CLIMATE CHANGE ADAPTATION ON RICE PRODUCTION

By

NAVYA, M

(2011-20-120)

ACADAMY OF CLIMATE CHANGE EDUCATION AND RESEARCH

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

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THESIS

Submitted in partial fulfillment of the requirement

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ACADAMY OF CLIMATE CHANGE EDUCATION AND RESEARCH

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

DECLARATION

I hereby declare that the thesis entitled **"Climate change adaptation on rice production"** is a bonafide record of research work done by me during the course of research and the thesis has not been previously formed the basis for the award to me any degree, diploma, fellowship or other similar title, of any other University or Society.

Date: 28.03.2017

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CERTIFICATE

Certified that this thesis entitled **"Climate change adaptation on rice production"** is a record of research work done independently by Ms. Navya, M (2011-20-120) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship with any other person.

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Navya, M

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ABBREVIATIONS

AR5	Assessment Report 5
BSH	Bright Sunshine Hours
CD	Critical Difference
CERES	Crop Estimation through Resource and Environment Synthesis
CRD	Completely randomized design
DSSAT	Decision Support System for Agro-technology Transfer
EC	Electrical conductivity
FAO	Food and Agriculture Organization
GCM	General Circulation Model
GDD	Growing Degree Days
IBSNAT	International Benchmark Sites Network for Agrotechnology Transfer
IPCC	Inter government panel on Climate Change
IRRI	International Rice Research Institute
KAU	Kerala Agricultural University
LAI	Leaf area index
POP	Package of practices
RARS	Regional Agricultural Research Station
RMSE	Root Mean Square error
STR	Soil test results
RCP	Representative Concentration Pathway
T_{max}	Maximum temperature
T_{min}	Minimum temperature

Agriculture is always susceptible to vagaries of nature and climate conditions. Despite technological advancements such as improved crop varieties and irrigation systems, weather and climate are important factors, which play a significant role to agricultural productivity. The impacts of climate change on agriculture are global concerns and for that matter India, where agriculture sector alone represents 23 per cent of India's Gross National Product (GNP) and the livelihood of nearly 70 per cent of the population is exposed to a great danger, as the country is one of the most vulnerable countries due to climate change. One of the most notable characteristics of climate change is the increase in temperature, so it has been mainly recognized as 'global warming'. This warming has been attributed to the enhanced greenhouse effect produced, among others, by the increased amounts of carbon dioxide from the burning of fossil fuel since the Industrial Revolution (Houghton, 2004).

The conclusions of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) published in early 2007 leave no doubt that the Earth's climate is changing in a manner unprecedented in the past 400,000 years. The report substantiated that by 2100 mean surface temperatures over the earth will rise by 1.4 to 5.8 ° C, precipitation will decrease in the sub-tropics, and extreme events will become more frequent (IPCC, 2007). However, changes in climate are already being observed and the last 60 years were the warmest in the last 1000 years and changes in precipitation patterns have brought greater incidence of floods or drought globally. These changes are driven by increasing concentrations of greenhouse gases, namely CO_2, CH_4 and N_2O, and will also affect agro-climatic conditions for food production systems. The potentially beneficial effects of increases in CO_2 may be offset by associated temperature stress and other factors such as the increases in ground level (tropospheric) ozone concentrations. Most of the developing countries are not well prepared to deal with the negative impacts to be expected as a result of climate change and are therefore most vulnerable to its consequences.

In Asia, rice is the staple food (up to 60% of energy intake), not only in the rural areas, but also for the urban poor. Rice production is of overwhelming economic significance in Asia and is the principal source of employment and income in rural areas. The availability of cheap rice is also an important factor to meet the nutritional needs of the underprivileged urban population. Rice production in the tropics is sensitive to climatic factors (temperature, rainfall, and solar radiation) and CO_2 which affect the crop in various ways during different stages of its growth. Increasing CO_2 concentration in the atmosphere has a positive effect on crop biomass production, but its net effect on rice yield depends on possible yield reductions associated with increasing temperature. For every 75 ppm increase in CO_2 concentration rice yields will increase by 0.5 t ha^{-1}, but yield will decrease by 0.6 t ha^{-1} for every 1 °C increase in temperature (Sheehy *et al.*, 2005). The fact that climate impacts often exceed 10 per cent of the rate of yield change indicates that climate changes are already exerting a considerable drag on yield growth (Lobell *et al.*, 2011). Climate change has negatively affected India's millions of rice producers and consumers. Harvest would have been 5.67 per cent higher in the absence of climate change. Future impacts of these changes on rice yield in India would thus likely be larger than the historical ones (Auffhammer *et al.*, 2012).

There is a huge gap between potential and actual grain yield of rice in Kerala. The growth and yield is largely depends on various weather factors like temperature, rainfall, solar radiation and relative humidity that prevail during the growing season. In this background the present study has undertaken with the following objectives:

1. Study the climate change adaptation in rice production through fertilizer management strategies.
2. Determination of optimum sowing period in purview of climate change and temperature stress tolerance in popular rice varieties using DSSAT model.

Numerous studies have reported that climate variability and climate change can have adverse effects on crop growth and yield and there by impacts on global food production and food security. Rice is the most important human food, eaten by more than half of the world population. . Climate change alters weather variables and there by affect the production of rice. General Circulation Models (GCM's) are very helpful tools in predicting the future climate. Crop weather simulation models with the help of GCM's can estimate the impact of future climate conditions on production of rice. In this chapter we are going to review about climate change, effect of different weather parameters on rice and how the changing climatic conditions influence the production of rice. The possible adaptation measures to address the effect of climate change were also reviewed.

2.1 CLIMATE CHANGE

Keeling (1960) found that a systematic variation with season and latitude in the concentration and isotopic abundance of atmospheric carbon dioxide in the northern hemisphere. He also reported a small but persistent increase in concentration in Antarctica.

A doubling of carbon dioxide from the existing level would bring about approximately 2.0°C increase in global temperature (Manabe and Wetherald, 1967).

IPCC was established in 1988 by two United Nations organizations, the World Meteorological Organization and the United Nations Environment Programme. In first report, they predict that under a "business as usual" scenario, global mean temperature will increase by about 0.3°C per decade during the 21st century. They judge that global mean surface air temperature has increased by 0.3 to 0.6 °C over the last 100 years, broadly consistent with prediction of climate models, but also of the same magnitude as natural climate variability.

The greenhouse gases (GHGs) are currently increasing at the rate of one percent for CH_4, 0.4-0.5 percent CO_2 and 0.2-0.3 percent for N_2O (Baker, 1989). General Circulation Models (GCMs) used to study climate changes project variable magnitude of change particularly on a regional basis (Mitchell *et al.*, 1990).

Giorgi *et al.* (1998) showed for most regions of the world, the inter-GCM model range of simulated temperature increase for a doubling of CO_2 was about 3.0-5.0°C. For South-east Asia different GCMs predicted an increase of 0.8 to 3.2°C for a doubling of CO_2.

Ahmed and Alam (1999) reported that there would be an increase of 1.3°C and 2.6°C rise in the temperatures by 2030 and 2075 respectively by using the General Circulation Model (GCM) for Bangladesh. They also found a seasonal variation in the temperature of +1.4°C in the winter and +0.7°C in the monsoon by 2030 while the variations are projected to be 2.1°C and 1.7°C for these seasons respectively by 2075. Rainfall will be reduced to an insignificant rate in 2030 while there will not be any noticeable rainfall in the winter by 2075.

Climate change affects the world's food supply system and it is expected to increase the yield at higher latitudes and decrease yields at lower latitudes (IPCC, 2007).

Climate change results in changes in long-term weather conditions globally. More explicitly, climate change denotes a significant statistical variation either in the average condition of the climate or in its variability that continues for long periods, typically decades or longer (Vijaya Venkata Raman *et al.*, 2011).

The globally averaged combined land and ocean surface temperature data as calculated by a linear trend show a warming of 0.85°C, over the period 1880 to 2012. Global surface temperature change for the end of the 21st century is likely to exceed 1.5°C relative to 1850 to 1900 for all RCP scenarios except RCP 2.6. It is likely to exceed 2.0°C for RCP 6.0 and RCP 8.5, and more likely than not to exceed 2.0°C for RCP 4.5. Warming will continue beyond 2100 under all RCP scenarios except RCP 2.6. Warming will continue to exhibit inter annual-to-decadal variability and will not be regionally uniform (IPCC, 2013).

The Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change (IPCC) reported that the future greenhouse gas emission will keep on rising, and the global average temperature is likely to be increased from 0.3 to 4.8°C, based on various scenarios (Stocker *et al.*, 2013).

2.2 IMPACT OF WEATHER ON RICE

Rice is a very sensitive crop that depends highly on weather condition. Among the different abiotic stresses, weather plays the dominant role in influencing the growth and yield of rice. Temperature, rainfall and solar radiation are the most key weather elements that influence growth and development of rice. Other weather elements such as relative humidity and wind velocity affect the growth to some extent.

2.2.1 Temperature

Nagato and Ebata (1966) indicated that temperature affects the ripening of rice in two major ways, firstly the low temperature lead to an increase in grain weight and secondly the low daily mean temperature extend the length of ripening period. They noted that generally grain yield is higher when temperature during ripening stage is relatively low, an effect attributed to a more favourable balance between photosynthesis and respiration

A negative correlation between yields and the minimum temperature at 30 days after transplanting and a significant correlation between yield and maximum temperature over the 45 days before maturity were reported by De-Datta and Chaudhury (1970).

According to Yoshida (1973) effect of temperature on tillering is influenced by the level of sunlight or illumination in an artificially lighted growth room. Basically, higher temperatures increase the rate of leaf emergence, and provide more tiller buds. Under low light conditions, some of the tiller buds may not develop into tillers because of a lack of carbohydrate necessary for growth. Under these conditions, low temperatures may produce more tillers. When light is adequate, however, higher temperatures increase tiller number.

Among the different weather parameters that affect the growth and yield of rice, temperature has got dominant importance. Growth processes in different development stages respond differently to the same temperature conditions (Ishizuka *et al.*, 1973).

Yoshida (1981) indicated that temperature has a very high influence on germination, especially in the first week of post germination growth.

Sreenivasan (1985) observed that tillering rate is inhibited by low temperature, but the period of tillering is lengthy in duration, resulting in more tillers and more panicles than at high temperature.

Ellis *et al.* (1993) stated that temperature affect the leaf appearance rate, the leaf number, panicle emergence and development.

The effect of maximum temperature, minimum temperature and relative humidity was favourable at the end of the seedling stage. During the vegetative growth stage, relative humidity and total rainfall were found to be beneficial, while increase in minimum temperature was harmful (Hoa and Singh 1993).

If the mean temperature is more than 26 °C, the tiller production stopped abruptly by 5th week after planting and whenever it fell below 26 °C the duration of tillering increased to 7-8 weeks after planting (Lalitha *et al.*, 2000).

Nigam and Mishra (2003) found that effect of weather variables vary according to the time of transplanting. Under early transplanting conditions, the number of sunshine hours was significantly correlated with rice yield. Minimum temperature, maximum relative humidity, minimum relative humidity and rainfall had a negative correlation with yield, whereas the number of rainy days, wind velocity and evaporation had a positive correlation with yield. Under timely transplanting conditions, the number of sunshine hours and maximum temperature showed a significant correlation with yield. Yield was negatively correlated with minimum temperature, maximum relative humidity, minimum relative humidity and rainfall, but was positively correlated with the number of rainy days, wind velocity and evaporation. Under late transplanting conditions, only the number of sunshine hours was significantly correlated with yield.

Peng *et al.* (2004) found that the yield of dry season rice crops in the Philippines decreased by as much as 15 percent for each 1°C increase in the growing season mean temperature.

Low temperature during vegetative phase of rice lead to poor tillering and less productive tillers. Similarly during reproductive phase higher temperature coupled with speedy wind may cause poor setting of seed, consequently leads to pitiable harvest (Singh and Singh 2007).

The yield of rice is considerably influenced by temperature throughout the crop growth period and was more pronounced from flowering to anthesis period (Chahal *et al.*, 2007).

According to Wahid *et al.* (2007) high temperature affects almost all the growth stages of rice from emergence to ripening and harvesting. The developmental stage at which the plant is exposed to heat stress determines the severity of the possible damage to the crop.

According to Aggarwal *et al.* (2010) high temperatures are reported to hasten the crop phenology lead to reduction in crop duration in future climate scenarios. They also added that about 13 days and 17 days reduction in crop duration is projected to be in B2 and A2 scenarios respectively.

Singh *et al.* (2010) showed that high-temperature stress (+2.5 °C) during the vegetative and reproductive growth phases caused greater and almost equal reduction in biomass (23 per cent and 26 per cent) and grain yield (23 per cent and 27 per cent), as compared to ripening phase, which showed eight per cent and seven per cent reduction in biomass and grain yield respectively. Among yield components, the number of panicles per square meter and grains per panicle showed greater sensitivity to high-temperature stress, whereas 1,000 grain weight was least affected by the same level of heat stress.

Shah (2011) indicated that high temperature affects almost all the growth stages of rice, *i.e.* from emergence to ripening and harvesting.

The elevated temperature on rice crop affects the crop duration by attaining the phonological stages earlier with low accumulated growing degree days. This reduction in grain yield may be due to the direct effect of temperature on rice development especially high temperature at flowering stage leading to spikelet sterility and, therefore, yield loss (Rani and Maragatham, 2013).

Karn (2014) stated that increase in maximum temperature up to a critical threshold of 29.9°C during the ripening phase will increase the rice yield. He also added that maximum temperature beyond this threshold decreases the rice yield.

Pattanayak and Kumar (2014) found that the negative impact of higher day time temperature on rice yield was more visible than the impact due to higher night time temperature.

Tokunaga *et al.* (2015) reported that 1°C increase in mean annual temperature would reduce rice production by 5.8% in the short term and 3.9% in the long term on Japan's agricultural production.

2.2.2 Solar radiation

Studies at IRRI discovered that the quantity of solar radiation has got profound influence on rice yield, particularly during the last 30-45 days of ripening period (Moonaw *et al.*, 1967).

Sreedharan (1975) indicated that the yield attributes such as panicles per square meter, grain yield etc., showed a positive correlation with solar energy during reproductive and ripening phases.

Low solar radiation during ripening phase reduces the grain yield considerably due to decrease in percentage of filled grains (Yoshida and Parao, 1976).

Krishnakumar (1986) reported that panicles per square meter, grains per square meter, degree of ripening and grain yield had showed a positive correlation with solar energy during ripening period.

According to Patro and Sahu (1986) the reduction in grain number per panicle by shading of the plants from flowering to harvest is only due to poor grain filling, which was evident from the high sterility percentage.

Low light stress reduced grain number per panicle in short duration varieties, increased spikelet sterility in medium duration varieties and decreased panicle number in long duration varieties (Murty and Sahu, 1987).

Thangaraj and Sivasubramanian (1990) observed that filled grains percentage and test weight are reduced due to light intensity or shading during ripening stage, hence it results in yield reduction.

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2.2.3 Rainfall

According to Sahu and Murty (1976) dry matter production and grain yield were invariably lower by about 50 and 54 per cent respectively in wet (July-October) season than in dry season (January-May).

Balakrishna Pillai and Prabhakaran (1978) reported that, at least one third of variablity in yield of Virippu can be explained through fluctuations in monthly rainfall at Pattambi.

Kamalam *et al.* (1988) found that, the accumulated rainfall during the tillering phase of the crop growth over and above the normal requirement had an adverse effect (significant negative correlation) on the straw yield.

Rice yield during summer season becomes almost double of that of monsoon season in eastern and southern India whereas it increases marginally in Punjab (Biswas, 1996).

Narayanan (2004) observed that there is a positive non-significant correlation between grain yield and total rainfall. He also found that total rainfall was negatively correlated with straw yield in a non-significant manner.

2.2.4 Relative humidity

Rice crop requires a fairly high degree of humidity for proper growth (Ghosh, 1961).

According to Sreedharan (1975), a relative humidity of 80-85 per cent is ideal for shoot and root growth.

Hirai *et al.* (1993) noted that nitrogen uptake and content of leaves and roots in plants grown at 90 per cent RH were higher than those of the plants grown in 60 per cent RH.

Sunil (2000) found that low relative humidity shortened the days taken from transplanting to panicle initiation.

Narayanan (2004) stated that relative humidity shows a negative correlation with straw yield and a positive correlation with grain yield during reproductive stage.

Karn (2014) noted that higher morning humidity cause a harmful effect on rice growth while afternoon humidity helps to increase the rice growth.

Kuthe *et al*. (2015) reported that higher maximum and minimum relative humidity increase the infestation of sucking pests in rice and ultimately affect the yield.

2.2.5 Wind

According to Kamalam *et al*. (1988) wind velocity during reproductive stage had the significant positive correlation with grain yield; the effect with straw yield was positive but not significant. But, Sunil (2000) observed a negative correlation between grain yield and wind speed during flowering stage.

Fertilization in rice was inhibited by wind speed of more than four meter per second (Viswambaran *et al*., 1989).

Sunil (2000) found that wind speed during active tillering to heading stage shows a significant negative correlation with number of panicles per plant and straw yield.

Prasada Rao (2003) reported that high wind speed during flowering had caused pollen dehydration and consequent spikelet sterility in rice.

2.3 CLIMATE CHANGE AND RICE PRODUCTION

Grain yields declined by an average of approximately 7–8% per 1°C rise in temperature from the 28/21/25 to 34/27/31°C temperature treatment. The reduced grain yields with increasing temperature treatment suggests potential detrimental effects on rice production in some areas if air temperatures increase, especially under conditions of low solar irradiance (Baker *et al*., 1992).

Rosenzweig and Parry (1994) reported that the global food production would be slightly reduced because of two fold increase in atmospheric CO_2 concentration using a crop growth model.

According to Rosegrant *et al*. (1995) there is a projection of 1% increase in world rice production need annually to meet the growing demand for food that will result from population growth and economic development despite of the world's temperature increase.

There is a possible decrease in rice production reported in the tropical region according to studies on the impact of global climate changes on land and water resources for rice production but in contrast a possible increase was reported in areas outside the tropical region (Nguyen, 2002).

Peng *et al.* (2004) reported that world rice production must increase by approximately 1% annually to meet the growing demand for food that will result from population growth and economic development.

Sheehy *et al.* (2006) noted that a 6% decline in rice yield with every 1 ◦C increase in average temperature in the Philippines.

Krishnan *et al.* (2007) reported that every 1.8°C increase in temperature decreases rice yield by 7.2 per cent at the current CO_2 concentration (380 ppm), but increases in CO_2 enrichment up to 700 ppm will lead to an average yield increase of about 31 per cent in India.

A growing body of literature suggests that climate change will significantly affect the agricultural sector in developing countries, leading to serious consequences related to food production and food security, with bigger impacts on small-holder farmers and the poor (IPCC, 2007; Thornton *et al.*, 2013; Morton, 2007).

Studies for the Southeast Asian region show that climate change could lower agricultural productivity by 15–26 per cent in Thailand, 2–15 per cent in Vietnam, 12–23 per cent in the Philippines, and 6–18 per cent in Indonesia (Zhai and Zhuang, 2009).

Basak *et al.* (2010) determined the impacts on the yields of BR3 and BR14 varieties of Boro rice for 12 districts using the DSSAT model. The model forecast an average yield reduction of over 20% and 50% for the two rice varieties for the years 2050 and 2070, respectively. They also found that rise in daily maximum and minimum temperatures were the main reason for this yield reduction. This study also reported that climate change might make rice yields more sensitive to planting date.

Geethalakshmi *et al.* (2011) reported that the projected yield loss estimated by agronomic models (DSSAT and PRECIS models) was 356 kg ha^{-1} per decade in Tamil Nadu.

Soora *et al.* (2011) reported that on an all India basis, climate change is projected to reduce irrigated rice yields by ~4 % in 2020 (2010–2039), ~7 % in 2050 (2040–2069) and ~10 % in 2080 (2070–2099) scenarios. They also noted that rainfed rice yields in India are likely to be reduced by ~6 % in the 2020 scenario, but in the 2050 and 2080 scenarios they are projected to decrease only marginally (<2.5 %).

Asian countries accounted for about 90 % of the total production out of 672 Mt of global rice (paddy) production in 2010; and about half of this came from China and India (FAOSTAT, 2012).

Study conducted in western zone of Tamil Nadu using the CERES-Rice model in the Decision Support System for Agro-technology Transfer (DSSAT) showed that a yield reduction from 4-56% with increase in temperature from 1to 5 degree Celsius respectively from the current climate under different dates of planting from 1st June to 15th July (Bhuvaneswari *et al.*, 2014).

According to Karn (2014) there is a 4.2 % reduction in yield relative to current levels by 2100 in Nepal. He also found that an estimated loss of rice yield ranging from 1.5 per cent by year 2030 to 4.2 per cent by 2060 and 9.8 per cent by 2090.

The demand for food is expected to increase in coming years, at a rate of about 2 percent a year due to negative impact of climate change on crop production (Banerjee *et al.*, 2016).

2.4 CLIMATE CHANGE ADAPTATION STRATEGIES FOR RICE

According to Smit *et al.* (1999) adaptation to climate change can be defined as an adjustment in natural or human systems in response to actual or expected climatic conditions or risks.

According to Smit and Skinner (2002) general adaptation strategies in crop management are improved varieties of crop and agronomy, including efficient use of fertilizers and water.

Akram *et al.* (2007) noted the effect of different planting dates from July 1 to 30 with 10 days interval on six rice varieties (98001, PK-5261-1-2-1, 97502, 98409, Basmati- 385 and super Basmati) at AARI, Faisalabad during 2002-2003.

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Different yield and yield parameters like number of tillers, grains per spike, plant height, 1000 grain weight and sterility were significantly affected. Basmati 385 and super Basmati produced maximum paddy yield when planted on July 11 and July 1 respectively. Prevailing weather conditions play a vital role in the performance of any crop including rice crop.

Kurukulasuriya and Mendelsohn (2008) stated that adaptation is a policy option for limiting the negative effects of climate change.

According to Munang *et al.* (2009) adjusting sowing date cannot be considered as a very effective method in mitigating the adverse effects of climate change. They also stated that the use of crop cultivars with specific genetic traits was a most effective method in reducing the adverse effects of climate change.

Nahar *et al.* (2009) reported that grain weight of Aman rice was influenced by transplanting dates. Among the planting dates 1^{st} September transplanting provided the highest results whereas 30^{th} September transplanting provided the lowest results for both cultivars (BRRI dhan 46 and BRRI dhan 31) during the year 2008 at Dhaka, Bangaladesh. BRRI dhan 46 had significantly higher values of yield attributes and yields than the BRRI dhan 31 in late transplanted conditions.

Aggarwal *et al.* (2010) noted that various adaptation methods such as growing improved varieties, efficient irrigation, fertiliser management and application of additional nitrogen will help to reduce the impact of climate change on rice. They also found that growing improved variety with better management of irrigation and fertiliser and provide additional but balanced fertilisers help to harvest a higher yield up to 15%.

According to Geethalakshmi *et al.* (2011) changing cultivation method can be accepted as an adaptation strategy on rice production. They also indicated that it will be helpful to reduce the use of water because under changing climatic conditions more water scarcity is expected. They also added that field experiment conducted in the farmer's field of the Cauvery basin with different cultivation methods indicated that under the system of rice intensification (SRI) method, 22% increase in grain yield and 24.5% water saving were noticed compared to transplanted rice.

Foliar fertilizers cannot replace soil applied fertilizer completely but foliar fertilization enhance the uptake of nutrients applied to the soil (Bhuyan *et al*., 2012).

According to Bhuyan *et al*. (2012) foliar fertilization is more suitable for micro nutrients but it is also applicable for major nutrients like Nitrogen, Phosphorous and Potassium mainly because the amount applied at any time is small and thus it requires several applications to meet the needs of a crop. They also added that foliar application of nitrogen fertilizer may be the most effective means for maximizing yield of rice.

Bhuyan *et al*. (2012) found that 9.33% increase in yield by foliar spray in bed planting over conventional method. They also noted a similar increase in number of panicles, grains per panicle and 1000 grain weight (gm).

Soora *et al*. (2013) reported that adaptation to climate change by sowing improved rice varieties can not only reduce negative impacts but also provide improved productivity—ranging from 1 % to 5 % in climate change scenarios. Even with current varieties, increasing input use efficiency and providing additional nitrogen fertilizers can improve yields by ~15 % in the 2020, and by ~25 % in the 2050 and later scenarios. In addition, adopting improved varieties can further improve yields by ~20 % in the 2020, and by ~35–38 % in the 2050 and later scenarios.

The different sowing windows tested as adaptation strategy to climate change indicated that the change in yield from current condition under early, normal, late planting during kharif season was -21.2, -15.0 and -16.3% respectively for 3°C increase in temperature and 650 ppm CO_2 enrichment, during rabi season, it was -9.2, +10.2 and +11.0% respectively (Bhuvaneswari *et al*., 2014).

According to Ahn Chun *et al*. (2015) adaptive management of fertilizer application rate and adjustment of planting dates in response to the changing climate are an effective combination as farmer-level adaptations. They also found that 100 kg N ha−1 of fertilizer application as the best fertilizer application in future to offset the negative impacts of climate change on rice. They also added that combinations of adaptation strategies such as irrigation, fertilizer management practices, and adjustment of planting dates may be able to substantially reduce the negative impacts of climate change on rice production. However, additional adaptation

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strategies may be required to offset the negative impacts of climate change on rice yields in the 2080s under RCP 8.5.

JiKun *et al*. (2015) stated that considering farm management measures as an adaptation option will significantly increases the rice yield.

Banerjee *et al*. (2016) found that the simplest and effective adaptation option for rice will be adjustment of sowing time. They also indicated that increased rate of nutrient application will also help to sustain the rice yield under future climate.

2.5 CROP GROWTH MODELS

The Decision Support System for Agrotechnology Transfer (DSSAT) model was developed by International Benchmark Site Network for Agrotechnology Transfer (IBSNAT) in 1989 (Tsuji *et al.*, 1998).

DSSAT also provides for evaluation of crop model outputs with experimental data, allowing users to compare simulated outcomes with observed results. Crop model evaluation is accomplished by inputting the user's minimum data, running the model and then comparing outputs with observed data. By simulating probable outcomes of crop management strategies, DSSAT offers users information with which to rapidly appraise new crops, products and practices for adoption (Jones *et al.*, 2003)

Crop models are simplification of the complex relationship between climate and crop performance by using established mathematical or statistical techniques or both. DSSAT v 4.5 (Hoogenboom *et al.*, 2012) is used in this for crop weather modelling.

Crop models are useful tools to assess the impact of environment, crop management, genetics and breeding strategies, as well as climate change and variability on growth and yield (Craufurd *et al.*, 2013).

Field experiments were conducted during 2015-16 to study the climate change adaptation on rice production and crop weather relationships in rice. The materials used and methods followed are described below:

3.1 DETAILS OF FIELD EXPERIMENT

3.1.1 Location

The field experiments were conducted during April 2016 to September 2016 at the Regional Agricultural Research Station of the Kerala Agricultural University at Pattambi, Palakkad district, Kerala. The station is located at 10° 48' N latitude and 76° 12' E longitude at an altitude of 25.36 m above mean sea level.

3.1.2 Climate

The general climate of the location has studied for 30 years (1983-2012). The different climate variables (monthly) of the location has presented in the Fig. 1-6.

3.1.3 Soil

The soil of the experimental field was sandy clay loam in texture. The physical characteristics of the soil are presented in Table 1.

3.1.4 Season

The experiments were conducted during the first crop season (April-May to September-October) in open field conditions as well as inside the climate controlled greenhouse.

3.1.5 Varieties

The most popular variety of Kerala Jyothi was selected for this study. Jyothi is a photoperiod insensitive variety with the duration of 110-115 days.

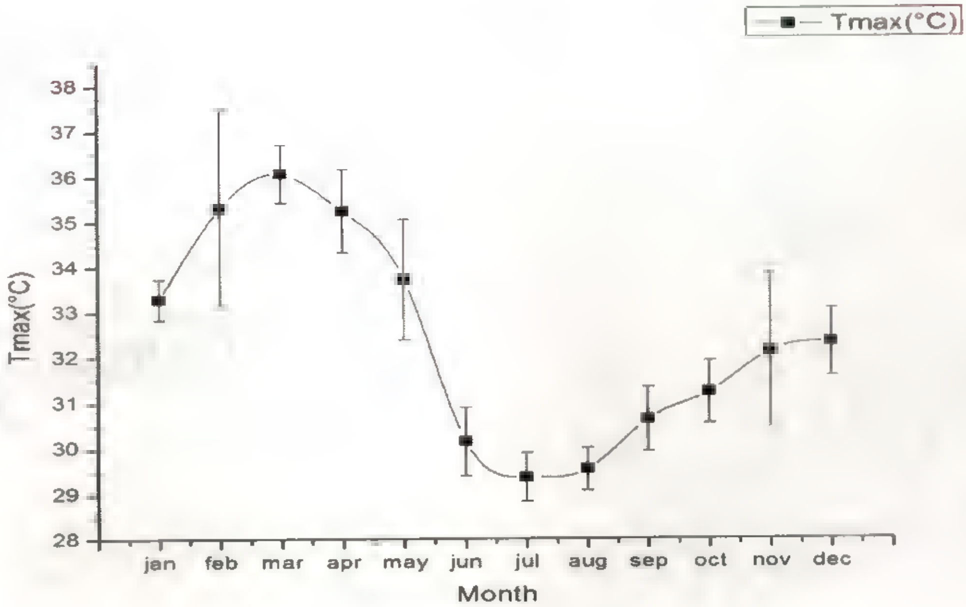

Fig 1. Monthly maximum temperature (°C) of Pattambi (1983-2012)

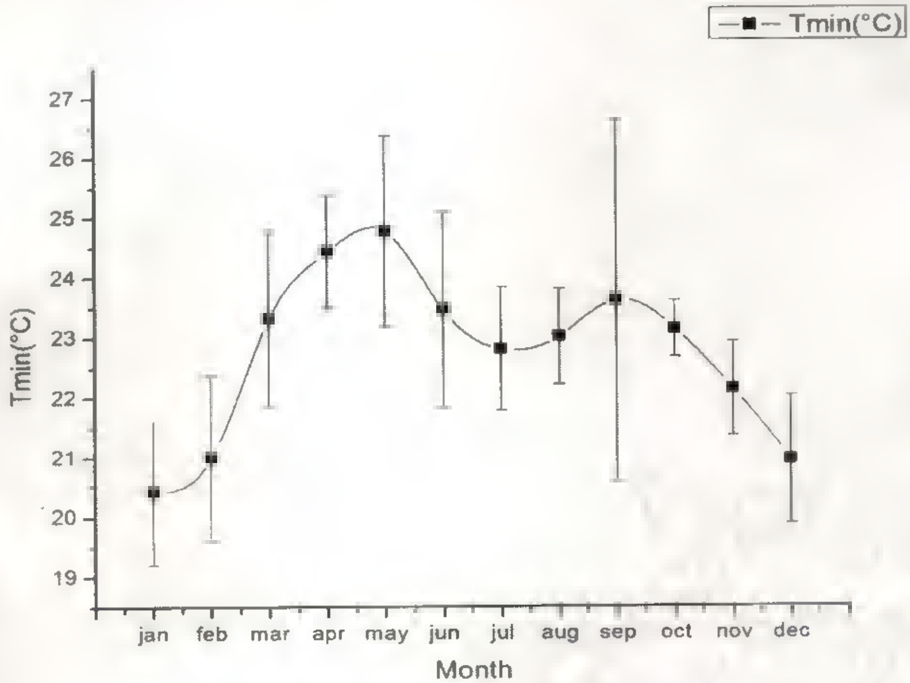

Fig 2. Monthly minimum temperature (°C) of Pattambi (1983-2012)

30

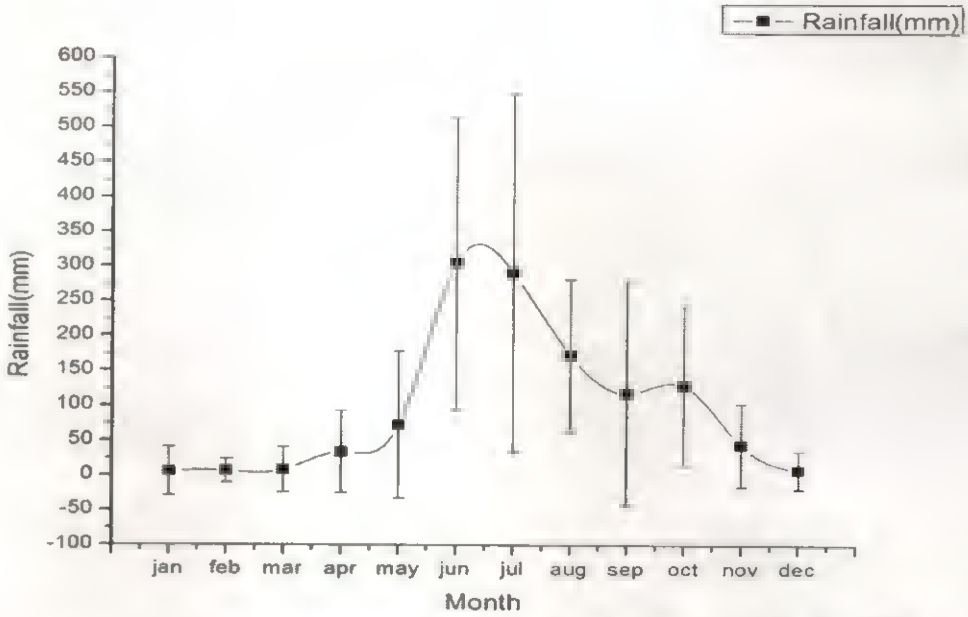

Fig. 3. Monthly rainfall (mm) of Pattambi (1983-2012)

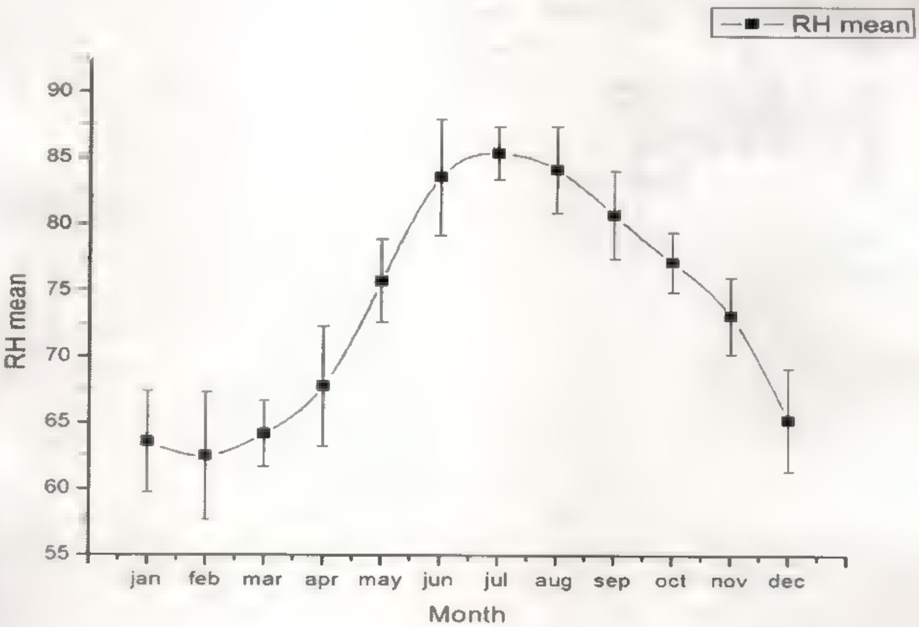

Fig.4. Monthly mean Relative humidity (%) of Pattambi (1983-2012)

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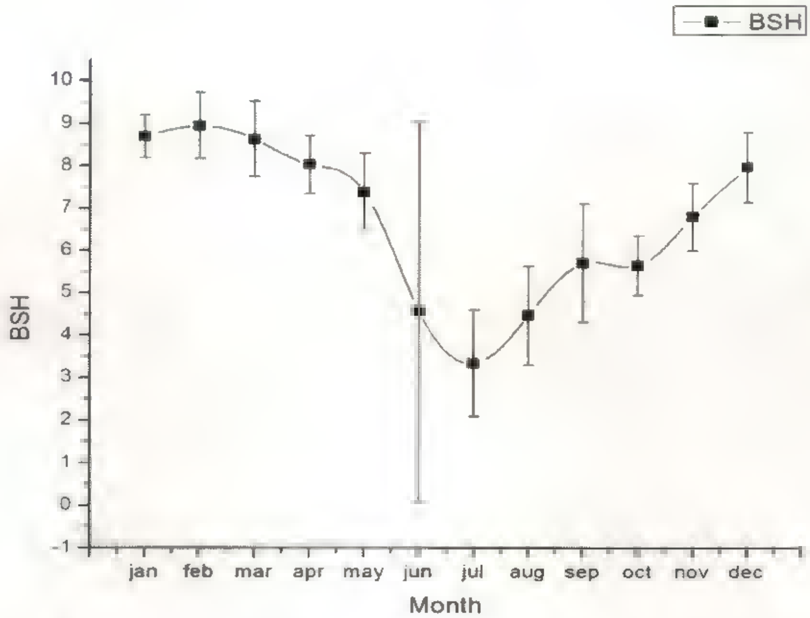

Fig.5. Monthly bright sun shine hours of Pattambi (1983-2012)

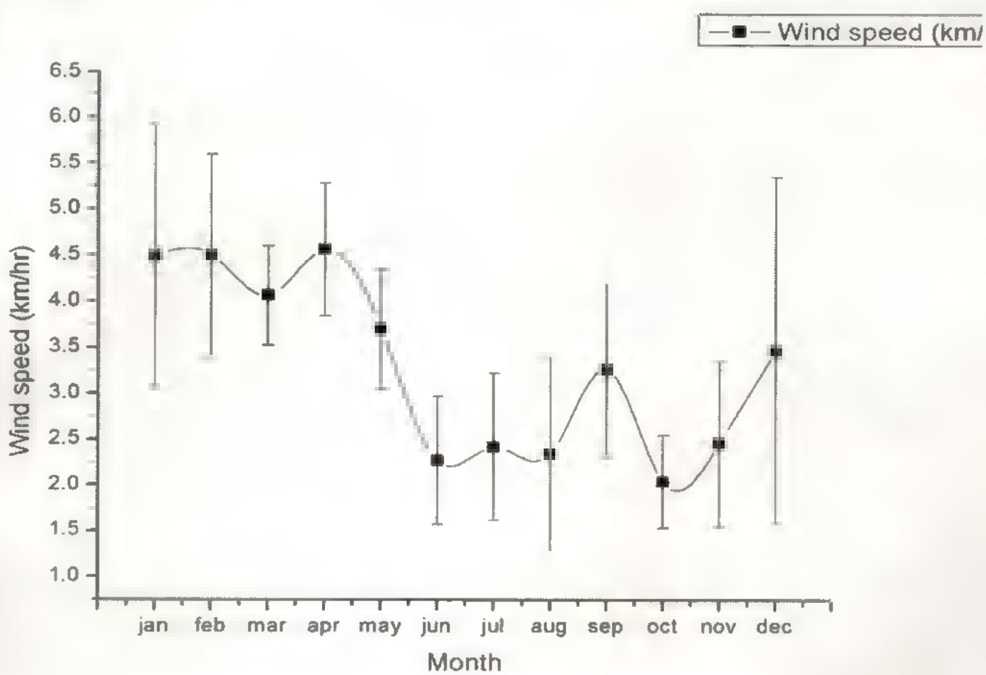

Fig.6. Monthly wind speed (km hr^{-1}) of Pattambi (1983-2012)

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Table1. Physico-chemical properties of soil in the experimental field

Particulars	Value	Method employed
A. Mechanical composition		
Sand (%)	64	Robinson's international Pipette method (Piper, 1966)
Silt (%)	3	
Clay (%)	33	
Bulk density (Kg m^{-3})	1.3	Core sampler method (Piper, 1966)

3.2 METHODS

The experiment was laid out in Three Factorial CRD with three replications. Factor 1 consists of three dates of planting ie., 1st, 15th and 30th of May. Factor 2 consists of four different fertilizer treatments and Factor 3 consists of two growing environments ie., open field and climate controlled greenhouse. Treatments and notations were given in the Table 2. The pot culture was conducted in pots and the spacing adopted was 10 x15 cm. The experiment was replicated thrice with a total number of 720 pots.

3.2.1 Cultural operations

3.2.1.1 *Nursery management*

Nursery was raised prior to the date of transplanting. Twenty one day old seedlings were transplanted with three seedlings per hill. Irrigation and drainage were provided as and when required. Adequate plant protection measures were also taken.

3.2.1.2 *Preparation of pots*

The experiment was conducted in pots with 40 cm diameter x 30 cm height. The pots were filled with top soil from the paddy field and were brought to puddle condition.

3.2.1.3 *Application of manures and fertilizers*

Farm yard manure at the rate of 500 gm and quick lime at the rate of 60 gm per pot was applied to all the pots. The different fertilizer and other inputs combination were as follows

1. F1-Control –Package of practice recommendation for rice 90:45:45 NPK
2. F2-Basal dose as per Package of practice recommendation that is half dose nitrogen and potassium and full dose of phosphorous. The rest of the fertilizer requirement was given through foliar application (19:19:19 NPK) 5gm per litre.
3. F3-The fertilizer requirements was met through foliar fertilizers according to the soil test results (Borax 0.15g per pot and Magnesium sulphate 1g per pot). In addition to that an amount of 1grams of Silica was also added to each pot.
4. F4- In addition to the above treatments (T3) micronutrients were also given to the crop as per the soil test results

Table 2. Treatments and notations

Factor 1	Factor 2	Factor 3	Notation
1-May	Open Field	POP	T1C1F1
		BASAL AS PER POP+FOLIAR	T1C1F2
		FOLIAR +SILICA+STR	T1C1F3
		FOLIAR +SILICA+STR+MICRO NUTRIENTS	T1C1F4
	Climate Controlled Greenhouse	POP	T1C2F1
		BASAL AS PER POP+FOLIAR	T1C2F2
		FOLIAR +SILICA+STR	T1C2F3
		FOLIAR +SILICA+STR+MICRO NUTRIENTS	T1C2F4
15-May	Open Field	POP	T2C1F1
		BASAL AS PER POP+FOLIAR	T2C1F2
		FOLIAR +SILICA+STR	T2C1F3

		FOLIAR +SILICA+STR+MICRO NUTRIENTS	T2C1F4
	Climate Controlled Greenhouse	POP	T2C2F1
		BASAL AS PER POP+FOLIAR	T2C2F2
		FOLIAR +SILICA+STR	T2C2F3
		FOLIAR +SILICA+STR+MICRO NUTRIENTS	T2C2F4
30-May	Open Field	POP	T3C1F1
		BASAL AS PER POP+FOLIAR	T3C1F2
		FOLIAR +SILICA+STR	T3C1F3
		FOLIAR +SILICA+STR+MICRO NUTRIENTS	T3C1F4
	Climate Controlled Greenhouse	POP	T3C2F1
		BASAL AS PER POP+FOLIAR	T3C2F2
		FOLIAR +SILICA+STR	T3C2F3
		FOLIAR +SILICA+STR+MICRO NUTRIENTS	T3C2F4

POP - Package of practices

STR – Soil test results

3.2.1.4 ***After cultivation***

The plots were hand weeded once at 30 days after transplanting. Pest and diseases were controlled by recommended plant protection measures.

3.3 OBSERVATIONS

Growth observations were taken at weekly intervals. Observations were taken as per standard procedure (IRRI, 1980).

3.3.1 Biometric characters

3.3.1.1 ***Height of the plant***

The plant height in cm was recorded weekly after transplanting. Height of the plants was measured from the bottom of the culm to the tip of the largest leaf or tip of the ear head.

3.3.1.2 ***Leaf area index (LAI)***

Leaf area index at weekly intervals was measured using Digital Plant Canopy Imager CI-110.

3.3.1.3 ***Dry matter accumulation at harvest***

Biomass production was recorded at the harvest

3.3.1.4 ***Number of tillers per plant***

The numbers of tillers per plant were recorded at weekly intervals

3.3.1.5 ***Number of panicles per plant***

Number of panicles per plant was recorded.

3.3.1.6 ***Number of spikelets per panicle***

Number of spikelets per panicles was recorded.

3.3.1.7 ***Number of filled grains per panicle***

The number of filled grains per panicle was recorded at harvest.

3.3.1.8 ***1000 grain weight***

One thousand grains were counted from each pot and the weight was recorded in grams.

3.3.1.9 ***Straw yield***

The straw from each pot was dried, weighed and expressed in kg ha^{-1}.

3.3.1.10 ***Grain yield***

The grain harvested was dried, weighed and expressed in kg ha^{-1}.

3.3.2 Phenological observations

3.3.2.1. ***Days taken for active tillering***

The duration from transplanting to active tillering in each observational plant was recorded.

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3.3.2.2. *Days taken for panicle initiation*

Days to panicle initiation after transplanting was recorded for each treatment.

3.3.2.3. *Days taken for 50 per cent flowering*

Days taken for 50 per cent flowering were recorded.

3.3.2.4. *Days taken for physiological maturity*

Number of days taken for physiological maturity was recorded.

3.4 WEATHER OBSERVATIONS

The data on the different weather elements were collected using automatic weather station installed in the experimental field.

Table 3. Weather parameters used in the experiment

Sl .No.	Weather parameter	Unit
1	Maximum temperature (T max)	°C
2	Minimum temperature (T min)	°C
3	Relative humidity (RH)	Percent (%)
4	Solar radiation	Watts/m-2
5	Soil Temperature	°C

3.5. SOIL DATA

The result of soil analysis of experimental site was presented in Table 4.

Table 4. Soil analysis of the experimental site

Sl No	Parameter	Availability
1	PH	5.4
2	EC	0.135 ds/m
3	Organic Carbon	0.88%
4	Phosphorous	11.82 kg/ha
5	Potassium	147.39 kg/ha
6	Sulphur	81.875 ppm

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7	Boron	0.15 ppm
8	Calcium	301.25 ppm
9	Magnesium	119 ppm
10	Copper	1.73 ppm
11	Iron	24.09 ppm
12	Manganese	17.46 ppm
13	Zinc	4.03 ppm

3.6. STATISTICAL ANALYSIS

The data recorded from the field experiment was analyzed statistically using Analysis of variance technique. Three factorial CRD was used in the analysis of weather and crop data.

Correlation and regression analysis were done between the yield and phenological characters with the weekly mean/total values of maximum temperature, minimum temperature, relative humidity, solar radiation and soil temperature to determine the effect of weather elements on the growth and yield of rice. Regression equations were worked out from these observations.

The different statistical software like Microsoft – excel and SPSS were used in the study for various statistical analyses.

3.7 CROP WEATHER MODEL

CERES-Rice model has been used to study the impact of changes in the sowing time on crop yield in the purview of climate change. The past data generated as a part of various research programmes under KAU has also been used for modelling the impact of changes in the planting time and high temperature stress tolerance. The past data were collected from the following research programmes.

1. Sreelatha, P. 1989. Influence of weather parameters on growth and yield of rice. M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur.

2. Sajitha Rani, T. 2002. Crop weather modelling in rice. Ph D thesis, Kerala Agricultural University, Thrissur.

3. Naziya. 2014. Simulation of environmental and varietal effects in rice using CERES Model. M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur.

4. Vysakh, A. 2015. Validation of CERES model to calibrate the genetic coefficients of rice (*Oryza sativa*). M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur.

5. Subramanyam, G. 2015. Impact of climate change on rice production. M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur.

The CERES models have been extensively used for assessment of the impact of climatic change on agricultural crop production. CERES-Rice model is physiologically oriented and simulates rice response to climate variables (Singh *et al.*, 1994). The model developed by the International Benchmark Sites Network for Agro-technology Transfer (IBSNAT). The IBSNAT models were employed for the simulation of crop response to climate change because they have been already validated for a wide range of climates all over the world and are independent of location or soil type encountered.

The CERES-Rice (Crop Estimation through Resource and Environment Synthesis) model (Ritchie, 1986 and Godwin *et al.*, 1990) was adopted as the basis to simulate the effects of cultivar, planting density, weather, soil water and nitrogen on crop growth, development and yield. CERES- Rice model shared a common input and output data format, which had been developed and embodied in a software package called Decision Support System for Agro-technology Transfer (DSSAT) (Tsuji *et al.*, 1994).

Validation of CERES-Rice requires developing genetic coefficients based on the varietal characters of the variety and the details are as follows:

Table 5. Genetic Coefficients for the CERES Rice model

P1	Time period (expressed as growing degree days [GDD] in °C above a base temperature of 9°C) from seedling emergence to end of juvenile phase 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.
P2R	Extent to which phasic development leading to panicle initiation is delayed (expressed as GDD in °C) for each hour increase in photoperiod above P2O.

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P2O	Critical photoperiod or longest day length (in hours) at which the development occurs at maximum rate. At values higher than P2O the development rate is slowed (depending on P2R), there is delay due to longer day length.
P5	Time period in GDD in °C from beginning of grain-filling (3-4 days after flowering) to physiological maturity with base temperature of 9.0°C
G1	Potential spikelet number coefficient as estimated from number of spikelets per g of main culm dry weight (less leaf blades and sheaths plus spikes at anthesis. A typical value is 55.
G2	Single dry grain weight (g) under ideal growing conditions. i.e., non-limiting light, water, nutrients, and absence of pests and diseases.
G3	Tillering coefficient (scalar value) relative to IR64 cultivars under ideal conditions. A higher tillering cultivar would have coefficient greater than 1.
G4	Temperature tolerance coefficient. Usually 1.0 for cultivars grown in normal environment. G4 for japonica type rice grown in warmer environments would be $\geq$ 1.0. Tropical rice grown in cooler environments or season will have G4 $<$ 1.0

The minimum data set required for the operation and calibration of the CERES -Rice is (Hoogenboom *et al.,* 2012) given below,

3.7.1. Data required

3.7.1.1 Level 1 Data

Weather Data Required (Daily)

1. Minimum and maximum temperature
2. Rainfall
3. Total solar radiation or sunshine hours
4. Dew point temperature or relative humidity
5. Average daily wind speed

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Soil Data

1. General site information

2. Soil surface information

3. Soil profile data, for each soil horizon in which roots are likely to grow

Initial Conditions

1. Previous field history

2. Initial soil profiles conditions

3. Surface residues at the start of simulation or at planting

Management Data

1. Planting

2. Input information

3.7.1.2 Level 2 Data

Crop and Soil Response Measurements

1. Treatments

2. Yield and yield components

3. General observations

3.7.1.3 *Level 3 Data*

1. Growth analysis measurements

2. Soil water content versus depth

3. Soil fertility versus depth

3.7.2 *Calibration of CERES-Rice model*

Data obtained from the past literature was used for estimating the genetic parameters of the varieties Jyothy, Kanchana, Athira, Vysakh and Jaya. The genetic coefficients that influence the occurrence of developmental stages in the CERES–Rice model were derived iteratively, by manipulating the relevant coefficients to achieve the best possible match between the simulated and observed phenological events as well as the model was calibrated for yield parameters and grain yield.

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3.7.3 *Validation of CERES Rice*

Validation is the comparison of the results of model simulations with observations that were not used for the calibration. The experimental data collected were used for independent model validation. Statistical index used for model validation is

$$\text{RMSE (Root Mean Square Error)} = \sqrt{\frac{\sum_{i=1}^{n}(\text{Pi} - \text{Oi})^2}{n}}$$

Where Pi and Oi refer to the predicted and observed values for the studied variables (e.g. grain yield and total biomass) respectively and n is the mean of the observed variables.

3.8 CLIMATE CHANGE SCENARIOS

Impacts of climate change will depend not only on the response of the Earth system but also on how mankind will respond. These responses are uncertain, so future scenarios are used to explore the consequences of different options. The scenarios provide a range of options for the world's governments and other institutions for decision making. Policy decisions based on risk and values will help determine the pathway to be followed.

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) has introduced a new way of developing scenarios. These scenarios span the range of plausible radiative forcing scenarios, and are called representative concentration pathways (RCPs).

RCPs are concentration pathways used in the IPCC Assessment Report5 (AR5). They are prescribed pathways for greenhouse gas and aerosol concentrations, together with land use change, that are consistent with a set of broad climate outcomes used by the climate modelling community. The pathways are characterized by the radiative forcing produced by the end of the 21st century. Radiative forcing is the extra heat the lower atmosphere will retain as a result of additional greenhouse gases, measured in Watts per square meter.

Table 6. Description of representative concentration pathway (RCP) scenarios (Moss, 2010)

RCP	Description
RCP2.6	Its radiative forcing level first reaches a value around 3.1 Wm^{-2} mid-century, returning to 2.6 Wm^{-2} by 2100. Under this scenario greenhouse gas (GHG) emissions and emissions of air pollutants are reduced substantially over time.
RCP4.5	It is a stabilization scenario where total radiative forcing is stabilized before 2100 by employing a range of technologies and strategies for reducing GHG emissions.
RCP6.0	It is a stabilization scenario where total radiative forcing is stabilized after 2100 without overshoot by employing a range of technologies and strategies for reducing GHG emissions.
RCP8.5	It is characterized by increasing GHG emissions over time representative of scenarios in the literature leading to high GHG concentration levels.

Climate change data projected by GCM's on daily basis is used for the present study. Daily data of the following variables has taken

1. Rainfall
2. Maximum Temperature
3. Minimum Temperature
4. Solar radiation

The regional climate scenarios including radiation, Maximum temperature (T_{max}), Minimum temperature (T_{min}) and precipitation as inputs of the CERES-Rice model to simulate the impacts of climate change on rice yields in Kerala.

3.7 GENERAL CIRCULATION MODELS (GCM's) USED

The Ensembled mean data of seventeen models has been used for the years 2030, 2050 and 2080.

Table 7. General Circulation Models used for the study

Sl.No	Model	Institution
1	BCC-CSM 1.1	Beijing Climate Center, China Meteorological Administration
2	BCC-CSM 1.1(m)	Beijing Climate Center, China Meteorological Administration
3	CSIRO-Mk3.6.0	Commonwealth Scientific and Industrial Research Organisation and the Queensland Climate Change Centre of Excellence
4	FIO-ESM	The First Institute of Oceanography, SOA, China
5	GFDL-CM3	Geophysical Fluid Dynamics Laboratory
6	GFDL-ESM2G	Geophysical Fluid Dynamics Laboratory
7	GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory
8	GISS-E2-H	NASA Goddard Institute for Space Studies
9	GISS-E2-R	NASA Goddard Institute for Space Studies
10	HadGEM2-ES	Met Office Hadley Centre
11	IPSL-CM5A-LR	Institut Pierre-Simon Laplace
12	IPSL-CM5A-MR	Institut Pierre-Simon Laplace
13	MIROC-ESM	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
14	MIROC-ESM-CHEM	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
15	MIROC5	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
16	MRI-CGCM3	Meteorological Research Institute
17	NorESM1-M	Norwegian Climate Centre

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The results of the experiment entitled "Climate change adaptation on rice production." are presented in this chapter. The effects of different dates of planting, fertilizer treatments and different growing condition namely open field and climate controlled greenhouse on growth and yield of rice, variety Jyothi were studied.

4.1 BIOMETRIC OBSERVATIONS

4.1.1 Plant Height

The weekly mean plant height was given in the Table 8. There was no significant difference in plant height during the first two weeks after planting and from eighth week onwards. From third week to seventh week the combined effect of weather and applications of fertilizer showed significant variation in plant height. Crop transplanted on 1st May 2016 inside the climate controlled greenhouse and fertilizer applied as per POP recommendations recorded the highest plant height of 116.7 cm. Generally plants grown inside the climate controlled greenhouse showed maximum plant height. Lowest maximum plant height (69.0 cm) was recorded by the crops grown in open field conditions transplanted on 15th May 2016 and fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) silica (1g per pot) and micronutrients.

4.1.2 Leaf area Index

The dates of planting and fertilizer application had a significant effect on leaf area index under the two different growing environments. During 2nd, 4th, 6th and 10th weeks after planting crop showed significant difference in leaf area index. The maximum leaf area index (2.79) recorded by the crops grown in open field transplanted on 30th May 2016 and fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot). The lowest maximum leaf area index (2.37) was recorded by the crops grown in open field transplanted on 15th May 2016 and fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot) (Table 9).

Table 8. Plant height (cm) at weekly intervals

DOP	Fertilizer	Environment	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
MAY 1 2016	POP	OPEN	21.7	26.5	48.1	59.3	63.4	68.8	70.9	69.8	79.2	88.0	88.7	88.8	88.2
		CC	23.1	24.7	46.7	58.0	59.8	83.2	91.5	96.7	102.0	113.3	116.3	115.7	116.7
	BASAL POP+ Foliar	OPEN	21.2	23.8	44.5	52.2	57.7	62.3	62.7	67.6	70.9	76.9	84.5	85.2	85.7
		CC	21.6	25.6	48.1	57.8	61.5	79.3	87.5	90.6	93.9	100.9	108.7	112.3	113.0
	Soil Test Results +Foliar+Silica	OPEN	22.2	24.6	40.2	48.0	54.0	59.1	63.0	65.5	71.3	79.5	85.3	85.3	83.2
		CC	22.4	24.2	45.1	53.3	57.8	71.4	79.9	87.9	92.7	96.5	109.3	109.3	107.3
	Soil Test Results +Foliar+Silica+ Micronutrient	OPEN	22.9	24.0	42.0	48.5	54.0	61.7	61.2	63.3	64.2	71.3	80.3	82.3	82.5
		CC	22.0	25.5	47.2	53.8	59.7	75.3	79.7	84.3	84.5	89.1	99.2	99.7	98.8
MAY 15 2016	POP	OPEN	15.7	19.2	32.3	45.6	53.6	60.2	61.0	61.3	62.8	72.8	77.8	76.3	77.2
		CC	15.8	16.0	27.8	47.3	73.7	82.0	87.2	91.2	92.7	99.0	109.0	109.7	109.3
	BASAL POP+ Foliar	OPEN	16.7	21.5	35.0	48.3	61.8	65.7	66.7	68.9	69.0	77.8	85.6	86.9	87.0
		CC	13.0	13.8	23.8	44.4	60.1	66.5	79.4	91.3	92.7	94.8	99.8	106.7	109.7
	Soil Test Results +Foliar+Silica	OPEN	16.7	17.7	24.3	38.1	50.0	57.0	58.8	59.5	60.0	66.2	73.2	76.2	76.7
		CC	14.0	19.7	32.2	53.8	71.7	82.3	88.0	89.2	90.0	92.0	95.7	104.2	104.2
	Soil Test Results +Foliar+Silica+ Micronutrient	OPEN	15.2	16.2	20.3	34.4	43.0	47.8	50.7	53.4	54.3	63.3	65.2	69.2	69.0
		CC	14.7	17.6	27.7	46.1	64.7	72.6	78.3	83.1	84.0	86.2	99.3	102.7	102.3
MAY 30 2016	POP	OPEN	21.0	29.5	42.1	50.5	65.8	67.8	70.5	74.7	75.2	82.5	87.2	87.5	86.5
		CC	20.3	31.5	45.5	62.8	83.3	88.6	90.8	96.1	99.2	110.0	112.3	112.3	111.5
	BASAL POP+ Foliar	OPEN	21.8	25.5	42.8	53.5	67.0	70.6	75.3	75.8	78.3	82.2	94.8	94.5	94.5
		CC	20.0	24.0	37.2	51.5	78.8	88.5	93.3	98.8	100.2	103.0	105.3	107.3	107.0
	Soil Test Results +Foliar+Silica	OPEN	19.7	21.2	26.1	34.2	44.1	48.7	53.8	57.5	59.7	60.7	68.1	73.0	72.0
		CC	22.5	24.7	41.2	54.2	74.6	85.7	90.5	91.5	92.2	93.7	93.0	93.5	93.2
	Soil Test Results +Foliar+Silica+ Micronutrient	OPEN	22.0	23.0	28.4	33.8	47.8	51.2	62.3	63.0	63.4	63.5	63.5	74.8	77.7
		CC	21.7	28.3	41.7	55.3	71.5	81.5	90.0	98.1	97.5	96.3	97.7	96.7	96.7
		CD 5%	2.7	4.2	5.8	6.5	8.3	7.9	7.8	6.9	7.9	10.5	11.3	8.6	9.2
		CD 1%	3.6	5.7	7.7	8.7	11.1	10.5	10.4	9.3	10.5	14.1	15.1	11.5	12.3

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4.1.3 Number of tillers

Number of tillers varied significantly with the treatment combinations during 1st, 2nd, 4th and 11th weeks. Generally plants grown in open field recorded maximum number of tillers. Crops transplanted on 1st May 2016 recorded maximum number of tillers (26.3) and they were grown under climate controlled greenhouse as per POP recommendations (Table 10).

4.1.4 Dry matter accumulation at harvest

The combined effect of weather and application of fertilizers showed significant variation in dry matter accumulation at harvest. Crops transplanted on 1st May 2016 has recorded highest dry matter accumulation (13093.3 kg/ha) grown in open field and their fertilizer treatments as per soil test result along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot). The lowest dry matter accumulation (8926.8 kg/ha) was recorded by the crops grown under climate controlled greenhouse transplanted on 30th May 2016 and fertilizer given as per POP recommendations (Table 12).

Considering the sole effect of dates of planting highest dry matter accumulation was recorded by the crop planted on 1st May 2016 (11442.9 kg/ha) whereas considering fertilizer treatment alone, fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per plot) has recorded highest dry matter accumulation (11367.9 kg/ha). Compared to the crops grown under climate controlled greenhouse, crops grown in open field has recorded highest dry matter accumulation (11678.7 kg/ha) (Table 13).

4.2 YIELD ATTRIBUTES

4.2.1 Number of panicles per plant

Number of panicles per plant varied significantly with treatment combinations. The maximum number of panicles recorded was 22.9 in crop grown inside the climate controlled greenhouse transplanted on 1st May 2016 and fertilizer application as per POP recommendation. The minimum number of panicles recorded was 7.4 in crops grown under climate controlled greenhouse transplanted on 30th May 2016 and fertilizer application as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval), silica (1g per pot) and micronutrients (Table 11).

Table 9. Leaf Area Index at weekly intervals

DOP	Fertilizer	Environment	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
MAY 1 2016	POP	OPEN	0.49	0.30	0.36	0.36	1.48	1.38	1.54	2.54	2.49	1.42	1.35	1.35	1.35
		CC	0.49	0.58	0.83	0.66	1.31	1.34	1.48	2.48	2.41	1.33	1.39	1.39	1.39
	BASAL POP+ Foliar	OPEN	0.42	0.51	0.55	0.42	1.59	1.65	1.44	2.44	2.38	1.31	1.42	1.42	1.42
		CC	0.42	0.63	0.92	0.62	1.54	1.36	1.40	2.40	2.50	1.60	1.59	1.59	1.59
	Soil Test Results +Foliar+Silica	OPEN	0.19	0.43	0.78	1.06	1.67	1.49	1.70	2.70	2.51	1.31	1.70	1.70	1.70
		CC	0.19	0.55	0.71	0.42	1.53	1.40	1.52	2.52	2.41	1.30	1.55	1.55	1.55
	Soil Test Results +Foliar+Silica+ Micronutrient	OPEN	0.45	0.61	0.42	0.54	1.55	1.48	1.43	2.43	2.43	1.43	1.51	1.51	1.51
		CC	0.45	0.45	0.78	0.36	1.38	1.40	1.44	2.44	2.46	1.48	1.61	1.61	1.61
MAY 15 2016	POP	OPEN	0.32	0.77	0.66	0.49	1.62	1.58	1.60	2.54	2.47	1.45	1.45	1.45	1.50
		CC	0.63	0.68	0.54	0.82	1.42	1.56	1.49	2.43	2.38	1.56	1.56	1.56	1.45
	BASAL POP+ Foliar	OPEN	0.51	0.69	0.48	0.32	1.46	1.29	1.38	2.40	2.42	1.58	1.58	1.58	1.61
		CC	0.64	0.81	0.66	0.75	1.59	1.57	1.58	2.46	2.33	1.39	1.39	1.39	1.48
	Soil Test Results +Foliar+Silica	OPEN	0.69	0.81	0.57	0.45	1.34	1.41	1.37	2.37	2.37	1.53	1.53	1.53	1.44
		CC	0.57	0.69	0.58	0.49	1.33	1.50	1.42	2.38	2.35	1.48	1.48	1.48	1.57
	Soil Test Results +Foliar+Silica+ Micronutrient	OPEN	0.60	0.43	0.88	0.47	1.49	1.46	1.48	2.41	2.33	1.85	1.85	1.85	1.33
		CC	0.66	0.60	0.47	0.51	1.28	1.67	1.47	2.39	2.31	1.40	1.40	1.40	1.51
MAY 30 2016	POP	OPEN	0.78	0.42	0.40	0.41	1.43	1.46	1.78	2.78	2.63	1.47	1.38	1.29	1.29
		CC	0.77	0.68	0.51	0.60	1.57	1.54	1.77	2.77	2.64	1.50	1.41	1.32	1.32
	BASAL POP+ Foliar	OPEN	0.52	0.41	0.27	0.34	1.31	1.27	1.49	2.49	2.51	1.53	1.39	1.25	1.25
		CC	0.82	0.51	0.66	0.59	1.44	1.30	1.47	2.47	2.51	1.54	1.48	1.41	1.41
	Soil Test Results +Foliar+Silica	OPEN	0.83	0.67	0.50	0.59	1.66	1.73	1.79	2.79	2.63	1.46	1.39	1.30	1.30
		CC	0.57	0.73	0.57	0.65	1.51	1.37	1.41	2.41	2.46	1.51	1.41	1.31	1.31
	Soil Test Results +Foliar+Silica+ Micronutrient	OPEN	0.88	0.76	0.72	0.74	1.57	1.40	1.76	2.76	2.65	1.53	1.43	1.33	1.33
		CC	0.73	0.59	0.45	0.52	1.39	1.27	1.53	2.53	2.58	1.63	1.49	1.34	1.34
		CD 5%	0.21	0.22	0.30	0.21	0.20	0.20	0.18	0.16	0.13	0.22	0.24	0.25	0.21
		CD 1%	0.28	0.29	0.40	0.28	0.27	0.26	0.24	0.22	0.18	0.30	0.32	0.33	0.28

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Table 10. Number of tillers per plant at weekly intervals

DOP	Fertilizer	Environment	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
MAY 1 2016	POP	OPEN	3.0	4.3	8.0	11.0	19.7	15.7	21.0	22.0	17.0	17.3	19.3	20.3	20.3
		CC	3.0	3.0	3.3	5.7	10.0	16.7	17.0	14.7	16.7	18.0	26.3	25.7	22.0
	BASAL POP+ Foliar	OPEN	3.0	3.3	6.0	8.7	15.3	15.7	17.3	17.0	14.0	12.7	12.0	10.3	12.3
		CC	3.0	3.0	3.7	7.0	10.7	11.7	14.3	14.7	13.3	12.3	13.7	12.3	11.3
	Soil Test Results +Foliar+Silica	OPEN	3.0	3.0	5.7	8.0	11.7	11.7	13.3	13.7	11.0	11.0	9.7	9.0	9.7
		CC	3.0	3.0	3.3	4.7	6.7	9.3	9.0	8.0	7.3	7.3	7.3	7.3	7.3
	Soil Test Results +Foliar+Silica+ Micronutrient	OPEN	3.0	3.0	6.3	9.0	9.3	10.0	10.3	11.7	9.7	8.3	8.7	8.3	8.0
		CC	3.0	3.0	3.7	4.0	6.7	9.7	9.3	8.3	8.3	9.3	9.0	8.3	7.3
MAY 15 2016	POP	OPEN	3.0	3.0	5.7	8.0	12.7	15.0	14.0	11.3	9.7	17.3	23.0	21.3	24.3
		CC	3.0	3.0	3.3	3.0	4.7	10.7	8.7	7.3	6.7	7.7	14.3	15.0	14.0
	BASAL POP+ Foliar	OPEN	3.0	3.0	6.7	10.7	15.0	15.3	16.3	13.0	11.3	11.0	11.3	8.7	9.7
		CC	3.0	3.0	2.7	2.7	4.3	8.0	7.0	7.0	7.0	5.0	7.7	6.7	7.3
	Soil Test Results +Foliar+Silica	OPEN	3.0	3.0	4.3	5.3	8.7	12.7	12.7	9.3	8.3	8.3	8.0	8.0	7.7
		CC	3.0	3.0	4.3	4.0	6.3	10.7	10.3	9.0	8.3	6.3	9.0	7.0	7.3
	Soil Test Results +Foliar+Silica+ Micronutrient	OPEN	3.0	3.0	3.7	4.0	7.7	10.0	7.3	9.7	7.0	5.7	6.0	5.3	5.3
		CC	3.0	3.0	4.3	4.3	5.7	11.0	11.0	8.3	7.7	6.3	7.3	6.0	7.0
MAY 30 2016	POP	OPEN	3.0	4.0	8.3	12.0	15.3	16.0	16.0	17.0	14.0	19.0	26.0	21.0	18.0
		CC	3.0	3.7	5.7	9.7	9.3	12.7	11.7	11.7	8.7	16.3	18.0	19.7	18.0
	BASAL POP+ Foliar	OPEN	3.0	5.3	10.7	14.7	21.7	24.0	24.7	19.7	18.7	14.3	14.0	14.0	12.3
		CC	3.0	2.7	4.7	5.3	5.7	11.7	12.3	10.7	10.7	9.3	9.3	10.0	10.0
	Soil Test Results +Foliar+Silica	OPEN	3.0	4.3	7.0	10.0	10.0	13.3	11.7	11.0	10.7	10.3	9.7	11.3	10.0
		CC	3.0	2.7	4.3	5.3	6.0	8.7	10.3	6.0	6.0	6.0	7.0	7.0	8.0
	Soil Test Results +Foliar+Silica+ Micronutrient	OPEN	3.0	3.0	6.0	7.0	8.3	10.3	10.3	10.0	12.7	9.7	7.7	9.0	7.7
		CC	3.0	3.0	5.7	6.7	9.7	14.7	15.3	7.7	9.7	9.0	8.0	8.7	9.0
		CD 5%		0.7	2.2	3.6	5.1	6.3	6.5	6.0	5.2	4.8	5.7	5.7	6.0
		CD 1%		0.9	3.0	4.8	6.9	8.5	8.7	8.1	7.0	6.4	7.7	7.6	8.0

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Regarding the effect of dates of planting on number of panicles the maximum (12.9) was recorded by the crop planted on 1st May 2016, whereas considering the sole impact of fertilizer treatment the number of panicles were maximum (17.7) when fertilizer given as per POP recommendations. Compared to the crops grown under climate controlled greenhouse crops grown in open field conditions recorded maximum number of panicles (12.0) (Table 13).

4.2.2 Number of spikelets per panicle

The dates of planting and fertilizer combination had no significant effect on number of spikelets per panicle under the two different growing environments. The maximum number of spikelets recorded was 13.3 by crops grown in open field transplanted on 1st May 2016 and fertilizer application given as basal dose as per POP and rest met by foliar application (19:19:19 NPK 5g at 15 days interval). The minimum number of spikelets recorded was 7.7 in crops grown under climate controlled greenhouse transplanted on 30th May 2016 and fertilizer application as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot) (Table 11)

Considering the effect of dates of planting on number of spikelets the maximum (11.2) was recorded by the crop transplanted on 1st May 2016, whereas considering the impact of fertilizer treatment alone fertilizer given as per POP recommendation and basal as per POP along with foliar application recorded maximum number of spikelets (10.4). Compared to the crops grown under climate controlled greenhouse, crops grown in open field conditions recorded maximum number of spikelets (10.4) (Table 13).

4.2.3 Number of filled grains per panicle

The combined effect of weather and fertilizer treatment had no significant effect on number of filled grains per panicle. The maximum number of filled grains (107) was recorded by the crops transplanted on 1st May 2016 in open field with fertilizer given basal as per POP along with foliar (19:19:19 NPK 5g at 15 days interval). The minimum number of filled grains (68) was recorded by the crops grown under climate controlled greenhouse transplanted on 30th May 2016 and fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot) (Table 12).

Considering the effect of dates of planting on number of filled grains, the maximum (89.9) was recorded by the crop transplanted on 1st May 2016 whereas considering the impact of fertilizer treatment alone fertilizer application as basal as per POP recommendations along with foliar (19:19:19 NPK 5g at 15 days interval) recorded maximum number of filled grains (84.1). Compared to the crops grown under climate controlled greenhouse, crops grown in open field conditions recorded maximum number of filled grains (87.2) (Table 13).

Table 11. Number of panicles per plant and Number of spikelets per panicle

DOP	Fertilizer	Environment	Number of Panicles/plant	Number of Spikelets/panicle
MAY 1 2016	POP	OPEN	20.6	10.7
		CC	22.9	10.3
	BASAL POP+ Foliar	OPEN	10.7	13.3
		CC	9.6	11.0
	Soil Test Results +Foliar+Silica	OPEN	10.9	11.7
		CC	10.5	11.3
	Soil Test Results +Foliar+Silica+Micronutrient	OPEN	9.0	9.3
		CC	9.3	12.0
MAY 15 2016	POP	OPEN	17.1	10.3
		CC	19.3	10.0
	BASAL POP+ Foliar	OPEN	10.9	8.3
		CC	10.5	8.7
	Soil Test Results +Foliar+Silica	OPEN	10.7	10.7
		CC	8.4	10.3
	Soil Test Results +Foliar+Silica+Micronutrient	OPEN	9.3	10.3
		CC	8.3	9.3
MAY 30 2016	POP	OPEN	17.2	11.3
		CC	8.9	9.7
	BASAL POP+ Foliar	OPEN	9.8	10.0
		CC	10.1	11.0
	Soil Test Results +Foliar+Silica	OPEN	9.9	8.7
		CC	9.9	7.7
	Soil Test Results +Foliar+Silica+Micronutrient	OPEN	7.7	10.0
		CC	7.4	9.3
	CD 5%		3.1	3.3
	CD 1%		4.2	4.4

4.2.4 1000 Grain weight

As is apparent from the Table 12, the dates of planting and fertilizer combination had a significant effect in 1000 grain weight under the two growing environments. Crop transplanted on 1st May 2016 recorded highest 1000 grain weight (30.2 g) grown in open field as per POP recommendations. The lowest 1000 grain weight (22.2 g) was recorded by the crops planted on 30th May 2016 in open field and fertilizer given as per POP recommendations.

Considering the effect of dates of planting on 1000 grain weight the maximum (27.4 g) was recorded by the crop transplanted on 15th May 2016, whereas considering the sole impact of fertilizer treatment, fertilizer given basal as per POP recommendation along with foliar application (19:19:19 NPK 5g at 15 days interval) has recorded highest 1000 grain weight (26.6 g). Compared to the crops grown under climate controlled greenhouse, crops grown in open field conditions recorded highest 1000 grain weight (26.9 g) (Table 13).

Table 12. Yield and Yield attributes

DOP	Fertilizer	Environment	Filled Grains	1000 Grain Weight (g)	Grain Yield kg/ha	Straw Yield kg/ha	Dry matter accumulation at harvest kg/ha
MAY 1 2016	POP	OPEN	90.7	30.2	5870.0	6685.3	12555.3
		CC	78.7	25.5	4757.0	5517.8	10274.8
	BASAL POP+ Foliar	OPEN	107.0	27.6	5960.0	6680.3	12640.3
		CC	90.0	27.7	5034.0	5654.5	10688.5
	Soil Test Results +Foliar+Silica	OPEN	103.7	27.6	6324.0	6769.3	13093.3
		CC	79.7	26.6	5286.0	5877.9	11163.9
	Soil Test Results +Foliar+Silica+ Micronutrient	OPEN	94.7	26.7	5452.0	6258.4	11710.4
		CC	75.0	26.5	4398.0	5018.8	9416.8
MAY 15 2016	POP	OPEN	92.7	29.5	5427.0	6292.3	11719.3
		CC	79.0	23.8	4653.0	5258.0	9911.0
	BASAL POP+ Foliar	OPEN	81.3	28.2	5648.0	6391.3	12039.3
		CC	69.0	27.5	4716.0	5318.8	10034.8
	Soil Test Results +Foliar+Silica	OPEN	82.3	27.9	5739.0	6374.3	12113.3
		CC	79.3	28.2	4987.0	5568.6	10555.6
	Soil Test Results +Foliar+Silica+ Micronutrient	OPEN	78.7	27.1	5102.0	5722.7	10824.7
		CC	77.0	27.0	4155.0	4927.8	9082.8
MAY 30 2016	POP	OPEN	71.3	22.2	5210.0	5694.7	10904.7
		CC	82.0	27.5	4152.0	4774.8	8926.8
	BASAL POP+ Foliar	OPEN	85.7	24.8	5485.0	6380.7	11865.7
		CC	71.7	23.8	4417.0	5175.7	9592.7
	Soil Test Results +Foliar+Silica	OPEN	74.7	25.0	5386.0	6123.8	11509.8
		CC	68.0	22.9	4618.0	5153.3	9771.3
	Soil Test Results +Foliar+Silica+ Micronutrient	OPEN	84.0	25.6	4263.0	4905.0	9168.0
		CC	76.7	24.1	5216.0	5998.4	11214.4
	CD 5%		23.6	2.1	504.2	584.8	1049.3
	CD 1%		31.5	2.8	673.1	780.6	1400.7

4.2.5 Grain yield

It can be observed from Table 12, that the combined effect of weather and application of fertilizers showed significant variation in grain yield under the two growing environments. The highest grain yield (6324.0 kg/ha) was recorded by crop transplanted on 1st May 2016 in the open field fertilizer application as per soil test result along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot). Crops transplanted on 30th May 2016 inside the climate controlled greenhouse fertilizer given as per POP recommendation recorded the lowest grain yield (4152 kg/ha).

Considering the effect of dates of planting on grain yield, the highest grain yield (5385.1 kg/ha) was recorded by the crops transplanted on 1st May 2016, whereas considering sole effect of fertilizer treatment fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot) was recorded highest grain yield (5390.0 kg/ha). Compared to the crops grown inside the climate controlled greenhouse, crops grown in open field has recorded highest grain yield (5488.8 kg/ha) (Table 13).

Crops grown in open field affected by bacterial leaf blight disease when the fertilizer was given based on soil test results through foliar application (19:19:19 NPK 5g at 15 days interval) silica (1g per pot) and micronutrients.

4.2.6 Straw yield

The combined effect of weather and application of fertilizers showed significant variation in straw yield under the two growing environments. Crops transplanted on 1st May 2016 in open field and fertilizer given as per soil test result along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot) has recorded highest straw yield (6769.3 kg/ha). Crops transplanted on 30th May 2016 inside the climate controlled greenhouse fertilizer application as per POP recommendation recorded the lowest straw yield (4774.8 kg/ha) (Table 12).

Table 13. Effect of individual treatments on yield and yield attributes

	No. of Panicles	No. of Spikelets	Filled Grains	1000 Grain Weight (g)	Grain Yield kg/ha	Straw Yield kg/ha	Dry matter accumulation at harvest kg/ha
Dates of Planting							
1MAY2016	12.9	11.2	89.9	27.3	5385.1	6057.8	11442.9
15 MAY 2016	11.8	9.8	79.9	27.4	5053.4	5731.7	10785.1
30 MAY 2016	10.1	9.7	76.8	24.5	4843.4	5525.8	10369.2
Application of fertilizers							
POP	17.7	10.4	82.4	26.4	5011.5	5703.8	10715.3
BASAL POP + Foliar	10.3	10.4	84.1	26.6	5210.0	5933.5	11143.5
Soil Test Results + Foliar + Silica	10.0	10.1	81.3	26.4	5390.0	5977.9	11367.9
Soil Test Results + Foliar + Silica +Micronutrient	8.5	10.1	81.0	26.2	4764.3	5471.8	10236.2
Growing Environment							
OPEN	12.0	10.4	87.2	26.9	5488.8	6189.8	11678.7
CC	11.3	10.1	77.2	25.9	4699.1	5353.7	10052.8

Considering the effect of dates of planting on straw yield, the highest straw yield (6057.8 kg/ha) was recorded by the crops transplanted on 1st May 2016, whereas considering the sole effect of fertilizer treatment, fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot) has recorded highest straw yield (5977.9 kg/ha). Compared to the crops grown under climate controlled greenhouse crops grown in open field has recorded highest straw yield (6189.8 kg/ha) (Table 13).

4.3 PHENOLOGICAL OBSERVATIONS

4.3.1 Days taken for active tillering

The dates of planting and fertilizer combination had a significant effect on days taken for active tillering under the two different growing environments (Table 14). Crop transplanted on 15th May 2016 inside the climate controlled greenhouse fertilizer application as basal as per POP along with foliar application (19:19:19 NPK 5g at 15 days interval) and also fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot) required the

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maximum days to reach active tillering stage (44 days). Crops planted on 1st May 2016 in open field fertilizer application as per POP recommendations took minimum days for active tillering (30.7 days) (Table 14).

Considering the effect of dates of planting alone on days taken for active tillering the maximum (40.1 days) was recorded by the crop transplanted on 15th May 2016 whereas considering the impact of fertilizer treatment alone the days taken for active tillering were maximum (39.5 days) when fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot). Compared to the crops grown in the open field, crops grown inside the climate controlled greenhouse took more number of days to reach active tillering stage (38.7 days) (Table 16).

4.3.2 Days taken for panicle initiation

The dates of planting and fertilizer combination had a substantial effect on days taken for panicle initiation under the two different growing environments (Table 14). The days taken for panicle initiation was found to be highest (47 days) in the crop transplanted on 15th May 2016 inside the climate controlled greenhouse fertilizer given basal as per POP along with foliar application (19:19:19 NPK 5g at 15 days interval) and also fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot). The crop planted in the open field on 1st May 2016 took the least (35.7 days) number of days for panicle initiation fertilizer application as per POP recommendations.

Considering the sole effect of dates of planting on days taken for panicle initiation the maximum (43.1 days) was recorded by the crop transplanted on 15th May 2016 whereas considering the impact of fertilizer treatment alone, the days taken for panicle initiation were maximum (42.9 days) when fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot). Considering the growing environment alone, crops grown inside the climate controlled greenhouse has recorded maximum days (42.1days) taken for panicle initiation (Table 16).

Table 14. Phenological observations

DOP	Fertilizer	Environment	Days taken for active tillering	Days taken for panicle initiation
MAY 1 2016	POP	OPEN	30.7	35.7
		CC	32.7	38.0
	BASAL POP+ Foliar	OPEN	35.0	39.0
		CC	36.0	39.0
	Soil Test Results +Foliar+Silica	OPEN	37.0	39.7
		CC	37.0	40.0
	Soil Test Results +Foliar+Silica+ Micronutrient	OPEN	39.0	42.0
		CC	39.0	42.0
MAY 15 2016	POP	OPEN	35.0	37.7
		CC	39.0	42.0
	BASAL POP+ Foliar	OPEN	37.0	40.0
		CC	44.0	47.0
	Soil Test Results +Foliar+Silica	OPEN	38.0	41.0
		CC	44.0	47.0
	Soil Test Results +Foliar+Silica+ Micronutrient	OPEN	42.0	45.0
		CC	42.0	45.0
MAY 30 2016	POP	OPEN	36.0	39.0
		CC	36.0	39.0
	BASAL POP+ Foliar	OPEN	39.0	42.0
		CC	36.0	39.0
	Soil Test Results +Foliar+Silica	OPEN	40.0	44.0
		CC	41.0	46.0
	Soil Test Results +Foliar+Silica+ Micronutrient	OPEN	37.0	39.0
		CC	37.7	40.7
		CD 5%	0.32	0.36
		CD 1%	0.43	0.48

4.3.3 Days taken for 50% flowering

It can be observed from Table 15, that the combined effect of weather and application of fertilizers showed significant variation in days taken for 50% flowering. Maximum days taken for 50% flowering (75.7 days) recorded by crop transplanted on 30th May 2016 grown in open field and fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval), silica (1g

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per pot) and micronutrients. The crops planted on 1st May 2016 grown in open field fertilizer given as per POP recommendations took minimum days to reach 50% flowering (60.7 days).

Considering the effect of dates of planting on days taken for 50% flowering the maximum (69.1 days) was recorded by the crop transplanted on 15th May 2016 whereas considering the impact of fertilizer treatment alone, the days taken for 50% flowering were maximum (70.1 days) when fertilizer given as per soil test results along with foliar application (5g at 15 days interval), silica (1g per pot) and micronutrients. Considering the growing environment alone, crops grown inside the climate controlled greenhouse were recorded maximum days taken for 50% flowering (67.9 days) (Table 16).

4.3.4 Days taken for physiological maturity

The effect of dates of planting and fertilizer combination had a significant effect on days taken for physiological maturity under the two different growing environments (Table 15). The crop transplanted in the open field on 30th May 2016 and fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot) took the maximum days for physiological maturity (104 days) while the crop transplanted on 1st May 2016 in the open field fertilized as per POP recommendations took the least number of days for physiological maturity (89.7 days).

Considering the effect of dates of planting on days taken for physiological maturity the maximum (99 days) was recorded by the crop transplanted on 15th May 2016 whereas the impact of fertilizer treatment take into account fertilizer given as per soil test results along with foliar application (5g at 15 days interval), silica (1g per pot) and micronutrients took maximum days (100.2 days) for physiological maturity. Considering the growing environment alone, crops grown inside the climate controlled greenhouse has taken maximum days for physiological maturity (97.6 days) (Table 16).

Table 15. Phenological observations

DOP	Fertilizer	Environment	Days taken for 50% Flowering	Days taken for Physiological maturity
MAY 1 2016	POP	OPEN	60.7	89.7
		CC	62.3	90.7
	BASAL POP+ Foliar	OPEN	62.7	93.7
		CC	65.0	93.3
	Soil Test Results +Foliar+Silica	OPEN	66.3	96.0
		CC	66.0	96.0
	Soil Test Results +Foliar+Silica+Micronutrient	OPEN	68.0	98.0
		CC	68.0	98.0
MAY 15 2016	POP	OPEN	64.0	94.0
		CC	68.0	97.0
	BASAL POP+ Foliar	OPEN	66.0	96.0
		CC	73.0	101.0
	Soil Test Results +Foliar+Silica	OPEN	67.0	98.0
		CC	73.0	103.0
	Soil Test Results +Foliar+Silica+Micronutrient	OPEN	71.0	102.0
		CC	71.0	101.0
MAY 30 2016	POP	OPEN	65.0	95.0
		CC	65.0	95.0
	BASAL POP+ Foliar	OPEN	68.0	98.0
		CC	65.0	95.0
	Soil Test Results +Foliar+Silica	OPEN	74.0	104.0
		CC	72.0	102.0
	Soil Test Results +Foliar+Silica+Micronutrient	OPEN	75.7	103.7
		CC	66.7	98.7
		CD 5%	0.53	0.52
		CD 1%	0.71	0.70

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Table 16. Effect of individual treatments on phenology

	Days taken for active tillering	Days taken for panicle initiation	Days taken for 50% Flowering	Days taken for Physiological maturity
Dates of Planting				
1 MAY 2016	35.8	39.4	64.9	94.4
15 MAY 2016	40.1	43.1	69.1	99.0
30 MAY 2016	37.8	41.1	68.9	98.9
Application of fertilizers				
POP	34.9	38.6	64.2	93.6
BASAL POP + Foliar	37.8	41.0	66.6	96.2
Soil Test Results + Foliar + Silica	39.5	42.9	69.7	99.8
Soil Test Results + Foliar + Silica + Micronutrient	39.4	42.3	70.1	100.2
Growing Environment				
OPEN	37.1	40.3	67.4	97.3
CC	38.7	42.1	67.9	97.6

4.4 WEATHER INSIDE THE DIFFERENT GROWING ENVIORNMENTS

4.4.1. Weekly maximum solar radiation (Wm^{-2})

4.4.1.1. Open field

The peak value of solar radiations for all the dates of transplanting namely 1 May 2016, 15 May 2016 and 30 May 2016 were 1259.6 Wm^{-2} respectively. While the lowest solar radiations received for the same dates of transplanting were 346.4 (Fig.7).

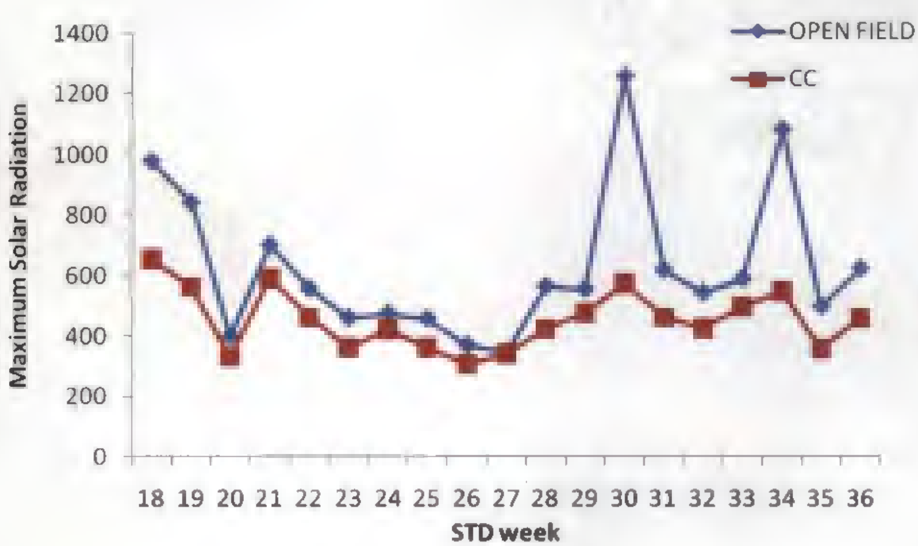

Fig 7. Weekly maximum solar radiation

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4.4.1.2. Climate controlled greenhouse

The highest values of weekly solar radiation for the different dates of transplanting namely 1 May 2016, 15 May 2016, and 30 May 2016 were 654, 589.4, 573.3 Wm^{-2} respectively. While the lowest solar radiations received for the same dates of transplanting were 307.3 (Fig. 7).

4.4.2 Weekly maximum temperature (°C)

4.4.2.1. Open field

The highest values of maximum temperatures recorded for the different dates of transplanting namely 1 and 15 May 2016 was 34.1°C and 30 May 2016 was 32.3°C. While the lowest values of maximum temperatures for the different dates of transplanting namely 1 and 15 May 2016 was 27.7°C and 30 May 2016 was 27°C (Fig. 8).

4.4.2.2. Climate controlled greenhouse

The lowest values of maximum temperatures recorded inside the climate controlled greenhouse for the crops transplanted on 1 and 15 May 2016 was 46.9°C while it was 46.7°C for the crops transplanted on 30 May 2016. The peak maximum temperatures were 60.5°C for the different dates of transplanting namely 1 May 2016, 15 May 2016 and 30 May 2016 (Fig. 8).

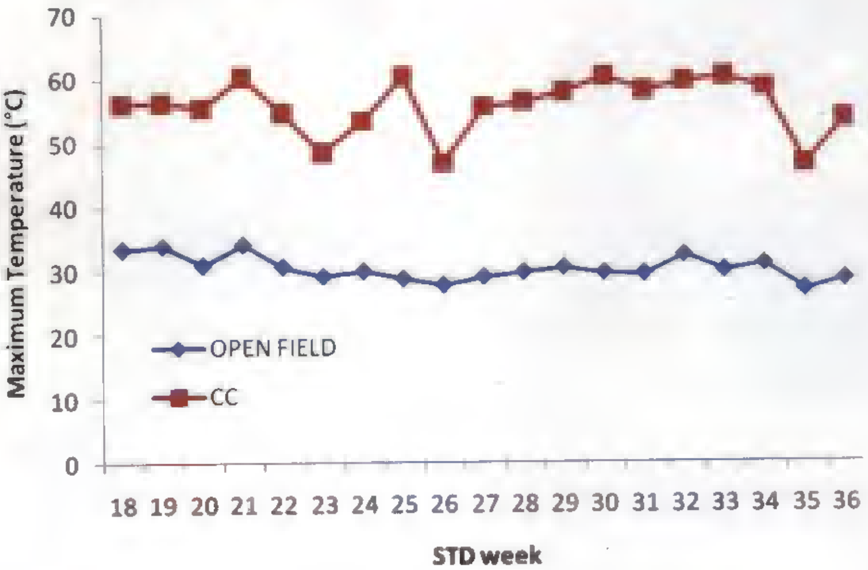

Fig 8. Weekly maximum temperature

4.4.3 Weekly minimum temperature (°C)

4.4.3.1. Open field

The highest values of minimum temperatures for the different dates of transplanting namely 1 and 15 May 2016 was 24.7°C and 30 May 2016 was 23.3°C. While the lowest values of minimum temperatures for the same dates of transplanting were 18.1°C (Fig. 9).

4.4.3.2. Climate controlled greenhouse

The peak values of minimum temperature for the different dates of transplanting namely 1 May 2016, 15 May 2016 and 30 May 2016 were 34°C. While the lowest values for the same dates of transplanting were 26.6°C (Fig.9).

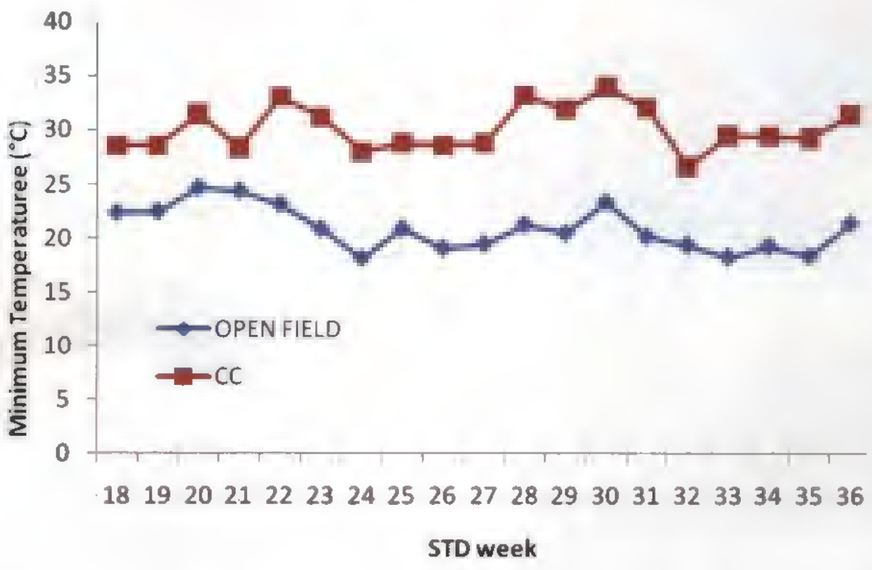

Fig 9. Weekly minimum temperature

4.4.4 Maximum relative humidity (percentage)

4.4.4.1 Open field

The highest maximum relative humidity was 100 per cent for all the three dates of planting whereas the lowest maximum relative humidity in the open field condition was 85.3 per cent for the first and second date of transplanting on 1 and 15 May 2016 and 85.4 per cent for 30 May 2016 (Fig10).

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4.4.4.2 Climate controlled greenhouse

The highest maximum relative humidity recorded inside the climate controlled greenhouse for the different dates of transplanting namely 1 May 2016 was 66.3 per cent and 15 and 30 May 2016 was 61.6 per cent. The lowest maximum relative humidity recorded inside the climate controlled greenhouse was 60.1 per cent for all the three different dates of transplanting namely 1 May 2016, 15 May 2016 and 30 May 2016 (Fig 10).

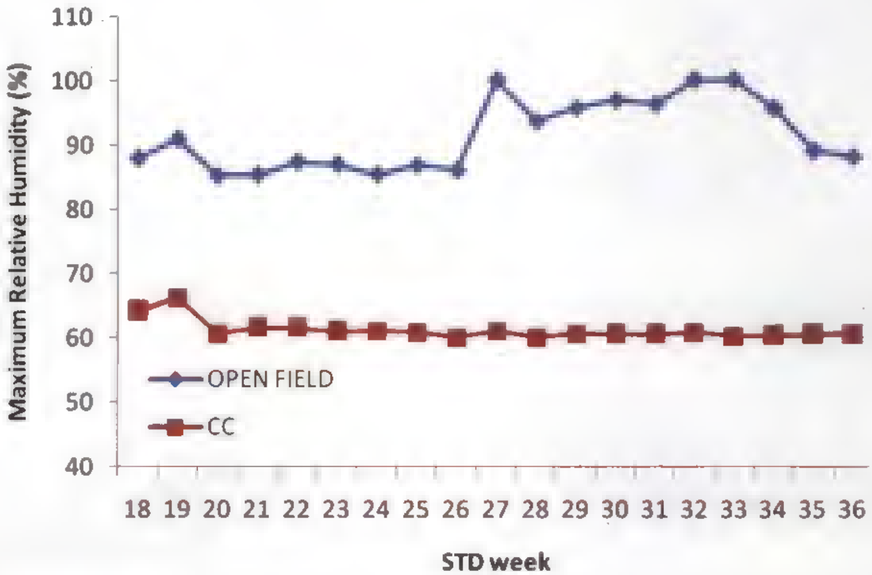

Fig 10. Weekly maximum relative humidity

4.4.5 Minimum relative humidity (percentage)

4.4.5.1. Open field

The highest minimum relative humidity documented for all the dates of planting namely 1, 15 and 30 May 2016 were 71 per cent. The lowest values of minimum relative humidity were 46.3 per cent for the three consecutive dates of transplanting (Fig.11).

4.4.5.2. Climate controlled greenhouse

The highest minimum relative humidity inside the climate controlled greenhouse was 55.9 per cent for first and second dates of transplanting namely 1 May 2016 and 15 May 2016 and 56.4 per cent for third dates of planting (30 May

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2016) whereas, the lowest minimum relative humidity was 37.6 per cent for the first, second and third dates of transplanting (Fig 11).

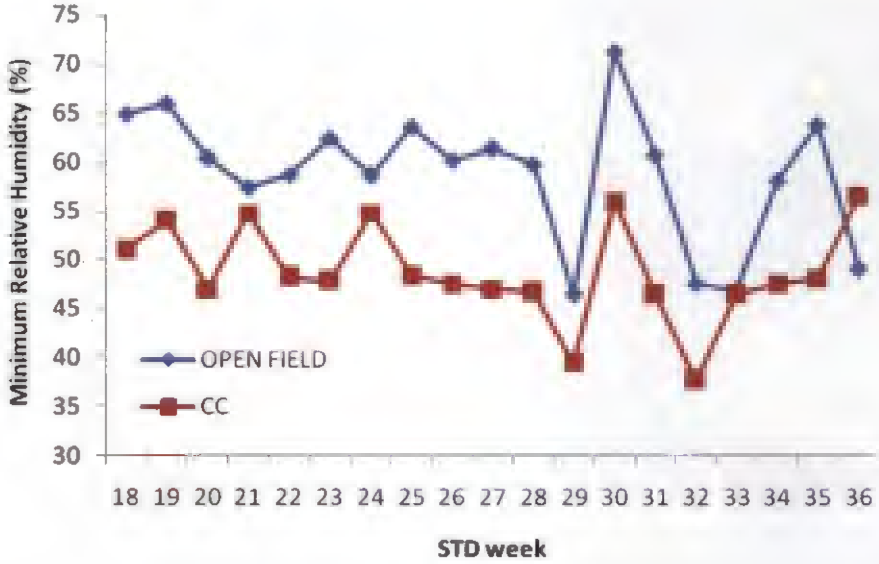

Fig 11. Weekly minimum relative humidity

4.4.6 Maximum soil temperature (°C)

4.4.6.1 Open field

The highest maximum soil temperature for the first date of transplanting (1 May 2016) was 41.3°C while it was 38.2°C during the second and third dates of transplanting (15 and 30 May 2016). The lowest value of maximum soil temperature was 31.6°C for all the three dates of transplanting (Fig. 12).

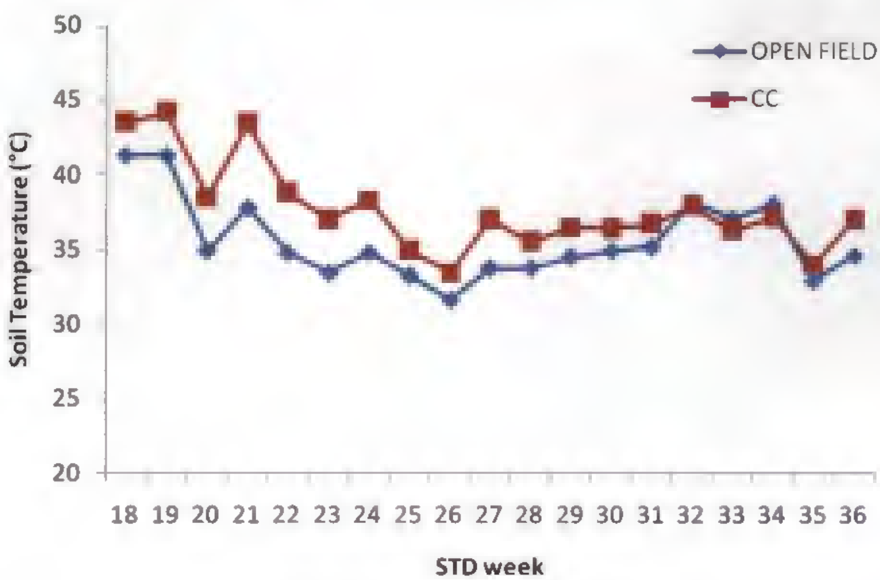

Fig 12. Weekly maximum soil temperature

4.4.6.2 Climate controlled greenhouse

The peak value of maximum soil temperature during the first date of transplanting (1 May 2016) crop season was 44.2°C and during the second and third dates of transplanting (15 and 30 May 2016) were 43.4°C and 38.8°C respectively. The lowest maximum soil temperature was 33.4°C for all the three dates of planting (Fig. 12).

4.4.7 Minimum soil temperature (°C)

4.4.7.1 Open field

The highest minimum soil temperature recorded in the open field during the first date of transplanting namely 1 May 2016 was 32.9°C and 27.1°C during the second and third date of transplanting (15 and 30 May 2016). While, the lowest value of minimum soil temperature recorded was 19.2°C for all the three dates of transplanting (Fig. 13).

4.4.7.2 Climate controlled greenhouse

The highest minimum soil temperature recorded inside the climate controlled greenhouse during the three dates of transplanting namely 1 May 2016, 15 May 2016 and 30 May 2016 was 35.2°C, 30.9°C and 27.5°C respectively. While, the lowest minimum soil temperature obtained was 21.4°C for all the three dates of transplanting (Fig. 13).

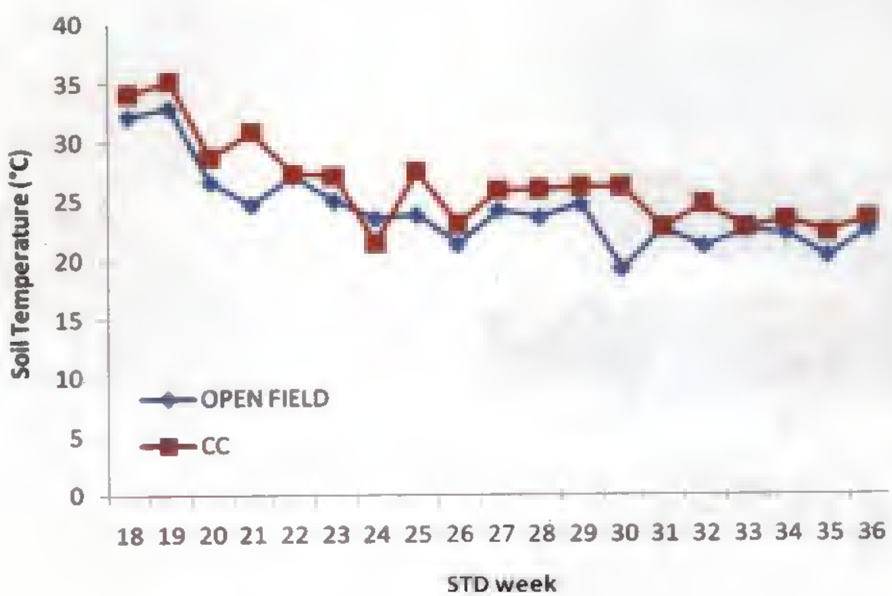

Fig 13. Weekly minimum soil temperature

4.5 CROP WEATHER RELATIONSHIPS

Simple linear correlations between important phenological and yield and mean weekly weather parameters like maximum solar radiation, average solar radiation, maximum temperature, minimum temperature, mean temperature, maximum relative humidity, minimum relative humidity mean relative humidity and maximum soil temperature, minimum soil temperature and mean soil temperature were carried out.

4.5.1 IMPACT OF WEATHER PARAMETERS ON YIELD

4.5.1.1 Fertilizer application as per POP

4.5.1.1.1 Vegetative stage

Grain yield had a positive correlation with maximum and average solar radiation during vegetative state (0.81, 0.58) whereas maximum, minimum and mean temperature showed a negative correlation with grain yield (-0.76, -0.73, -0.72). Relative humidity (maximum, minimum and mean) positively correlated with grain yield (0.84, 0.86, 0.79). Soil temperature had no correlation with grain yield during vegetative stage (Table 17).

Table 17. Correlation of weather and yield fertilizer given as per PoP

Weather parameters	Vegetative stage	Reproductive stage	Ripening stage
MAX Solar radiation	0.81*	-0.55*	-0.71*
AVG Solar radiation	0.58*	-0.59*	-0.84*
MAX Temperature	-0.76*	-0.85*	-0.80*
MIN Temperature	-0.73*	-0.88*	-0.69*
AVG Temperature	-0.72*	-0.87*	-0.79*
MAX Relative Humidity	0.84*	0.77*	0.81*
MIN Relative Humidity	0.86*	0.84*	0.91*
AVG Relative Humidity	0.79*	0.64*	0.89*
MAX Soil Temperature	-0.22	-0.88*	-0.62*
MIN Soil Temperature	0.07	-0.75*	-0.52*
AVG Soil Temperature	-0.19	-0.87*	-0.78*

4.5.1.1.2 Reproductive stage

Correlation between grain yield and different weather parameters during reproductive stage was found out and is presented in the Table 17. Maximum and average solar radiation during reproductive stage showed a negative correlation with grain yield (-0.55, -0.59). Maximum, minimum and mean temperature during reproductive stage exhibited a negative correlation with grain yield (-0.85, -0.88, -0.87). Relative humidity (maximum, minimum and mean) positively correlated with grain yield (0.77, 0.84, 0.64) whereas soil temperature (maximum, minimum and mean) negatively correlated with grain yield (-0.88, -0.75, -0.87).

4.5.1.1.3 Ripening stage

Maximum and average solar radiation had a negative correlation with grain yield during ripening stage (-0.71, -0.84). Maximum, minimum and mean temperature during ripening stage had showed a negative correlation with grain yield (-0.80, -0.69, -0.79). Maximum, minimum and mean relative humidity during ripening stage exhibit a strong positive correlation with grain yield (0.81, 0.91, 0.89). Maximum, minimum and mean soil temperature negatively correlated with grain yield (-0.62, -0.52, -0.78) (Table 17).

Generally grain yield of crops grown as per POP recommendations were highly dependable on weather parameters.

4.5.1.2 Fertilizer application basal as per POP along with Folia application

4.5.1.2.1 Vegetative stage

Correlation between grain yield and various weather parameters are provided in the Table 18. Grain yield was positively correlated with maximum and average solar radiation during vegetative stage (0.74, 0.51) whereas maximum, minimum and mean temperature during vegetative stage had showed a negative correlation with grain yield (-0.75, -0.74, -0.71). Relative humidity (maximum, minimum and mean) positively correlated with grain yield (0.82, 0.84, 0.78). During vegetative stage soil temperature had no correlation with grain yield.

4.5.1.2.2 Reproductive stage

Maximum and average solar radiation had showed a negative correlation with grain yield during reproductive stage (-0.51, -0.52). Maximum, minimum and mean temperature exhibited a negative correlation with grain yield (-0.83, -0.85, -0.85) during reproductive stage. Relative humidity (maximum, minimum and mean) positively correlated with grain yield (0.77, 0.83, 0.63) whereas soil temperature (maximum, minimum and mean) negatively correlated with grain yield (-0.82, -0.76, -0.82) during reproductive stage (Table 18).

Table 18. Correlation of weather and yield fertilizer given as per PoP as basal and Foliar fertilizers

Weather parameters	Vegetative stage	Reproductive stage	Ripening stage
MAX Solar radiation	0.74*	-0.51*	-0.70*
AVG Solar radiation	0.51*	-0.52*	-0.82*
MAX Temperature	-0.75*	-0.83*	-0.79*
MIN Temperature	-0.74*	-0.85*	-0.68*
AVG Temperature	-0.71*	-0.85*	-0.77*
MAX Relative Humidity	0.82*	0.77*	0.79*
MIN Relative Humidity	0.84*	0.83*	0.86*
AVG Relative Humidity	0.78*	0.63*	0.86*
MAX Soil Temperature	-0.26	-0.82*	-0.56*
MIN Soil Temperature	0.04	-0.76*	-0.52*
AVG Soil Temperature	-0.22	-0.82*	-0.77*

4.5.1.2.3 Ripening stage

Grain yield had a negative correlation with maximum and average solar radiation during ripening stage (-0.70, -0.82). Maximum, minimum and mean temperature has got significant negative correlation with grain yield (-0.79, -0.68, -0.77). Maximum, minimum and mean relative humidity exhibit a positive correlation with grain yield (0.79, 0.86, 0.86) whereas maximum, minimum and mean soil temperature negatively correlated with grain yield (-0.56, -0.52, -0.77) during ripening stage (Table 18).

Generally grain yield of crops grown basal as per POP recommendations along with foliar application were highly dependable on weather parameters.

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4.5.1.3 Fertilizer application on the basis of Soil test results along with foliar application and silica

4.5.1.3.1 Vegetative stage

Correlation between grain yield and different weather parameters during vegetative stage has found out and presented in the Table 19. Grain yield had a positive correlation with maximum and average solar radiation during vegetative stage (0.83, 0.67). Maximum, minimum and mean temperature had negatively influenced the grain yield (-0.62, -0.58, -0.57). Relative humidity (maximum, minimum and mean) was positively correlated with grain yield (0.71, 0.74, 0.65). Soil temperature had no correlation with grain yield.

4.5.1.3.2 Reproductive stage

Grain yield had a negative correlation with maximum and average solar radiation during reproductive stage (-0.52, -0.57) whereas maximum, minimum and mean temperature had a negative correlation with grain yield (-0.73, -0.76, -0.75). Relative humidity (maximum, minimum and mean) positively correlated with grain yield (0.63, 0.74, 0.52) whereas soil temperature (maximum, minimum and mean) negatively correlated with grain yield (-0.77, -0.62, -0.75) (Table 19).

4.5.1.3.3 Ripening stage

Maximum and average solar radiation during ripening stage showed a negative correlation with grain yield (-0.59, -0.75). Grain yield exhibited negative correlation with maximum, minimum and mean temperature (-0.68, -0.54, -0.66). Relative humidity (maximum, minimum and mean) had a positive correlation with grain yield (0.68, 0.82, 0.78). Maximum and mean soil temperature had a negative correlation with grain yield (-0.68, -0.69) (Table 19).

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Table 19. Correlation of weather and yield fertilizer given as per soil test results through foliar fertilizers with Silica

Weather parameters	Vegetative stage	Reproductive stage	Ripening stage
MAX Solar radiation	0.83*	-0.52*	-0.59*
AVG Solar radiation	0.67*	-0.57*	-0.75*
MAX Temperature	-0.62*	-0.73*	-0.68*
MIN Temperature	-0.58*	-0.76*	-0.54*
AVG Temperature	-0.57*	-0.75*	-0.66*
MAX Relative Humidity	0.71*	0.63*	0.68*
MIN Relative Humidity	0.74*	0.74*	0.82*
AVG Relative Humidity	0.65*	0.52*	0.78*
MAX Soil Temperature	-0.07	-0.77*	-0.68*
MIN Soil Temperature	0.21	-0.62*	-0.37
AVG Soil Temperature	-0.03	-0.75*	-0.69*

4.5.1.4 Fertilizer application on the basis of Soil test results along with foliar application, silica and micronutrients

4.5.1.4.1 Vegetative stage

All the important weather parameters had no correlation with grain yield during vegetative stage. Grain yield of crops grown as per soil test results along with foliar application, silica and micronutrients were not influenced by all the weather parameters during the vegetative period of the crop (Table 20).

4.5.1.4.2 Reproductive stage

Average relative humidity exhibited positive correlation with grain yield (0.46). Rest of the weather parameters had no correlation with grain yield (Table 20).

4.5.1.4.3 Ripening stage

Grain yield had a negative correlation with average solar radiation (-0.46). Maximum and average soil temperature was negatively correlated with grain yield during ripening stage (-0.64, -0.49) (Table 20).

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Table 20. Correlation of weather and yield fertilizer given as per soil test results through foliar fertilizers with Silica and Micronutrients

Weather parameters	Vegetative stage	Reproductive stage	Ripening stage
MAX Solar radiation	0.41	0.33	-0.42
AVG Solar radiation	0.37	0.23	-0.46*
MAX Temperature	-0.29	-0.27	-0.35
MIN Temperature	-0.19	-0.27	-0.30
AVG Temperature	-0.26	-0.27	-0.32
MAX Relative Humidity	0.30	0.22	0.30
MIN Relative Humidity	0.27	0.33	0.40
AVG Relative Humidity	0.24	0.46*	0.16
MAX Soil Temperature	-0.16	-0.34	-0.64*
MIN Soil Temperature	-0.04	-0.18	-0.32
AVG Soil Temperature	-0.13	-0.35	-0.49*

Changes in fertilizer use, soil test based fertilizer recommendation, application of micronutrients and additional inputs like silica reduced the weather dependency in rice production.

4.5.2 IMPACT OF WEATHER PARAMETERS ON 50% FLOWERING

4.5.2.1 Fertilizer application as per POP

Correlation between different weather parameters and duration from planting to 50% flowering was done and presented in Table 21. Generally maximum and average solar radiation was negatively correlated with days taken for 50% flowering whereas in week 3 average solar radiation showed a positive correlation with days taken for 50% flowering. Days taken for 50% flowering were positively influenced with maximum (week 2, week 3 and week 6), minimum (week 1 and week 7) and average (week 2, week 6 and week 8) temperature. Maximum, minimum and average relative humidity exhibited a negative correlation with days taken for 50% flowering. Maximum (week 3 and week 8) and average soil temperature (week 8) showed a positive correlation with days taken for 50% flowering whereas minimum soil temperature (week 5) showed a negative correlation.

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Table 21. Correlation of weather and days taken for 50% flowering fertilizer given as per POP

Weather parameters	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
MAX Solar radiation	-0.872*	-0.541*	0.373	-0.898*	-0.617*	-0.593*	-0.470*	-0.159
AVG Solar radiation	-0.832*	-0.620*	0.690*	-0.809*	-0.233	-0.281	-0.687*	-0.112
MAX Temperature	0.418	0.481*	0.446*	0.192	0.415	0.621*	0.321	0.418
MIN Temperature	0.610*	0.377	0.307	0.415	0.105	0.328	0.520*	0.415
AVG Temperature	0.390	0.440*	0.376	0.086	0.370	0.569*	0.389	0.489*
MAX Relative Humidity	-0.537*	-0.591*	-0.444*	-0.454*	-0.494*	-0.324	-0.395	-0.340
MIN Relative Humidity	-0.715*	-0.489*	-0.465*	-0.449*	-0.108	-0.457*	-0.609*	-0.614*
AVG Relative Humidity	-0.431*	-0.483*	-0.444*	-0.263	-0.460*	-0.441*	-0.467*	0.035
MAX Soil Temperature	-0.423	-0.064	0.494*	-0.313	0.136	0.164	-0.339	0.824*
MIN Soil Temperature	-0.557*	-0.330	-0.185	0.056	-0.850*	0.385	0.170	0.295
AVG Soil Temperature	-0.371	-0.089	0.282	-0.284	-0.156	0.279	-0.141	0.616*

4.5.2.2 Fertilizer application basal as per POP along with foliar application

As is apparent from the Table 22, generally maximum and average solar radiation was negatively correlated with days taken for 50% flowering whereas in week 3 average solar radiation showed a positive correlation with days taken for 50% flowering. Minimum and average temperature had no significance with days taken for 50% flowering whereas maximum temperature (week 2 and week 6) exhibited a positive correlation with day taken for 50% flowering. Minimum relative humidity (week 1 and week 3) and average relative humidity (week 6) showed negative correlation with days taken for 50% flowering. Maximum relative humidity had no significance with days taken for 50% flowering. Maximum (week 8) and average soil temperature (week 8) showed a positive correlation with days taken for 50% flowering whereas minimum soil temperature (week 5) showed a negative correlation.

Table 22. Correlation of weather and days taken for 50% flowering fertilizer given as per PoP as basal and foliar fertilizers

Weather parameters	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
MAX Solar radiation	-0.706*	-0.248	0.348	-0.667*	-0.307	-0.441*	-0.727*	-0.395
AVG Solar radiation	-0.645*	-0.350	0.627*	-0.616*	0.059	-0.014	-0.798*	-0.303
MAX Temperature	0.282	0.433*	0.308	0.000	0.337	0.473*	0.110	0.257
MIN Temperature	0.369	0.134	0.293	0.346	0.030	0.200	0.265	0.203
AVG Temperature	0.262	0.398	0.252	-0.048	0.263	0.382	0.152	0.282
MAX Relative Humidity	-0.370	-0.399	-0.293	-0.301	-0.322	-0.185	-0.245	-0.222
MIN Relative Humidity	-0.530*	-0.177	-0.465*	-0.310	0.133	-0.289	-0.409	-0.372
AVG Relative Humidity	-0.285	-0.290	-0.296	-0.160	-0.286	-0.490*	-0.297	0.010
MAX Soil Temperature	-0.358	0.102	0.364	-0.191	0.277	-0.064	-0.382	0.647*
MIN Soil Temperature	-0.373	-0.156	0.107	-0.026	-0.746*	0.398	-0.074	0.166
AVG Soil Temperature	-0.340	0.086	0.348	-0.210	-0.020	0.171	-0.296	0.512*

4.5.2.3 Fertilizer application on the basis of Soil test results along with foliar application and silica

Correlation between different weather parameters and duration from planting to 50% flowering has found out and presented in the Table 23. Maximum and average solar radiation was negatively correlated with days taken for 50% flowering whereas in week 3 average solar radiation showed a positive correlation with days taken for 50% flowering. Temperature (Maximum, minimum and mean) and Relative humidity (Maximum and mean) had no correlation with days taken for 50% flowering. Minimum relative humidity was negatively correlated with days taken for 50% flowering (week 1, week 7 and week 8). Soil temperature (Maximum, minimum and mean) has shown negative correlation with days taken for 50% flowering.

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Table 23. Correlation of weather and days taken for 50% flowering fertilizer given as per soil test results through foliar fertilizers with Silica

Weather parameters	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
MAX Solar radiation	-0.567*	-0.699*	0.296	-0.775*	-0.786*	-0.718*	-0.061	0.372
AVG Solar radiation	-0.683*	-0.756*	0.434*	-0.761*	-0.657*	-0.690*	-0.479*	0.465*
MAX Temperature	0.143	0.078	0.155	0.011	0.064	0.349	0.152	0.164
MIN Temperature	0.354	0.073	-0.130	0.150	-0.108	0.012	0.395	0.250
AVG Temperature	0.075	-0.025	0.065	-0.101	0.056	0.337	0.254	0.278
MAX Relative Humidity	-0.239	-0.310	-0.198	-0.190	-0.220	0.045	-0.069	-0.153
MIN Relative Humidity	-0.462*	-0.240	-0.075	-0.239	0.053	-0.245	-0.440*	-0.710*
AVG Relative Humidity	-0.130	-0.079	-0.195	-0.048	-0.173	-0.042	-0.241	0.297
MAX Soil Temperature	-0.535*	-0.497*	0.200	-0.538*	-0.387	0.062	-0.286	0.655*
MIN Soil Temperature	-0.646*	-0.506*	-0.632*	-0.268	-0.900*	0.087	0.564*	0.072
AVG Soil Temperature	-0.529	-0.492*	-0.175	-0.526*	-0.544*	0.071	-0.054	0.303

4.5.2.4 Fertilizer application on the basis of Soil test results along with foliar application, silica and micronutrients

It can be observed from Table 24, that maximum solar radiation exhibited positive correlation in week 3 and a negative correlation in week 7 with days taken for 50% flowering. Average solar radiation showed negative correlation with days taken for 50% flowering. Days taken for 50% flowering had a negative correlation with maximum temperature (except week 6), minimum temperature (except week 7) and average temperature. Maximum, minimum and mean relative humidity had a positive correlation with days taken for 50% flowering. Soil temperature (Maximum, minimum and mean) was negatively correlated with days taken for 50% flowering.

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Table 24. Correlation of weather and days taken for 50% flowering fertilizer given as per soil test results through foliar fertilizers with Silica and Micronutrients

Weather parameters	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
MAX Solar radiation	-0.297	-0.152	0.550*	-0.266	-0.191	-0.224	-0.478*	-0.127
AVG Solar radiation	-0.472*	-0.389	-0.035	-0.480*	-0.259	-0.149	-0.653*	0.220
MAX Temperature	-0.538*	-0.463*	-0.507*	-0.664*	-0.493*	-0.415	-0.572*	-0.493*
MIN Temperature	-0.447*	-0.655*	-0.627*	-0.562*	-0.644*	-0.576*	-0.412	-0.550*
AVG Temperature	-0.524*	-0.478*	-0.586*	-0.714*	-0.575*	-0.460*	-0.541*	-0.488*
MAX Relative Humidity	0.473*	0.419	0.497*	0.518*	0.482*	0.695*	0.622*	0.569*
MIN Relative Humidity	0.231	0.431*	0.262	0.596*	0.684*	0.472*	0.441*	-0.045
AVG Relative Humidity	0.534*	0.545*	0.502*	0.672*	0.533*	0.263	0.509*	0.320
MAX Soil Temperature	-0.743*	-0.578*	-0.475*	-0.541*	-0.432*	-0.563*	-0.533*	-0.118
MIN Soil Temperature	-0.506*	-0.571*	-0.114	-0.590*	-0.656*	-0.437*	-0.176	-0.358
AVG Soil Temperature	-0.804*	-0.569*	-0.518*	-0.611*	-0.538*	-0.508*	-0.546*	-0.227

4.5.3 IMPACT OF WEATHER PARAMETERS ON PHYSIOLOGICAL MATURITY

4.5.3.1 Fertilizer application as per POP

As is apparent from the Table 25, that initial weeks both maximum and average solar radiation had negative correlation with days taken for physiological maturity whereas both maximum and average solar radiation had a positive correlation with days taken for physiological maturity during last weeks. Maximum temperature (week 6 and week 9), minimum temperature (week 1, week 9 and week 10) and average temperature (week 9) had a positive correlation with days taken for physiological maturity. Maximum relative humidity (week 2) and minimum relative humidity (week 1-2, week 7-8, and week 10) was negatively correlated with days taken for physiological maturity. Average relative humidity showed a positive correlation in week 11 and a negative correlation in week 12 with days taken physiological maturity. Maximum and average soil temperature showed a negative correlation during initial weeks whereas they showed a positive correlation during last weeks. Minimum soil temperature had a negative correlation with days taken for physiological maturity.

4.5.3.2 Fertilizer application basal as per POP along with foliar application

Maximum and average solar radiation was negatively correlated with days taken for physiological maturity whereas they showed a positive correlation during last weeks (Week 10 and 11). Temperature (maximum, minimum and mean) and relative humidity (maximum and minimum) had no correlation with physiological maturity. Average relative humidity showed a positive correlation in week 11 and a negative correlation in week 12 with days taken physiological maturity. Maximum and average soil temperature showed a negative correlation during initial weeks whereas during last weeks it showed a positive correlation with days taken for physiological maturity (Table 26). Minimum soil temperature had a negative correlation with days taken for physiological maturity.

4.5.3.3 Fertilizer application on the basis of Soil test results along with foliar application and silica

It can be observed from Table 27, that during initial weeks both maximum and average solar radiation showed negative correlation with days taken for physiological maturity whereas both maximum and average solar radiation showed positive correlation with days taken for physiological maturity during last weeks. Temperature and maximum relative humidity had no correlation with days taken for physiological maturity. Minimum relative humidity (week 1 and week 8) and average relative humidity (week 12) had negative correlation with days taken for physiological maturity. Maximum and average soil temperature had a negative correlation during initial weeks whereas during last weeks it had a positive correlation. Minimum soil temperature was negatively correlated with days taken for physiological maturity.

4.5.3.4 Fertilizer application on the basis of Soil test results along with foliar application, silica and micronutrients

Correlation between various weather parameters and days taken for physiological maturity presented in the Table 28. Maximum and average solar radiation was negatively correlated with days taken for physiological maturity. Temperature showed negative correlation with days taken for physiological maturity whereas relative humidity showed positive correlation with days taken for physiological maturity. Maximum soil temperature minimum and average soil temperature was negatively correlated with days taken for physiological maturity.

Table 25. Correlation of weather and days taken for physiological maturity fertilizer given as per POP

WEATHER PARAMETERS	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6	WEEK 7	WEEK 8	WEEK 9	WEEK 10	WEEK 11	WEEK 12
MAX Solar radiation	-0.884*	-0.570*	0.566*	-0.952*	-0.694*	-0.512*	-0.345	0.003	0.496*	0.868*	0.627*	0.516*
AVG Solar radiation	-0.893*	-0.700*	0.714*	-0.938*	-0.452*	-0.369	-0.730*	0.038	0.559*	0.842*	0.774*	0.311
MAX Temperature	0.213	0.239	0.241	0.021	0.176	0.449*	0.162	0.222	0.468*	0.324	0.359	0.275
MIN Temperature	0.501*	0.255	0.066	0.203	-0.129	0.112	0.408	0.266	0.573*	0.427*	0.195	0.200
AVG Temperature	0.175	0.199	0.164	-0.113	0.148	0.414	0.255	0.332	0.506*	0.376	0.269	0.208
MAX Relative Humidity	-0.356	-0.431*	-0.247	-0.261	-0.312	-0.133	-0.202	-0.135	-0.145	-0.347	-0.198	-0.229
MIN Relative Humidity	-0.566*	-0.437*	-0.202	-0.303	0.023	-0.273	-0.503*	-0.566*	-0.019	-0.516*	-0.127	0.256
AVG Relative Humidity	-0.229	-0.329	-0.246	-0.060	-0.279	-0.163	-0.286	0.282	-0.015	-0.215	0.503*	-0.637*
MAX Soil Temperature	-0.640*	-0.328	0.287	-0.574*	-0.138	0.023	-0.517*	0.718*	0.866*	0.382	0.697*	0.615*
MIN Soil Temperature	-0.776*	-0.584*	-0.388	-0.171	-0.954*	0.122	0.290	0.090	0.434*	-0.090	-0.029	-0.831*
AVG Soil Temperature	-0.586*	-0.357	0.012	-0.539*	-0.432*	0.055	-0.280	0.405	0.791*	0.300	0.518*	0.739*

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Table 26. Correlation of weather and days taken for physiological maturity fertilizer given as per PoP as basal and foliar fertilizers

WEATHER PARAMETERS	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6	WEEK 7	WEEK 8	WEEK 9	WEEK 10	WEEK 11	WEEK 12
MAX Solar radiation	-0.656*	-0.203	0.473*	-0.656*	-0.298	-0.365	-0.690*	-0.298	0.040	0.514*	0.865*	0.422
AVG Solar radiation	-0.630*	-0.340	0.655*	-0.667*	-0.049	-0.040	-0.868*	-0.213	0.124	0.503*	0.885*	0.141
MAX Temperature	0.100	0.244	0.123	-0.178	0.140	0.325	-0.060	0.072	0.240	0.165	0.213	0.114
MIN Temperature	0.232	-0.028	0.111	0.195	-0.161	0.001	0.127	0.050	0.351	0.245	0.245	0.132
AVG Temperature	0.066	0.199	0.065	-0.230	0.073	0.233	0.001	0.121	0.305	0.245	0.184	0.081
MAX Relative Humidity	-0.198	-0.235	-0.115	-0.125	-0.145	-0.004	-0.066	-0.058	-0.046	-0.179	-0.075	-0.089
MIN Relative Humidity	-0.379	-0.039	-0.262	-0.196	0.307	-0.117	-0.308	-0.295	-0.076	-0.371	0.113	0.126
AVG Relative Humidity	-0.099	-0.111	-0.119	-0.002	-0.108	-0.295	-0.131	0.216	-0.361	0.252	0.731*	-0.436*
MAX Soil Temperature	-0.500*	-0.057	0.185	-0.368	0.093	-0.235	-0.529*	0.550*	0.530*	0.197	0.414	0.539*
MIN Soil Temperature	-0.493*	-0.292	-0.001	-0.243	-0.823*	0.224	0.006	-0.035	0.194	0.216	0.062	-0.626*
AVG Soil Temperature	-0.493*	-0.071	0.164	-0.397	-0.210	-0.019	-0.435*	0.328	0.476*	0.078	0.285	0.568*

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Table 27. Correlation of weather and days taken for physiological maturity fertilizer given as per soil test results through foliar fertilizers with Silica

WEATHER PARAMETERS	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6	WEEK 7	WEEK 8	WEEK 9	WEEK 10	WEEK 11	WEEK 12
MAX Solar radiation	-0.626*	-0.685*	0.390	-0.813*	-0.786*	-0.673*	-0.100	0.332	0.564*	0.761*	0.412	0.444
AVG Solar radiation	-0.740*	-0.772*	0.468*	-0.821*	-0.667*	-0.654*	-0.541*	0.429*	0.655*	0.646*	0.546*	0.621*
MAX Temperature	0.094	0.040	0.110	-0.042	0.019	0.311	0.103	0.118	0.350	0.189	0.252	0.165
MIN Temperature	0.335	0.054	-0.168	0.093	-0.177	-0.033	0.357	0.201	0.479*	0.290	-0.050	0.032
AVG Temperature	0.032	-0.051	0.019	-0.165	0.007	0.297	0.207	0.236	0.379	0.234	0.125	0.084
MAX Relative Humidity	-0.204	-0.280	-0.149	-0.144	-0.181	0.078	-0.030	-0.088	-0.021	-0.209	-0.058	-0.080
MIN Relative Humidity	-0.437*	-0.245	-0.038	-0.192	0.094	-0.195	-0.405	-0.674*	0.262	-0.139	-0.387	0.015
AVG Relative Humidity	-0.087	-0.069	-0.145	0.016	-0.134	0.000	-0.193	0.342	0.183	-0.210	0.368	-0.546*
MAX Soil Temperature	-0.613*	-0.537*	0.155	-0.603*	-0.410	0.012	-0.368	0.631*	0.835*	0.311	0.867*	0.714*
MIN Soil Temperature	-0.717*	-0.582*	-0.626*	-0.309	-0.940*	0.025	0.525*	0.027	0.123	-0.399	-0.019	-0.786*
AVG Soil Temperature	-0.601*	-0.537*	-0.214	-0.589*	-0.589*	0.009	-0.132	0.270	0.651*	0.324	0.571*	0.526*

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Table 28. Correlation of weather and days taken for physiological maturity fertilizer given as per soil test results through foliar fertilizers with Silica and Micronutrients

WEATHER PARAMETERS	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6	WEEK 7	WEEK 8	WEEK 9	WEEK 10	WEEK 11	WEEK 12
MAX Solar radiation	-0.531*	-0.247	0.765*	-0.500*	-0.340	-0.186	-0.443*	-0.100	-0.018	0.321	0.240	-0.236
AVG Solar radiation	-0.684*	-0.525*	0.177	-0.722*	-0.402	-0.179	-0.759*	0.181	0.084	0.499*	0.295	-0.044
MAX Temperature	-0.512*	-0.449*	-0.473*	-0.636*	-0.491*	-0.342	-0.527*	-0.463*	-0.331	-0.424	-0.384	-0.464*
MIN Temperature	-0.293	-0.504*	-0.614*	-0.560*	-0.709*	-0.554*	-0.316	-0.487*	-0.176	-0.354	-0.403	-0.510*
AVG Temperature	-0.500*	-0.448*	-0.557*	-0.735*	-0.560*	-0.376	-0.471*	-0.414*	-0.284	-0.377	-0.432*	-0.490
MAX Relative Humidity	0.399	0.322	0.470*	0.477*	0.421	0.617*	0.557*	0.584*	0.599*	0.364	0.543*	0.516*
MIN Relative Humidity	0.138	0.220	0.306	0.524*	0.620*	0.441*	0.325	-0.091	0.595*	0.107	0.220	0.491*
AVG Relative Humidity	0.491*	0.401	0.474*	0.679*	0.465*	0.334	0.463*	0.451*	0.158	0.387	0.516*	0.165
MAX Soil Temperature	-0.914*	-0.682*	-0.441*	-0.736*	-0.498*	-0.538*	-0.706*	-0.013	0.367	-0.185	0.496*	0.425
MIN Soil Temperature	-0.754*	-0.789*	-0.242	-0.619*	-0.805*	-0.510*	-0.099	-0.382	-0.343	-0.305	-0.644*	-0.738*
AVG Soil Temperature	-0.936*	-0.693*	-0.560*	-0.772*	-0.676*	-0.549*	-0.640*	-0.206	0.085	-0.184	-0.110	0.130

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4.6 MULTIPLE REGRESSION MODELS DEVELOPED

Stepwise regression analysis was carried out to select the critical variables, which contributed to yield and physiological maturity

4.6.1 Grain yield (kg/ha)

4.6.1.1 Fertilizer application as per POP

Grain yield (kg/ha) = 2533.964+87.957*RH_{min} (RIP) -11.259*SR_{avg}(REP) (R^2 = 0.85)

Where,

RH_{min} (RIP) = Minimum relative humidity during ripening stage

SR_{avg} (REP) = Average solar radiation during reproductive stage

4.6.1.2 Fertilizer application basal as per POP along with foliar application

Grain yield (kg/ha) = 322.868 + 95.17* RH_{min} (RIP) (R^2 =0.73)

Where,

RH_{min} (RIP) = Minimum relative humidity during ripening stage

4.6.1.3 Fertilizer application on the basis of Soil test results along with foliar application and silica

Grain yield (kg/ha) = 9760.34 +3.744*SR_{max} (VEG) –204.71*ST_{avg} (REP) (R^2 =0.73)

Where,

SR_{max} (VEG) = Maximum solar radiation during vegetative stage

ST_{avg}(REP) = Average soil temperature during reproductive stage

4.6.1.4 Fertilizer application on the basis of Soil test results along with foliar application, silica and micronutrients

Grain yield (kg/ha) =91.292+4.696*SR_{max}(REP) –5.03*SR_{max} (VEG) (R^2 = 0.57)

Where,

SR_{max} (REP) = Maximum solar radiation during reproductive stage

SR_{max} (VEG) = Maximum solar radiation during vegetative stage

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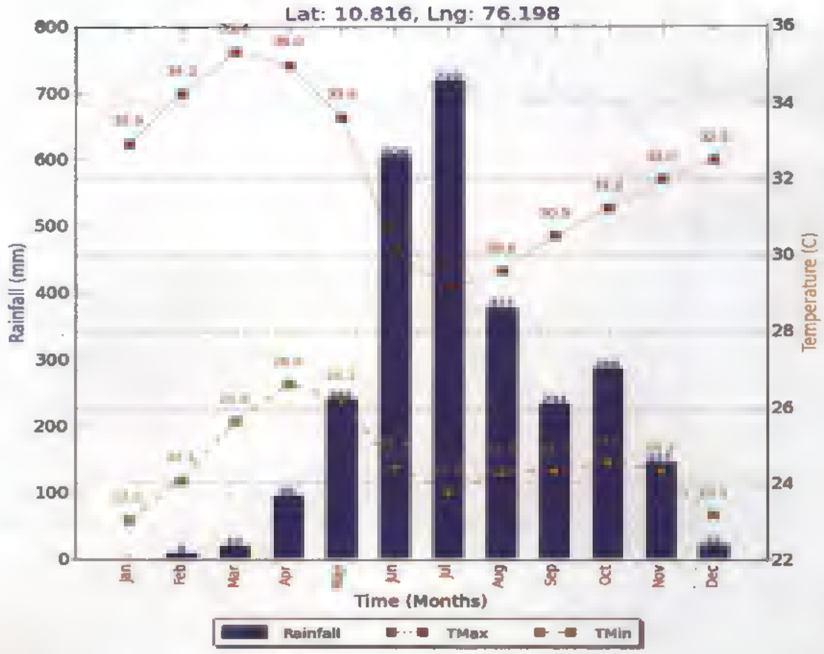

Fig 14. Climate of Pattambi in 2030s under RCP 2.6

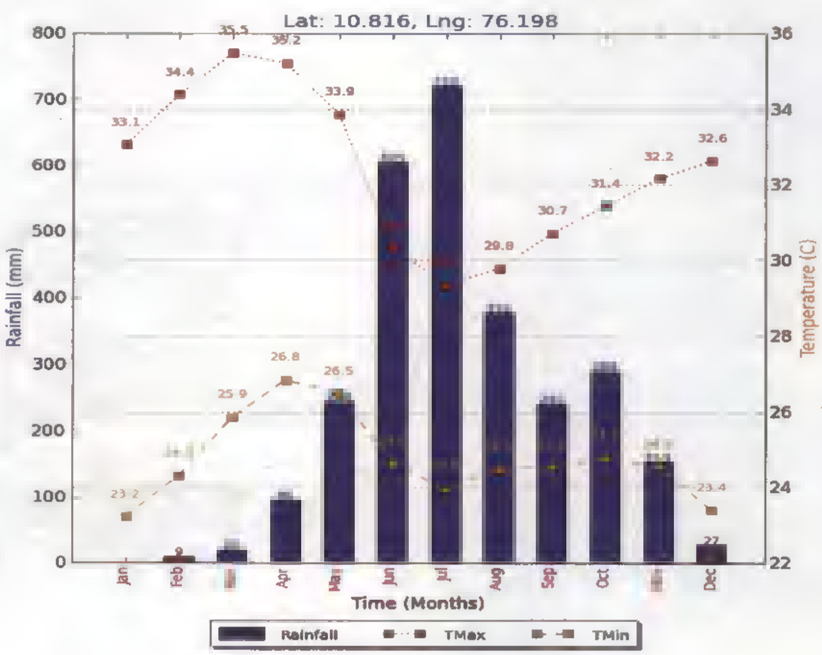

Fig 15. Climate of Pattambi in 2050s under RCP 2.6

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4.7 DSSAT MODEL VALIDATION

The Genetic coefficients of the rice varieties were worked out based on the past data generated as a part of various research programmes under KAU (Table 29).

Table 29. Genetic coefficients of varieties

Variety	Genetic coefficients							
	P1	P2R	P5	P20	G1	G2	G3	G4
Jyothi	680.0	164.0	450.0	13.0	45.0	0.0270	1.00	1.00
Kanchana	452.7	160.0	445.5	13.9	59.5	0.0230	1.30	1.10
Athira	741.0	55.0	270.0	10.8	44.0	0.0222	1.00	0.90
Vysakh	830.0	1.0	390.0	10.8	54.0	0.0290	1.00	1.00

The observed and simulated yields of rice varieties were presented in the Table 30. The observed and simulated yields of all the varieties were in good agreement.

Table 30. Observed and Predicted Yield (kg/ha.)

Variety	Observed Yield	Predicted Yield
Jyothi	6405	6421
Kanchana	6132	6064
Athira	5340	5280
Vysakh	5010	4963
Jaya	3194	3208

4.7 CLIMATE CHANGE IMPACT ON RICE PRODUCTION

The future climatic projections have taken from Ensemble of 17 General Circulation Models (GCMs). The future carbon dioxide concentrations and climate data has been incorporated into crop simulation model-DSSAT and predicted the future yield for the years 2030, 2050 and 2080. The climate data for the years 2030, 2050 and 2080 under different RCPs has been presented in the Figures 14 to 25.

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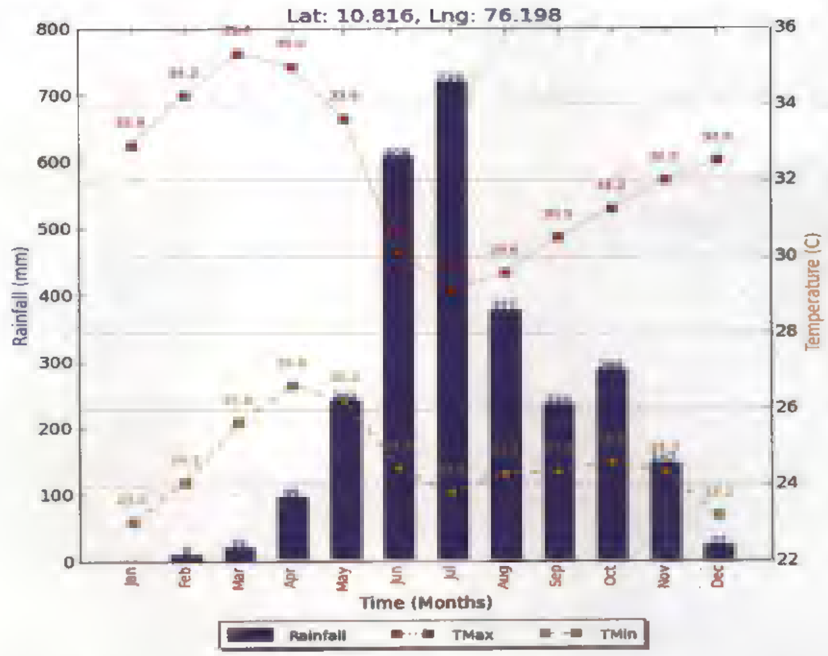

Fig 14. Climate of Pattambi in 2030s under RCP 2.6

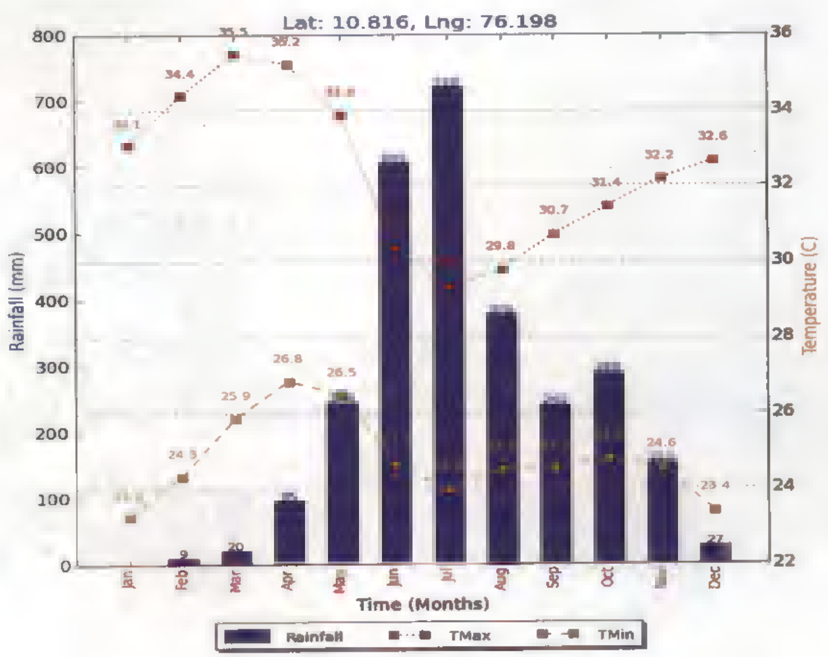

Fig 15. Climate of Pattambi in 2050s under RCP 2.6

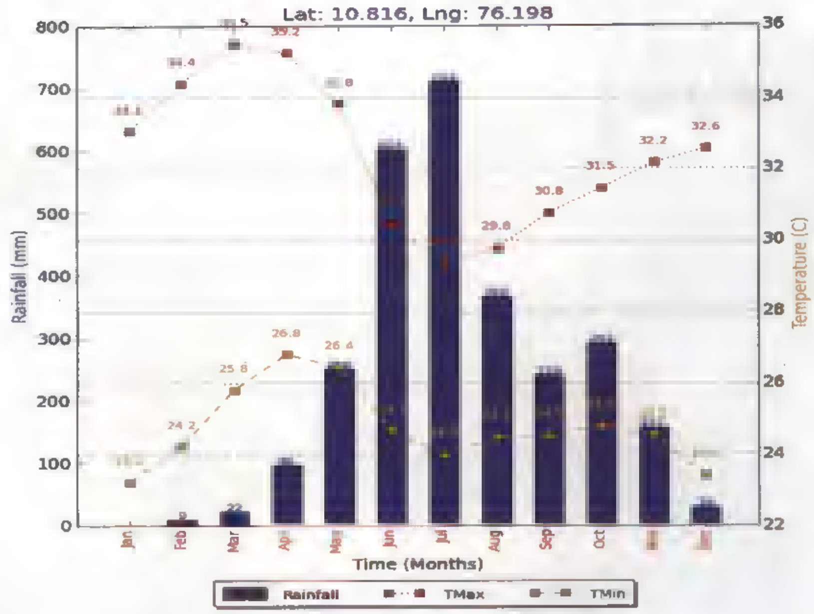

Fig 16. Climate of Pattambi in 2080s under RCP 2.6

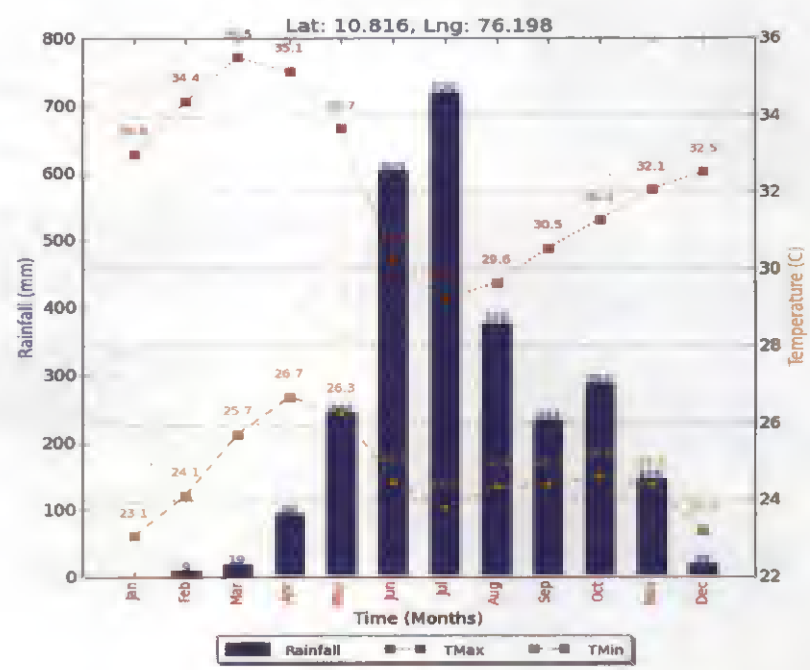

Fig 17. Climate of Pattambi in 2030s under RCP 4.5

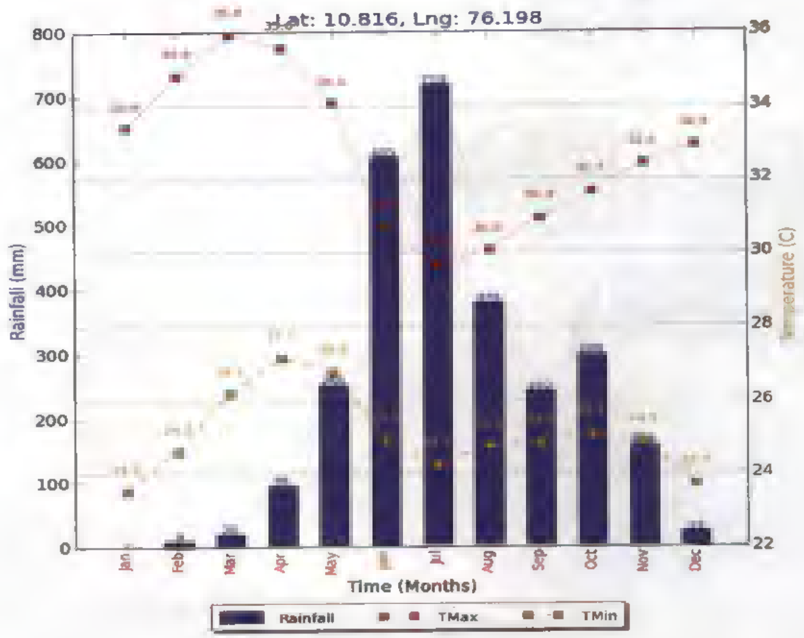

Fig 18. Climate of Pattambi in 2050s under RCP 4.5

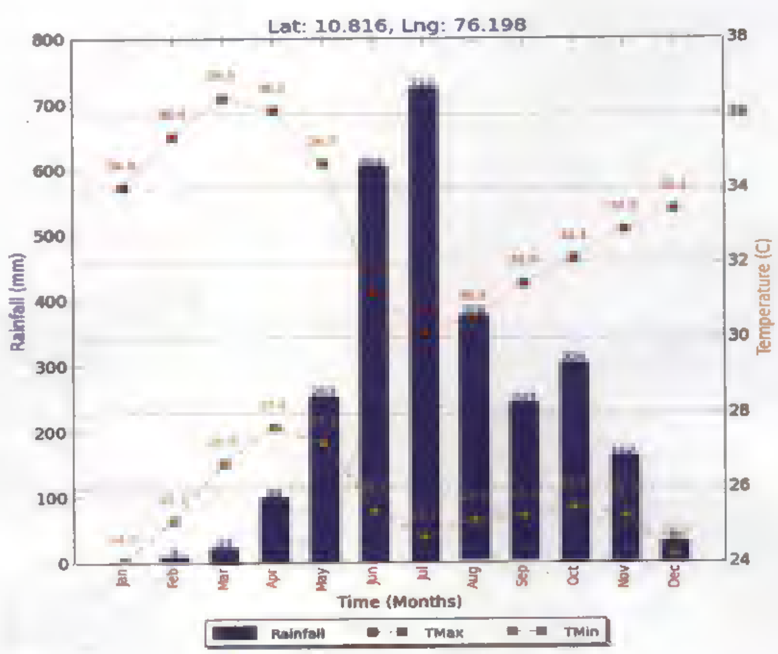

Fig 19. Climate of Pattambi in 2080s under RCP 4.5

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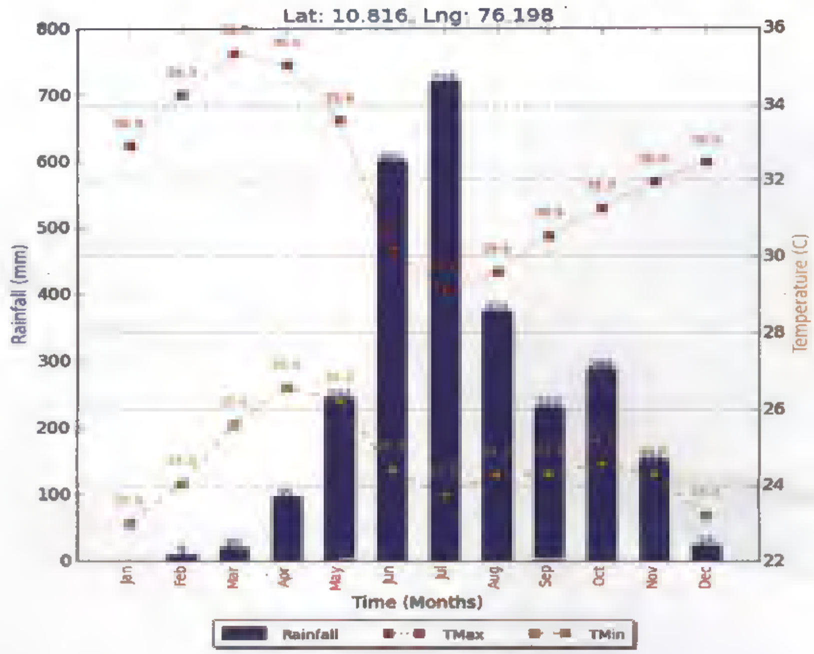

Fig 20. Climate of Pattambi in 2030 under RCP 6.0

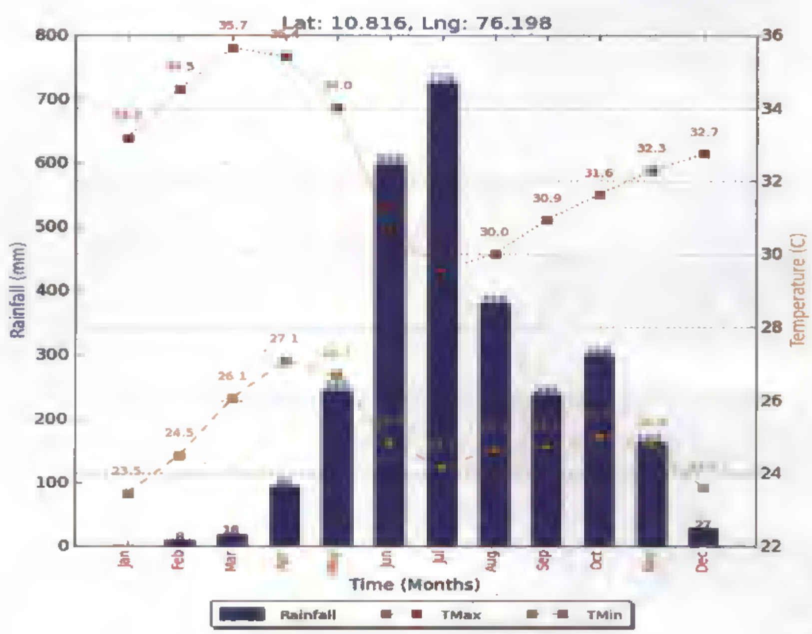

Fig 21. Climate of Pattambi in 2050s under RCP 6.0

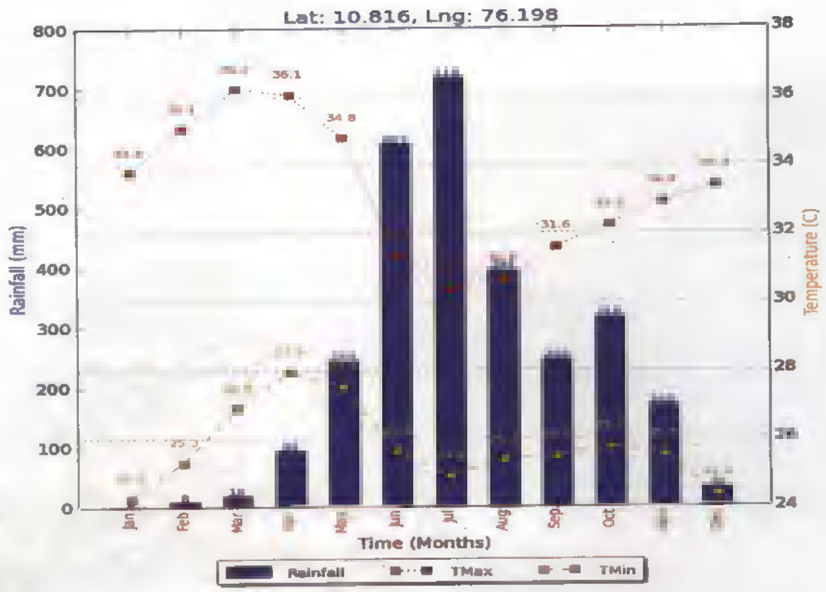

Fig 22. Climate of Pattambi in 2080s under RCP 6.0

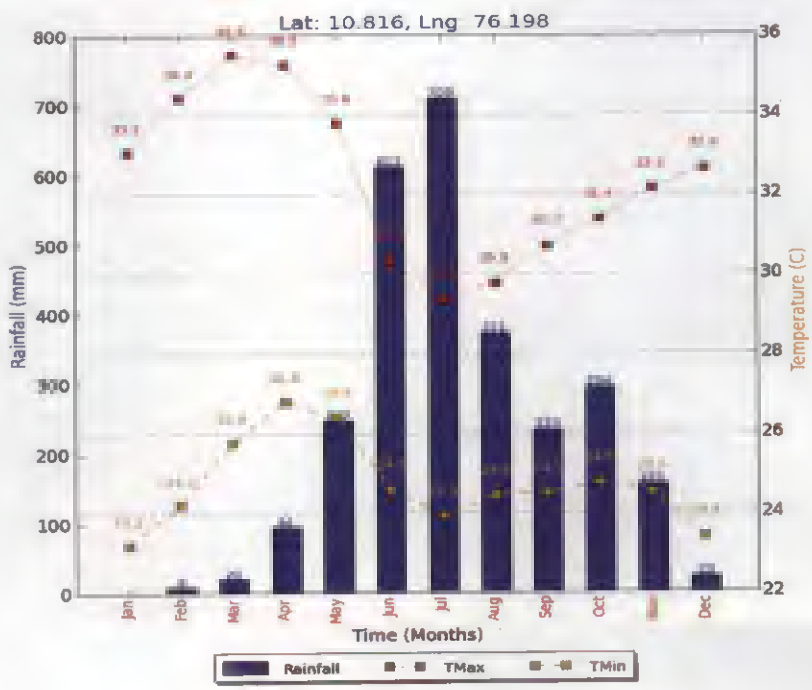

Fig 23. Climate of Pattambi in 2030s under RCP 8.5

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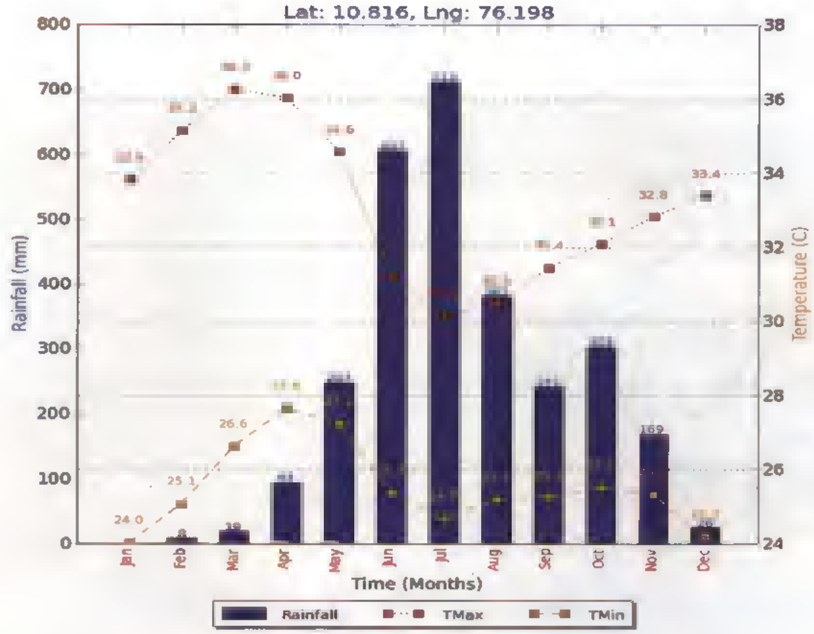

Fig 24. Climate of Pattambi in 2050s under RCP 8.5

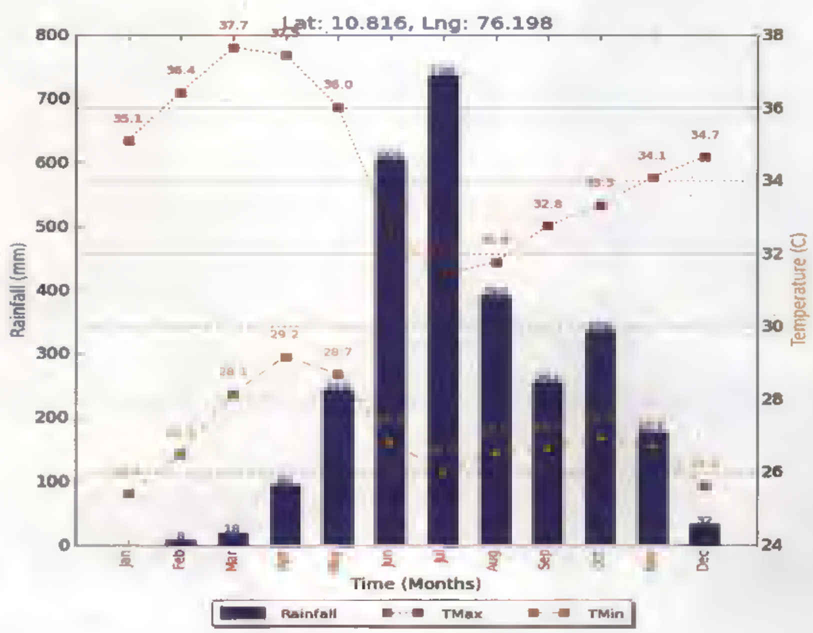

Fig 25. Climate of Pattambi in 2080s under RCP 8.5

4.8 SCREENING OF VARIETIES FOR HIGH TEMPERATURE STRESS TOLERANCE

High temperature stress tolerance of the popular varieties of Kerala ie., Jyothi, Kanchana, Athira, Vysakh and Jaya were worked out based on the past data generated as a part of various research programmes under KAU using DSSAT model and presented in Table 31.

Variety Jyothi showed a very slight decrease in yield when the temperature was increased by 1°C, 2°C and 5°C. Compared to other varieties Jyothi showed high tolerance to temperature stress. Varieties like Kanchana, Athira and Jaya had showed continuous decrease in yield to 1°C, 2°C and 5°C increase in temperature whereas variety Vysakh showed an increase in yield up to 2°C increase in temperature compared to the present condition. This is mainly because Vysakh is a drought tolerant variety in Kerala. But the yield was drastically reduced when the temperature was elevated to 5°C.

Table 31. Screening of varieties for high temperature stress tolerance

Variety	Dates of planting	Observed Yield (Kg/ha)	Predicted Yield (Kg/ha)	Increase in temperature		
				1°C	2°C	5°C
Jyothi	July 5 2013	6405	6421	5903	5834	5512
Kanchana	July 5 2014	6132	6064	4285	3942	2518
Athira	June 30 2014	5340	5280	4818	3091	2159
Vysakh	June 30 2015	5010	4963	5565	5186	3206
Jaya	June 30 2016	3194	3208	3093	2881	2431

4.9 ADJUSTING SOWING WINDOW FOR OPTIMIZING THE YIELD

Adjusting the planting time is considered one of the climate change adaptation strategy for improving the rice production. An attempt was made to quantify the impact of planting time on crop yield of variety Jyothi using DSSAT model and the results are given in the Table 32.

The observed and projected yield for the first crop season for the variety Jyothi showed more or less a continuous increase in yield starting from May 1st to

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August 1st. Crops planted on August 1st (6810 kg/ha) recorded the highest grain yield and the lowest was recorded during the May 15 planting (2212 kg/ha). During 2030, 2050 and 2080 showed a similar trend in the yield pattern corresponding to the above sowing periods. It is interesting to notice that the yields of crops planted during the month of May showing an increasing trend during 2030, 2050 and 2080 whereas the yields during the conventional sowing periods showed a declining trend. The yields of late planted crops will also going to increase as per the projected climate change scenarios, but it will prevent the possibility of second crop rice.

Table 32. Grain yield (kg/ha) in future by adjusting sowing window

Dates of planting	2013	2030	2050	2080
1-May	3070	4421	4093	4595
15-May	2212	3933	3834	4173
1-June	3515	4368	4219	4441
15-June	4945	4920	4877	4968
1-July	6010	5753	5836	5877
15-July	5976	6445	6029	6660
1-August	6810	6452	6336	6528

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This study was taken up to analyse the effect of different dates of planting, fertilizer treatments and different growing environment namely open field and climate controlled greenhouse on growth and yield of rice in variety Jyothi. The results presented in the previous chapter are discussed here.

5.1 BIOMETRIC OBSERVATIONS

5.1.1 Plant Height

Crop transplanted on 1st May 2016 inside the climate controlled greenhouse and fertilizer applied as per POP recommendations recorded the highest plant height of 116.7 cm. Generally plants grown inside the climate controlled greenhouse showed maximum plant height. Lowest maximum plant height (69.0 cm) was recorded by the crops grown in open field conditions transplanted on 15th May 2016 and fertilizer given as per soil test results, foliar application (19:19:19 NPK 5g at 15 days interval) silica (1g per pot) and micronutrients. So it can be inferred from the study that high solar radiation in terms had an inverse relationship with the vegetative vigour. Lower light intensities inside the climate controlled greenhouse retard the destruction of auxin (IAA) and thus promote cell division and cell expansion in the apical portion and hence plants have greater heights. Similar results have been noted by El-Aidy *et al.* (1988), and Abou Habid *et al.* (1994).

5.1.2 Leaf area Index

The dates of planting and fertilizer application had a significant effect on leaf area index under the two different growing environments. The maximum leaf area index (2.79) recorded by the crops grown in open field transplanted on 30th May 2016 and fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot). The lowest maximum leaf area index (2.37) was recorded by the crops grown in open field transplanted on 15th May 2016 and fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot). The lower LAI in the crops inside the climate controlled greenhouse may be due to high air temperature. Temperature is a principal environmental determinant of leaf appearance in rice. Similar results were reported by Gao *et al.*, 1992; Ritchie, 1993).

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5.1.3 Number of tillers

Number of tillers varied significantly with the treatment combinations. Generally crop grown in open field conditions recorded the maximum number of tillers per plant. Optimum temperature for tillering is 25-31 °C. The number of tillers was found to be lower in high-temperature conditions than in ambient conditions inside climate controlled green house. This is in agreement with the findings of Oh-e *et al.*, 2007.

5.1.4 Dry matter accumulation at harvest

The combined effect of weather and application of fertilizers showed significant variation in dry matter accumulation at harvest. Crops transplanted on 1st May 2016 has recorded highest dry matter accumulation (13093.3 kg/ha) grown in open field and their fertilizer treatments as per soil test result along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot). The lowest dry matter accumulation (8926.8 kg/ha) was recorded by the crops grown under climate controlled greenhouse transplanted on 30th May 2016 and fertilizer given as per POP recommendations. The dry matter of rice grain mainly originates from photosynthetic outcome. This is mainly due to high temperature at heading stage, usually over 35°C, often causes floret sterility, which results in yield reduction at maturing stage (Tang *et al*., 2005; Morita *et al*., 2005; Matsui *et al*., 2007; Guo *et al.*, 2000).

5.2 YIELD ATTRIBUTES

5.2.1 Number of panicles per plant

Number of panicles per plant varied significantly with treatment combinations. The maximum number of panicles recorded was 22.9 in crop grown inside the climate controlled greenhouse transplanted on 1st May 2016 and fertilizer application as per POP recommendation. The minimum number of panicles recorded was 7.4 in crops grown under climate controlled greenhouse transplanted on 30th May 2016 and fertilizer application as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval), silica (1g per pot) and micronutrients. This is because, panicle differentiation occurs generally at temperatures between 18 and 30 °C. During tillering stage, the number of panicles will increase if the air temperature is lower than 20.0°C (Yamamoto *et al.,* 1985). After the active tillering stage, high temperatures decrease the number of panicles, especially at maturity.

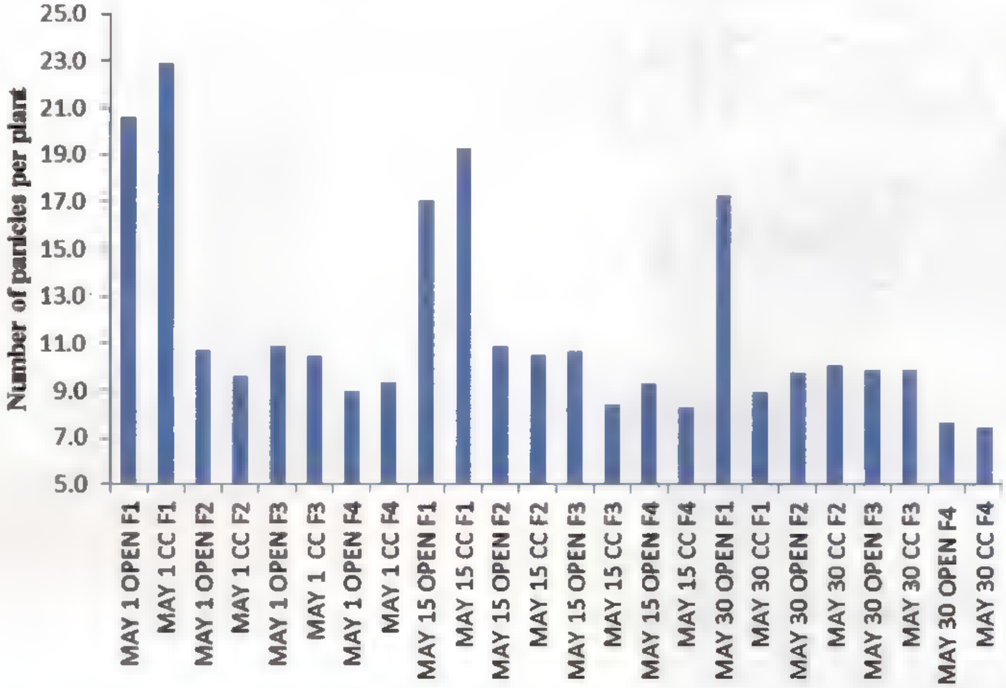

Fig. 26. Number of panicles per plant influenced by dates of planting, fertilizer treatment and growing environment

5.2.2 Number of spikelets per panicle

The dates of planting and fertilizer combination had no significant effect on number of spikelets per panicle under the two different growing environments. The maximum number of spikelets recorded was 13.3 by crops grown in open field transplanted on 1st May 2016 and fertilizer application given as basal dose as per POP and rest met by foliar application (19:19:19 NPK 5g at 15 days interval). The minimum number of spikelets recorded was 7.7 in crops grown under climate controlled greenhouse transplanted on 30th May 2016 and fertilizer application as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot). This is mainly due to the high maximum temperature during the reproductive period. This is in agreement with the findings of Yoshida (1978) and Kovi *et al.,* (2011).

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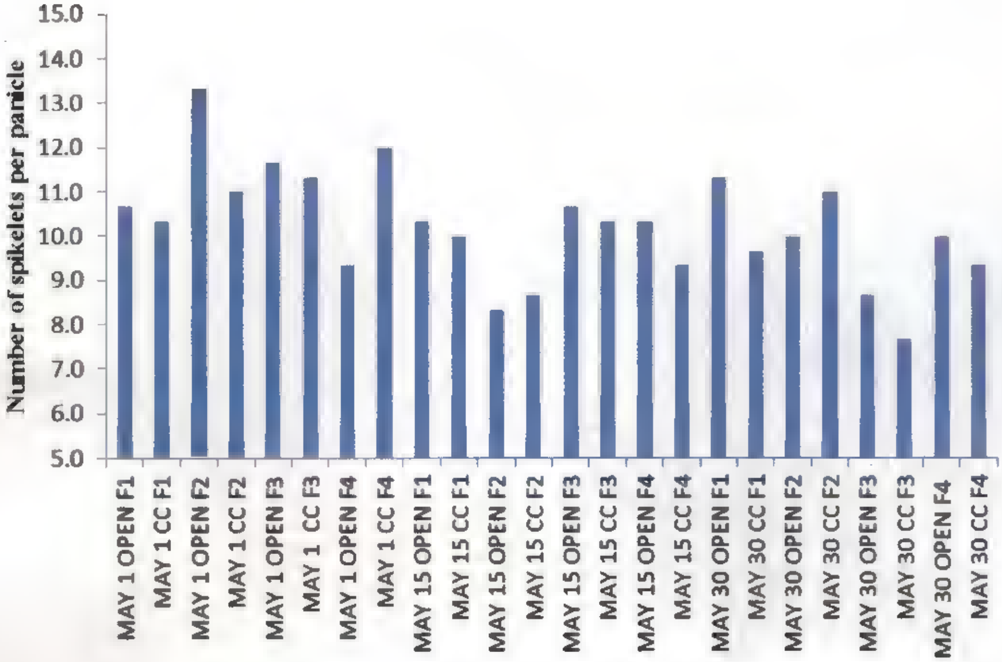

Fig. 27. Number of spikelets per panicle influenced by dates of planting, fertilizer treatment and growing environment

5.2.3 Number of filled grains per panicle

The combined effect of weather and fertilizer treatment had no significant effect on number of filled grains per panicle. The maximum number of filled grains (107) was recorded by the crops transplanted on 1st May 2016 in open field with fertilizer given basal as per POP along with foliar (19:19:19 NPK 5g at 15 days interval). The minimum number of filled grains (68) was recorded by the crops grown under climate controlled greenhouse transplanted on 30th May 2016 and fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot). High maximum temperature during the reproductive period might be the reason for lesser number of filled grains for crop inside climate controlled greenhouse. This is in agreement with the findings of Yoshida (1978) and Kovi *et al.,* (2011).

5.2.4 1000 Grain weight

The dates of planting and fertilizer combination had a significant effect in 1000 grain weight under the two growing environments. Crop transplanted on 1st May 2016 recorded highest 1000 grain weight (30.2 g) grown in open field as per POP recommendations. The lowest 1000 grain weight (22.2 g) was recorded by the crops planted on 30th May 2016 in open field and fertilizer given as per POP recommendations.

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In general crops grown in open field conditions recorded highest 1000 grain weight (26.9 g). This is in agreement with the finding of Newman *et al.*, 2001; Oh-e *et al.*, 2007; Ziska *et al.*, 1996). Kim *et al.* (1996) reported that the rate of increase in dry matter in the panicle after the heading decreased under high temperature.

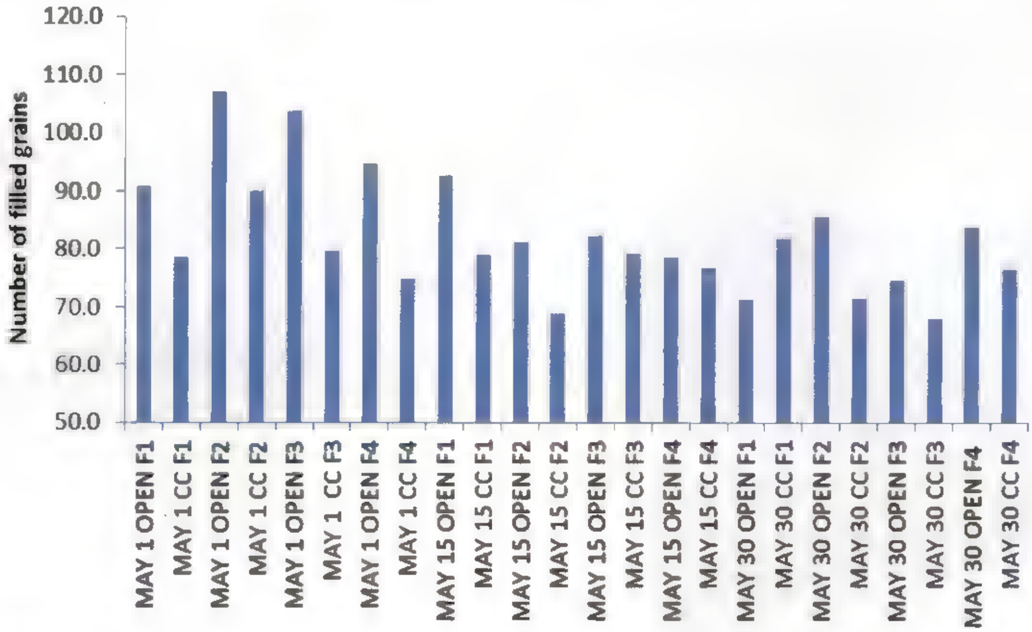

Fig. 28. Filled grains influenced by dates of planting, fertilizer treatment and growing environment

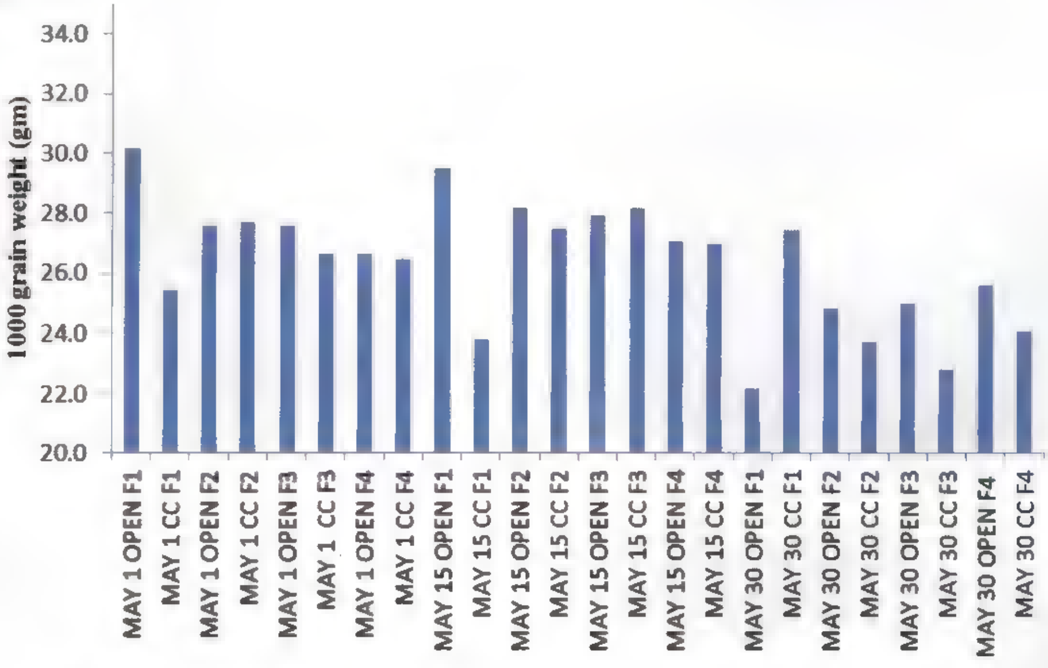

Fig. 29. 1000 grain weight influenced by dates of planting, fertilizer treatment and growing environment

5.2.5 Grain yield

The combined effect of weather and application of fertilizers showed significant variation in grain yield under the two growing environments. The highest grain yield (6324.0 kg/ha) was recorded by crop transplanted on 1st May 2016 in the open field fertilizer application as per soil test result along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot). Crops transplanted on 30th May 2016 inside the climate controlled greenhouse fertilizer given as per POP recommendation recorded the lowest grain yield (4152 kg/ha). Compared to the crops grown under climate controlled greenhouse, crops grown in open field has recorded highest grain yield (5488.8 kg/ha). This is mainly because of high temperatures at flowering and during grain-filling phase reduce yield by causing spikelet sterility and shortening the duration of grain-filling phase (Tian *et al.*, 2007; Xie *et al.*, 2009).

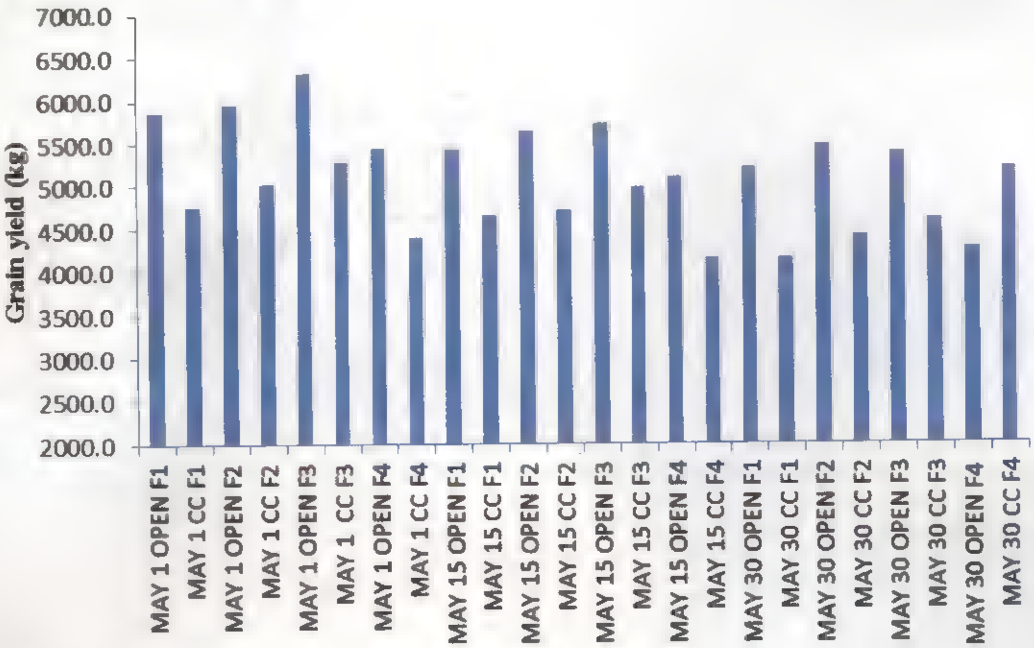

Fig. 30. Grain yield influenced by dates of planting, fertilizer treatment and growing environment

5.2.6 Straw yield

The combined effect of weather and application of fertilizers showed significant variation in straw yield under the two growing environments. Crops transplanted on 1st May 2016 in open field and fertilizer given as per soil test result along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot) has recorded highest straw yield (6769.3 kg/ha). Crops transplanted on 30th May

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2016 inside the climate controlled greenhouse fertilizer application as per POP recommendation recorded the lowest straw yield (4774.8 kg/ha).

5.3 PHENOLOGICAL OBSERVATIONS

5.3.1 Days taken for active tillering

The dates of planting and fertilizer combination had a significant effect on days taken for active tillering under the two different growing environments (Table 14). Crop transplanted on 15th May 2016 inside the climate controlled greenhouse fertilizer application as basal as per POP along with foliar application (19:19:19 NPK 5g at 15 days interval) and also fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot) required the maximum days to reach active tillering stage (44 days). Crops planted on 1st May 2016 in open field fertilizer application as per POP recommendations took minimum days for active tillering (30.7 days).

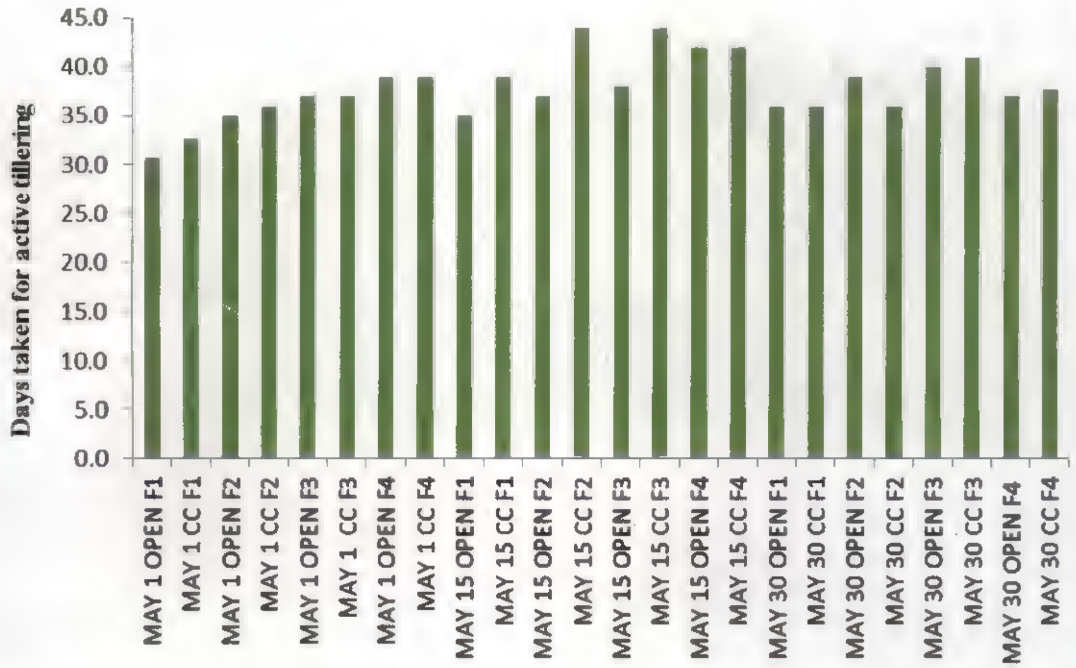

Fig. 31. Days taken for active tillering influenced by dates of planting, fertilizer treatment and growing environment

Compared to the crops grown in the open field, crops grown inside the climate controlled greenhouse took more number of days for active tillering (38.7 days). This may be due to high Carbon dioxide accumulation inside the climate controlled green

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house. Under elevated carbon dioxide levels increase in temperature delayed the onset of phenophases (Manalo *et al.*, 1994; Safia, 2015)

5.3.2 Days taken for panicle initiation

The dates of planting and fertilizer combination had a substantial effect on days taken for panicle initiation under the two different growing environments (Table 14). The days taken for panicle initiation was found to be highest (47 days) in the crop transplanted on 15th May 2016 inside the climate controlled greenhouse fertilizer given basal as per POP along with foliar application (19:19:19 NPK 5g at 15 days interval) and also fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot). The crop planted in the open field on 1st May 2016 took the least (35.7 days) number of days for panicle initiation fertilizer application as per POP recommendations.

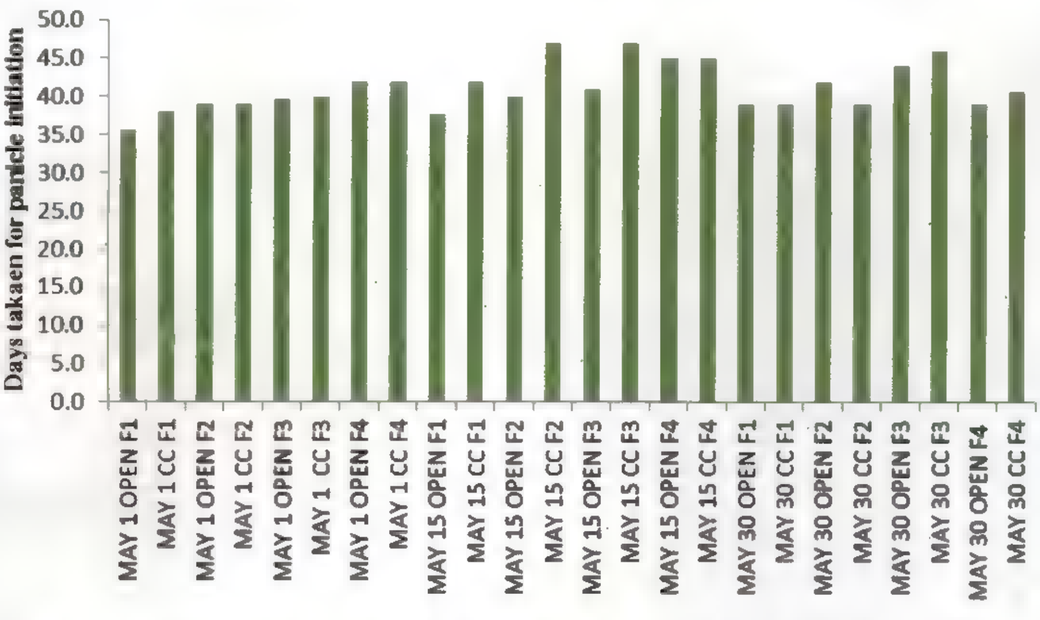

Fig. 32. Days taken for panicle initiation influenced by dates of planting, fertilizer treatment and growing environment

Considering the growing environment alone, crops grown inside the climate controlled greenhouse was recorded maximum days taken for panicle initiation (42.1 days). This is on par with the findings of Manalo *et al.* 1994; Safia, 2015.

5.3.3 Days taken for 50% flowering

The combined effect of weather and application of fertilizers showed significant variation in days taken for 50% flowering. Maximum days taken for 50% flowering (75.7 days) has recorded by crop transplanted on 30th May 2016 grown in open field and fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval), silica (1g per pot) and micronutrients. The crops planted on 1st May 2016 grown in open field fertilizer given as per POP recommendations took minimum days to reach 50% flowering (60.7 days).

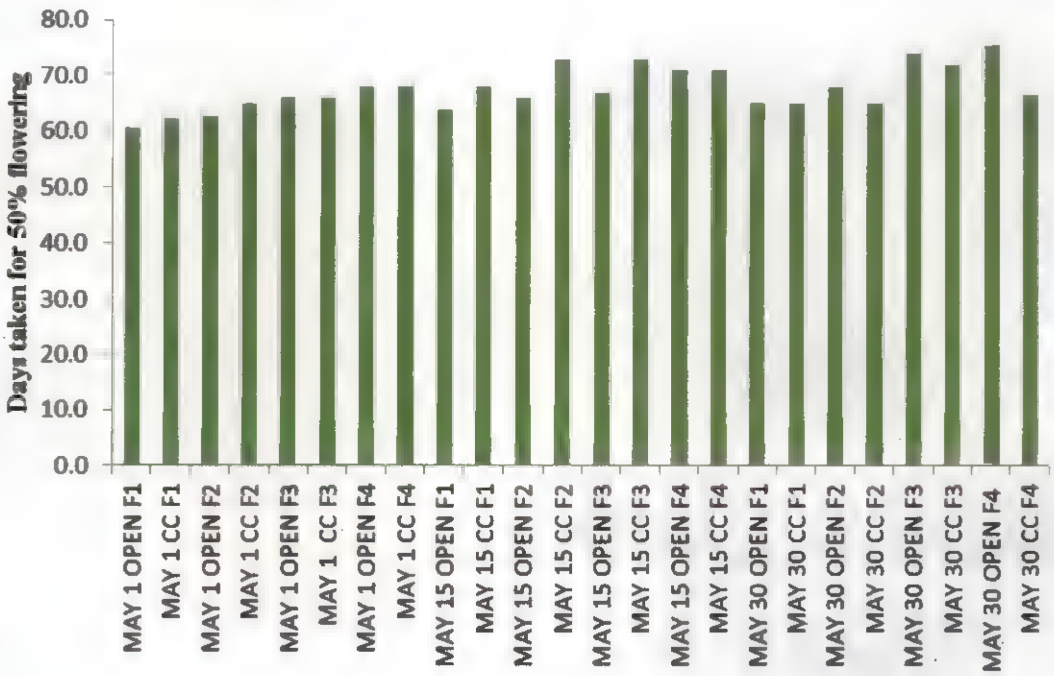

Fig. 33. Days taken for 50% flowering influenced by dates of planting, fertilizer treatment and growing environment

Considering the growing environment alone, crops grown inside the climate controlled greenhouse were showed the maximum days taken for 50% flowering (67.9 days). This is on par with the findings of Manalo *et al.,* 1994; Safia, 2015.

5.3.4 Days taken for physiological maturity

The effect of dates of planting and fertilizer combination had a significant effect on days taken for physiological maturity under the two different growing environments (Table 15). The crop transplanted in the open field on 30th May 2016 and fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot) took the maximum days for physiological maturity (104 days) while the crop transplanted on 1st May 2016 in the open field fertilized as per POP recommendations took the least number of days for physiological maturity (89.7 days).

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Considering the growing environment alone, crops grown inside the climate controlled greenhouse has taken maximum days for physiological maturity (97.6 days). This is on par with the findings of Manalo *et al.*, 1994; Safia, 2015.

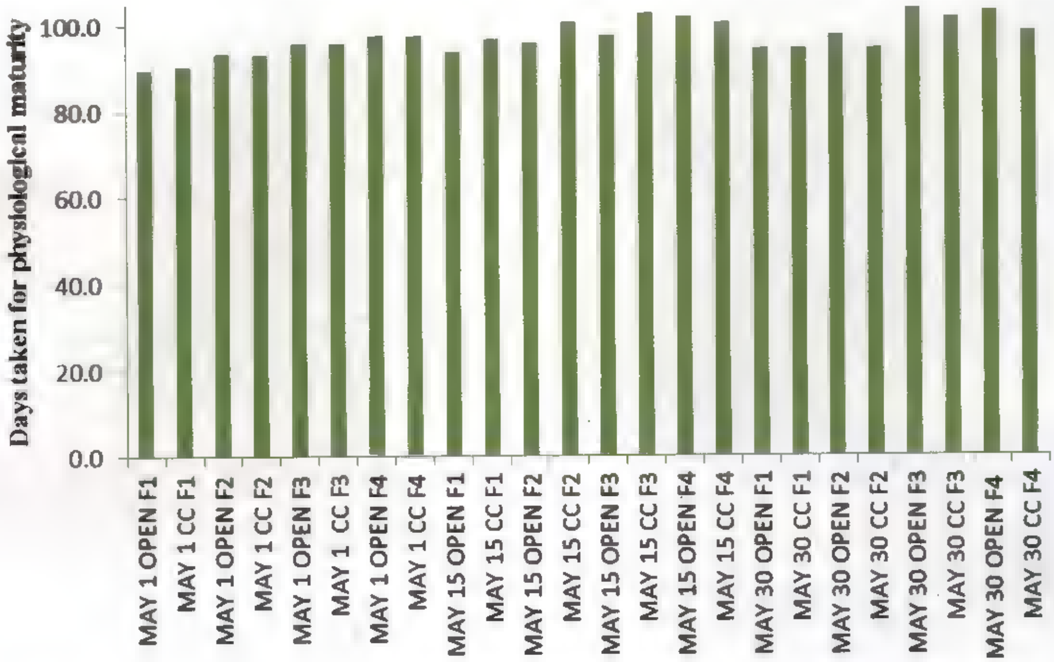

Fig. 34. Days taken for physiological maturity influenced by dates of planting, fertilizer treatment and growing environment

5.4 CROP WEATHER RELATIONSHIPS

5.4.1 IMPACT OF WEATHER PARAMETERS ON YIELD

5.4.1.1 Vegetative stage

Except the fertilizer treatment as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval), silica (1g per pot) and micronutrients, solar radiation showed a positive correlation with yield during vegetative stage in all the other fertilizer treatments (Figure 35, 36 and 37). Temperature was negatively correlated with yield during vegetative stage except the treatment soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval), silica (1g per pot) and micronutrients. Relative humidity had a positive correlation with yield except the treatment soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval), silica (1g per pot) and micronutrients. Soil temperature had no significance with yield during vegetative stage with all the fertilizer treatments. Grain yield was not affected by all the weather parameters during vegetative stage when fertilized as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval), silica (1g per pot) and micronutrients.

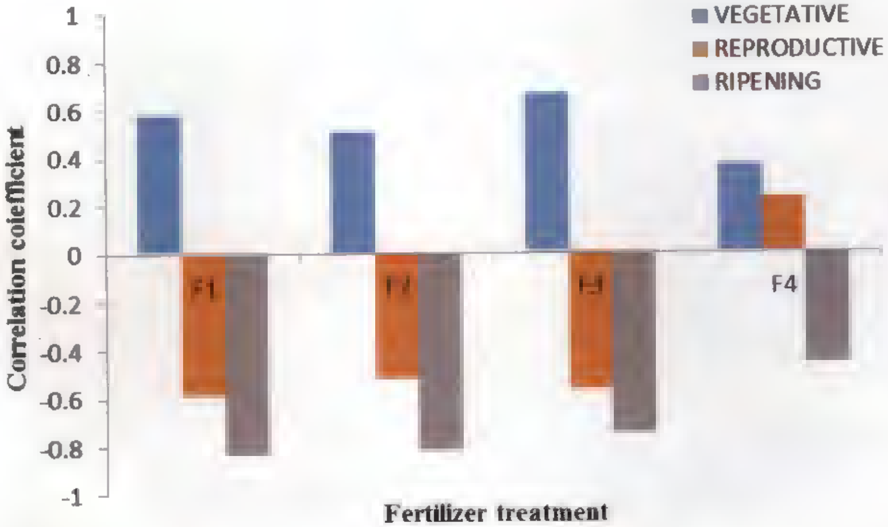

Fig. 35. Influence of Solar radiation with rice yield under different fertilizer treatments

5.4.1.2 Reproductive stage

Solar radiation was negatively correlated with grain yield during reproductive stage in all fertilizer treatments except the treatment soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval), silica (1g per pot) and micronutrients. Temperature had a negative correlation with yield except fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval), silica (1g per pot) and micronutrients. Relative humidity (Maximum and minimum) showed positive correlation during reproductive stage in all fertilizer treatments except the treatment soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval), silica (1g per pot) and micronutrients whereas average relative humidity showed a positive correlation with yield in all the fertilizer treatments. Soil temperature had a negative correlation with yield except the treatment soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval), silica (1g per pot) and micronutrients. Weather parameters except average relative humidity had no significance with yield when fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval), silica (1g per pot) and micronutrients.

5.4.1.3 Ripening stage

Maximum solar radiation had a negative correlation with grain yield during ripening stage in all fertilizer treatments except the treatment soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval), silica (1g per pot) and micronutrients. During ripening stage average solar radiation was negatively correlated with yield in all fertilizer treatments. Grain yield had a negative correlation with temperature in all fertilizer treatments except fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval), silica (1g per pot) and micronutrients. Relative humidity showed positive correlation during ripening stage except the treatment soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval), silica (1g per pot) and micronutrients. Soil temperature (Maximum and average) had a negative correlation with yield in all treatments. During ripening stage minimum soil temperature had a negative correlation with yield in all the fertilizer treatments except soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval), silica (1g per pot) and micronutrients.

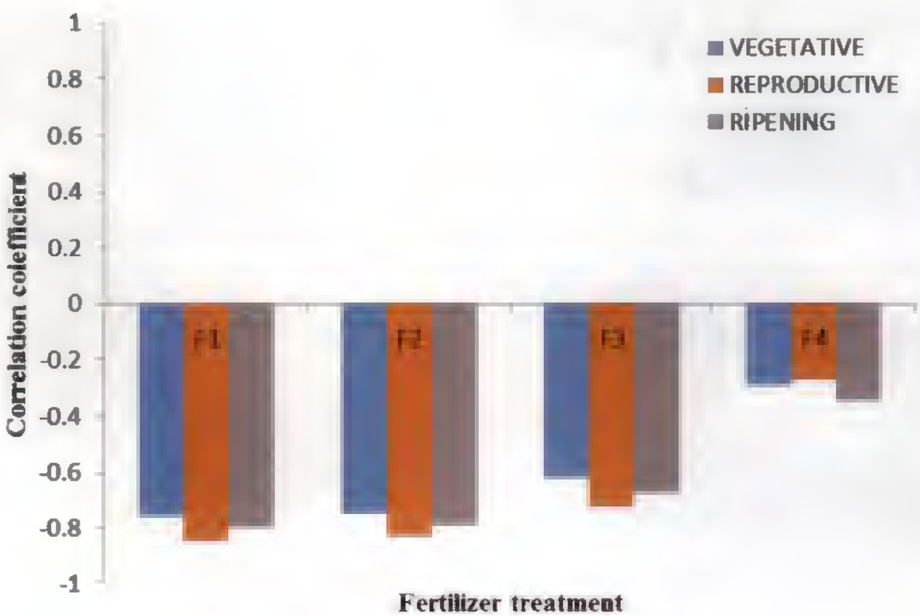

Fig. 36. Influence of maximimum temperature with rice yield under different fertilizer treatments

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Each crop species will have an optimum range of temperature, below and above of which a disturbance is induced in the metabolic processes. Temperature influences rice yield by directly affecting the physiological processes involved in grain production. During the reproductive stage, the spikelet number per plant increases as the temperature drops. In general, the optimal temperature shifts from high to low as growth advances from the vegetative to the reproductive stages.

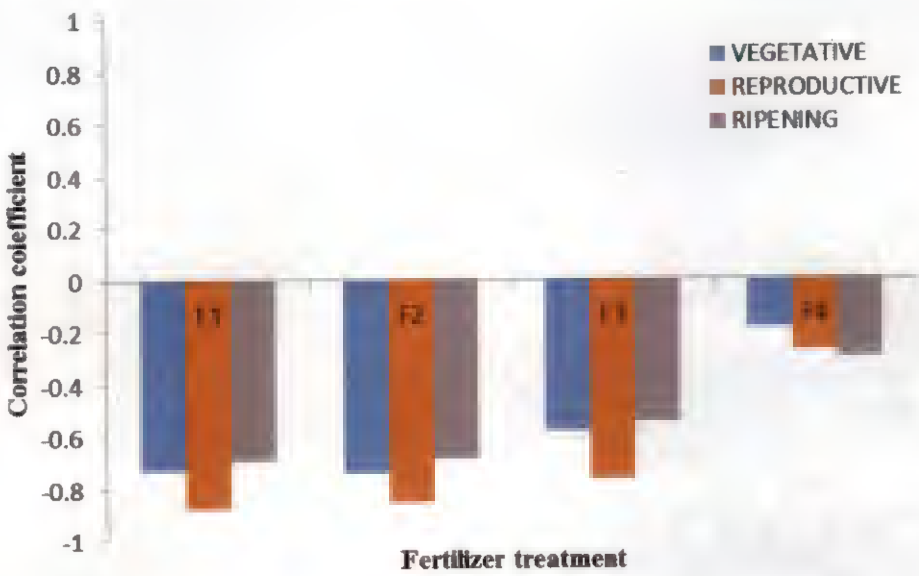

Fig.37. Influence of minimum temperature with rice yield under different fertilizer treatments

Progressive increase in night temperature must have impaired the different morpho-physiological processes and enzymatic behaviour controlled by thermal mechanism. The night temperature during the panicle initiation to flowering stage has significantly affected the grain yield (Peng *et al.*, 2004 and Nagarajan *et al.*, 2010).

5.4.2 IMPACT OF WEATHER PARAMETERS ON 50% FLOWERING

The major weather parameters affecting the 50% flowering are solar radiation, temperature, relative humidity and soil temperature. Maximum solar radiation was negatively correlated with days taken for 50% flowering in all fertilizer treatments except treatment as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval), silica (1g per pot) and micronutrients in which week 3 showed a positive correlation and week 7 showed a negative correlation. Generally average solar radiation showed a negative correlation with days taken for 50% flowering in all

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fertilization treatments. Whereas in week 3 average solar radiation showed a positive correlation with days taken for 50% flowering in all the fertilizer treatments except fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval), silica (1g per pot) and micronutrients. Days taken for 50% flowering were positively influenced with maximum temperature in fertilizer treatment as per POP recommendations (week 2, week 3 and week 6) and basal as per POP along with foliar application (19:19:19 NPK 5g at 15 days interval) (week 2 and week 6). Days taken for 50% flowering had a positive correlation with minimum (week 1 and week 7) and average (week 2, week 6 and week 8) temperature in fertilizer treatment as per POP recommendations. Minimum and average temperature had no significance when fertilizer given basal as per POP along with foliar application (19:19:19 NPK 5g at 15 days interval). Temperature (Maximum, minimum and average) had no significance with days taken for 50% flowering when fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot). Days taken for 50% flowering had a negative correlation with maximum temperature (except week 6), minimum temperature (except week 7) and average temperature in fertilizer treatment as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval), silica (1g per pot) and micronutrients. Generally relative humidity (maximum, minimum and average) had a negative correlation with days taken for 50% flowering in fertilizer given as per POP recommendations. Days taken for 50% flowering had no significance with maximum relative humidity in fertilizer treatments basal as per POP along with foliar application (19:19:19 NPK 5g at 15 days interval) and treatment as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot). Minimum relative humidity (week 1 and week 3) and average relative humidity (week 6) showed negative correlation with days taken for 50% flowering when fertilizer given basal as per POP along with foliar application (19:19:19 NPK 5g at 15 days interval). Minimum relative humidity (week 1 week 7 and week 8) was negatively correlated with days taken for 50% flowering whereas average relative humidity had no correlation in fertilizer treatment soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot). Relative humidity (maximum, minimum and average) showed positive correlation when fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval), silica (1g per pot) and micronutrients.

Maximum (week 3 and week 8) and average soil temperature (week 8) showed a positive correlation with days taken for 50% flowering whereas minimum soil temperature (week 5) showed a negative correlation in fertilizer treatment as per POP recommendations and basal as per POP along with foliar application (19:19:19 NPK 5g at 15 days interval). Generally soil temperature was (maximum, minimum and average) negatively influenced with days taken for 50% flowering in fertilizer treatments soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval), silica (1g per pot) and also soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval), silica (1g per pot) and micronutrients.

5.4.3 IMPACT OF WEATHER PARAMETERS ON PHYSIOLOGICAL MATURITY

Generally solar radiation showed a negative correlation with days taken for physiological maturity from week 1 to week 7 whereas it showed a positive correlation during last weeks in all fertilizer treatments. Maximum temperature (week 6 and week 9), minimum temperature (week 1, week 9 and week 10) and average temperature (week 9) had a positive correlation with days taken for physiological maturity in fertilizer treatment as per POP recommendations. Temperature (maximum, minimum and average) had no significance with days taken for physiological maturity when fertilizer application as basal as per POP along with foliar application (19:19:19 NPK 5g at 15 days interval). Days taken physiological maturity had no significance with maximum and average temperature whereas it had a positive correlation with minimum temperature (week 9) when the fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot). Generally temperature (maximum, minimum and average) showed negative correlation with days taken for physiological maturity when fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval), silica (1g per pot) and micronutrients. Maximum relative humidity (week 2) and minimum relative humidity (week 1-2, week 7-8, and week 10) was negatively correlated with days taken for physiological maturity when fertilizer given as per POP recommendations whereas both had no significance with days taken for physiological maturity when fertilizer application as basal as per POP along with foliar application (19:19:19 NPK 5g at 15 days interval). Average relative humidity showed a positive correlation in week 11 and a negative correlation in week

12 with days taken physiological maturity in fertilizer treatment as per POP and also treatment basal as per POP along with foliar application (19:19:19 NPK 5g at 15 days interval). Days taken physiological maturity had no significance with maximum relative humidity when fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot) whereas minimum relative humidity (week 1 and week 8) and average relative humidity (week 12) had negative correlation with days taken for physiological maturity in the fertilizer treatment soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot). Whereas relative humidity (maximum, minimum and average) showed a positive correlation with days taken for physiological maturity when fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval), silica (1g per pot) and micronutrients. Generally soil temperature (maximum and average) showed a negative correlation during initial weeks whereas during last week's it showed a positive correlation with days taken for physiological maturity in all fertilizer treatments except the treatment soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval), silica (1g per pot) and micronutrients in which a negative correlation was observed. Minimum soil temperature had a negative correlation with days taken for physiological maturity in all fertilizer treatments.

Generally, high temperature accelerates and low temperature delays heading. In contrast, Asakuma and Iwashita (1961) and Azmi (1969) reported that high temperature delayed flowering. A generalized relationship between temperature and length of time required to complete development shows that the existence of a critical low temperature below (normally below 20 °C) which the plant will not progress to anthesis. An intermediate optimum temperature permits the most rapid development. Adverse temperatures above the optimum cause a lengthening of the time required for development. There is no linear relationship between temperature and growth duration, limiting the use of temperature summation.

5.5 MULTIPLE REGRESSION MODELS DEVELOPED

Stepwise regression analysis was carried out to select the critical variables, which contributed to yield. Regression equation has developed for the prediction of the yield as,

5.5.1 Grain yield (kg/ha)

5.5.1.1 Fertilizer application as per POP

Grain yield (kg/ha) = 2533.964 87.957*RH_{min} (RIP) -11.259*SR_{avg} (REP) (R^2 = 0.85)

Where, RH_{min} (RIP) = Minimum relative humidity during ripening stage

SR_{avg} (REP) = Average solar radiation during reproductive stage

5.5.1.2 Fertilizer application basal as per POP along with foliar application

Grain yield (kg/ha) = 322.868 + 95.17*RH_{min} (RIP) (R^2 =0.727)

Where, RH_{min} (RIP) = Minimum relative humidity during ripening stage

5.5.1.3 Fertilizer application on the basis of Soil test results along with foliar application and silica

Grain yield (kg/ha) = 9760.34 + 3.744*SR_{max} (VEG) –204.71*ST_{avg}(REP) (R^2 =0.73)

Where, SR_{max}(VEG) = Maximum solar radiation during vegetative stage

ST_{avg} (REP) = Average soil temperature during reproductive stage

5.5.1.4 Fertilizer application on the basis of Soil test results along with foliar application, silica and micronutrients

Grain yield (kg/ha) =91.292+ 4.696*SR_{max} (REP)–5.03*SR_{max} (VEG) (R= 0.57)

Where, SR_{max} (REP) = Maximum solar radiation during reproductive stage

SR_{max} (VEG) = Maximum solar radiation during vegetative stage

Rice requires a fairly high degree of humidity solar radiation during ripening period for proper growth and yield. RH of 80-85 per cent is ideal for shoot growth. Rice grown at 22, 28 or 34 °C, the photosynthetic rate is increased with increase in humidity and vice versa. The increase is greatest at 28 °C and smallest at 34 °C. (Hirai *et al.*, 1989, Sreedharan 1975 and Yoshida and Parao 1976)

5.6 DSSAT MODEL VALIDATION

The Genetic coefficients of the varieties were worked out based on the past data generated as a part of various research programmes under KAU. The observed and simulated yields of all the varieties were in good agreement (Figure 38). Similar results were also reported by Timsina and Humphreys (2006).

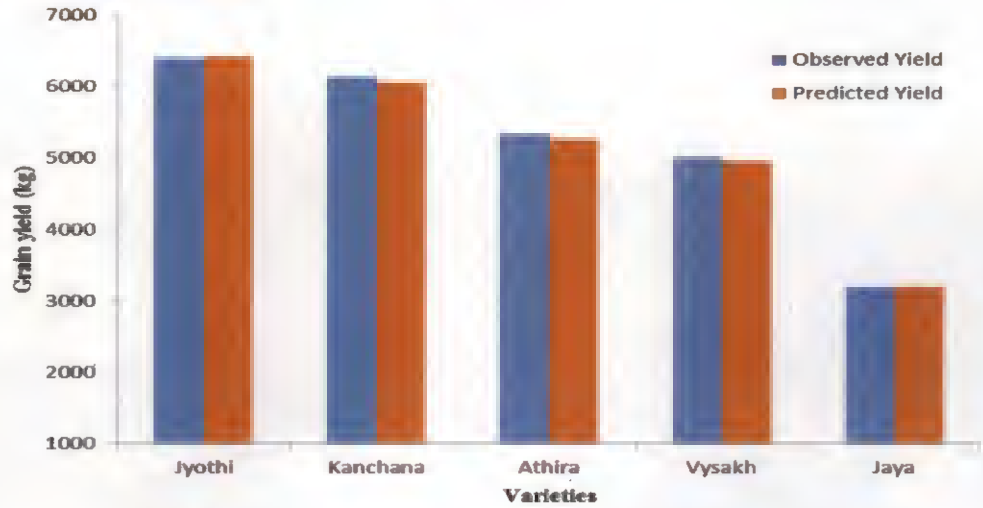

Fig. 38. Observed and predicted yield by DSSAT model

5.7 SCREENING OF VARIETIES FOR HIGH TEMPERATURE STRESS TOLERANCE

High temperature stress tolerance of the popular varieties i.e., Jyothi, Kanchana, Athira, Vysakh and Jaya were worked out based on the past data generated as a part of various research programmes under KAU using DSSAT model and presented in figure 39.

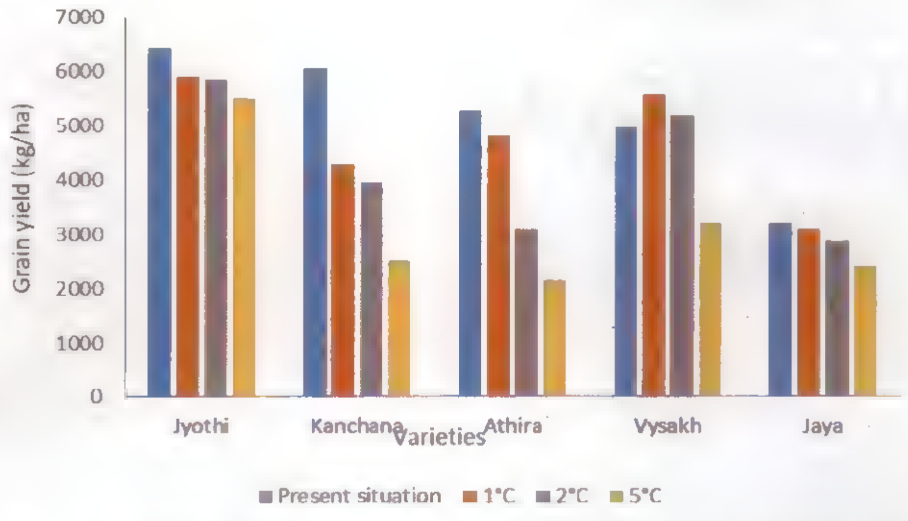

Fig. 39. Screening of varieties for high temperature stress tolerance

Variety Jyothi showed a very slight decrease in yield when the temperature was increased by 1°C, 2°C and 5°C. Compared to other varieties Jyothi showed high tolerance to temperature stress. Varieties like Kanchana, Athira and Jaya had showed continuous decrease in yield to 1°C, 2°C and 5°C increase in temperature whereas variety Vysakh showed an increase in yield up to 2°C increase temperature compared to the present condition. This is mainly because Vysakh is a drought tolerant variety in Kerala. But the yields was drastically reduced when the temperature was elevated to 5°C. Higher temperatures caused by future climate change will bring more frequent heat stress events and pose an increasing risk to global rice production. Crop models have been widely used to simulate future crop productivity (Bing Liu *et al.*, 2016).

5.8 ADJUSTING SOWING WINDOW FOR OPTIMIZING THE YIELD

Adjusting the planting time is considered one of the climate change adaptation strategy for improving the rice production. An attempt was made to quantify the impact of planting time on crop yield of variety Jyothi using DSSAT model and the results are given in the figure 40.

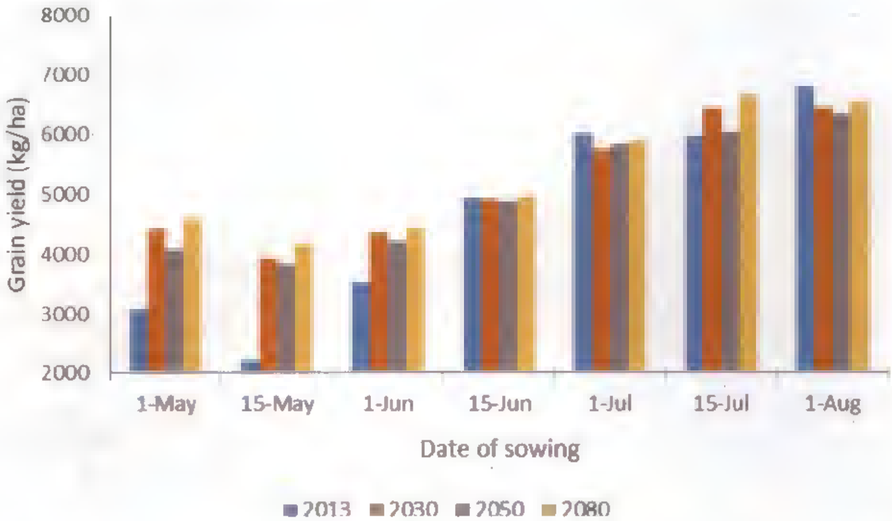

Fig. 40. Projected Grain yield (kg/ha) in future by adjusting sowing window

The observed and projected yield for the first crop season for the variety Jyothi showed more or less a continuous increase in yield starting from May 1st to August 1st. Crops planted on August 1st (6810 kg/ha) recorded the highest grain yield and the lowest was recorded during the May 15 planting (2212 kg/ha). During 2030, 2050 and 2080 showed a similar trend in the yield pattern corresponding to the above sowing periods. It is interesting to notice that the yields of crops planted during the month of May showing an increasing trend during 2030, 2050 and 2080 whereas the yields during the conventional sowing periods showed a declining trend. The yields of late planted crops will also going to increase as per the projected climate change scenarios, but it will prevent the possibility of second crop rice.

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Crop modelling is becoming a valuable tool to understand and mimic climatic constraints and yield gaps. So, it is more appropriate and can be parameterized to simulate crop growth under changing climatic scenarios to select suitable genotypes, sowing time, cropping pattern, fertilizer and weed management strategies enabling crop to cope with environmental hazards. Therefore, studies have clearly depicted crop simulation model as potential agronomic and decision making tool to understand heat crop bio-dynamism under variable climatic conditions of agriculture (Mukhtar Ahmeda and Fayyaz-ul-Hassana. 2011).

An experiment was conducted at Regional Agricultural Research Station, Pattambi to study the effect of different dates of planting, fertilizer treatments and different growing environments namely open field and climate controlled greenhouse on growth and yield of rice, variety Jyothi. Screening of varieties for high temperature stress tolerance and determination of optimum sowing period in purview of climate change were achieved using DSSAT model.

The salient findings are summarised as follows:

1. The results of the study showed that the dates of transplanting, fertilizer treatments and the growing environment has a significant effect on the morphological, phenological, and yield parameters.
2. Crop transplanted on 1st May 2016 inside the climate controlled greenhouse and fertilizer applied as per POP recommendations recorded the highest plant height of 116.7 cm. Generally plants grown inside the climate controlled greenhouse showed maximum plant height.
3. The maximum leaf area index (2.79) was recorded by the crops grown in open field transplanted on 30th May 2016 and fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot).
4. Generally plants grown in open field recorded maximum number of tillers. Crops transplanted on 1st May 2016 recorded maximum number of tillers (26.3) and they were grown under climate controlled greenhouse as per POP recommendations.
5. Crops transplanted on 1st May 2016 recorded highest dry matter accumulation (13093.3 kg/ha) grown in open field and their fertilizer treatments as per soil test result along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot).
6. The maximum number of panicles recorded was 22.9 in crop grown under climate controlled greenhouse transplanted on 1st May 2016 and fertilizer application as per POP recommendation.

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7. The maximum number of spikelets recorded was 13.3 by crops grown in open field transplanted on 1st May 2016 and fertilizer application given as basal dose as per POP and rest met by foliar application (19:19:19 NPK 5g at 15 days interval).
8. The maximum number of filled grains (107) was recorded by the crops transplanted on 1st May 2016 in open field with fertilizer given basal as per POP along with foliar (19:19:19 NPK 5g at 15 days interval).
9. Crops transplanted on 1st May 2016 grown in open field as per POP recommendations recorded highest 1000 grain weight (30.2 g).
10. The highest grain yield (6324.0 kg/ha) was recorded by crop transplanted on 1st May 2016 in the open field fertilizer application as per soil test result along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot).
11. Crops transplanted on 1st May 2016 in open field and fertilizer given as per soil test result along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot) has recorded highest straw yield (6769.3 kg/ha).
12. Crop transplanted on 15th May 2016 inside the climate controlled greenhouse fertilizer application as basal as per POP along with foliar application (19:19:19 NPK 5g at 15 days interval) and also fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot) required the maximum days to reach active tillering stage (44 days).
13. The days taken for panicle initiation was found to be highest (47 days) in the crop transplanted on 15th May 2016 inside the climate controlled greenhouse fertilizer given basal as per POP along with foliar application (19:19:19 NPK 5g at 15 days interval) and also fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot).
14. Maximum days taken for 50% flowering (75.7 days) recorded by crop transplanted on 30th May 2016 grown in open field and fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval), silica (1g per pot) and micronutrients. Considering the growing environment alone, crops grown inside the climate controlled greenhouse have recorded maximum days taken for 50% flowering (67.9 days).
15. The crop transplanted in the open field on 30th May 2016 and fertilizer given as per soil test results along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot) took the maximum days for physiological maturity

(104 days). Considering the growing environment alone, crops grown inside the climate controlled greenhouse has taken maximum days for physiological maturity (97.6 days).

16. Solar radiation, temperature, relative humidity and soil temperature are the major weather parameters that influence the yield and phenology of rice. Changes in fertilizer use, soil test based fertilizer recommendation, application of micronutrients and additional inputs like silica reduced the weather dependency in rice production.
17. Multiple regression equations has predicted the grain yield and duration with good accuracy.
18. High temperature stress tolerance of the popular varieties of Kerala ie., Jyothi, Kanchana, Athira, Vysakh and Jaya were worked out based on the past data generated as a part of various research programmes under KAU using DSSAT model.
19. Compared to other varieties Jyothi showed high tolerance to temperature stress. Varieties like Kanchana, Athira and Jaya had showed continuous decrease in yield to 1°C, 2°C and 5°C increase in temperature whereas variety Vysakh showed an increase in yield up to 2°C increase temperature compared to the present condition but the yield were drastically reduced when the temperature was elevated to 5°C.
20. Adjusting the planting time is considered one of the climate change adaptation strategy for improving the rice production. Impact of planting time on crop yield of variety Jyothi was studied using DSSAT model.
21. The yields of crops planted during the month of May showing an increasing trend during 2030, 2050 and 2080 whereas the yields during the conventional sowing periods showed a declining trend. The yields of late planted crops will also going to increase as per the projected climate change scenarios, but it will prevent the possibility of second crop rice.

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CLIMATE CHANGE ADAPTATION ON RICE PRODUCTION

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ABSTRACT OF THE THESIS

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The impacts of climate change on agriculture are global concerns and for that matter India, where agriculture sector alone represents 23 per cent of India's Gross National Product (GNP) and the livelihood of nearly 70 per cent of the population is exposed to a great danger, as the country is one of the most vulnerable countries due to climate change. One of the most notable characteristics of climate change is the increase in temperature, so it has been mainly recognized as 'global warming'. The conclusions of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) published in early 2007 leave no doubt that the Earth's climate is changing in a manner unprecedented in the past 400,000 years. The report substantiated that by 2100 mean surface temperatures over the earth will rise by 1.4 to 5.8 ° C, precipitation will decrease in the sub-tropics, and extreme events will become more frequent (IPCC, 2007). However, changes in climate are already being observed and the last 60 years were the warmest in the last 1000 years and changes in precipitation patterns have brought greater incidence of floods or drought globally.

Climate change has negatively affected India's millions of rice producers and consumers. Harvest would have been 5.67 per cent higher in the absence of climate change. Future impacts of these changes on rice yield in India would thus likely be larger than the historical ones (Auffhammer *et al.*, 2012). There is a huge gap between potential and actual grain yield of rice in Kerala. The growth and yield is largely depends on the various weather factors like temperature, rainfall, solar radiation and relative humidity that prevail during the growing season.

Objectives of the study were to study the climate change adaptation in rice production through fertilizer management strategies and to determine the optimum sowing period in purview of climate change and temperature stress tolerance in popular rice varieties of Kerala using DSSAT model. The fileld experiments were conducted during April 2016 to September 2016 at the Regional Agricultural Research Station of the Kerala Agricultural University at Pattambi, Palakkad district, Kerala in variety Jyothi.

The result showed that the dates of planting, fertilizer treatment and different growing environment had significance on yield of rice. The highest grain yield (6324.0 kg/ha) was recorded by crop transplanted on 1st May 2016 in the open field fertilizer application as per soil test result along with foliar application (19:19:19 NPK 5g at 15 days interval) and silica (1g per pot). Solar radiation, temperature, relative humidity and soil temperature are the major weather parameters that influence the yield and phenology of rice. Changes in fertilizer use, soil test based fertilizer recommendation, application of micronutrients and additional inputs like silica reduced the weather dependency in rice production.

High temperature stress tolerance of the popular varieties of Kerala i.e., Jyothi, Kanchana, Athira, Vysakh and Jaya were worked out based on the past data generated as a part of various research programmes under KAU using DSSAT model. Variety Jyothi showed a very slight decrease in yield when the temperature was increased by 1°C, 2°C and 5°C. Compared to other varieties Jyothi showed high tolerance to temperature stress. Varieties like Kanchana, Athira and Jaya had showed continuous decrease in yield to 1°C, 2°C and 5°C increase in temperature whereas variety Vysakh showed an increase in yield up to 2°C increase temperature compared to the present condition but the yield were drastically reduced when the temperature was elevated to 5°C.

Adjusting the planting time is considered one of the climate change adaptation strategy for improving the rice production. An attempt was made to quantify the impact of planting time on crop yield of variety Jyothi using DSSAT model. The observed and projected yield for the first crop season for the variety Jyothi showed more or less a continuous increase in yield starting from May 1st to August 1st. Crops planted on August 1st (6810 kg/ha) recorded the highest grain yield and the lowest was recorded during the May 15 planting (2212 kg/ha). During 2030, 2050 and 2080 showed a similar trend in the yield pattern corresponding to the above sowing periods. It is interesting to notice that the yields of crops planted during the month of May showing an increasing trend during 2030, 2050 and 2080 whereas the yields during the conventional sowing periods showed a declining trend. The yields of late planted crops will also going to increase as per the projected climate change scenarios, but it will prevent the possibility of second crop rice.