | 120 | 1.1 | 0.00 | 0.00 | 0.00 | 0.00 | 5 |
| 17 OCT | 90 | End Ti Fil | 10629 | 2.17 | 16.0 | 120 | 1.1 | 0.00 | 0.00 | 0.00 | 0.00 | 6 |
| 18 OCT | 91 | Maturity | 10629 | 2.17 | 16.0 | 120 | 1.1 | 0.00 | 0.00 | 0.00 | 0.00 | 20 |
| 18 OCT | 91 | Harvest | 10629 | 2.17 | 16.0 | 120 | 1.1 | 0.00 | 0.00 | 0.00 | 0.00 | 20 |

*MAIN GROWTH AND DEVELOPMENT VARIABLES

| @ VARIABLE | SIMULATED | MEASURED |
|---|---|---|
| Panicle Initiation day (dap) | 30 | -99 |
| Anthesis day (dap) | 63 | -99 |
| Physiological maturity day (dap) | 91 | -99 |
| Yield at harvest maturity (kg [dm]/ha) | 4685 | -99 |
| Unit wt at maturity (g [dm]/unit) | 0.0231 | -99 |
| Number at maturity (no/m2) | 20280 | -99 |
| Pod or panicle number (no/m2) | 137.02 | -99 |
| Leaf area index, maximum | 3.72 | -99 |
| Tops weight at anthesis (kg [dm]/ha) | 6120 | -99 |
| Tops N at anthesis (kg/ha) | 102 | -99 |
| Tops weight at maturity (kg [dm]/ha) | 10629 | -99 |
| By-product produced (stalk) at maturity (kg[dm]/ha | 5945 | -99 |
| Harvest index at maturity | 0.441 | -99 |
| Leaf number per stem at maturity | 16 | -99 |
| Grain N at maturity (kg/ha) | 71 | -99 |
| Tops N at maturity (kg/ha) | 120 | -99 |
| Stem N at maturity (kg/ha) | 48 | -99 |
| Grain N at maturity (%) | 1.52 | -99 |

*ENVIRONMENTAL AND STRESS FACTORS

```
 |-----Development
Phase------|-------------Environment--------------|----------------Stress-------
----------|
                               |--------Average-------|---Cumulative--|
(0=Min, 1=Max Stress)          |
                         Time  Temp  Temp Solar Photop         Evapo
|----Water---|--Nitrogen--|--Phosphorus-|
                         Span   Max   Min   Rad  [day]   Rain  Trans  Photo
```

```
   Photo         Photo
                         days    øC    øC MJ/m2     hr     mm     mm  synth
Growth  synth Growth  synth Growth
--------------------------------------------------------------------------------
------------------------------
 Emergence-End Juvenile    23  30.4  25.3  16.7  13.47  190.6   88.7  0.000
0.000  0.000  0.000  0.000  0.000
 End Juvenil-Panicl Init    7  32.0  25.0  19.3  13.11   24.2   33.8  0.000
0.000  0.000  0.015  0.000  0.000
 Panicl Init-End Lf Grow   33  30.5  24.8  15.9  12.54  355.7  133.8  0.000
0.000  0.000  0.000  0.000  0.000
 End Lf Grth-Beg Grn Fil    7  31.4  21.9  19.9  11.93    3.8   34.4  0.000
0.000  0.000  0.000  0.000  0.000
 Grain Filling Phase       20  31.6  19.8  19.4  11.52    0.0   92.6  0.000
0.000  0.000  0.000  0.000  0.000

 Planting to Harvest       91  30.9  23.5  17.5  12.53  574.3  387.6  0.000
0.000  0.000  0.001  0.000  0.000
--------------------------------------------------------------------------------
------------------------------

*Water Productivity
 Growing season length:  91 days

 Precipitation during growth season        574.3 mm[rain]
   Dry Matter Productivity                  1.85 kg[DM]/m3[rain]          =
18.5 kg[DM]/ha per mm[rain]
   Yield Productivity                       0.82 kg[grain yield]/m3[rain] =
8.2 kg[yield]/ha per mm[rain]

 Evapotranspiration during growth season   387.6 mm[ET]
   Dry Matter Productivity                  2.74 kg[DM]/m3[ET]            =
27.4 kg[DM]/ha per mm[ET]
   Yield Productivity                       1.21 kg[grain yield]/m3[ET]   =
12.1 kg[yield]/ha per mm[ET]

 Transpiration during growth season        228.0 mm[EP]
   Dry Matter Productivity                  4.66 kg[DM]/m3[EP]            =
46.6 kg[DM]/ha per mm[EP]
   Yield Productivity                       2.05 kg[grain yield]/m3[EP]   =
20.5 kg[yield]/ha per mm[EP]

--------------------------------------------------------------------------------
------------------------------

                      Rice YIELD :     4685 kg/ha    [Dry weight]

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*DSSAT Cropping System Model Ver. 4.5.0.030          AUG 29, 2015; 03:16:21

*RUN   2         : T1 2012
 MODEL           : RICER045 - Rice
 EXPERIMENT      : IITR7901 RI IITR1001RI IITR, ROORKEE, RICE EXPERIMENT, 2010
 TREATMENT  2    : T1 2012


 CROP            : Rice             CULTIVAR : Sharbati        ECOTYPE :IB0001
 STARTING DATE   : JUL 20 1911
 PLANTING DATE   : JUL 20 1911    PLANTS/m2 : 25.0     ROW SPACING :  20.cm
 WEATHER         : RCM1   1911
```

```
                          20 OVERVIEW 2012.OUT
 SOIL              : IITR791201     TEXTURE : SL    - Dhanauri
 SOIL INITIAL C : DEPTH:120cm EXTR. H2O:127.2mm  NO3:186.7kg/ha  NH4: 21.1kg/ha
 WATER BALANCE   : IRRIGATE ON REPORTED DATE(S)
 IRRIGATION      :      350 mm IN     7 APPLICATIONS
 NITROGEN BAL.   : SOIL-N & N-UPTAKE SIMULATION; NO N-FIXATION
 N-FERTILIZER    :       100 kg/ha IN     4 APPLICATIONS

 RESIDUE/MANURE : INITIAL :    50 kg/ha ;       0 kg/ha IN     1 APPLICATIONS
 ENVIRONM. OPT. : DAYL= A  0.00  SRAD= A  0.00  TMAX= A  0.00  TMIN= A  0.00
                  RAIN= A  0.00  CO2 = R 328.0  DEW =A  0.00  WIND=A  0.00
 SIMULATION OPT : WATER   :Y  NITROGEN:Y  N-FIX:N  PHOSPH :N  PESTS  :N
                  PHOTO   :C  ET      :R  INFIL:S  HYDROL :R  SOM    :G
                  CO2     :D  NSWIT   :1  EVAP :R  SOIL   :2
 MANAGEMENT OPT : PLANTING:R  IRRIG   :R  FERT :R  RESIDUE:R  HARVEST:M
                  WEATHER :M  TILLAGE :N

*SUMMARY OF SOIL AND GENETIC INPUT PARAMETERS

   SOIL LOWER UPPER   SAT  EXTR  INIT   ROOT   BULK     pH    NO3    NH4    ORG
  DEPTH LIMIT LIMIT    SW    SW    SW   DIST   DENS                          C
   cm   cm3/cm3    cm3/cm3    cm3/cm3          g/cm3         ugN/g  ugN/g     %
--------------------------------------------------------------------------------
  0-  5 0.121 0.224 0.414 0.103 0.210   1.00   1.47   7.80  10.60   1.20   0.60
  5- 15 0.121 0.224 0.414 0.103 0.210   1.00   1.47   7.80  10.60   1.20   0.60
 15- 30 0.121 0.224 0.414 0.103 0.206   1.00   1.47   7.80  10.60   1.20   0.60
 30- 45 0.104 0.208 0.406 0.104 0.206   0.41   1.49   7.80  10.60   1.20   0.20
 45- 60 0.104 0.208 0.406 0.104 0.198   0.41   1.49   7.80  10.60   1.20   0.20
 60- 90 0.097 0.201 0.407 0.104 0.197   0.22   1.49   7.80  10.60   1.20   0.10
 90-120 0.082 0.195 0.419 0.113 0.203   0.12   1.42   7.80  10.60   1.20   0.01

TOT-120  12.1  24.8  49.4  12.7  24.3  <--cm   -  kg/ha-->  186.7   21.1  40296
SOIL ALBEDO    : 0.13      EVAPORATION LIMIT : 6.00        MIN. FACTOR  : 1.00
RUNOFF CURVE # :73.00      DRAINAGE RATE     : 0.40        FERT. FACTOR : 1.00

 Rice        CULTIVAR :IB0054-Sharbati1         ECOTYPE :IB0001
 P1      : 780.0  P2R     :  90.0  P5      : 400.0  P2O     :  15.4
 G1      :  60.0  G2      :0.0230  G3      :  0.70  G4      :  0.80
*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

 RUN NO.     4     T1 2012

        CROP GROWTH     BIOMASS         LEAF   CROP N     STRESS      STRESS

   DATE   AGE STAGE         kg/ha     LAI   NUM  kg/ha  %   H2O     N    P1    P2
RSTG
------  --- ----------   -----  -----  ----  ---  ---  ----  ----  ----  ----
----
 19 JUL    0 Transplant      40   0.08   5.0    2  4.7  0.00  0.00  0.00  0.00
  1
 19 JUL    0 Start Sim       40   0.08   5.0    2  4.7  0.00  0.00  0.00  0.00
  1
 11 AUG   23 End Juveni     381   0.56  10.0   12  3.3  0.00  0.00  0.00  0.00
  2
 18 AUG   30 Pan Init      1065   1.17  12.0   33  3.1  0.00  0.02  0.00  0.00
  3
 20 SEP   63 Heading       7733   4.48  16.0  126  1.6  0.00  0.00  0.00  0.00
  4
 27 SEP   70 Beg Gr Fil    9456   3.98  16.0  132  1.4  0.00  0.00  0.00  0.00
  5
 16 OCT   89 End Mn Fil   12530   2.62  16.0  142  1.1  0.00  0.00  0.00  0.00
  5
 17 OCT   90 End Ti Fil   12530   2.62  16.0  142  1.1  0.00  0.00  0.00  0.00
  6
```

```
 18 OCT   91 Maturity     12530   2.62  16.0  142  1.1  0.00  0.00  0.00  0.00
20
 18 OCT   91 Harvest      12530   2.62  16.0  142  1.1  0.00  0.00  0.00  0.00
20


*MAIN GROWTH AND DEVELOPMENT VARIABLES

@     VARIABLE                                         SIMULATED    MEASURED
      --------                                         ---------    --------
      Panicle Initiation day (dap)                            30         -99
      Anthesis day (dap)                                      63         -99
      Physiological maturity day (dap)                        91         -99
      Yield at harvest maturity (kg [dm]/ha)                5718         -99
      Unit wt at maturity (g [dm]/unit)                   0.0231         -99
      Number at maturity (no/m2)                           24753         -99
      Pod or panicle number (no/m2)                       148.02         -99
      Leaf area index, maximum                              4.48         -99
      Tops weight at anthesis (kg [dm]/ha)                  7437         -99
      Tops N at anthesis (kg/ha)                             124         -99
      Tops weight at maturity (kg [dm]/ha)                 12530         -99
      By-product produced (stalk) at maturity (kg[dm]/ha    6812         -99
      Harvest index at maturity                            0.456         -99
      Leaf number per stem at maturity                        16         -99
      Grain N at maturity (kg/ha)                             87         -99
      Tops N at maturity (kg/ha)                             142         -99
      Stem N at maturity (kg/ha)                              55         -99
      Grain N at maturity (%)                               1.52         -99


*ENVIRONMENTAL AND STRESS FACTORS

 |-----Development
Phase------|-------------Environment--------------|----------------Stress-------
----------|
                              |--------Average-------|---Cumulative--|
(0=Min, 1=Max Stress)         |
                         Time  Temp  Temp Solar Photop         Evapo
|----Water---|--Nitrogen--|--Phosphorus-|
                         Span   Max   Min   Rad  [day]   Rain  Trans  Photo
   Photo         Photo
                         days    øC    øC MJ/m2     hr     mm     mm  synth
Growth  synth Growth  synth Growth
--------------------------------------------------------------------------------
------------------------------
 Emergence-End Juvenile    23  30.4  25.3  16.7  13.47  190.6   87.4  0.000
0.000  0.000  0.000  0.000  0.000
 End Juvenil-Panicl Init    7  32.0  25.0  19.3  13.11   24.2   34.2  0.000
0.000  0.000  0.016  0.000  0.000
 Panicl Init-End Lf Grow   33  30.5  24.8  15.9  12.54  355.7  130.4  0.000
0.000  0.000  0.000  0.000  0.000
 End Lf Grth-Beg Grn Fil    7  31.4  21.9  19.9  11.93    3.8   33.7  0.000
0.000  0.000  0.000  0.000  0.000
 Grain Filling Phase       20  31.6  19.8  19.4  11.52    0.0   92.6  0.000
0.000  0.000  0.004  0.000  0.000

 Planting to Harvest       91  30.9  23.5  17.5  12.53  574.3  382.7  0.000
0.000  0.000  0.002  0.000  0.000
--------------------------------------------------------------------------------
------------------------------

*Water Productivity
 Growing season length:  91 days
```

```
 Precipitation during growth season        574.3 mm[rain]
   Dry Matter Productivity                  2.18 kg[DM]/m3[rain]          =
21.8 kg[DM]/ha per mm[rain]
   Yield Productivity                       1.00 kg[grain yield]/m3[rain] =
10.0 kg[yield]/ha per mm[rain]

 Evapotranspiration during growth season   382.7 mm[ET]
   Dry Matter Productivity                  3.27 kg[DM]/m3[ET]            =
32.7 kg[DM]/ha per mm[ET]
   Yield Productivity                       1.49 kg[grain yield]/m3[ET]   =
14.9 kg[yield]/ha per mm[ET]

 Transpiration during growth season        231.9 mm[EP]
   Dry Matter Productivity                  5.40 kg[DM]/m3[EP]            =
54.0 kg[DM]/ha per mm[EP]
   Yield Productivity                       2.47 kg[grain yield]/m3[EP]   =
24.7 kg[yield]/ha per mm[EP]

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                      Rice YIELD :     5718 kg/ha    [Dry weight]

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*DSSAT Cropping System Model Ver. 4.5.0.030             AUG 29, 2015; 03:16:21

*RUN   3         : T2 2012
 MODEL           : RICER045 - Rice
 EXPERIMENT      : IITR7901 RI IITR1001RI IITR, ROORKEE, RICE EXPERIMENT, 2010
 TREATMENT  3    : T2 2012


 CROP            : Rice              CULTIVAR : Sharbati         ECOTYPE :IB0001
 STARTING DATE   : JUL 20 1911
 PLANTING DATE   : JUL 20 1911    PLANTS/m2 : 25.0     ROW SPACING :  20.cm
 WEATHER         : RCM1   1911
 SOIL            : IITR791201     TEXTURE : SL    - Dhanauri
 SOIL INITIAL C  : DEPTH:120cm EXTR. H2O:127.2mm  NO3:186.7kg/ha  NH4: 21.1kg/ha
 WATER BALANCE   : IRRIGATE ON REPORTED DATE(S)
 IRRIGATION      :      350 mm IN     7 APPLICATIONS
 NITROGEN BAL.   : SOIL-N & N-UPTAKE SIMULATION; NO N-FIXATION
 N-FERTILIZER    :       100 kg/ha IN     4 APPLICATIONS

 RESIDUE/MANURE  : INITIAL :    50 kg/ha ;       0 kg/ha IN     1 APPLICATIONS
 ENVIRONM. OPT.  : DAYL= A  0.00  SRAD= A  0.00  TMAX= A  0.00  TMIN= A  0.00
                   RAIN= A  0.00  CO2 = R 321.0  DEW =A  0.00  WIND=A  0.00
 SIMULATION OPT  : WATER   :Y  NITROGEN:Y  N-FIX:N  PHOSPH :N  PESTS  :N
                   PHOTO   :C  ET      :R  INFIL:S  HYDROL :R  SOM    :G
                   CO2     :D  NSWIT   :1  EVAP :R  SOIL   :2
 MANAGEMENT OPT  : PLANTING:R  IRRIG   :R  FERT :R  RESIDUE:R  HARVEST:M
                   WEATHER :M  TILLAGE :N

*SUMMARY OF SOIL AND GENETIC INPUT PARAMETERS

   SOIL LOWER UPPER   SAT  EXTR  INIT   ROOT   BULK     pH    NO3    NH4    ORG
  DEPTH LIMIT LIMIT    SW    SW    SW   DIST   DENS                          C
   cm   cm3/cm3    cm3/cm3    cm3/cm3         g/cm3         ugN/g  ugN/g     %
--------------------------------------------------------------------------------
  0-   5 0.121 0.224 0.414 0.103 0.210   1.00   1.47   7.80  10.60   1.20   0.60
```

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5- 15 | 0.121 | 0.224 | 0.414 | 0.103 | 0.210 | 1.00 | 1.47 | 7.80 | 10.60 | 1.20 | 0.60 |
| 15- 30 | 0.121 | 0.224 | 0.414 | 0.103 | 0.206 | 1.00 | 1.47 | 7.80 | 10.60 | 1.20 | 0.60 |
| 30- 45 | 0.104 | 0.208 | 0.406 | 0.104 | 0.206 | 0.41 | 1.49 | 7.80 | 10.60 | 1.20 | 0.20 |
| 45- 60 | 0.104 | 0.208 | 0.406 | 0.104 | 0.198 | 0.41 | 1.49 | 7.80 | 10.60 | 1.20 | 0.20 |
| 60- 90 | 0.097 | 0.201 | 0.407 | 0.104 | 0.197 | 0.22 | 1.49 | 7.80 | 10.60 | 1.20 | 0.10 |
| 90-120 | 0.082 | 0.195 | 0.419 | 0.113 | 0.203 | 0.12 | 1.42 | 7.80 | 10.60 | 1.20 | 0.01 |
| TOT-120 | 12.1 | 24.8 | 49.4 | 12.7 | 24.3 | <--cm | - | kg/ha--> | 186.7 | 21.1 | 40296 |

SOIL ALBEDO : 0.13 EVAPORATION LIMIT : 6.00 MIN. FACTOR : 1.00
RUNOFF CURVE # :73.00 DRAINAGE RATE : 0.40 FERT. FACTOR : 1.00

Rice CULTIVAR :IB0054-Sharbati1 ECOTYPE :IB0001
P1 : 780.0 P2R : 90.0 P5 : 400.0 P2O : 15.4
G1 : 60.0 G2 :0.0230 G3 : 0.70 G4 : 0.80

*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

RUN NO. 6 T2 2012

| DATE | CROP AGE | GROWTH STAGE | BIOMASS kg/ha | LAI | LEAF NUM | CROP N kg/ha | CROP N % | STRESS H2O | STRESS N | STRESS P1 | STRESS P2 | RSTG |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19 JUL | 0 | Transplant | 40 | 0.08 | 5.0 | 2 | 4.7 | 0.00 | 0.00 | 0.00 | 0.00 | 1 |
| 19 JUL | 0 | Start Sim | 40 | 0.08 | 5.0 | 2 | 4.7 | 0.00 | 0.00 | 0.00 | 0.00 | 1 |
| 11 AUG | 23 | End Juveni | 445 | 0.65 | 10.0 | 14 | 3.2 | 0.00 | 0.00 | 0.00 | 0.00 | 2 |
| 18 AUG | 30 | Pan Init | 1458 | 1.56 | 12.0 | 45 | 3.1 | 0.00 | 0.02 | 0.00 | 0.00 | 3 |
| 20 SEP | 63 | Heading | 9188 | 5.51 | 16.0 | 142 | 1.6 | 0.00 | 0.00 | 0.00 | 0.00 | 4 |
| 27 SEP | 70 | Beg Gr Fil | 11289 | 4.89 | 16.0 | 146 | 1.3 | 0.00 | 0.08 | 0.00 | 0.00 | 5 |
| 16 OCT | 89 | End Mn Fil | 15352 | 3.21 | 16.0 | 156 | 1.0 | 0.00 | 0.21 | 0.00 | 0.00 | 5 |
| 17 OCT | 90 | End Ti Fil | 15352 | 3.21 | 16.0 | 156 | 1.0 | 0.00 | 0.00 | 0.00 | 0.00 | 6 |
| 18 OCT | 91 | Maturity | 15352 | 3.21 | 16.0 | 156 | 1.0 | 0.00 | 0.00 | 0.00 | 0.00 | 20 |
| 18 OCT | 91 | Harvest | 15352 | 3.21 | 16.0 | 156 | 1.0 | 0.00 | 0.00 | 0.00 | 0.00 | 20 |

*MAIN GROWTH AND DEVELOPMENT VARIABLES

| @ VARIABLE | SIMULATED | MEASURED |
|---|---|---|
| Panicle Initiation day (dap) | 30 | -99 |
| Anthesis day (dap) | 63 | -99 |
| Physiological maturity day (dap) | 91 | -99 |
| Yield at harvest maturity (kg [dm]/ha) | 6669 | -99 |
| Unit wt at maturity (g [dm]/unit) | 0.0231 | -99 |
| Number at maturity (no/m2) | 28869 | -99 |
| Pod or panicle number (no/m2) | 166.38 | -99 |
| Leaf area index, maximum | 5.52 | -99 |
| Tops weight at anthesis (kg [dm]/ha) | 8889 | -99 |
| Tops N at anthesis (kg/ha) | 142 | -99 |
| Tops weight at maturity (kg [dm]/ha) | 15352 | -99 |
| By-product produced (stalk) at maturity (kg[dm]/ha | 8683 | -99 |
| Harvest index at maturity | 0.434 | -99 |

```
      Leaf number per stem at maturity                         16          -99
      Grain N at maturity (kg/ha)                             102          -99
      Tops N at maturity (kg/ha)                              156          -99
      Stem N at maturity (kg/ha)                               55          -99
      Grain N at maturity (%)                                1.53          -99


*ENVIRONMENTAL AND STRESS FACTORS

 |-----Development
Phase------|-------------Environment--------------|----------------Stress-------
----------|
                              |--------Average-------|---Cumulative--|
(0=Min, 1=Max Stress)         |
                         Time  Temp  Temp Solar Photop         Evapo
|----Water---|--Nitrogen--|--Phosphorus-|
                         Span   Max   Min   Rad  [day]   Rain  Trans  Photo
   Photo         Photo
                         days    øC    øC MJ/m2     hr     mm     mm  synth
Growth  synth Growth  synth Growth
--------------------------------------------------------------------------------
------------------------------
 Emergence-End Juvenile    23  30.4  25.3  16.7  13.47  190.6   86.0  0.000
0.000  0.000  0.000  0.000  0.000
 End Juvenil-Panicl Init    7  32.0  25.0  19.3  13.11   24.2   32.1  0.000
0.000  0.000  0.017  0.000  0.000
 Panicl Init-End Lf Grow   33  30.5  24.8  15.9  12.54  355.7  127.7  0.000
0.000  0.000  0.001  0.000  0.000
 End Lf Grth-Beg Grn Fil    7  31.4  21.9  19.9  11.93    3.8   33.3  0.000
0.000  0.000  0.091  0.000  0.000
 Grain Filling Phase       20  31.6  19.8  19.4  11.52    0.0   89.3  0.000
0.000  0.105  0.199  0.000  0.000

 Planting to Harvest       91  30.9  23.5  17.5  12.53  574.3  372.8  0.000
0.000  0.023  0.053  0.000  0.000
--------------------------------------------------------------------------------
------------------------------

*Water Productivity
 Growing season length:  91 days

 Precipitation during growth season        574.3 mm[rain]
   Dry Matter Productivity                  2.67 kg[DM]/m3[rain]          =
26.7 kg[DM]/ha per mm[rain]
   Yield Productivity                       1.16 kg[grain yield]/m3[rain] =
11.6 kg[yield]/ha per mm[rain]

 Evapotranspiration during growth season   372.8 mm[ET]
   Dry Matter Productivity                  4.12 kg[DM]/m3[ET]            =
41.2 kg[DM]/ha per mm[ET]
   Yield Productivity                       1.79 kg[grain yield]/m3[ET]   =
17.9 kg[yield]/ha per mm[ET]

 Transpiration during growth season        233.6 mm[EP]
   Dry Matter Productivity                  6.57 kg[DM]/m3[EP]            =
65.7 kg[DM]/ha per mm[EP]
   Yield Productivity                       2.85 kg[grain yield]/m3[EP]   =
28.5 kg[yield]/ha per mm[EP]

--------------------------------------------------------------------------------
------------------------------
                      Rice YIELD :     6669 kg/ha    [Dry weight]
```

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*******************************************************************************
******************************

*DSSAT Cropping System Model Ver. 4.5.0.030               AUG 29, 2015; 03:16:21

*RUN   4         : T3 2012
 MODEL           : RICER045 - Rice
 EXPERIMENT      : IITR7901 RI IITR1001RI IITR, ROORKEE, RICE EXPERIMENT, 2010
 TREATMENT  4    : T3 2012


 CROP            : Rice              CULTIVAR : Sharbati         ECOTYPE :IB0001
 STARTING DATE   : JUL 20 1911
 PLANTING DATE   : JUL 20 1911    PLANTS/m2 : 25.0     ROW SPACING :  20.cm
 WEATHER         : RCM1   1911
 SOIL            : IITR791201     TEXTURE : SL    - Dhanauri
 SOIL INITIAL C  : DEPTH:120cm EXTR. H2O:127.2mm  NO3:186.7kg/ha  NH4: 21.1kg/ha
 WATER BALANCE   : IRRIGATE ON REPORTED DATE(S)
 IRRIGATION      :      350 mm IN     7 APPLICATIONS
 NITROGEN BAL.   : SOIL-N & N-UPTAKE SIMULATION; NO N-FIXATION
 N-FERTILIZER    :       100 kg/ha IN     4 APPLICATIONS

 RESIDUE/MANURE : INITIAL :    50 kg/ha ;       0 kg/ha IN     1 APPLICATIONS
 ENVIRONM. OPT. : DAYL= A  0.00  SRAD= A  0.00  TMAX= A  0.00  TMIN= A  0.00
                  RAIN= A  0.00  CO2 = R 735.0  DEW =A  0.00  WIND=A  0.00
 SIMULATION OPT : WATER   :Y  NITROGEN:Y  N-FIX:N  PHOSPH :N  PESTS  :N
                  PHOTO   :C  ET      :R  INFIL:S  HYDROL :R  SOM    :G
                  CO2     :D  NSWIT   :1  EVAP :R  SOIL   :2
 MANAGEMENT OPT : PLANTING:R  IRRIG   :R  FERT :R  RESIDUE:R  HARVEST:M
                  WEATHER :M  TILLAGE :N

*SUMMARY OF SOIL AND GENETIC INPUT PARAMETERS

   SOIL LOWER UPPER   SAT  EXTR  INIT   ROOT   BULK     pH    NO3    NH4    ORG
  DEPTH LIMIT LIMIT    SW    SW    SW   DIST   DENS                          C
   cm   cm3/cm3    cm3/cm3    cm3/cm3          g/cm3         ugN/g  ugN/g    %
--------------------------------------------------------------------------------
  0-  5 0.121 0.224 0.414 0.103 0.210   1.00   1.47   7.80  10.60   1.20   0.60
  5- 15 0.121 0.224 0.414 0.103 0.210   1.00   1.47   7.80  10.60   1.20   0.60
 15- 30 0.121 0.224 0.414 0.103 0.206   1.00   1.47   7.80  10.60   1.20   0.60
 30- 45 0.104 0.208 0.406 0.104 0.206   0.41   1.49   7.80  10.60   1.20   0.20
 45- 60 0.104 0.208 0.406 0.104 0.198   0.41   1.49   7.80  10.60   1.20   0.20
 60- 90 0.097 0.201 0.407 0.104 0.197   0.22   1.49   7.80  10.60   1.20   0.10
 90-120 0.082 0.195 0.419 0.113 0.203   0.12   1.42   7.80  10.60   1.20   0.01

TOT-120  12.1  24.8  49.4  12.7  24.3  <--cm   -  kg/ha-->  186.7   21.1  40296
SOIL ALBEDO    : 0.13      EVAPORATION LIMIT : 6.00         MIN. FACTOR  : 1.00
RUNOFF CURVE # :73.00      DRAINAGE RATE     : 0.40         FERT. FACTOR : 1.00

 Rice       CULTIVAR :IB0054-Sharbati1         ECOTYPE :IB0001
 P1     : 780.0  P2R    :  90.0  P5     : 400.0  P2O    :  15.4
 G1     :  60.0  G2     :0.0230  G3     :  0.70  G4     :  0.80
*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

 RUN NO.     8     T3 2012

       CROP GROWTH     BIOMASS         LEAF    CROP N     STRESS      STRESS

   DATE  AGE STAGE          kg/ha     LAI    NUM  kg/ha  %   H2O     N     P1     P2
RSTG
 ------  --- ----------   -----  -----  ----  ---  ---  ----  ----  ----  ----
```

```
----
 19 JUL    0 Transplant      40    0.08   5.0     2  4.7  0.00   0.00   0.00   0.00
  1
 19 JUL    0 Start Sim       40    0.08   5.0     2  4.7  0.00   0.00   0.00   0.00
  1
 11 AUG   23 End Juveni     537    0.77  10.0    18  3.3  0.00   0.00   0.00   0.00
  2
 18 AUG   30 Pan Init      1703    1.81  12.0    52  3.1  0.00   0.02   0.00   0.00
  3
 20 SEP   63 Heading      10097    5.20  16.0   149  1.5  0.00   0.05   0.00   0.00
  4
 27 SEP   70 Beg Gr Fil   12186    4.50  16.0   153  1.3  0.00   0.22   0.00   0.00
  5
 16 OCT   89 End Mn Fil   15739    2.51  16.0   162  1.0  0.00   0.37   0.00   0.00
  5
 17 OCT   90 End Ti Fil   15739    2.51  16.0   162  1.0  0.00   0.00   0.00   0.00
  6
 18 OCT   91 Maturity     15739    2.51  16.0   162  1.0  0.00   0.00   0.00   0.00
 20
 18 OCT   91 Harvest      15739    2.51  16.0   162  1.0  0.00   0.00   0.00   0.00
 20


*MAIN GROWTH AND DEVELOPMENT VARIABLES

@      VARIABLE                                             SIMULATED     MEASURED
       --------                                             ---------     --------
       Panicle Initiation day (dap)                                30          -99
       Anthesis day (dap)                                          63          -99
       Physiological maturity day (dap)                            91          -99
       Yield at harvest maturity (kg [dm]/ha)                    7260          -99
       Unit wt at maturity (g [dm]/unit)                       0.0231          -99
       Number at maturity (no/m2)                               31430          -99
       Pod or panicle number (no/m2)                           204.99          -99
       Leaf area index, maximum                                  5.69          -99
       Tops weight at anthesis (kg [dm]/ha)                      9805          -99
       Tops N at anthesis (kg/ha)                                 149          -99
       Tops weight at maturity (kg [dm]/ha)                     15739          -99
       By-product produced (stalk) at maturity (kg[dm]/ha        8479          -99
       Harvest index at maturity                                0.461          -99
       Leaf number per stem at maturity                            16          -99
       Grain N at maturity (kg/ha)                                111          -99
       Tops N at maturity (kg/ha)                                 162          -99
       Stem N at maturity (kg/ha)                                  51          -99
       Grain N at maturity (%)                                   1.53          -99


*ENVIRONMENTAL AND STRESS FACTORS

 |-----Development
Phase------|-------------Environment--------------|----------------Stress-------
----------|
                             |--------Average-------|---Cumulative--|
(0=Min, 1=Max Stress)        |
                        Time  Temp  Temp Solar Photop         Evapo
|----Water---|--Nitrogen--|--Phosphorus-|
                        Span   Max   Min   Rad  [day]   Rain  Trans  Photo
   Photo         Photo
                        days    øC    øC MJ/m2     hr     mm     mm  synth
Growth  synth Growth  synth Growth
--------------------------------------------------------------------------------
------------------------------
 Emergence-End Juvenile    23  30.4  25.3  16.7  13.47  190.6   82.4  0.000
```

```
0.000  0.000  0.000  0.000  0.000
 End Juvenil-Panicl Init    7  32.0  25.0  19.3  13.11   24.2   32.0  0.000
0.000  0.000  0.015  0.000  0.000
 Panicl Init-End Lf Grow   33  30.5  24.8  15.9  12.54  355.7  126.5  0.000
0.000  0.000  0.046  0.000  0.000
 End Lf Grth-Beg Grn Fil    7  31.4  21.9  19.9  11.93    3.8   33.3  0.000
0.000  0.000  0.217  0.000  0.000
 Grain Filling Phase       20  31.6  19.8  19.4  11.52    0.0   88.5  0.000
0.000  0.207  0.362  0.000  0.000

 Planting to Harvest       91  30.9  23.5  17.5  12.53  574.3  366.7  0.000
0.000  0.045  0.114  0.000  0.000
--------------------------------------------------------------------------------
------------------------------

*Water Productivity
 Growing season length:  91 days

 Precipitation during growth season        574.3 mm[rain]
   Dry Matter Productivity                  2.74 kg[DM]/m3[rain]          =
27.4 kg[DM]/ha per mm[rain]
   Yield Productivity                       1.26 kg[grain yield]/m3[rain] =
12.6 kg[yield]/ha per mm[rain]

 Evapotranspiration during growth season   366.7 mm[ET]
   Dry Matter Productivity                  4.29 kg[DM]/m3[ET]            =
42.9 kg[DM]/ha per mm[ET]
   Yield Productivity                       1.98 kg[grain yield]/m3[ET]   =
19.8 kg[yield]/ha per mm[ET]

 Transpiration during growth season        232.3 mm[EP]
   Dry Matter Productivity                  6.78 kg[DM]/m3[EP]            =
67.8 kg[DM]/ha per mm[EP]
   Yield Productivity                       3.13 kg[grain yield]/m3[EP]   =
31.3 kg[yield]/ha per mm[EP]

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                      Rice YIELD :     7260 kg/ha    [Dry weight]

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APPENDIX IV

OVERVIEW FILE GENERATED FOR CALIBRATION OF DSSAT CERES RICE MODEL USING KHARIF 2013 FIELD EXPERIMENT DATA

```
*SIMULATION OVERVIEW FILE

*DSSAT Cropping System Model Ver. 4.5.0.030          AUG 31, 2015; 08:41:53

*RUN   1        : D1
 MODEL          : RICER045 - Rice
 EXPERIMENT     : IITR1301 RI IITR1101RI CLIMATE CHANGE EFFECT ON CROPS
 TREATMENT  1   : D1

 CROP           : Rice             CULTIVAR : Sharbati         ECOTYPE :IB0001
 STARTING DATE  : JUL  8 1913
 PLANTING DATE  : JUL  8 1913    PLANTS/m2 : 33.0     ROW SPACING :  20.cm
 WEATHER        : 2013   1913
 SOIL           : IITR791201     TEXTURE : SL    - Dhanauri
 SOIL INITIAL C : DEPTH:120cm EXTR. H2O:127.2mm  NO3:269.4kg/ha  NH4: 29.9kg/ha
 WATER BALANCE  : IRRIGATE ON REPORTED DATE(S)
 IRRIGATION     :      420 mm IN     7 APPLICATIONS
 NITROGEN BAL.  : SOIL-N & N-UPTAKE SIMULATION; NO N-FIXATION
 N-FERTILIZER   :      120 kg/ha IN     5 APPLICATIONS
 RESIDUE/MANURE : INITIAL :    50 kg/ha ;       0 kg/ha IN     1 APPLICATIONS
 ENVIRONM. OPT. : DAYL=    0.00  SRAD=    0.00  TMAX=    0.00  TMIN=    0.00
                  RAIN=    0.00  CO2 =    0.00  DEW =    0.00  WIND=    0.00
 SIMULATION OPT : WATER   :Y  NITROGEN:Y  N-FIX:N  PHOSPH :N  PESTS  :N
                  PHOTO   :C  ET      :R  INFIL:S  HYDROL :R  SOM    :G
                  CO2     :W  NSWIT   :1  EVAP :R  SOIL   :2
 MANAGEMENT OPT : PLANTING:R  IRRIG   :R  FERT :R  RESIDUE:R  HARVEST:A
                  WEATHER :M  TILLAGE :N
```

*SUMMARY OF SOIL AND GENETIC INPUT PARAMETERS

| SOIL DEPTH cm | LOWER LIMIT cm3/cm3 | UPPER LIMIT cm3/cm3 | SAT SW cm3/cm3 | EXTR SW cm3/cm3 | INIT SW cm3/cm3 | ROOT DIST | BULK DENS g/cm3 | pH | NO3 ugN/g | NH4 ugN/g | ORG C % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0- 5 | 0.121 | 0.224 | 0.414 | 0.103 | 0.183 | 1.00 | 1.47 | 7.80 | 15.30 | 1.70 | 0.60 |
| 5- 15 | 0.121 | 0.224 | 0.414 | 0.103 | 0.183 | 1.00 | 1.47 | 7.80 | 15.30 | 1.70 | 0.60 |
| 15- 30 | 0.121 | 0.224 | 0.414 | 0.103 | 0.183 | 1.00 | 1.47 | 7.80 | 15.30 | 1.70 | 0.60 |
| 30- 45 | 0.104 | 0.208 | 0.406 | 0.104 | 0.166 | 0.41 | 1.49 | 7.80 | 15.30 | 1.70 | 0.20 |
| 45- 60 | 0.104 | 0.208 | 0.406 | 0.104 | 0.166 | 0.41 | 1.49 | 7.80 | 15.30 | 1.70 | 0.20 |
| 60- 90 | 0.097 | 0.201 | 0.407 | 0.104 | 0.159 | 0.22 | 1.49 | 7.80 | 15.30 | 1.70 | 0.10 |
| 90-120 | 0.082 | 0.195 | 0.419 | 0.113 | 0.150 | 0.12 | 1.42 | 7.80 | 15.30 | 1.70 | 0.01 |

```
TOT-120  12.1  24.8  49.4  12.7  19.7  <--cm   -  kg/ha-->  269.4   29.9  40296
SOIL ALBEDO    : 0.13      EVAPORATION LIMIT : 6.00        MIN. FACTOR  : 1.00
RUNOFF CURVE # :73.00      DRAINAGE RATE     : 0.40        FERT. FACTOR : 1.00

 Rice       CULTIVAR :IB0054-Sharbati1        ECOTYPE :IB0001
 P1     : 780.0  P2R    :  90.0  P5     : 400.0  P2O    :  15.4
 G1     :  60.0  G2     :0.0230  G3     :  0.70  G4     :  0.80
*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

 RUN NO.     1     D1
```

| DATE | CROP AGE | GROWTH STAGE | BIOMASS kg/ha | LAI | LEAF NUM | CROP N kg/ha | CROP N % | STRESS H2O | STRESS N | STRESS P1 | STRESS P2 | RSTG |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ------ | --- | ---------- | ----- | ----- | ---- | --- | --- | ---- | ---- | ---- | ---- | ---- |
| 8 JUL | 0 | Transplant | 53 | 0.11 | 5.0 | 2 | 4.1 | 0.00 | 0.00 | 0.00 | 0.00 | 1 |
| 8 JUL | 0 | Start Sim | 53 | 0.11 | 5.0 | 2 | 4.1 | 0.00 | 0.00 | 0.00 | 0.00 | 1 |
| 30 JUL | 22 | End Juveni | 208 | 0.32 | 10.0 | 7 | 3.3 | 0.20 | 0.01 | 0.00 | 0.00 | 2 |
| 6 AUG | 29 | Pan Init | 711 | 0.76 | 12.0 | 22 | 3.0 | 0.00 | 0.01 | 0.00 | 0.00 | 3 |
| 7 SEP | 61 | Heading | 6969 | 3.79 | 16.0 | 113 | 1.6 | 0.00 | 0.00 | 0.00 | 0.00 | 4 |
| 13 SEP | 67 | Beg Gr Fil | 8203 | 3.46 | 16.0 | 113 | 1.4 | 0.00 | 0.00 | 0.00 | 0.00 | 5 |
| 25 SEP | 79 | End Mn Fil | 10365 | 2.72 | 16.0 | 112 | 1.1 | 0.00 | 0.00 | 0.00 | 0.00 | 5 |
| 26 SEP | 80 | End Ti Fil | 10365 | 2.72 | 16.0 | 112 | 1.1 | 0.00 | 0.00 | 0.00 | 0.00 | 6 |
| 27 SEP | 81 | Maturity | 10365 | 2.72 | 16.0 | 112 | 1.1 | 0.00 | 0.00 | 0.00 | 0.00 | 20 |
| 27 SEP | 81 | Harvest | 10365 | 2.72 | 16.0 | 112 | 1.1 | 0.00 | 0.00 | 0.00 | 0.00 | 20 |

*MAIN GROWTH AND DEVELOPMENT VARIABLES

| @ VARIABLE | SIMULATED | MEASURED |
|---|---|---|
| -------- | --------- | -------- |
| Panicle Initiation day (dap) | 29 | -99 |
| Anthesis day (dap) | 61 | -99 |
| Physiological maturity day (dap) | 81 | -99 |
| Yield at harvest maturity (kg [dm]/ha) | 4403 | -99 |
| Unit wt at maturity (g [dm]/unit) | 0.0231 | -99 |
| Number at maturity (no/m2) | 19060 | -99 |
| Pod or panicle number (no/m2) | 68.74 | -99 |
| Leaf area index, maximum | 3.81 | -99 |
| Tops weight at anthesis (kg [dm]/ha) | 6749 | -99 |
| Tops N at anthesis (kg/ha) | 112 | -99 |
| Tops weight at maturity (kg [dm]/ha) | 10365 | -99 |
| By-product produced (stalk) at maturity (kg[dm]/ha | 5962 | -99 |
| Harvest index at maturity | 0.425 | -99 |
| Leaf number per stem at maturity | 16 | -99 |
| Grain N at maturity (kg/ha) | 56 | -99 |
| Tops N at maturity (kg/ha) | 112 | -99 |
| Stem N at maturity (kg/ha) | 55 | -99 |
| Grain N at maturity (%) | 1.28 | -99 |

*ENVIRONMENTAL AND STRESS FACTORS

```
 |-----Development
Phase------|-------------Environment--------------|----------------Stress-------
----------|
                               |--------Average-------|---Cumulative--|
(0=Min, 1=Max Stress)          |
                         Time  Temp  Temp Solar Photop        Evapo
|----Water---|--Nitrogen--|--Phosphorus-|
                         Span   Max   Min   Rad  [day]   Rain  Trans  Photo
```

```
   Photo          Photo
                         days    øC    øC MJ/m2     hr     mm     mm  synth
Growth  synth Growth  synth Growth
--------------------------------------------------------------------------------
------------------------------
 Emergence-End Juvenile    22  31.6  25.5  19.1  13.64   90.0   60.1  0.115
0.197  0.000  0.015  0.000  0.000
 End Juvenil-Panicl Init    7  32.4  26.0  18.9  13.38  102.8   32.9  0.000
0.000  0.000  0.007  0.000  0.000
 Panicl Init-End Lf Grow   32  31.7  24.3  19.3  12.89  517.9  159.4  0.000
0.000  0.000  0.000  0.000  0.000
 End Lf Grth-Beg Grn Fil    6  30.6  22.9  17.8  12.36   10.6   25.9  0.000
0.000  0.000  0.000  0.000  0.000
 Grain Filling Phase       13  32.7  22.9  20.1  12.08    6.2   65.4  0.000
0.000  0.000  0.000  0.000  0.000

 Planting to Harvest       81  31.8  24.4  19.2  12.96  727.5  348.7  0.031
0.054  0.000  0.005  0.000  0.000
--------------------------------------------------------------------------------
------------------------------

*Water Productivity
 Growing season length:  81 days

 Precipitation during growth season        727.5 mm[rain]
   Dry Matter Productivity                  1.42 kg[DM]/m3[rain]          =
14.2 kg[DM]/ha per mm[rain]
   Yield Productivity                       0.61 kg[grain yield]/m3[rain] =
6.1 kg[yield]/ha per mm[rain]

 Evapotranspiration during growth season   348.7 mm[ET]
   Dry Matter Productivity                  2.97 kg[DM]/m3[ET]            =
29.7 kg[DM]/ha per mm[ET]
   Yield Productivity                       1.26 kg[grain yield]/m3[ET]   =
12.6 kg[yield]/ha per mm[ET]

 Transpiration during growth season        196.5 mm[EP]
   Dry Matter Productivity                  5.27 kg[DM]/m3[EP]            =
52.7 kg[DM]/ha per mm[EP]
   Yield Productivity                       2.24 kg[grain yield]/m3[EP]   =
22.4 kg[yield]/ha per mm[EP]

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                      Rice YIELD :     4403 kg/ha    [Dry weight]

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*DSSAT Cropping System Model Ver. 4.5.0.030             AUG 31, 2015; 08:41:53

*RUN   2         : D2
 MODEL           : RICER045 - Rice
 EXPERIMENT      : IITR1301 RI IITR1101RI CLIMATE CHANGE EFFECT ON CROPS
 TREATMENT  2    : D2


 CROP            : Rice             CULTIVAR : Sharbati         ECOTYPE :IB0001
 STARTING DATE   : JUL 15 1913
 PLANTING DATE   : JUL 15 1913    PLANTS/m2 : 33.0     ROW SPACING :  20.cm
 WEATHER         : 2013   1913
 SOIL            : IITR791201     TEXTURE : SL    - Dhanauri
```

```
 SOIL INITIAL C : DEPTH:120cm EXTR. H2O:127.2mm  NO3:269.4kg/ha  NH4: 29.9kg/ha
 WATER BALANCE  : IRRIGATE ON REPORTED DATE(S)
 IRRIGATION     :      420 mm IN     7 APPLICATIONS
 NITROGEN BAL.  : SOIL-N & N-UPTAKE SIMULATION; NO N-FIXATION
 N-FERTILIZER   :      120 kg/ha IN     5 APPLICATIONS
 RESIDUE/MANURE : INITIAL :    50 kg/ha ;        0 kg/ha IN     1 APPLICATIONS
 ENVIRONM. OPT. : DAYL=    0.00  SRAD=    0.00  TMAX=    0.00  TMIN=    0.00
                  RAIN=    0.00  CO2 =    0.00  DEW =    0.00  WIND=    0.00
 SIMULATION OPT : WATER   :Y  NITROGEN:Y  N-FIX:N  PHOSPH :N  PESTS  :N
                  PHOTO   :C  ET      :R  INFIL:S  HYDROL :R  SOM    :G
                  CO2     :W  NSWIT   :1  EVAP :R  SOIL   :2
 MANAGEMENT OPT : PLANTING:R  IRRIG   :R  FERT :R  RESIDUE:R  HARVEST:A
                  WEATHER :M  TILLAGE :N
```

*SUMMARY OF SOIL AND GENETIC INPUT PARAMETERS

| SOIL DEPTH cm | LOWER LIMIT cm3/cm3 | UPPER LIMIT | SAT SW cm3/cm3 | EXTR SW | INIT SW cm3/cm3 | ROOT DIST | BULK DENS g/cm3 | pH | NO3 ugN/g | NH4 ugN/g | ORG C % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0- 5 | 0.121 | 0.224 | 0.414 | 0.103 | 0.183 | 1.00 | 1.47 | 7.80 | 15.30 | 1.70 | 0.60 |
| 5- 15 | 0.121 | 0.224 | 0.414 | 0.103 | 0.183 | 1.00 | 1.47 | 7.80 | 15.30 | 1.70 | 0.60 |
| 15- 30 | 0.121 | 0.224 | 0.414 | 0.103 | 0.183 | 1.00 | 1.47 | 7.80 | 15.30 | 1.70 | 0.60 |
| 30- 45 | 0.104 | 0.208 | 0.406 | 0.104 | 0.166 | 0.41 | 1.49 | 7.80 | 15.30 | 1.70 | 0.20 |
| 45- 60 | 0.104 | 0.208 | 0.406 | 0.104 | 0.166 | 0.41 | 1.49 | 7.80 | 15.30 | 1.70 | 0.20 |
| 60- 90 | 0.097 | 0.201 | 0.407 | 0.104 | 0.159 | 0.22 | 1.49 | 7.80 | 15.30 | 1.70 | 0.10 |
| 90-120 | 0.082 | 0.195 | 0.419 | 0.113 | 0.150 | 0.12 | 1.42 | 7.80 | 15.30 | 1.70 | 0.01 |
| TOT-120 | 12.1 | 24.8 | 49.4 | 12.7 | 19.7 | <--cm | - | kg/ha--> | 269.4 | 29.9 | 40296 |

```
SOIL ALBEDO    : 0.13      EVAPORATION LIMIT : 6.00         MIN. FACTOR  : 1.00
RUNOFF CURVE # :73.00      DRAINAGE RATE     : 0.40         FERT. FACTOR : 1.00

 Rice       CULTIVAR :IB0054-Sharbati1         ECOTYPE :IB0001
 P1     : 780.0  P2R    :  90.0  P5     : 400.0  P2O    :  15.4
 G1     :  60.0  G2     :0.0230  G3     :  0.70  G4     :  0.80
```

*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

RUN NO.     2     D2

| DATE | CROP AGE | GROWTH STAGE | BIOMASS kg/ha | LAI | LEAF NUM | CROP N kg/ha | CROP N % | STRESS H2O | STRESS N | STRESS P1 | STRESS P2 | RSTG |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 JUL | 0 | Transplant | 53 | 0.11 | 5.0 | 2 | 4.1 | 0.00 | 0.00 | 0.00 | 0.00 | 1 |
| 15 JUL | 0 | Start Sim | 53 | 0.11 | 5.0 | 2 | 4.1 | 0.00 | 0.00 | 0.00 | 0.00 | 1 |
| 6 AUG | 22 | End Juveni | 224 | 0.35 | 10.0 | 7 | 3.3 | 0.11 | 0.02 | 0.00 | 0.00 | 2 |
| 14 AUG | 30 | Pan Init | 918 | 0.97 | 12.0 | 28 | 3.0 | 0.00 | 0.01 | 0.00 | 0.00 | 3 |
| 15 SEP | 62 | Heading | 7453 | 4.20 | 16.0 | 122 | 1.6 | 0.00 | 0.00 | 0.00 | 0.00 | 4 |
| 22 SEP | 69 | Beg Gr Fil | 8986 | 3.79 | 16.0 | 122 | 1.4 | 0.00 | 0.00 | 0.00 | 0.00 | 5 |
| 4 OCT | 81 | End Mn Fil | 10946 | 2.97 | 16.0 | 121 | 1.1 | 0.00 | 0.00 | 0.00 | 0.00 | 5 |
| 5 OCT | 82 | End Ti Fil | 10946 | 2.97 | 16.0 | 121 | 1.1 | 0.00 | 0.00 | 0.00 | 0.00 | 6 |
| 6 OCT | 83 | Maturity | 10946 | 2.97 | 16.0 | 121 | 1.1 | 0.00 | 0.00 | 0.00 | 0.00 | 20 |

```
  6 OCT   83 Harvest      10946   2.97  16.0  121  1.1  0.00  0.00  0.00  0.00
 20
```

Conditions not met during defined window for harvesting

between DAY 1913 279 and DAY 1911 298

*MAIN GROWTH AND DEVELOPMENT VARIABLES

| @ VARIABLE | SIMULATED | MEASURED |
|---|---|---|
| Panicle Initiation day (dap) | 30 | -99 |
| Anthesis day (dap) | 62 | -99 |
| Physiological maturity day (dap) | 83 | -99 |
| Yield at harvest maturity (kg [dm]/ha) | 5110 | -99 |
| Unit wt at maturity (g [dm]/unit) | 0.0231 | -99 |
| Number at maturity (no/m2) | 22121 | -99 |
| Pod or panicle number (no/m2) | 67.97 | -99 |
| Leaf area index, maximum | 4.20 | -99 |
| Tops weight at anthesis (kg [dm]/ha) | 7202 | -99 |
| Tops N at anthesis (kg/ha) | 121 | -99 |
| Tops weight at maturity (kg [dm]/ha) | 10946 | -99 |
| By-product produced (stalk) at maturity (kg[dm]/ha | 5836 | -99 |
| Harvest index at maturity | 0.467 | -99 |
| Leaf number per stem at maturity | 16 | -99 |
| Grain N at maturity (kg/ha) | 60 | -99 |
| Tops N at maturity (kg/ha) | 121 | -99 |
| Stem N at maturity (kg/ha) | 60 | -99 |
| Grain N at maturity (%) | 1.18 | -99 |

*ENVIRONMENTAL AND STRESS FACTORS

```
 |-----Development
Phase------|-------------Environment--------------|----------------Stress-------
----------|
                              |--------Average-------|---Cumulative--|
(0=Min, 1=Max Stress)         |
                         Time  Temp  Temp Solar Photop         Evapo
|----Water---|--Nitrogen--|--Phosphorus-|
                         Span   Max   Min   Rad  [day]   Rain  Trans  Photo
   Photo          Photo
                         days    øC    øC MJ/m2     hr     mm     mm  synth
Growth  synth Growth  synth Growth
--------------------------------------------------------------------------------
-----------------------------
 Emergence-End Juvenile    22  31.8  25.5  19.1  13.52  186.7   80.3  0.080
0.114  0.000  0.018  0.000  0.000
 End Juvenil-Panicl Init    8  30.3  24.4  17.5  13.21  366.0   39.1  0.000
0.000  0.000  0.009  0.000  0.000
 Panicl Init-End Lf Grow   32  31.9  24.0  19.4  12.68  162.5  158.9  0.000
0.000  0.000  0.000  0.000  0.000
 End Lf Grth-Beg Grn Fil    7  33.1  22.0  21.5  12.11    6.2   35.5  0.000
0.000  0.000  0.000  0.000  0.000
 Grain Filling Phase       13  31.6  23.4  17.7  11.81    0.2   57.3  0.000
0.000  0.000  0.000  0.000  0.000

 Planting to Harvest       83  31.7  24.1  19.0  12.76  721.6  375.4  0.021
0.030  0.000  0.006  0.000  0.000
--------------------------------------------------------------------------------
```

```
------------------------------

*Water Productivity
 Growing season length:  83 days

 Precipitation during growth season        721.6 mm[rain]
   Dry Matter Productivity                  1.52 kg[DM]/m3[rain]          =
15.2 kg[DM]/ha per mm[rain]
   Yield Productivity                       0.71 kg[grain yield]/m3[rain] =
7.1 kg[yield]/ha per mm[rain]

 Evapotranspiration during growth season   375.4 mm[ET]
   Dry Matter Productivity                  2.92 kg[DM]/m3[ET]            =
29.2 kg[DM]/ha per mm[ET]
   Yield Productivity                       1.36 kg[grain yield]/m3[ET]   =
13.6 kg[yield]/ha per mm[ET]

 Transpiration during growth season        214.6 mm[EP]
   Dry Matter Productivity                  5.10 kg[DM]/m3[EP]            =
51.0 kg[DM]/ha per mm[EP]
   Yield Productivity                       2.38 kg[grain yield]/m3[EP]   =
23.8 kg[yield]/ha per mm[EP]

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                      Rice YIELD :     5110 kg/ha    [Dry weight]

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*DSSAT Cropping System Model Ver. 4.5.0.030           AUG 31, 2015; 08:41:54

*RUN   3          : D3
 MODEL            : RICER045 - Rice
 EXPERIMENT       : IITR1301 RI IITR1101RI CLIMATE CHANGE EFFECT ON CROPS
 TREATMENT  3     : D3


 CROP             : Rice             CULTIVAR : Sharbati         ECOTYPE :IB0001
 STARTING DATE    : JUL 22 1913
 PLANTING DATE    : JUL 22 1913    PLANTS/m2 : 33.0     ROW SPACING :  20.cm
 WEATHER          : 2013   1913
 SOIL             : IITR791201     TEXTURE : SL    - Dhanauri
 SOIL INITIAL C   : DEPTH:120cm EXTR. H2O:127.2mm  NO3:269.4kg/ha  NH4: 29.9kg/ha
 WATER BALANCE    : IRRIGATE ON REPORTED DATE(S)
 IRRIGATION       :      420 mm IN     7 APPLICATIONS
 NITROGEN BAL.    : SOIL-N & N-UPTAKE SIMULATION; NO N-FIXATION
 N-FERTILIZER     :      120 kg/ha IN     5 APPLICATIONS
 RESIDUE/MANURE   : INITIAL :    50 kg/ha ;       0 kg/ha IN     1 APPLICATIONS
 ENVIRONM. OPT.   : DAYL=    0.00  SRAD=    0.00  TMAX=    0.00  TMIN=    0.00
                    RAIN=    0.00  CO2 =    0.00  DEW =    0.00  WIND=    0.00
 SIMULATION OPT   : WATER   :Y  NITROGEN:Y  N-FIX:N  PHOSPH :N  PESTS  :N
                    PHOTO   :C  ET      :R  INFIL:S  HYDROL :R  SOM    :G
                    CO2     :W  NSWIT   :1  EVAP :R  SOIL   :2
 MANAGEMENT OPT   : PLANTING:R  IRRIG   :R  FERT :R  RESIDUE:R  HARVEST:A
                    WEATHER :M  TILLAGE :N

*SUMMARY OF SOIL AND GENETIC INPUT PARAMETERS

   SOIL LOWER UPPER   SAT  EXTR  INIT   ROOT   BULK     pH    NO3    NH4    ORG
  DEPTH LIMIT LIMIT    SW    SW    SW   DIST   DENS                          C
   cm   cm3/cm3    cm3/cm3    cm3/cm3        g/cm3         ugN/g  ugN/g     %
```

```
--------------------------------------------------------------------------------
  0-  5 0.121 0.224 0.414 0.103 0.183   1.00   1.47   7.80  15.30   1.70   0.60
  5- 15 0.121 0.224 0.414 0.103 0.183   1.00   1.47   7.80  15.30   1.70   0.60
 15- 30 0.121 0.224 0.414 0.103 0.183   1.00   1.47   7.80  15.30   1.70   0.60
 30- 45 0.104 0.208 0.406 0.104 0.166   0.41   1.49   7.80  15.30   1.70   0.20
 45- 60 0.104 0.208 0.406 0.104 0.166   0.41   1.49   7.80  15.30   1.70   0.20
 60- 90 0.097 0.201 0.407 0.104 0.159   0.22   1.49   7.80  15.30   1.70   0.10
 90-120 0.082 0.195 0.419 0.113 0.150   0.12   1.42   7.80  15.30   1.70   0.01

TOT-120  12.1  24.8  49.4  12.7  19.7  <--cm   -  kg/ha-->  269.4   29.9  40296
SOIL ALBEDO    : 0.13      EVAPORATION LIMIT : 6.00         MIN. FACTOR  : 1.00
RUNOFF CURVE # :73.00      DRAINAGE RATE     : 0.40         FERT. FACTOR : 1.00

 Rice        CULTIVAR :IB0054-Sharbati1          ECOTYPE :IB0001
 P1      : 780.0  P2R    :  90.0  P5     : 400.0  P2O    :  15.4
 G1      :  60.0  G2     :0.0230  G3     :  0.70  G4     :  0.80

*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

 RUN NO.     3     D3

        CROP GROWTH     BIOMASS         LEAF   CROP N     STRESS      STRESS

   DATE  AGE STAGE         kg/ha    LAI   NUM  kg/ha  %   H2O     N    P1    P2
RSTG
 ------  --- ----------   -----  -----  ----  ---  ---  ----  ----  ----  ----
----
 22 JUL    0 Transplant      53   0.11   5.0    3  4.7  0.00  0.00  0.00  0.00
  1
 22 JUL    0 Start Sim       53   0.11   5.0    3  4.7  0.00  0.00  0.00  0.00
  1
 14 AUG   23 End Juveni     274   0.43  10.0    9  3.3  0.02  0.00  0.00  0.00
  2
 20 AUG   29 Pan Init       843   0.92  12.0   26  3.1  0.00  0.01  0.00  0.00
  3
 21 SEP   61 Heading       7321   4.07  16.0  121  1.6  0.00  0.00  0.00  0.00
  4
 28 SEP   68 Beg Gr Fil    8791   3.63  16.0  120  1.4  0.00  0.00  0.00  0.00
  5
 10 OCT   80 End Mn Fil   10643   2.85  16.0  119  1.1  0.00  0.00  0.00  0.00
  5
 11 OCT   81 End Ti Fil   10643   2.85  16.0  119  1.1  0.00  0.00  0.00  0.00
  6
 12 OCT   82 Maturity     10643   2.85  16.0  119  1.1  0.00  0.00  0.00  0.00
 20
 12 OCT   82 Harvest      10643   2.85  16.0  119  1.1  0.00  0.00  0.00  0.00
 20

     Conditions not met during defined window for harvesting

     between DAY 1913 285 and DAY 1911 298



*MAIN GROWTH AND DEVELOPMENT VARIABLES

@      VARIABLE                                        SIMULATED     MEASURED
       --------                                        ---------     --------
       Panicle Initiation day (dap)                           29          -99
       Anthesis day (dap)                                     61          -99
       Physiological maturity day (dap)                       82          -99
       Yield at harvest maturity (kg [dm]/ha)               5094          -99
```

```
      Unit wt at maturity (g [dm]/unit)                    0.0231          -99
      Number at maturity (no/m2)                            22052          -99
      Pod or panicle number (no/m2)                         68.88          -99
      Leaf area index, maximum                               4.12          -99
      Tops weight at anthesis (kg [dm]/ha)                   7137          -99
      Tops N at anthesis (kg/ha)                              120          -99
      Tops weight at maturity (kg [dm]/ha)                  10643          -99
      By-product produced (stalk) at maturity (kg[dm]/ha     5549          -99
      Harvest index at maturity                             0.479          -99
      Leaf number per stem at maturity                         16          -99
      Grain N at maturity (kg/ha)                              61          -99
      Tops N at maturity (kg/ha)                              119          -99
      Stem N at maturity (kg/ha)                               58          -99
      Grain N at maturity (%)                                1.19          -99


*ENVIRONMENTAL AND STRESS FACTORS

 |-----Development
Phase------|-------------Environment--------------|----------------Stress-------
----------|
                              |--------Average-------|---Cumulative--|
(0=Min, 1=Max Stress)         |
                         Time  Temp  Temp Solar Photop         Evapo
|----Water---|--Nitrogen--|--Phosphorus-|
                         Span   Max   Min   Rad  [day]   Rain  Trans  Photo
   Photo         Photo
                         days    øC    øC MJ/m2     hr     mm     mm  synth
Growth  synth Growth  synth Growth
--------------------------------------------------------------------------------
------------------------------
 Emergence-End Juvenile    23  31.6  25.2  18.9  13.37  486.1   93.8  0.000
0.019  0.000  0.000  0.000  0.000
 End Juvenil-Panicl Init    6  31.4  24.6  19.0  13.04   23.4   24.9  0.000
0.000  0.000  0.011  0.000  0.000
 Panicl Init-End Lf Grow   32  32.2  23.5  19.9  12.51  142.1  160.3  0.000
0.000  0.000  0.000  0.000  0.000
 End Lf Grth-Beg Grn Fil    7  32.1  23.6  18.7  11.93    3.2   31.9  0.000
0.000  0.000  0.000  0.000  0.000
 Grain Filling Phase       13  31.1  23.1  16.1  11.64    0.2   50.6  0.000
0.000  0.000  0.000  0.000  0.000

 Planting to Harvest       82  31.8  24.0  18.8  12.59  655.0  364.3  0.000
0.005  0.000  0.001  0.000  0.000
--------------------------------------------------------------------------------
------------------------------


*Water Productivity
 Growing season length:  82 days

 Precipitation during growth season        655.0 mm[rain]
   Dry Matter Productivity                  1.62 kg[DM]/m3[rain]          =
16.2 kg[DM]/ha per mm[rain]
   Yield Productivity                       0.78 kg[grain yield]/m3[rain] =
7.8 kg[yield]/ha per mm[rain]

 Evapotranspiration during growth season   364.3 mm[ET]
   Dry Matter Productivity                  2.92 kg[DM]/m3[ET]            =
29.2 kg[DM]/ha per mm[ET]
   Yield Productivity                       1.40 kg[grain yield]/m3[ET]   =
14.0 kg[yield]/ha per mm[ET]

 Transpiration during growth season        207.2 mm[EP]
```

```
   Dry Matter Productivity                     5.14 kg[DM]/m3[EP]           =
51.4 kg[DM]/ha per mm[EP]
   Yield Productivity                          2.46 kg[grain yield]/m3[EP]   =
24.6 kg[yield]/ha per mm[EP]

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                      Rice YIELD :     5094 kg/ha    [Dry weight]

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*DSSAT Cropping System Model Ver. 4.5.0.030           AUG 31, 2015; 08:41:54

*RUN   4         : D4
 MODEL           : RICER045 - Rice
 EXPERIMENT      : IITR1301 RI IITR1101RI CLIMATE CHANGE EFFECT ON CROPS
 TREATMENT  4    : D4


 CROP            : Rice              CULTIVAR : Sharbati         ECOTYPE :IB0001
 STARTING DATE   : JUL 31 1913
 PLANTING DATE   : JUL 31 1913    PLANTS/m2 : 33.0     ROW SPACING :  20.cm
 WEATHER         : 2013   1913
 SOIL            : IITR791201     TEXTURE : SL    - Dhanauri
 SOIL INITIAL C  : DEPTH:120cm EXTR. H2O:127.2mm  NO3:269.4kg/ha  NH4: 29.9kg/ha
 WATER BALANCE   : IRRIGATE ON REPORTED DATE(S)
 IRRIGATION      :      300 mm IN     5 APPLICATIONS
 NITROGEN BAL.   : SOIL-N & N-UPTAKE SIMULATION; NO N-FIXATION
 N-FERTILIZER    :      120 kg/ha IN     5 APPLICATIONS
 RESIDUE/MANURE  : INITIAL :    50 kg/ha ;        0 kg/ha IN     1 APPLICATIONS
 ENVIRONM. OPT.  : DAYL=    0.00  SRAD=    0.00  TMAX=    0.00  TMIN=    0.00
                   RAIN=    0.00  CO2 =    0.00  DEW =    0.00  WIND=    0.00
 SIMULATION OPT  : WATER   :Y  NITROGEN:Y  N-FIX:N  PHOSPH :N  PESTS  :N
                   PHOTO   :C  ET      :R  INFIL:S  HYDROL :R  SOM    :G
                   CO2     :W  NSWIT   :1  EVAP :R  SOIL   :2
 MANAGEMENT OPT  : PLANTING:R  IRRIG   :R  FERT :R  RESIDUE:R  HARVEST:A
                   WEATHER :M  TILLAGE :N

*SUMMARY OF SOIL AND GENETIC INPUT PARAMETERS

   SOIL LOWER UPPER   SAT  EXTR  INIT   ROOT   BULK     pH    NO3    NH4    ORG
  DEPTH LIMIT LIMIT    SW    SW    SW   DIST   DENS                          C
   cm   cm3/cm3    cm3/cm3    cm3/cm3          g/cm3         ugN/g  ugN/g    %
--------------------------------------------------------------------------------
  0-  5 0.121 0.224 0.414 0.103 0.183   1.00   1.47   7.80  15.30   1.70   0.60
  5- 15 0.121 0.224 0.414 0.103 0.183   1.00   1.47   7.80  15.30   1.70   0.60
 15- 30 0.121 0.224 0.414 0.103 0.183   1.00   1.47   7.80  15.30   1.70   0.60
 30- 45 0.104 0.208 0.406 0.104 0.166   0.41   1.49   7.80  15.30   1.70   0.20
 45- 60 0.104 0.208 0.406 0.104 0.166   0.41   1.49   7.80  15.30   1.70   0.20
 60- 90 0.097 0.201 0.407 0.104 0.159   0.22   1.49   7.80  15.30   1.70   0.10
 90-120 0.082 0.195 0.419 0.113 0.150   0.12   1.42   7.80  15.30   1.70   0.01

TOT-120  12.1  24.8  49.4  12.7  19.7  <--cm   -  kg/ha-->  269.4   29.9  40296
SOIL ALBEDO    : 0.13      EVAPORATION LIMIT : 6.00        MIN. FACTOR  : 1.00
RUNOFF CURVE # :73.00      DRAINAGE RATE     : 0.40        FERT. FACTOR : 1.00

 Rice       CULTIVAR :IB0054-Sharbati1        ECOTYPE :IB0001
 P1     : 780.0  P2R    :  90.0  P5     : 400.0  P2O    :  15.4
 G1     :  60.0  G2     :0.0230  G3     :  0.70  G4     :  0.80
*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES
```

RUN NO. 4 D4

| DATE | CROP AGE | GROWTH STAGE | BIOMASS kg/ha | LAI | LEAF NUM | CROP N kg/ha | CROP N % | STRESS H2O | STRESS N | STRESS P1 | STRESS P2 | RSTG |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 31 JUL | 0 | Transplant | 53 | 0.11 | 5.0 | 2 | 4.1 | 0.00 | 0.00 | 0.00 | 0.00 | 1 |
| 31 JUL | 0 | Start Sim | 53 | 0.11 | 5.0 | 2 | 4.1 | 0.00 | 0.00 | 0.00 | 0.00 | 1 |
| 23 AUG | 23 | End Juveni | 289 | 0.43 | 10.0 | 10 | 3.3 | 0.12 | 0.02 | 0.00 | 0.00 | 2 |
| 29 AUG | 29 | Pan Init | 839 | 0.91 | 12.0 | 26 | 3.1 | 0.00 | 0.01 | 0.00 | 0.00 | 3 |
| 1 OCT | 62 | Heading | 7456 | 4.19 | 16.0 | 121 | 1.6 | 0.00 | 0.00 | 0.00 | 0.00 | 4 |
| 8 OCT | 69 | Beg Gr Fil | 8769 | 3.72 | 16.0 | 121 | 1.4 | 0.00 | 0.00 | 0.00 | 0.00 | 5 |
| 21 OCT | 82 | End Mn Fil | 10821 | 2.85 | 16.0 | 119 | 1.1 | 0.00 | 0.00 | 0.00 | 0.00 | 5 |
| 22 OCT | 83 | End Ti Fil | 10821 | 2.85 | 16.0 | 119 | 1.1 | 0.00 | 0.00 | 0.00 | 0.00 | 6 |
| 23 OCT | 84 | Maturity | 10821 | 2.85 | 16.0 | 119 | 1.1 | 0.00 | 0.00 | 0.00 | 0.00 | 20 |
| 23 OCT | 84 | Harvest | 10821 | 2.85 | 16.0 | 119 | 1.1 | 0.00 | 0.00 | 0.00 | 0.00 | 20 |

Conditions not met during defined window for harvesting

between DAY 1913 296 and DAY 1911 298

*MAIN GROWTH AND DEVELOPMENT VARIABLES

| @ VARIABLE | SIMULATED | MEASURED |
|---|---|---|
| Panicle Initiation day (dap) | 29 | -99 |
| Anthesis day (dap) | 62 | -99 |
| Physiological maturity day (dap) | 84 | -99 |
| Yield at harvest maturity (kg [dm]/ha) | 4593 | -99 |
| Unit wt at maturity (g [dm]/unit) | 0.0231 | -99 |
| Number at maturity (no/m2) | 19884 | -99 |
| Pod or panicle number (no/m2) | 69.24 | -99 |
| Leaf area index, maximum | 4.25 | -99 |
| Tops weight at anthesis (kg [dm]/ha) | 7259 | -99 |
| Tops N at anthesis (kg/ha) | 121 | -99 |
| Tops weight at maturity (kg [dm]/ha) | 10821 | -99 |
| By-product produced (stalk) at maturity (kg[dm]/ha | 6228 | -99 |
| Harvest index at maturity | 0.424 | -99 |
| Leaf number per stem at maturity | 16 | -99 |
| Grain N at maturity (kg/ha) | 54 | -99 |
| Tops N at maturity (kg/ha) | 119 | -99 |
| Stem N at maturity (kg/ha) | 65 | -99 |
| Grain N at maturity (%) | 1.18 | -99 |

*ENVIRONMENTAL AND STRESS FACTORS

|-----Development

```
Phase------|-------------Environment--------------|----------------Stress-------
----------|
                               |--------Average-------|---Cumulative--|
(0=Min, 1=Max Stress)          |
                          Time  Temp  Temp Solar Photop         Evapo
|----Water---|--Nitrogen--|--Phosphorus-|
                          Span   Max   Min   Rad  [day]   Rain  Trans  Photo
   Photo          Photo
                          days    øC    øC MJ/m2     hr     mm     mm  synth
Growth  synth Growth  synth Growth
--------------------------------------------------------------------------------
------------------------------
 Emergence-End Juvenile    23  31.8  24.9  19.1  13.17  431.2   87.3  0.092
0.120  0.000  0.021  0.000  0.000
 End Juvenil-Panicl Init    6  33.4  25.3  20.9  12.79   39.0   24.2  0.000
0.000  0.000  0.008  0.000  0.000
 Panicl Init-End Lf Grow   33  31.7  23.1  19.0  12.23  106.5  159.3  0.000
0.000  0.000  0.000  0.000  0.000
 End Lf Grth-Beg Grn Fil    7  30.9  22.4  16.1  11.64    0.0   26.3  0.000
0.000  0.000  0.000  0.000  0.000
 Grain Filling Phase       14  30.0  21.3  15.8  11.33   16.2   54.4  0.000
0.000  0.000  0.000  0.000  0.000

 Planting to Harvest       84  31.5  23.3  18.4  12.31  592.9  355.7  0.025
0.033  0.000  0.006  0.000  0.000
--------------------------------------------------------------------------------
------------------------------

*Water Productivity
 Growing season length:  84 days

 Precipitation during growth season        592.9 mm[rain]
   Dry Matter Productivity                  1.83 kg[DM]/m3[rain]          =
18.3 kg[DM]/ha per mm[rain]
   Yield Productivity                       0.77 kg[grain yield]/m3[rain] =
7.7 kg[yield]/ha per mm[rain]

 Evapotranspiration during growth season   355.7 mm[ET]
   Dry Matter Productivity                  3.04 kg[DM]/m3[ET]            =
30.4 kg[DM]/ha per mm[ET]
   Yield Productivity                       1.29 kg[grain yield]/m3[ET]   =
12.9 kg[yield]/ha per mm[ET]

 Transpiration during growth season        201.4 mm[EP]
   Dry Matter Productivity                  5.37 kg[DM]/m3[EP]            =
53.7 kg[DM]/ha per mm[EP]
   Yield Productivity                       2.28 kg[grain yield]/m3[EP]   =
22.8 kg[yield]/ha per mm[EP]

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                      Rice YIELD :     4593 kg/ha    [Dry weight]

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*APPENDIX V*

**PRECIS RCM forecasted average annual maximum and minimum temperatures and annual total rainfall for the period 2014 – 2090.**

| S.No. | Year | T Max ($^0$C) | T Min ($^0$C) | RF mm | S.No. | Year | T Max ($^0$C) | T Min ($^0$C) | RF mm | S.No. | Year | T Max ($^0$C) | T Min ($^0$C) | RF mm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | **2014** | 31.4 | 22.0 | 1180.7 | **27** | **2040** | 31.9 | 22.6 | 1383.8 | **53** | **2066** | 35.2 | 24.5 | 978.6 |
| **2** | **2015** | 32.2 | 22.6 | 683.5 | **28** | **2041** | 32.8 | 23.2 | 922.0 | **54** | **2067** | 32.9 | 23.5 | 1543.0 |
| **3** | **2016** | 30.9 | 21.6 | 1004.2 | **29** | **2042** | 32.9 | 23.1 | 912.8 | **55** | **2068** | 34.8 | 25.0 | 951.9 |
| **4** | **2017** | 31.9 | 22.5 | 1093.6 | **30** | **2043** | 34.4 | 24.5 | 680.3 | **56** | **2069** | 34.3 | 24.9 | 1159.0 |
| **5** | **2018** | 30.7 | 21.8 | 1309.3 | **31** | **2044** | 32.0 | 22.8 | 1209.2 | **57** | **2070** | 33.4 | 24.1 | 1231.7 |
| **6** | **2019** | 30.0 | 20.9 | 1013.8 | **32** | **2045** | 32.3 | 22.4 | 977.0 | **58** | **2071** | 32.8 | 23.4 | 1445.8 |
| **7** | **2020** | 31.5 | 22.2 | 975.1 | **33** | **2046** | 33.5 | 23.3 | 910.4 | **59** | **2072** | 34.6 | 24.9 | 973.2 |
| **8** | **2021** | 31.2 | 22.1 | 899.4 | **34** | **2047** | 34.7 | 24.2 | 695.7 | **60** | **2073** | 35.5 | 24.9 | 780.3 |
| **9** | **2022** | 33.4 | 23.4 | 486.3 | **35** | **2048** | 33.1 | 24.1 | 1180.3 | **61** | **2074** | 33.7 | 24.3 | 1078.7 |
| **10** | **2023** | 32.0 | 22.8 | 585.7 | **36** | **2049** | 32.3 | 23.1 | 1419.1 | **62** | **2075** | 34.3 | 24.8 | 1228.2 |
| **11** | **2024** | 32.5 | 23.0 | 1050.4 | **37** | **2050** | 32.5 | 23.4 | 1074.6 | **63** | **2076** | 33.5 | 24.4 | 793.3 |
| **12** | **2025** | 31.9 | 22.4 | 789.4 | **38** | **2051** | 35.2 | 24.4 | 656.4 | **64** | **2077** | 33.6 | 24.2 | 1277.9 |
| **13** | **2026** | 32.9 | 23.0 | 708.7 | **39** | **2052** | 33.9 | 23.8 | 1258.1 | **65** | **2078** | 36.2 | 25.7 | 1197.9 |
| **14** | **2027** | 33.6 | 23.2 | 644.3 | **40** | **2053** | 33.3 | 24.1 | 1027.3 | **66** | **2079** | 35.0 | 25.4 | 1496.8 |
| **15** | **2028** | 32.6 | 23.1 | 907.3 | **41** | **2054** | 32.8 | 23.6 | 1250.9 | **67** | **2080** | 33.9 | 24.8 | 1480.7 |
| **16** | **2029** | 31.0 | 22.3 | 1465.5 | **42** | **2055** | 33.6 | 23.8 | 1155.8 | **68** | **2081** | 35.1 | 24.8 | 1318.0 |
| **17** | **2030** | 33.5 | 22.9 | 545.7 | **43** | **2056** | 33.0 | 23.5 | 1125.1 | **69** | **2082** | 35.6 | 25.3 | 1518.7 |
| **18** | **2031** | 33.1 | 23.4 | 672.4 | **44** | **2057** | 33.7 | 24.1 | 971.8 | **70** | **2083** | 34.4 | 24.6 | 779.3 |
| **19** | **2032** | 30.9 | 22.5 | 895.6 | **45** | **2058** | 33.9 | 24.4 | 1263.0 | **71** | **2084** | 34.3 | 24.7 | 1286.3 |
| **20** | **2033** | 32.2 | 22.5 | 821.6 | **46** | **2059** | 34.3 | 24.4 | 961.1 | **72** | **2085** | 33.2 | 24.3 | 1441.9 |
| **21** | **2034** | 32.1 | 22.9 | 982.6 | **47** | **2060** | 35.1 | 25.2 | 782.3 | **73** | **2086** | 34.5 | 24.8 | 1894.0 |
| **22** | **2035** | 33.6 | 23.5 | 722.2 | **48** | **2061** | 33.8 | 24.1 | 756.0 | **74** | **2087** | 34.3 | 25.2 | 1357.9 |
| **23** | **2036** | 32.2 | 23.1 | 984.4 | **49** | **2062** | 35.6 | 25.3 | 728.7 | **75** | **2088** | 37.4 | 26.3 | 1213.2 |
| **24** | **2037** | 32.4 | 22.8 | 872.3 | **50** | **2063** | 33.8 | 24.0 | 1406.7 | **76** | **2089** | 35.3 | 25.4 | 1223.9 |
| **25** | **2038** | 33.2 | 23.4 | 601.4 | **51** | **2064** | 34.5 | 24.7 | 861.4 | **77** | **2090** | 34.8 | 25.3 | 1150.5 |
| **26** | **2039** | 32.2 | 22.9 | 1373.6 | **52** | **2065** | 35.0 | 25.1 | 926.8 | **Average** | | **33.4** | **23.8** | **1046.3** |

*APPENDIX VI*

**Simulated grain yield (kgs/ha) of rice cv Sharbati under various $CO_2$ enrichment treatments for the period 2014 – 2090; weather parameters during crop growth period.**

| S.No | Year | Present Scenario | A2 | B2 | Tmax | Tmin | SRAD | Photoperiod | RF | ET |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | ($^0$C) | ($^0$C) | MJ/m$^2$/day | Hours | mm | |
| **1** | **2014** | 6666 | 5878 | 5878 | 31.1 | 22.9 | 19.3 | 12.67 | 970.3 | 449.3 |
| **2** | **2015** | 6172 | 6055 | 5975 | 31.1 | 23.7 | 18.5 | 12.7 | 603.4 | 444 |
| **3** | **2016** | 6343 | 6166 | 5913 | 31.1 | 23.1 | 19 | 12.68 | 575.1 | 456 |
| **4** | **2017** | 5724 | 6103 | 6151 | 32.3 | 24.2 | 19.3 | 12.73 | 697.2 | 432.6 |
| **5** | **2018** | 5787 | 6284 | 5899 | 31.2 | 23.9 | 18.3 | 12.71 | 832.7 | 431.6 |
| **6** | **2019** | 6189 | 6344 | 6064 | 30.2 | 21.7 | 19.3 | 12.6 | 712.7 | 477.3 |
| **7** | **2020** | 6391 | 6210 | 6163 | 31 | 23.7 | 18.3 | 12.7 | 889.7 | 423.3 |
| **8** | **2021** | 6889 | 6212 | 6131 | 31.1 | 23.3 | 19 | 12.7 | 663.3 | 449.6 |
| **9** | **2022** | 5558 | 5803 | 6071 | 32.6 | 24.7 | 19.4 | 12.77 | 414.4 | 422.9 |
| **10** | **2023** | 6202 | 5998 | 6097 | 32.4 | 24.5 | 19.6 | 12.77 | 412.6 | 447.3 |
| **11** | **2024** | 5997 | 6142 | 6048 | 31.4 | 23.9 | 18.6 | 12.71 | 956.4 | 440.9 |
| **12** | **2025** | 5942 | 5455 | 6045 | 32.5 | 24.4 | 19.6 | 12.77 | 444 | 448.8 |
| **13** | **2026** | 6034 | 6171 | 6091 | 32.6 | 24.4 | 19.7 | 12.77 | 503.5 | 435.2 |
| **14** | **2027** | 5778 | 6847 | 6121 | 32.4 | 24 | 19.7 | 12.74 | 604.9 | 449 |
| **15** | **2028** | 6113 | 6063 | 6132 | 31.9 | 24.4 | 18.5 | 12.74 | 791.8 | 432 |
| **16** | **2029** | 5541 | 6010 | 6119 | 31.2 | 24 | 18.2 | 12.71 | 1114 | 419 |
| **17** | **2030** | 5712 | 6232 | 6008 | 32.9 | 24.5 | 20 | 12.8 | 496.4 | 433.5 |
| **18** | **2031** | 5488 | 6432 | 6074 | 32.5 | 24.9 | 19 | 12.77 | 576.2 | 441.2 |
| **19** | **2032** | 6105 | 6683 | 6046 | 31.3 | 24.2 | 18.3 | 12.73 | 798.3 | 415.6 |
| **20** | **2033** | 6290 | 6413 | 6090 | 31.6 | 23.4 | 18.9 | 12.68 | 545.4 | 439.1 |
| **21** | **2034** | 5769 | 6523 | 6116 | 31.9 | 24.3 | 18.7 | 12.75 | 774.6 | 441.8 |
| **22** | **2035** | 5511 | 6756 | 6027 | 32.7 | 25.1 | 18.9 | 12.8 | 662.6 | 434.9 |
| **23** | **2036** | 5828 | 6713 | 6121 | 31.4 | 24.1 | 18.2 | 12.7 | 890.5 | 435.6 |
| **24** | **2037** | 5643 | 6525 | 6048 | 31.7 | 24.4 | 18.3 | 12.74 | 831.8 | 420.8 |
| **25** | **2038** | 5164 | 6393 | 6017 | 32.4 | 24.6 | 19.2 | 12.75 | 571.7 | 413.6 |
| **26** | **2039** | 5675 | 6312 | 6026 | 31.6 | 24 | 18.6 | 12.73 | 1108 | 439 |
| **27** | **2040** | 5883 | 6799 | 6143 | 31.9 | 24.1 | 19.1 | 12.73 | 931.9 | 451.8 |
| **28** | **2041** | 5711 | 7182 | 6809 | 32.4 | 24.6 | 19 | 12.77 | 710.8 | 439.6 |
| **29** | **2042** | 5918 | 7174 | 6313 | 32.1 | 24.6 | 18.9 | 12.77 | 674.2 | 444.9 |
| **30** | **2043** | 5170 | 6974 | 6377 | 33.6 | 26.1 | 19 | 12.86 | 655.6 | 419.4 |
| **31** | **2044** | 5495 | 7414 | 6340 | 31.7 | 24.4 | 18.3 | 12.74 | 1012 | 410 |
| **32** | **2045** | 5714 | 7329 | 6834 | 31.8 | 24 | 18.9 | 12.74 | 911.4 | 447.1 |
| **33** | **2046** | 5557 | 7115 | 6725 | 32 | 24.6 | 18.5 | 12.75 | 875 | 422.4 |
| **34** | **2047** | 4620 | 6834 | 6230 | 33.8 | 25.9 | 19.4 | 12.8 | 631.6 | 454.8 |
| **35** | **2048** | 5063 | 7374 | 6369 | 32.3 | 25.3 | 18.2 | 12.78 | 1032 | 427 |
| **36** | **2049** | 5579 | 7077 | 6906 | 32.2 | 25 | 18.5 | 12.78 | 912.2 | 416.8 |
| **37** | **2050** | 5658 | 7422 | 7068 | 32.4 | 25.1 | 18.5 | 12.78 | 610.1 | 447.1 |
| **38** | **2051** | 4665 | 7244 | 6838 | 33.9 | 26.2 | 19.5 | 12.87 | 624.9 | 430.3 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **39** | **2052** | 5008 | 7254 | 6778 | 33.2 | 25.2 | 19.4 | 12.77 | 973 | 454.9 |
| **40** | **2053** | 5161 | 7302 | 6542 | 32.7 | 25.5 | 18.7 | 12.81 | 931.2 | 430.9 |
| **41** | **2054** | 5467 | 7160 | 6411 | 32.6 | 25.2 | 18.7 | 12.8 | 943.2 | 418.5 |
| **42** | **2055** | 5192 | 7191 | 6476 | 32.8 | 25.6 | 18.4 | 12.81 | 1034 | 418 |
| **43** | **2056** | 5667 | 7284 | 6387 | 32 | 24.6 | 18.7 | 12.75 | 919.5 | 441.9 |
| **44** | **2057** | 5318 | 7331 | 6540 | 33.2 | 25.7 | 18.8 | 12.83 | 859.4 | 434 |
| **45** | **2058** | 4973 | 7282 | 7050 | 32.7 | 25.3 | 18.6 | 12.77 | 1167 | 421 |
| **46** | **2059** | 4900 | 7322 | 7040 | 33.2 | 25.8 | 18.9 | 12.83 | 936.9 | 429.9 |
| **47** | **2060** | 4867 | 7159 | 6377 | 34.4 | 26.6 | 19.6 | 12.87 | 605.3 | 461.6 |
| **48** | **2061** | 4912 | 7278 | 6428 | 33.6 | 26 | 19.2 | 12.83 | 333.3 | 418.6 |
| **49** | **2062** | 4302 | 7255 | 6653 | 35.5 | 27.2 | 20.2 | 12.91 | 591.9 | 435.8 |
| **50** | **2063** | 4657 | 7448 | 6676 | 33 | 26 | 18.2 | 12.83 | 1199 | 431 |
| **51** | **2064** | 4901 | 7352 | 6587 | 33.7 | 26.5 | 18.9 | 12.86 | 760.2 | 406.5 |
| **52** | **2065** | 4393 | 7341 | 6616 | 34.9 | 26.8 | 20.1 | 12.88 | 743.8 | 475 |
| **53** | **2066** | 4423 | 7200 | 6659 | 35 | 26.6 | 20.4 | 12.88 | 752.8 | 444.8 |
| **54** | **2067** | 5194 | 7340 | 6747 | 33.6 | 25.6 | 19.6 | 12.78 | 1203 | 450 |
| **55** | **2068** | 4659 | 7382 | 6569 | 34 | 26.7 | 19.1 | 12.87 | 789.9 | 418.4 |
| **56** | **2069** | 4563 | 7438 | 6546 | 33.3 | 26.4 | 18.5 | 12.87 | 856.2 | 411.2 |
| **57** | **2070** | 4763 | 7509 | 6747 | 33.2 | 26.1 | 18.5 | 12.84 | 845.1 | 430.6 |
| **58** | **2071** | 5011 | 7456 | 6593 | 33.1 | 25.9 | 18.9 | 12.84 | 1039 | 407 |
| **59** | **2072** | 4697 | 7338 | 6719 | 34.5 | 26.6 | 19.6 | 12.83 | 695 | 485 |
| **60** | **2073** | 4956 | 7275 | 6428 | 34.7 | 26.7 | 20.1 | 12.88 | 667.8 | 473 |
| **61** | **2074** | 4762 | 7357 | 6535 | 33.6 | 26.4 | 18.7 | 12.81 | 791.6 | 409.4 |
| **62** | **2075** | 4170 | 7354 | 6679 | 33.7 | 26.6 | 18.6 | 12.87 | 1088 | 424 |
| **63** | **2076** | 4526 | 7467 | 6449 | 33.5 | 26.4 | 18.7 | 12.86 | 641.8 | 438.5 |
| **64** | **2077** | 4716 | 7508 | 6371 | 33.4 | 26.7 | 18.1 | 12.86 | 970.3 | 421.6 |
| **65** | **2078** | 4937 | 7294 | 6735 | 35.7 | 27.1 | 20.6 | 12.87 | 1197 | 477 |
| **66** | **2079** | 4300 | 7227 | 6681 | 34.2 | 27.1 | 18.5 | 12.86 | 1270 | 424 |
| **67** | **2080** | 4529 | 7219 | 6284 | 34.3 | 26.8 | 19.1 | 12.84 | 1108 | 425 |
| **68** | **2081** | 5007 | 7208 | 6258 | 34.7 | 26.8 | 19.5 | 12.83 | 1216 | 461 |
| **69** | **2082** | 4371 | 7219 | 6282 | 34.1 | 26.7 | 19 | 12.87 | 1510 | 434 |
| **70** | **2083** | 5587 | 7212 | 6242 | 34.2 | 26.3 | 19.2 | 12.81 | 382.9 | 451.2 |
| **71** | **2084** | 4454 | 7204 | 6211 | 33.9 | 26.7 | 18.7 | 12.86 | 990.3 | 442.7 |
| **72** | **2085** | 4876 | 7218 | 6233 | 33.2 | 26.5 | 18.1 | 12.86 | 1223 | 424 |
| **73** | **2086** | 4478 | 7217 | 6274 | 34.3 | 26.6 | 19.4 | 12.86 | 1558 | 446 |
| **74** | **2087** | 4220 | 7216 | 6180 | 34.8 | 27.1 | 19.6 | 12.86 | 1029 | 435 |
| **75** | **2088** | 4190 | 7209 | 6171 | 37.3 | 28.2 | 20.8 | 12.87 | 1059 | 505 |
| **76** | **2089** | 4911 | 7203 | 6265 | 36.1 | 27.7 | 20.5 | 12.91 | 851.6 | 463 |
| **77** | **2090** | 4124 | 7203 | 6170 | 34.5 | 27.3 | 19 | 12.88 | 923.9 | 439.7 |