IMPACT OF CLIMATE CHANGE ON RICE PRODUCTION

By

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THESIS

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DECLARATION

I hereby declare that the thesis entitled **"Impact of climate change 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.

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ABBREVIATIONS

AR5	Assessment Report 5
BSH	Bright Sunshine Hours
CD	Critical Difference
CERES	Crop Estimation through Resource and Environment Synthesis
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
NS	Non significant
PI	Panicle Initiation
RARS	Regional Agricultural Research Station
RH-I	Morning Relative humidity
RH-II	After noon Relative humidity
RMSE	Root Mean Square error
RCP	Representative Concentration Pathway
T_{max}	Maximum temperature
T_{min}	Minimum temperature

Introduction

1. INTRODUCTION

Agriculture is always vulnerable to vagaries weather events and climate conditions. Despite technological advances 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 remarkable 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 rate of global warming is expected to continue increasing if no mitigation efforts take place to reduce the carbon intensity of the world economy and the consequent emission of green-house gases (Raupach *et al.*, 2007). Agricultural production, and thus global food security, is directly affected by global warming (Ainsworth and Ort, 2010). Increasing atmospheric greenhouse gas concentrations are expected to induce significant climate change over the next century and beyond, but the impacts on society remain highly uncertain (Chavas, *et al.*, 2009). The agriculture sector is already under pressure for increasing food demand, problems associated with agricultural land and water resource depletion. The issues of climate change make the pressure more acute for the sector.

Rice (*Oryza sativa* L.) is the major staple food for more than half of the world's population, accounting for approximately 30 percent of the total dietary intake, globally and in South Asia (Lobell *et al.*, 2008). Rice production in the tropics is sensitive to climatic factors (temperature, rainfall, and solar radiation) which affect the crop in two various ways during different stages of its growth (Yoshida, 1978). 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 evidently already negatively affected India's hundreds of 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).

With 1.28 billion people, India is the second most populous country in the world and will take the number one position by 2030. It is imperative to increase food production in order to meet the growing demand for food emanating from population growth. Although, there have been ups and downs in the domestic production of food grain. The diverse climatic phenomena like cyclone, drought, changing rainfall patterns and temperature; there has been a significant lost in food grain production in every year.

There is a wide gap between potential and actual grain yield of rice in Kerala and 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. With a view to study these weather influence on rice and to study the climate change impact, we have taken following objectives:

1. Development of crop weather relationships for the selected rice varieties.
2. Assessment of possible change in yield of rice due to climate change.
3. Evaluate the hardiness and climate adaptability of selected rice varieties under the projected climatic conditions using DSSAT model.

Review of Literature

2. REVIEW OF LITERATURE

The growth and yield of any crop is highly associated with environmental factors. Interactions between crop and weather are the backbone for the productivity and stabilized yield. Climate change alters weather conditions considerably which is sufficiently evident from observations all around the world. Climate change alters weather variables and there by affect the production of rice. General Circulation Models (GCM's) are very useful 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 the effect of different weather variables on rice and how the climate change is altering weather and its impact on the production of rice is being reviewed.

2.1 WEATHER AND RICE

2.1.1 Vegetative stage

2.1.1.1Temperature

Seasonal temperature is an important climatic factor which can have profound effects on the yield of crops. Changes in seasonal temperature affect the grain yield, mainly through phenological development processes.

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

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.

The marked reduction in grain yield of rice under high-temperature stress during vegetative growth was attributed to the reduction in the number of panicles per square meter (24 per cent), followed by the number of grains per panicle (nine per cent). The 1000 grain weight increased to a lesser extent (two per cent). The reduction in grain yield by high-temperature stress during the reproductive growth phase was caused by a significant decrease in the number of panicles per square meter (12 per cent) and number of grains per panicle (12 per cent) and the marginal reduction in 1,000 grain weight (four per cent). However, the relatively low reduction in grain yield (Eight per cent) due to heat stress during ripening was probably caused by the small reduction in 1,000 grain weight (five per cent) and the number of grains per panicle (six per cent), which could be the consequence of a greater respiratory loss of assimilates in the panicles.

Hoa and Singh (1993) reported that the effect of maximum temperature, minimum temperature and relative humidity was beneficial 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.

Choudhary and Sodhi (1979) reported that the growth duration varied with air temperature and increased in proportion to the length of time of low temperature during vegetative growth and flowering. Temperature accounted for 86 per cent of the variation in the growth.

Nigam and Mishra (2003) reported 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 were negatively correlated with yield, whereas the number of rainy days, wind velocity and evaporation were positively correlated 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.

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.

Rai and Chandrahas (1997) reported that the relative humidity and number of rainy days were beneficial up to early growth phase whereas sunshine and maximum temperature in addition to relative humidity contributed positively towards rice yield up to the vegetative phase.

Low temperature during active vegetative phase may result its 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).

Plant height and length of first three leaves were high at 27.0-28.0°C and low at 20.0-22.0°C. Stem dry weight per cm decreased as plant height increased. Increase in temperature at the early stage gave further increases plant height and the length of the 1^{st} and 2^{nd} leaves (Chiba, 1990). Kakizaki (1991) stated from experiments with ten different temperature treatments that tiller number was higher at 15.0°C and tiller emergence was inhibited at 33.0°C. At 33.0°C, emergence of secondary tillers ceased completely in the variety Zosan No.1, whereas six secondary tillers were formed in the variety Norin No.1. Tillers which emerged under 15.0°C base temperature were inhibited when the temperature was switched to 33.0°C and those which were inhibited under 33.0°C developed again when switched back to 15.0°C.

Temperature influenced the leaf appearance rate, the leaf number, panicle emergence and development (Ellis *et al.*, 1993). The rate of leaf emergence was no greater at 28.0°C than at 24.0°C, the optimum being about 26.0°C.

2.1.1.2 Rainfall

Rainfall affects the rice crop at different stages of vegetative growth period. Variability in rainfall affects stand, establishment and the growth duration of rice. Chandler (1963) reported that many rice varieties respond better to nitrogen in dry season than in wet season. According to Chatterjee (1970), tillering in a number of rice varieties continued up to 42-45 days in rainy season, whereas it was up to 50-55 days in dry season.

2.1.1.3 Solar radiation

Yoshida (1973) found that rice yield increased with increasing total solar radiation and heat sums and decreased with increased water stress but was not significantly affected by total sunshine hours or rainfall.

2.1.1.4 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.

In rice grown at 22.0, 28.0 or 34.0°C, the photosynthetic rate increased with increase in humidity and *vice versa.* The increase was greatest at 28.0° and was smallest at 34.0°C. Leaf temperature and stomatal aperture of leaves in the upper part of the canopy also increased with increasing humidity (Hirai *et al.*, 1992).

2.1.1.5 Wind

Robertson (1975) reported that wind is an important factor for rice production. Transpiration rates increase under high wind condition. According to Suge and Takaisin (1982), wind increased ethylene, ethane production in rice, decreased gibberlic acid content of roots and shoots and also stirs the air and transports CO_2 to the canopy.

The probability of damage to rice crop due to strong winds was higher during night. Types of damage included white heads, white and discoloured glumes (Kim *et al.*, 1989).

2.1.2 Reproductive stage

2.1.2.1 Temperature

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).

The yield of rice is significantly influenced by temperature throughout the crop growth period and was more pronounced from flowering to anthesis period (Chahal *et al.*, 2007). Ghosh *et al.*, (1973) reported that high maximum temperature (29.0 to 31.5°C) and high total sunshine hours for three weeks after flowering favoured panicle number and grain weight in the mid season cultivar T-141.

During the reproductive phase, minimum temperature and rainfall had the deleterious effect on the yield of rice (Reddy and Reddy, 1997). During reproductive phase higher temperature coupled with speedy wind may cause poor setting of seed, consequently leading to low harvest (Singh and Singh 2007).

Nishiyama *et al.*, (1969) reported that the critical low temperature for inducing sterility is 15.0-17.0°C in highly cold tolerant varieties. A negative correlation between yield 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 Satake and Hayase (1970), the stage most sensitive to coolness is the young microspore stage after meiotic division at anthesis.

According to Baker *et al.* (1992) grain yield was decreased by an average of about 7-8 per cent per 1.0°C rise in temperature from the 28.0/21.0/25.0°C to 34.0/27.0/31.0°C (day time dry bulb air temperature/night time dry bulb air temperature/paddy water temperature) temperature treatment.

2.1.2.2 Rain fall

The number of showers during the flowering period affects the yield of rice considerably (Chahal *et al.* 2007).

Grain yield was negatively correlated with number of rainy days and humidity during the reproductive stage, but was positively correlated with sunshine hours during the pre and post flowering stages (Reddy and Reddy, 1997).

Rainfall affects the rice crop at the reproductive stage. Variability in rainfall is associated with an untimely cessation at the reproductive and ripening stage, the yield reduction is severe. The number of panicles was more (500 m^{-2}) in Rabi compared to Kharif (400 m^{-2}) season, thus being responsible for high yield in the former (Venkateswarlu *et al.*, 1976).

2.1.2.3 Wind

During reproductive phase higher temperature coupled with speedy wind may cause poor setting of seed, consequently leads to pitiable harvest (Singh and Singh 2007).

Ebata and Ishikawa (1989) reported that wind damage to rice crop at the reproductive phase was triggered by temporary water stress in the panicle spikelet and the injury was less when wind was accompanied by rain

2.1.2.4 Solar radiation

Dry matter production and yield are highly dependent on solar radiation and it is the major factor governing photosynthesis. Vijayalakshmi *et al.*, (1991) reported that the productivity of October sown rice crop is relatively low (1.2 t ha^{-1}) as compared to that of January sown *rabi* crop. This reduced productivity is due to the insufficient solar radiation during *kharif*. The low light intensity up to flowering in *kharif*, imposes a ceiling on tillering and reduces dry matter production as compared to *rabi* season (Venkateswarlu, 1977).

According to Vijayalakshmi *et al.*, (1991), yield reduction due to shading (50 per cent) was 11-14 per cent in the shade-tolerant cultivars and 29-34 per cent in the susceptible ones compared to 100 per cent sunlight. Corresponding reductions in total dry matter accumulation were 8-13 and 23-25 per cent respectively. The shade susceptible cultivars showed the greatest increases in percentage of unfilled grains. According to Islam and Morison (1992), grain yield was reduced progressively as irradiance was reduced by up to 77 per cent. The effect of 22 per cent and 52 per cent shading during either the reproductive or ripening phase had the same effect, but 77 per cent shading had a greater adverse effect when applied during the ripening phase.

2.1.2.4 Relative humidity

A decrease in the fertility of spikelets at high air temperatures with increased humidity was reported by Matsui *et al.*, (2001) who suggested that humidity modified the impact of high temperature on spikelet fertility. Spikelet fertility was reduced with increasing relative humidity.

The minimum RH required for the flowering of rice is 40 per cent, the optimum being around 70-80 per cent. High humidity during post-flowering stage appeared to have a detrimental effect on yield (CRRI, 1967).

Spikelet fertility in rice crop was reduced with increasing RH and decreasing temperature. RH was the most significant meteorological factor affecting spikelet fertility followed by mean temperature at three days after heading (Shi and Shen, 1990).

2.1.3 Ripening stage

2.1.3.1 Temperature

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. Temperature influences the ripening of rice in two ways - first, low temperature favours an increase in grain weight and second, low daily mean temperature increased the length of ripening period (Nagato and Ebata, 1966).

Night time warming at the end of the growing season had a greater impact on yield during 1966–2002 than changes in monsoon characteristics (Auffhammer *et al.*, 2012).

Higher grain yield in temperate countries than in tropics could have generally been attributed to the lower temperature during ripening, which extends the ripening period, so more time grain filling. At low temperature, translocation of photosynthates to grain takes place at a slower rate and thus maturity period gets delayed (Boerma, 1974).

According to Kwon e*t al.*, (1989), low temperature treatment reduced ripening ratio and yield while fertilizer application reduced low temperature injury in rice. The effective heat sum and base temperature (BT) for specific stages of the reproductive phase were analysed by Ebata (1990) observed that, BT for panicle emergence and flowering of cv. Sasamishiki were 12.1 and 11.5°C respectively. During ripening, BT showed its highest value of 9.4-10.1°C at the earliest stage and declined to 4-5°C at the latest stage of ripening (Ebata, 1990).

2.1.3.2 Rainfall

Absence of rainy days during the ripening phase is not beneficial to grain weight (Ghosh *et al.*1973).

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

2.1.3.3 Solar radiation

Studies at IRRI revealed 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) reported that the yield attributes such as panicles per square meter, grain yield etc., recorded a positive correlation with solar energy during reproductive and ripening phases.

According to Yoshida and Parao (1976), low solar radiation during ripening phase reduces the grain yield considerably, because of the decrease in percentage of filled grains. Krishnakumar (1986) reported that panicles per square meter, grains per square meter, degree of ripening and grain yield are positively correlated with solar energy during ripening period.

2.2 CLIMATE CHANGE

The atmosphere acts like the glass of a hothouse, because it lets through the light rays of the sun but retains the dark rays from the ground (Fourier, 1824). The diurnal and annual variations of the temperature were lessened by the absorption of atmosphere (Tyndall, 1861). Water vapor, hydrocarbons like methane (CH_4), and carbon dioxide (CO_2) strongly block the radiation (Tyndall, 1872).

The air retains heat (light or dark) in two different ways. The heat suffers a selective diffusion on its passage through the air. On the other hand, some of the atmospheric gases absorb considerable quantities of heat. These two actions are very different. The selective diffusion is extra ordinarily great for the ultra-violet rays, and diminishes continuously with increasing wave-length of the light, so that it is insensible for the rays that form the chief part of the radiation from a body of the mean temperature of the earth (Langley, 1884).

Cutting CO_2 in half would suffice to produce an ice age. A doubling of atmospheric CO_2 would give a total warming of 5.0-6.0 degrees Celsius (Arrhenius, 1896)

A systematic variation with season and latitude in the concentration and isotopic abundance of atmospheric carbon dioxide has been found in the northern hemisphere. In Antarctica, a small but persistent increase in concentration has been found (Keeling, 1960).

A doubling of carbon dioxide from the current level would result in approximately 2.0°C increase in global temperature (Manabe and Wetherald, 1967). In 1975, Manabe (1975) had developed a three-dimensional global climate model that gave a roughly accurate representation of the current climate. Doubling CO_2 in the model's atmosphere gave a roughly 2.0°C rise in global temperature.

Chlorofluorocarbons (CFCs) could have a global warming effect (Lovelock *et al.,* 1973). A CFC molecule could be 10,000 times more effective in absorbing infrared radiation than a carbon dioxide molecule, making CFCs potentially important despite their very low concentrations in the atmosphere (Ramanathan, 1975). After 1980, scenarios become main stream in futures research (Hafele *et al*, 1981, Robertson, 1983, Svedin, 1987)

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 presently 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.

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).

2.3 CLIMATE CHANGE IMPACT ON RICE PRODUCTION

The rise in atmospheric temperature causes detrimental effects on growth, yield and quality of the rice crop by affecting its phenology, physiology and yield components (Singh 2001, Sheehy *et al.*, 2005, Peng *et al.*, 2004)

Currently, most of the rice production occurs in regions where temperatures are already above the optimum for crop growth (daytime maximum 28.8°C and night time minimum22.8°C) (Krishnan *et al.*, 2011).

Each 18°C increase in the day time maximum-night time minimum temperatures within the 288.0-218.0 to 348.0-278.0°F range can decrease rice yields by about 7-8 per cent (Baker *et al.*, 1992).

A net negative impact on yield from moderate warming in coming decades may be observed. The impact of maximum temperature becomes negative at higher levels. Diurnal temperature variation must be considered when investigating the impacts of climate change on irrigated rice in Asia. Rice crops in tropical and subtropical Asia have higher yields as maximum daily temperatures increase and lower yields as minimum daily temperatures increase (Welch *et al.*, 2010).

Towards the end of this century (2091-2100), the yield loss would be around one tone per ha with the rise of 3.1°C of temperature and 46 per cent increase in rainfall, respectively. It is worth noting that the projected yield loss estimated by agronomic models (DSSAT and PRECIS models) was 356 kg ha^{-1} per decade (Geethalakshmi *et al.*, 2011) in Tamil Nadu.

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.

According to Bhuvaneswari *et al.,* (2014), rice yield reduction will be ranged from 4 -56 per cent with increase in temperature from 1.0 to 5.0°C respectively from the current climate. 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 per cent respectively for 3.0°C increase in temperature and 650 ppm CO_2 enrichment, during rabi season, it was -9.2, +10.2 and +11.0 per cent respectively.

On an average over the state with the climate change scenario studied, the rice maturity period is projected to shorten by 8 per cent and yield increase by 12 per cent. When temperature elevations only are taken into consideration, the crop simulations show a decrease of 8 per cent in crop maturity period and 6 per cent in yield. This shows that the increase in yield due to fertilization effect of elevated CO_2 and increased rainfall over the state as projected in the climate change scenario nearly makes up for the negative impact on rice yield due to temperature rise (Saseendran *et al.*, 2000).

Without adaptation, losses in aggregate production are expected for wheat, rice and maize in both temperate and tropical regions by 2.0°C of local warming. Crop level adaptations increase simulated yields by an average of 7 to 15 per cent, with adaptations more effective for wheat and rice than maize. Yield losses are greater in magnitude for the second half of the century than for the first (Challinor *et al.*, 2014).

Direct effect of climate change in irrigated and well managed rice crops will always be positive in different agro climatic regions in India irrespective of the various uncertainties. Southern and western India, which are at present relatively cooler during the rice season compared to northern and eastern regions, are likely to show a greater sensitivity to climate change. In case climatic change has a negative effect on productivity effect on productivity varieties with greater temperature tolerance can easily mitigate the negative effects. There is an urgent need to document the temperature sensitivities of major crop varieties to changes in temperature (Aggarwal and Mall, 2002).

Some areas show no significant influence of climate variability, in substantial areas of the global bread baskets, more than 60 per cent of the yield variability can be explained by climate variability. Globally, climate variability accounts for roughly a third (-32 to -39 per cent) of the observed yield variability (Deepak *et al.*, 2015)

The change in yield from current condition under early, normal, late planting during kharif season was -21.2, -15.0 and -16.3 per cent respectively for 3.0°C increase in temperature and 650 ppm CO_2 enrichment. During rabi season, it was -9.2, +10.2 and +11.0 per cent, respectively (Bhuvaneswari, *et al.*, 2014).

Two potent short-lived climate pollutants (SLCPs), tropospheric ozone and black carbon, have direct effects on crop yields beyond their indirect effects through climate, emissions of black carbon and ozone precursors have risen dramatically in India over the past three decades. Yields in 2010 were up to 20 per cent lower for Rice than they otherwise would have been, absent climate and pollutant emissions trends (Burney and Ramanathan, 2014)

Aggregate yields are projected to decrease by an average of 18 per cent by 2030-2050 relative to 1980-2000 while the coefficient of variation of yield increases by an average of 47 per cent. Projections from 13 out of 15 climate models result in an aggregate increase in national yield coefficient of variation, indicating that maize yields are likely to become more volatile (Urban *et al.*, 2012).

Both maize and rice exhibit non-linear increases with time, with total area exposed for rice, during reproductive stage to critical temperature, projected to grow from eight per cent in the 2000s to 27 per cent by the 2050s, and maize from 15 to 44 per cent over the same period.

Warming is already slowing yield gains at a majority of wheat-growing locations. Global wheat production is estimated to fall by 6 per cent for each °C of further temperature increase and become more variable over space and time.

2.4 DATE OF PLANTING

Choudhury *et al.,* (2007) run the CERES-Rice, a dynamic crop simulation model incorporated in DSSAT v.3.5 to simulate the rice yield at Raipur, for the period of 30 years. They reported that the potential productivity of rice ranged from 81.97 to 105.50 q ha^{-1}, whereas in rainfed condition, the range was 33.67 to 89.49 q ha^{-1}.

Transplanting of rice in mid June onwards has favourable weather conditions for rice production in Indian Punjab. With the shifting of transplanting dates of rice from higher (mid May) to lower (end of June onwards) evaporative demand, there is an increase in grain yield of rice while there is a reduction in evapotranspiration and irrigation water applied (Chahal *et al.*, 2007).

Akram *et al.*, (2007) find 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. 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. Low temperature during active vegetative phase may result poor tillering and less productive tillers. Similarly during reproductive phase higher temperature coupled with speedy wind may cause poor setting of seed (Singh and Singh, 2007).

According to Nahar *et al.,* (2009) grain weight of Aman rice was influenced by transplanting dates. Among the planting dates 1st September transplanting provided the highest results whereas 30th 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.

According to Praveen *et al.*, (2013), higher grain yield and straw yield along with the heat units, accumulated growing days, photothermal unit, heliothermal unit, radiation use efficiency were recorded maximum in crop sown on 10^{th} June as compared to 20^{th} June and 30^{th} June sown crop. The highest GDD was accumulated in the first date of sowing (10^{th} June) during all growth stages starting from planting to maturity.

According to Khalifa *et al.*, (2014), maximum tillering, panicle initiation, heading dates, leaf area index, cholorophyll content, 1000 grain weight were increased by increased seed rates up to 143 kg seed/ha. Earlier sowing time (20^{th} April) gave highest value of all studied characters in Sakha 101 variety during the year 2006 and 2007 in Egypt.

2.5 CROP GROWTH MODELS

Crop models are essential tools for assessing the threat of climate change (Challinor *et al.*, 2014) to local and global food production and 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).

Crop models are the softwares that simplify the complex relationship between climate and crop performance by using established mathematical or statistical techniques or both. In present study we have used DSSAT v 4.5 (Hoogenboom *et al.*, 2010) for crop weather modelling.

2.5.1 DSSAT

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 is a software application program that comprises crop simulation models for 28 crops. The program integrates the effects of soil, crop phenotype, weather and management options. The DSSAT software combines crop, soil and weather databases into standard formats for access by crop models and application programs. The user can then simulate multi-year outcomes of crop management strategies. The program and its crop simulation models have been used for many applications, ranging from on-farm and precision management to regional assessments of the impact of climate variability and climate change.

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).We have used CERES- Rice model (Ritche, 1986) for our study.

2.5.1.1 *CERES- Rice model*

The individual origin CERES crop models were combined into a single module to simulate wheat, maize, barley, sorghum, and millet (Tsuji *et al.,*1998). There is only the CERES rice model kept separate, because its major differences in soil water, nitrogen balance routines, and the need to simulate transplanting effects. The CERES models increment grow in a daily time steps and require daily weather data (maximum and minimum temperature, solar radiation, and precipitation). To compute crop basic morphological development temperature, day length, and cultivar characteristics are input factors. The daily dry matter growth is based on light intercepted by the leaf area index multiplied by conversion factors. Biomass partitioning into various plant components is based on potential growth of organs and daily amount of growth supply to demand ratios of water and nitrogen balance. Sub-models providing daily values of supply to demand ratios of water and nitrogen, respectively, which are used to influence growth and development rates.

Godwin *et al.,* (1990) used the CERES- Rice model, which simulates the effect of weather, soil properties and crop management on nitrogen dynamics, crop growth and its performance in simulating field experiments.

Kumar and Sharma (2004) used the CERES-Rice model to simulate the growth, development and yield of four different rice cultivars (RP 2421, HPR 927, HPR 957 and Kasturi). The model was efficient in predicting the phenology of all cultivars and the association between actual and simulated data on number of days to flowering and physiological maturity was significant.

CERES-Rice model is a process based, management oriented model that could simulate the growth and development of rice as affected by varying levels of water and Nitrogen (Boutraa, 2010).

Materials and methods

3. MATERIALS AND METHODS

Field experiments were conducted during 2014-15 to study the climate change impact 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 January 2014 to March 2015 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 in three seasons, i.e. in January, 2014-15 by planting at fortnightly interval during the third crop season (December-January to March-April), first crop (April-May to September-October) and second crop (September-October to December-January) respectively. Accordingly, crop harvests were done during May, October and January for the above three seasons.

3.1.5 Varieties

Two popular varieties of Kerala Aathira and Vaisakh were selected for this study. Aathira and Vaisakh are photo insensitive varieties with the duration of 117-125 days and 113-120 days respectively.

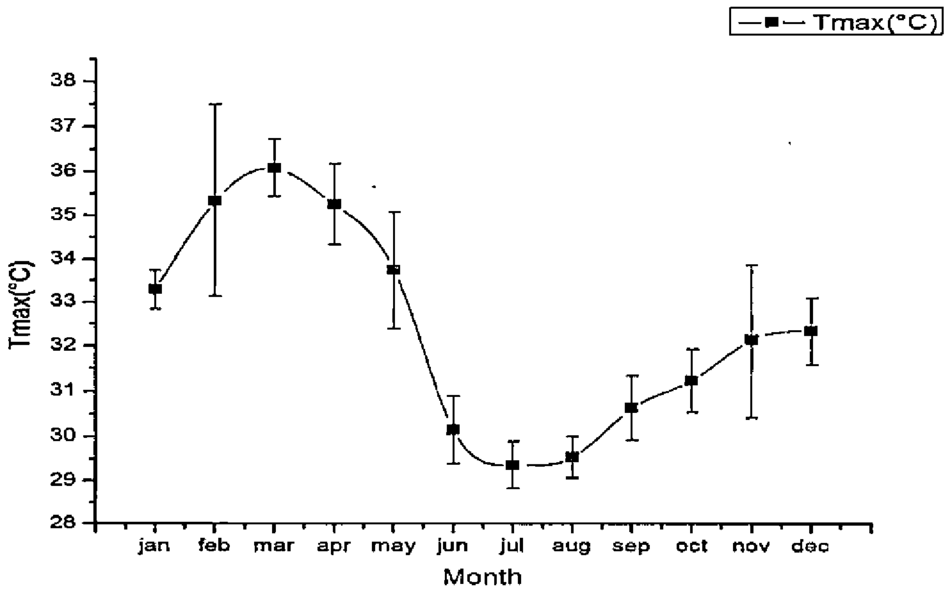

Fig. 1. Monthly maximum temperature (°C) of Pattambi (1983-2012)

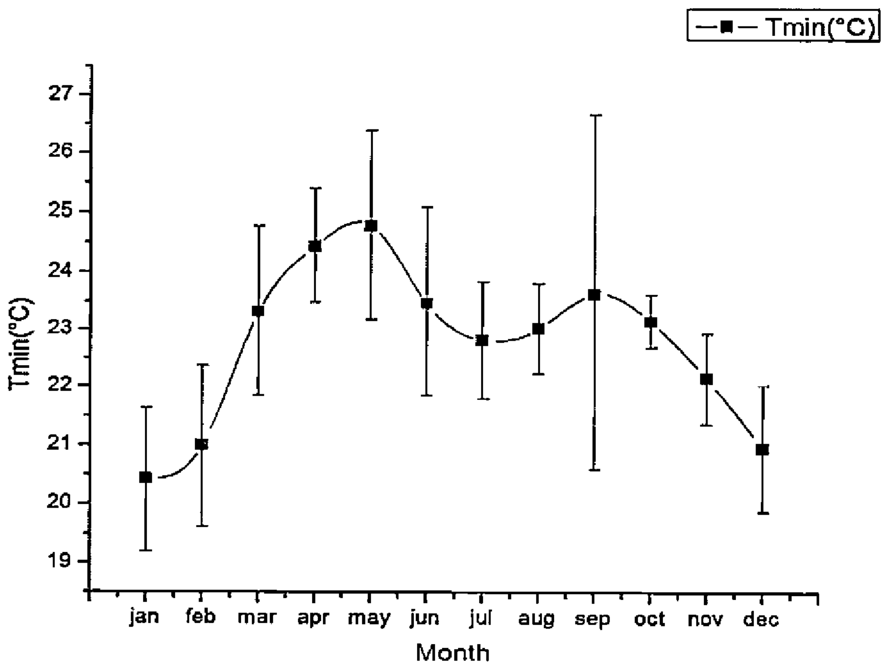

Fig. 2. Monthly minimum temperature (°C) of Pattambi (1983-2012)

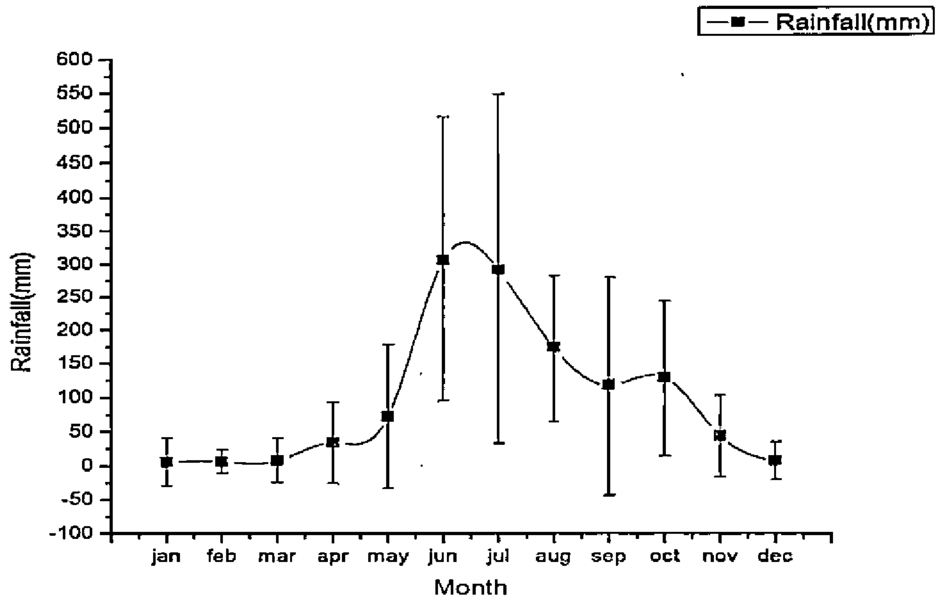

Fig. 3. Monthly rainfall (mm) of Pattambi (1983-2012)

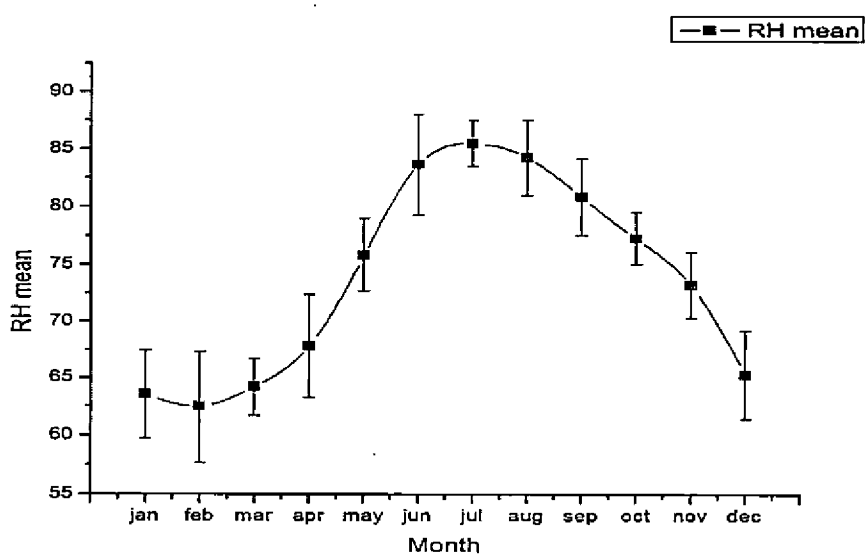

Fig.4. Monthly mean Relative humidity (%) of Pattambi (1983-2012)

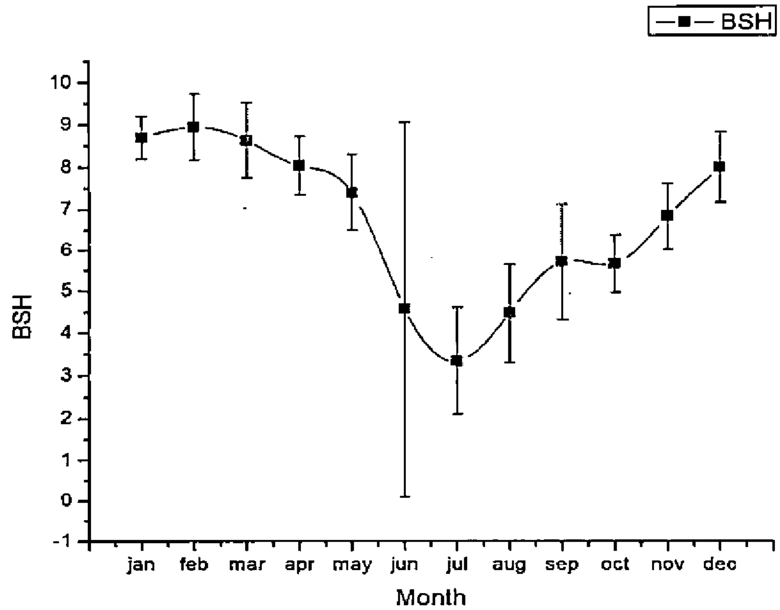

Fig.5. Monthly bright sun shine hours of Pattambi (1983-2012)

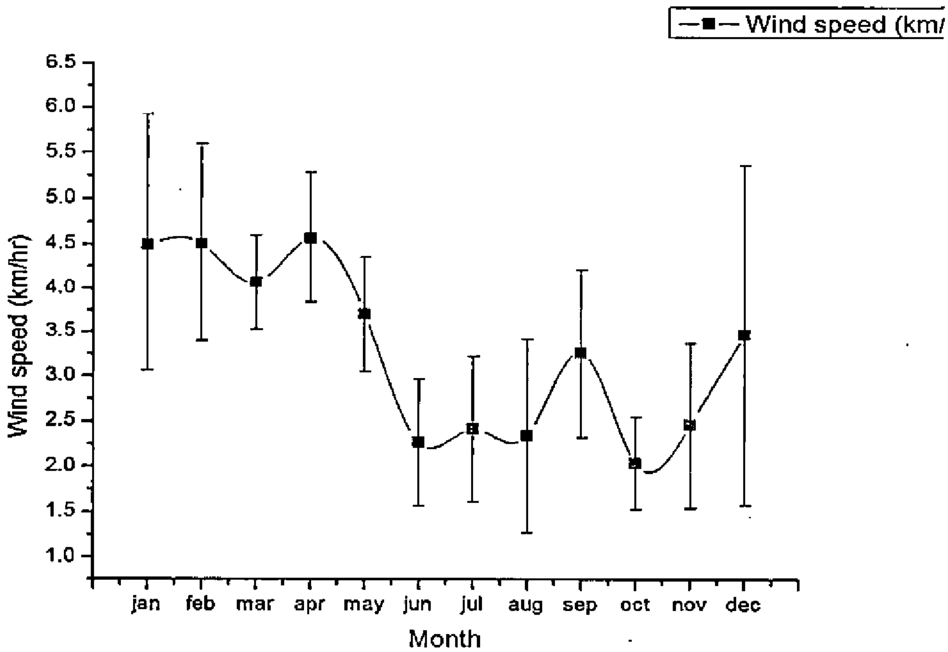

Fig.6. Monthly wind speed (km hr^{-1}) of Pattambi (1983-2012)

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 Split plot design with three replications. The Main plot treatments consists of three dates of planting i.e., 1^{st}, 15^{th} and 30^{th} of January (Puncha), June (Virippu) and October (Mundakan) and two varieties i.e. Aathira and Vaisakh as subplot treatments. Treatments and notations were given in the Table 2. The plot size was 40 $m^2$and the spacing adopted was 20 cm × 15 cm. The experiment was replicated three times with total experimental plots of 54.

3.2.1 Cultural operations

3.2.1.1 *Nursery management*

Nurseries were raised prior to each 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 *Land preparation*

The experimental area was cleared off. The land was ploughed well and the soil was brought to puddled condition.

3.2.1.3 *Application of manures and fertilizers*

Farm yard manure at the rate of 5000 kg ha^{-1} was incorporated into the field at the time of land preparation. Urea, Phosphate and Muriate of Potash were used as fertilizers to supply the required amount of nutrients (90 N: 45 P_2O_5: 45 K_2O kg ha^{-1}). The entire dose of P_2O_5, half dose of N and K_2O were applied as basal and the remaining fertilizers were top dressed at 30 days after transplanting.

Table 2.Treatments and notations

Sl.No.	Main plot Treatment	Sub plot Treatment	Notation	Seasons
1	June 1st	Aathira	T1V1	
		Vaisakh	T1V2	
2	June 15th	Aathira	T2V1	First season
		Vaisakh	T2V2	(*Virippu*)
3	June 30th	Aathira	T3V1	
		Vaisakh	T3V2	
4	October 1st	Aathira	T4V1	
		Vaisakh	T4V2	
5	October 15th	Aathira	T5V1	Second season
		Vaisakh	T5V2	(*Mundakan*)
6	October 30th	Aathira	T6V1	
		Vaisakh	T6V2	
7	January 1st	Aathira	T7V1	
		Vaisakh	T7V2	
8	January 15th	Aathira	T8V1	Third season
		Vaisakh	T8V1	(*Puncha*)
9	January 30th	Aathira	T9V1	
		Vaisakh	T9V2	

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

Observations on growth and yield parameters were recorded on randomly selected plants in each replication for each treatment after leaving the three border rows. 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 was computed at weekly intervals. Two sample hills were randomly selected in each plot and number of tillers was counted in each hill. The length and maximum width of leaves in the middle tiller of the sample hills were measured separately and leaf area was computed based on length- width method.

$$\text{Leaf area} = L \times W \times K$$, where

K is the Adjustment factor (0.75), L is the length and W is the width (Gomez, 1972). The leaf area index was calculated using the following formulae.

$$\text{Leaf area per hill} = \text{Total area of middle tiller} \times \text{Total number of tillers}$$

$$\text{LAI} = \frac{\text{Sum of leaf area per hill of "n" sample hill } (cm^2)}{\text{Area of land covered by "n" hills } (cm^2)}$$

3.3.1.3 *Dry matter accumulation*

Biomass production was also estimated at weekly intervals. Two sample hills were selected randomly and uprooted from the sampling row. Thereafter, samples were first sun dried and then oven dried to a temperature of 80°C to constant weight and biomass was recorded in gram per plant.

3.3.1.4 *Number of panicles per unit area*

Number of panicles per unit area was recorded.

3.3.1.5 *Number of spikelets per panicle*

Number of spikelets per panicles was recorded.

3.3.1.6 *Number of filled grains per panicle*

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

3.3.1.7 *1000 grain weight*

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

3.3.1.8 *Straw yield*

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

3.3.1.9 *Grain yield*

The grain harvested was dried, weighed and expressed in t 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.

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 booting*

Number of days taken for booting was recorded from each treatment.

3.3.2.4. *Days taken for heading*

The duration from transplanting to heading was recorded.

3.3.2.5. *Days taken for 50 per cent flowering*

Days taken for 50 per cent flowering were recorded.

3.3.2.6. *Days taken for physiological maturity*

Number of days taken for physiological maturity was recorded.

3.3.2.7. *Days taken for harvesting*

Days taken for harvesting after transplanting were recorded.

3.4 WEATHER OBSERVATIONS

The data on the different weather elements were collected from the Agromet observatory of RARS, Pattambi.

Table 3.Weather parameters used in the experiment

Sl .No.	Weather parameter	Unit
1	Maximum temperature (Tmax)	°C
2	Minimum temperature (Tmin)	°C
3	Rainfall (RF)	mm
4	Forenoon relative humidity (RH I)	Per cent (%)
	Afternoon relative humidity (RH II)	
5	Bright Sunshine hours (BSS)	hrs
6	Wind speed (WS)	km hr^{-1}
7	Evaporation (EVP)	mm

3.5. SOIL DATA

The result of soil analysis of experimental site was presented in table.

Table 4. Soil analysis of the experimental site

Sl.No	Parameter	Availability
1	Organic carbon (Per cent)	1.00
2	Available Phosphorous (kg ha^{-1})	16.50
3	Exchangeable Potassium (kg ha^{-1})	117.60
4	Available Nitrogen(Per cent)	2.50

3.6. STATISTICAL ANALYSIS

The data recorded from the field experiment was analyzed statistically using Analysis of variance technique. Split plot design was used in the analysis of weather and crop data.

Correlation and regression analysis were done between the growth and yield characters with the weekly mean/total values of rainfall, maximum temperature, minimum temperature, relative humidity and sunshine hours 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 has been used in this study to model the effect of weather parameters on crop growth and yield. 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 simulation of rice growth was performed with the CERES-Rice. Model developed by the International Benchmark Sites Network for Agrotechnology 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 co-efficients 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.
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 ≥ 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(a)) 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

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 experiments carried out with rice cultivars Aathira and Vaisakh under nine dates of sowing were used for estimating the genetic parameters. 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.

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

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

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 humankind responds. 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 characterised 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 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 Organization 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

Results

4. RESULTS

The results of the experiment entitled "Impact of climate change on rice production" are presented in this chapter. The effect of different weather parameters on growth and yield of different varieties i.e. Aathira and Vaisakh were studied. The Crop simulation model DSSAT-developed by IBSNAT was validated for both varieties and used for studying the impact of climate change based on IPCC projections for the year 2030, 2050 and 2080 under different Representative Concentration Pathways (RCP 2.6, 4.5, 6.0 and 8.5).

4.1 WEATHER DURING THE CROP PERIOD

The daily weather parameters viz., maximum and minimum temperatures, rainfall, morning and afternoon relative humidity, wind speed and Bright sunshine hours recorded at Agro-meteorological observatory, Regional Agricultural Research Station, Pattambi were used for the study and the weekly mean of the weather variables are depicted in Table 8.

The highest weekly temperature recorded during the first, second and third crop seasons were 33.6, 33.7 and 38.6°C respectively. The lowest weekly temperature recorded during the first, second and third crop seasons were 22.8, 19.3 and 18.1°C respectively. Maximum morning Relative humidity during the first, second and third crop season was 95.7, 96.1 and 90.4 per cent respectively. Lowest morning Relative humidity during the first, second and third crop season was 91.9, 84.4 and 71.0 per cent respectively. The highest afternoon Relative humidity during the first, second and third crop season was 95.0, 73.7 and 52.4 per cent respectively. The lowest afternoon Relative humidity during the first, second and third crop season was 64.6, 43.1 and 21.9 per cent respectively. Highest wind speed in the entire crop growing season was 7.6 km $hr^{-1}$and the lowest is 1.3 km hr^{-1}. Average wind speed is 3.4 km hr^{-1}. A total rainfall of 2534mm recorded during the entire year out of which 2040.7 mm was recorded in the first crop season. Second and third crop seasons were recorded 450.8 and 28 mm of rainfall respectively. Total evaporation is 1440.7 mm and the average weekly evaporation is 25.3 mm.

4.2. BIOMETRIC OBSERVATIONS

4.2.1 Plant height

The weekly mean plant height was given in the Table 9. In all the dates of planting variety Vaisakh recorded the highest plant height compared to Aathira. In both the varieties, crops planted during June 1st, June 15th, June 30th and Oct 1st recorded the highest plant height (145.33, 145.33, 145.00 and 145.33 for Vaisakh and 133, 133, 133 and 133 for Aathira). The effect of weather on plant height varied significantly with the varieties (Table.9).

4.2.2 Biomass accumulation (g plant^{-1})

The effect of weather on biomass accumulation has varied with variety significantly. During the first crop season both Aathira and Vysakh recorded the highest biomass during the 13th week after transplanting. However, during second and third crop seasons, the highest biomass was recorded in the 12th week after planting. The highest biomass accumulation was recorded in variety Vaisakh planted on 15th Oct (64.33 g) (Table.10).

4.2.3 Number of tillers

Crops transplanted during first crop season (June planting) recorded the highest number of tillers per plant for both Aathira and Vaisakh. In Vaisakh maximum number of tillers per plant was observed (22.33) in the crop transplanted during Jan 1st, whereas in case of Aathira crops planted during June 1st (20) and June 30th (20) recorded the maximum number of tillers (Table 11).

The effect of weather on number of tillers varied significantly with the variety. Variety Vaisakh was superior to Aathira in all the treatments.

4.2.4. Leaf Area Index (LAI)

The effect of weather on LAI significantly varied with the variety. During second and third crop seasons, crop has attained maximum LAI during flowering stage. But in first crop season, crop has attained maximum LAI during grain filling stage. The maximum LAI recorded by the variety Vaisakh was 9.96 and Aathira was 9.36 in the crop transplanted on June 15th (Table 12).

Table 8. Weekly weather variables during the study period

WeeK NO.	Max temp	Min temp	RH I	RH II	Wind	Rainfall	BSH	Evaporation
1	33.1	20.0	82.7	45.6	4.7	0.0	8.6	34.1
2	33.4	22.6	77.6	38.4	5.2	0.0	7.9	35.1
3	33.5	21.6	71.1	37.6	5.5	0.0	7.7	38.4
4	33.0	22.5	71.0	38.0	7.6	0.0	8.6	48.5
5	33.9	21.1	71.1	42.7	7.0	0.0	9.2	40.2
6	35.7	18.1	90.4	39.3	3.6	0.0	8.9	36.2
7	33.9	21.1	90.4	47.9	2.9	0.0	7.4	33.4
8	35.3	23.0	83.1	43.4	5.5	4.2	6.7	39.8
9	35.7	23.5	85.1	50.0	5.6	0.0	8.6	47.7
10	35.4	23.9	76.6	43.9	5.4	0.0	7.0	43.9
11	38.1	20.7	75.7	21.9	5.1	0.0	9.6	50.5
12	37.9	24.4	85.0	29.0	3.3	0.0	9.0	44.5
13	38.6	23.6	82.9	34.1	3.6	0.0	8.9	46.6
14	36.8	25.5	83.3	50.4	3.5	0.0	7.5	38.9
15	35.3	24.1	86.7	51.3	2.8	22.6	5.3	28.7
16	35.9	25.5	85.7	49.0	3.0	1.2	8.0	38.5
17	36.1	26.2	85.0	52.4	3.0	0.0	4.9	36.6
18	35.9	24.7	81.0	47.0	3.6	0.0	7.8	10.6
22	33.3	24.8	93.0	65.4	2.5	45	5.1	18.8
23	31.1	24.2	92.0	77.1	2.2	58.6	4.3	36.2
24	31.1	24.1	93.3	73.6	2.4	181.9	4.2	27.1
25	30.7	24.1	94.3	75.4	3.0	170.1	3.2	16.9
26	31.6	24.3	93.6	68.0	2.7	180	5.8	14.7
27	31.5	23.6	91.9	91.9	3.2	44.1	5.3	11.7
28	28.6	23.0	95.0	95.0	2.7	5.1	0.7	11.3
29	29.8	23.2	94.1	83.4	2.4	208.4	2.1	16.6
30	30.1	23.2	94.0	78.7	2.6	136.8	1.8	10
31	28.6	22.9	95.7	85.9	2.2	356.9	0.8	21
32	28.8	22.8	95.2	79.6	1.9	63.3	0.7	10
33	30.9	24.2	92.9	64.6	2.6	18.3	6.3	12.1
34	31.7	23.4	94.3	70.4	2.3	108.4	5.5	7.4
35	26.8	22.9	95.6	77.6	2.8	162.7	2.6	10.5

36	30.3	23.0	93.6	73.0	2.2	38.9	4.6	21.3
37	31.3	23.1	94.0	67.7	2.9	21.1	7.8	19.3
38	31.4	23.7	93.6	66.0	2.9	0.6	7.9	8.8
39	33.6	23.2	92.9	68.6	2.5	80.2	6.7	16.7
40	32.2	23.7	94.2	73.7	1.8	80.7	5.3	24.2
41	30.8	24.4	95.0	72.7	1.6	79.6	5.1	26.7
42	32.9	23.1	93.6	67.6	1.9	137.0	5.4	14.9
43	32.2	23.6	92.7	62.1	2.4	43.3	5.4	4.9
44	32.3	24.8	93.4	61.7	1.3	83.9	4.7	15.4
45	32.8	22.6	96.0	62.0	1.5	18.5	5.9	16.9
46	32.5	23.0	91.4	54.0	4.6	5.4	7.5	22.6
47	32.3	21.9	89.1	54.9	3.0	2.4	5.7	16.3
48	30.9	20.9	85.7	58.6	2.4	0	2.4	26
49	33.0	20.8	86.0	60.4	3.3	0	7.7	27.7
50	33.7	22.3	89.4	56.6	3.2	0	6.9	21.2
51	32.4	22.9	86.6	61.6	6.8	0	5.8	13.2
52	32.2	22.1	88.0	62.6	2.8	0	5.2	23.1
1	33.3	20.4	96.1	53.0	2.0	0.0	8.1	22
2	32.8	19.3	84.4	45.1	4.0	0.0	8.2	28.7
3	33.4	19.9	69.9	43.1	4.7	0.0	8.4	21.2
4	33.3	20.6	86.1	55.6	5.5	0.0	8.6	23.7
5	33.2	21.6	85.3	67.0	4.8	0.0	8.0	28.5

Table 9. Plant height (cm) at weekly intervals

Variety	Treatment	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9	Week10	Week11	Week12	Week13
Aathira	T_1	17.00^{b}	17.50^{d}	18.33^{f}	21.00^{g}	30.00^{f}	66.00^{e}	73.66^{f}	76.00^{f}	103.00^{e}	110.33^{e}	120.00^{d}	125.33^{ef}	133.00^{f}
	T_2	17.00^{b}	17.00^{e}	18.33^{f}	38.00^{c}	52.33^{b}	70.00^{d}	79.22^{e}	98.66^{b}	103.00^{e}	110.33^{e}	120.00^{d}	125.33^{ef}	133.00^{f}
	T_3	16.00^{d}	16.50^{f}	18.00^{f}	18.00^{h}	30.00^{f}	70.00^{d}	73.66^{f}	75.00^{f}	101.00^{f}	110.00^{e}	120.00^{d}	130.00^{d}	133.00^{f}
	T_4	17.00^{b}	17.50^{d}	18.00^{f}	21.00^{g}	30.00^{f}	65.00^{ef}	73.66^{f}	76.00^{f}	103.00^{e}	114.00^{d}	120.00^{d}	125.00^{ef}	133.00^{f}
	T_5	15.86^{d}	16.15^{fg}	25.35^{bc}	41.00^{ab}	48.33^{c}	69.33^{de}	79.66^{e}	88.00^{d}	101.33^{f}	117.00^{c}	121.00^{d}	126.33^{ef}	128.00^{g}
	T_6	18.06^{a}	19.13^{b}	26.36^{b}	30.20^{f}	40.93^{e}	63.00^{ef}	73.00^{f}	74.00^{f}	89.00^{h}	115.00^{d}	120.00^{d}	125.00^{ef}	128.00^{g}
	T_7	18.26^{a}	20.40^{a}	25.35^{bc}	30.37^{f}	41.83^{e}	62.11^{f}	72.99^{f}	74.90^{f}	90.33^{h}	91.66^{f}	98.64^{f}	117.50^{f}	117.50^{h}
	T_8	16.57^{c}	19.01b^{e}	24.62^{c}	35.75^{d}	44.42^{d}	62.23^{f}	84.00^{d}	84.00^{e}	85.66^{i}	94.66^{f}	117.00^{e}	117.00^{f}	117.00^{h}
	T_9	15.97^{d}	16.28^{fg}	25.53b^{c}	40.96^{ab}	48.00^{c}	67.33^{de}	78.33^{e}	82.33^{e}	96.33^{g}	95.00^{f}	98.00^{f}	117.00^{f}	117.00^{h}
Vaisakh	T_1	16.00^{d}	16.00^{g}	21.00^{e}	30.66e^{f}	48.33^{c}	65.00^{ef}	78.66^{e}	98.00^{bc}	110.66^{d}	133.00^{a}	136.66^{b}	140.00^{b}	145.33^{a}
	T_2	16.00^{d}	16.00^{g}	21.00^{e}	43.00^{a}	53.33^{b}	76.66^{c}	99.66^{b}	102.00^{b}	110.66^{d}	133.00^{a}	136.66^{b}	140.00^{b}	145.33^{a}
	T_3	16.00^{d}	16.00^{g}	21.00^{e}	30.00^{f}	48.00^{c}	65.00^{ef}	78.00^{e}	98.00^{bc}	111.00^{d}	133.00^{a}	136.00^{b}	140.00^{b}	145.00^{a}
	T_4	16.00^{d}	16.00^{f}	21.00^{e}	30.66^{ef}	48.33^{c}	65.00^{ef}	78.66^{e}	98.00^{bc}	110.66^{d}	133.00^{a}	136.66^{b}	140.00^{b}	145.33^{a}
	T_5	13.90^{e}	16.06^{g}	26.13^{b}	40.00^{b}	57.00^{a}	89.00^{a}	115.00^{a}	116.00^{a}	120.00^{b}	134.00^{a}	134.00^{bc}	142.00^{a}	142.00^{b}
	T_6	14.12^{e}	18.62^{c}	27.85^{a}	31.94^{e}	48.27^{c}	69.01^{de}	78.22^{c}	94.77^{c}	117.23^{c}	122.5^{b}	133.00^{c}	135.00^{c}	139.00^{c}
	T_7	14.12^{e}	18.62^{c}	27.85^{a}	31.94^{e}	48.27^{c}	69.01^{de}	78.22^{e}	94.77^{c}	117.23^{c}	122.50^{b}	133.00^{c}	135.00^{c}	135.00^{e}
	T_8	14.00^{e}	17.76^{d}	23.22^{d}	42.36^{a}	46.44^{cd}	65.30^{ef}	89.00^{c}	115.66^{a}	124.33^{a}	134.00^{a}	139.66^{a}	139.66^{b}	136.66^{d}
	T_9	14.00^{c}	16.17^{fg}	26.44^{b}	40.33^{b}	56.66^{a}	86.33^{b}	115.00^{a}	116.33^{a}	119.66^{b}	134.00^{a}	135.33^{b}	141.66^{a}	136.66^{d}
	CD	0.24	0.43	0.919	1.526	2.88	3.427	2.79	3.367	1.36	1.807	1.514	1.425	0.85

Table 10. Biomass accumulation (g plant^{-1}) at weekly intervals

Variety	Treatment	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9	Week10	Week11	Week12	Week13
Aathira	T_1	0.09a	0.14^{b}	0.50^{bc}	$0.72d^{e}$	3.35^{c}	3.50e	8.20^{cd}	9.46^{e}	22.86^{c}	17.50^{de}	24.59^{fg}	27.47^{d}	39.34^{cd}
	T_2	0.08b	0.14^{b}	0.50^{bc}	2.75^{a}	2.86^{c}	3.60e	8.96^{cd}	10.76^{de}	$27.00b^{c}$	16.20^{e}	23.60^{fg}	27.00^{d}	40.13^{c}
	T_3	0.09a	0.15^{b}	0.51^{bc}	0.94^{d}	3.75^{bc}	3.50e	9.50^{cd}	11.20^{de}	$24.33b^{c}$	28.00^{cd}	30.13^{ef}	32.76^{c}	40.13^{c}
	T_4	0.08b	0.13^{b}	0.63^{b}	0.96^{d}	3.73^{bc}	3.53e	7.63^{d}	9.82^{de}	$25.35b^{c}$	28.90^{cd}	35.04^{e}	44.42^{b}	46.68^{bc}
	T_5	0.06d	0.15^{b}	0.55^{b}	1.40^{c}	2.57^{d}	9.89c	15.83^{b}	21.23^{bc}	29.30^{b}	31.09^{c}	45.83^{d}	53.67^{ab}	53.36^{a}
	T_6	0.08b	0.21^{ab}	0.89^{a}	1.26^{cd}	4.07^{b}	12.06b	$15.22b^{c}$	16.80^{cd}	29.86^{b}	38.00^{b}	57.10^{b}	52.66^{ab}	45.50^{bc}
	T_7	0.09a	0.14^{b}	0.50^{bc}	1.02^{cd}	3.62^{bc}	10.08c	7.84^{cd}	18.03^{c}	23.04^{c}	23.09^{d}	37.49^{de}	39.47^{bc}	36.56^{cd}
	T_8	0.09a	0.15^{b}	0.49^{bc}	1.38^{c}	4.08^{b}	7.85d	10.49^{cd}	17.76^{c}	$23.86b^{c}$	26.05^{cd}	46.68^{cd}	37.46^{c}	36.33^{cd}
	T_9	0.06d	0.15^{b}	0.45^{c}	1.40^{c}	2.41^{d}	8.88cd	11.68^{c}	13.33^{d}	22.74^{c}	25.99^{cd}	37.05^{de}	43.18^{b}	43.09^{bc}
Vaisakh	T_1	0.07c	0.11^{b}	0.48^{bc}	$0.79d^{e}$	2.80^{cd}	3.90e	8.13^{cd}	11.35^{de}	19.79^{cd}	16.87^{de}	25.86^{fg}	24.03^{d}	41.86^{bc}
	T_2	0.06d	0.11^{b}	0.47^{bc}	2.36^{b}	2.93^{cd}	3.56e	8.00^{cd}	13.36^{d}	19.76^{cd}	19.56^{de}	28.63^{fg}	32.93^{c}	42.50^{bc}
	T_3	0.05e	0.11^{b}	0.50^{bc}	$1.03c^{d}$	2.80^{cd}	3.80e	9.70^{cd}	12.42^{de}	17.49^{d}	17.23^{e}	21.83^{g}	23.63^{d}	36.46^{cd}
	T_4	0.07c	0.11^{b}	0.48^{bc}	$1.03c^{d}$	2.70^{cd}	3.96e	9.96^{cd}	12.68^{de}	18.82^{cd}	35.50^{bc}	44.92^{d}	49.16^{ab}	36.30^{cd}
	T_5	0.07c	0.08^{b}	0.40^{cd}	0.54^{e}	4.65^{b}	19.96a	34.90^{a}	42.50^{a}	40.76^{a}	45.10^{a}	64.33^{a}	54.40^{a}	43.33^{bc}
	T_6	0.06d	0.09^{b}	0.46^{bc}	0.98^{d}	5.59^{a}	9.74^{c}	12.77^{bc}	21.89^{b}	28.30^{b}	38.00^{b}	42.44^{d}	51.34^{ab}	44.16^{bc}
	T_7	0.06d	0.09^{b}	0.46^{bc}	0.98^{d}	5.59^{a}	9.74^{c}	10.47^{cd}	21.89^{b}	27.70^{b}	26.95^{cd}	42.44^{dd}	51.16^{ab}	44.12^{bc}
	T_8	0.06d	0.07^{b}	0.34^{d}	1.73^{c}	6.10^{a}	10.22^{c}	15.92^{b}	24.00^{b}	30.73^{b}	40.01^{b}	38.98^{de}	34.67^{c}	34.67^{d}
	T_9	0.06d	0.36^{a}	0.42^{cd}	$0.87d^{e}$	4.23^{b}	11.79^{b}	17.80^{b}	23.25^{b}	29.75^{b}	40.17^{b}	44.36^{d}	46.86^{b}	40.28^{bc}
	CD	0.001	0.19	0.08	0.37	0.70	1.33	3.87	3.55	4.54	6.38	5.48	7.76	5.37

Table 11. Number of tillers per plant at weekly intervals

Variety	Treatment	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9	Week10	Week11	Week12	Week13
Aathira	T_1	2.00^{b}	3.00^{c}	4.00^{cd}	10.00^{b}	10.00^{d}	9.00^{e}	10.00^{d}	12.66^{cd}	15.00^{b}	12.00^{bc}	19.33^{a}	20.00^{a}	19.00^{b}
	T_2	2.00^{b}	3.00^{c}	5.66^{b}	6.66^{cd}	7.00^{f}	9.33^{de}	12.00^{cd}	15.33^{bc}	18.33^{a}	19.66^{a}	18.33^{a}	18.33^{a}	15.66^{c}
	T_3	2.00^{b}	3.00^{c}	4.00^{cd}	10.00^{b}	10.00^{d}	9.00^{e}	10.00^{d}	13.00^{c}	15.00^{b}	12.00^{bc}	19.00^{a}	20.00^{a}	19.00^{b}
	T_4	2.00^{b}	2.00^{d}	4.00^{cd}	4.00^{e}	11.00^{d}	10.00^{de}	13.00^{bc}	10.00^{d}	13.66^{bc}	13.66^{b}	16.00^{ab}	16.00^{ab}	13.00^{d}
	T_5	2.00^{b}	5.00^{a}	8.00^{a}	12.66^{a}	16.66^{b}	12.66^{c}	16.00^{b}	12.66^{cd}	12.66^{bc}	11.66^{bc}	11.00^{c}	9.66^{d}	9.33^{f}
	T_6	2.00^{b}	2.00^{d}	3.00^{d}	4.00^{e}	15.00^{bc}	18.00^{a}	18.00^{ab}	18.00^{b}	17.00^{ab}	10.00^{c}	12.00^{bc}	11.33^{cd}	11.33^{e}
	T_7	3.00^{a}	3.00^{c}	3.33^{cd}	5.33^{de}	14.33^{c}	19.00^{a}	18.00^{ab}	21.66^{a}	16.66^{ab}	11.33^{bc}	14.33^{b}	14.33^{bc}	12.33^{de}
	T_8	3.00^{a}	3.00^{c}	3.66^{cd}	8.00^{c}	16.33^{b}	13.67^{bc}	16.00^{b}	10.66^{cd}	13.33^{bc}	15.66^{ab}	12.33^{bc}	13.00^{c}	11.33^{e}
	T_9	3.00^{a}	3.00^{c}	8.00^{a}	14.00^{a}	17.33^{b}	13.00^{bc}	16.00^{b}	16.00^{bc}	17.00^{ab}	11.66^{bc}	11.00^{c}	11.33^{cd}	11.33^{e}
Vaisakh	T_1	2.66^{a}	2.66^{c}	3.00^{d}	4.00^{e}	8.00^{e}	10.66^{d}	11.00^{cd}	11.33^{cd}	13.00^{bc}	15.66^{ab}	17.66^{a}	17.66^{ab}	20.00^{ab}
	T_2	2.66^{a}	2.66^{c}	3.00^{d}	4.33^{de}	5.00^{g}	5.00^{f}	11.00^{cd}	11.33^{cd}	12.33^{bc}	16.33^{ab}	17.66^{a}	20.00^{a}	21.33^{a}
	T_3	2.33^{ab}	2.33^{cd}	3.00^{d}	4.00^{e}	8.00^{e}	10.00^{de}	11.00^{cd}	11.00^{cd}	12.66^{bc}	16.00^{ab}	18.00^{a}	18.00^{ab}	20.00^{ab}
	T_4	2.00^{b}	2.00^{d}	3.00^{d}	4.00^{e}	8.00^{e}	11.00^{d}	12.66^{c}	20.00^{ab}	12.00^{bc}	14.00^{b}	14.00^{b}	13.00^{c}	10.00^{ef}
	T_5	2.00^{b}	5.00^{a}	6.00^{b}	9.00^{bc}	14.00^{c}	12.00^{cd}	15.00^{b}	20.00^{ab}	13.00^{bc}	12.00^{bc}	12.00^{bc}	11.00^{cd}	11.00^{e}
	T_6	2.00^{b}	2.00^{d}	3.66^{cd}	4.66^{de}	16.33^{b}	14.33^{b}	18.66^{a}	20.33^{ab}	13.00^{bc}	13.33^{bc}	14.00^{b}	15.00^{b}	13.33^{d}
	T_7	2.66^{a}	4.00^{b}	4.33^{c}	6.66^{cd}	16.33^{b}	14.33^{b}	20.33^{a}	22.33^{a}	16.66^{ab}	14.33^{b}	15.33^{b}	17.00^{ab}	12.33^{de}
	T_8	2.66^{a}	4.00^{b}	4.33^{c}	6.00^{d}	20.33^{a}	15.66^{b}	18.66^{a}	13.33^{c}	19.66^{a}	13.00^{bc}	14.33^{b}	13.33^{c}	13.33^{d}
	T_9	2.67^{a}	4.00^{b}	6.33^{b}	9.00^{bc}	14.33^{c}	12.66^{c}	15.33^{b}	11.00^{cd}	14.33^{b}	12.33^{bc}	11.66^{c}	10.33^{d}	10.33^{ef}
	CD	0.57	0.46	1.23	1.86	1.70	1.34	2.20	2.73	2.85	3.39	2.10	2.21	1.65

Table 12. Leaf Area Index at weekly intervals

Variety	Treatment	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9	Week10	Week11	Week12	Week13
Aathira	T_1	0.03^{ab}	0.10^{ab}	0.12^{NS}	0.56bc	1.76^{e}	1.90^{f}	3.52^{h}	3.55^{h}	6.56^{c}	8.14^{b}	8.12^{d}	9.20^{b}	8.80^{ab}
	T_2	0.03^{ab}	0.10^{ab}	0.13^{NS}	0.86b	1.30^{f}	1.58^{f}	1.66^{j}	3.70^{h}	4.90^{d}	7.96^{b}	8.07^{d}	9.36^{ab}	8.56^{b}
	T_3	0.03^{ab}	0.10^{ab}	0.13^{NS}	0.57bc	1.76^{e}	2.00^{f}	3.46^{h}	3.60^{h}	6.94^{bc}	7.10^{c}	8.06^{d}	8.93^{bc}	8.56^{b}
	T_4	0.03^{ab}	0.11^{ab}	0.18^{NS}	0.80b	1.60^{ef}	2.60^{e}	3.76^{h}	4.80^{g}	7.13^{bc}	8.03^{b}	8.66^{c}	8.56^{cd}	7.90^{c}
	T_5	0.037^{a}	0.22^{a}	0.36^{NS}	1.35a	3.09^{c}	5.47^{b}	6.90^{c}	6.78^{e}	8.30^{ab}	7.02^{c}	6.20^{f}	4.61^{ef}	3.33^{f}
	T_6	0.041^{a}	0.16^{ab}	0.16^{NS}	0.59bc	2.68^{cd}	5.28^{b}	6.37^{d}	7.58^{d}	8.30^{ab}	5.28^{e}	5.15^{h}	4.57^{ef}	2.96^{h}
	T_7	0.035^{ab}	0.043^{b}	0.13^{NS}	0.65bc	2.36^{d}	4.56^{c}	6.08^{d}	8.07^{c}	8.28^{ab}	5.85^{e}	5.57^{gh}	4.87^{e}	3.23^{fg}
	T_8	0.038^{a}	0.048^{b}	0.20^{NS}	0.91b	1.89^{de}	3.86^{d}	4.93^{f}	6.81^{e}	8.17^{ab}	6.22^{d}	5.97^{fg}	4.73^{e}	3.10^{fg}
	T_9	0.033^{ab}	0.045^{b}	0.04^{NS}	1.35a	2.88^{c}	5.28^{b}	7.19^{b}	6.5^{e}	6.53^{c}	6.25^{d}	6.20^{f}	4.15^{f}	3.13^{fg}
Vaisakh	T_1	0.02^{b}	0.10^{ab}	0.15^{NS}	0.45^{c}	1.30^{f}	1.51^{f}	5.36^{e}	5.18^{fg}	8.95^{a}	9.55^{a}	9.89^{a}	9.79^{a}	8.93^{a}
	T_2	0.02^{b}	0.10^{ab}	0.15^{NS}	1.05^{ab}	1.43^{ef}	1.85^{f}	2.50^{i}	5.18^{fg}	7.62^{b}	9.25^{a}	9.73^{a}	9.96^{a}	9.23^{a}
	T_3	0.02^{b}	0.10^{ab}	0.16^{NS}	0.45^{6c}	1.30^{f}	1.52^{f}	5.38^{e}	5.12^{fg}	9.20^{a}	9.60^{a}	9.81^{a}	9.76^{a}	8.90^{ab}
	T_4	0.02^{b}	0.10^{ab}	0.15^{NS}	0.50^{bc}	1.46^{ef}	1.53^{f}	4.43^{g}	4.90^{fg}	9.14^{a}	8.40^{ab}	9.06^{bc}	8.20^{d}	6.53^{d}
	T_5	0.02^{b}	0.043^{b}	0.34^{NS}	1.06^{ab}	4.41^{a}	6.13^{a}	8.76^{a}	8.44^{b}	7.93^{b}	7.37^{bc}	6.46^{f}	8.20^{d}	3.76^{e}
	T_6	0.049^{a}	0.067^{b}	0.15^{NS}	0.78^{bc}	2.32^{d}	5.39^{b}	7.46^{b}	9.58^{a}	9.59^{a}	7.22^{c}	7.09^{e}	4.06^{fg}	$3.30f^{g}$
	T_7	0.049^{a}	0.054^{b}	0.15^{NS}	0.78^{bc}	2.32^{d}	5.39^{b}	7.46^{b}	9.58^{a}	9.59^{a}	7.22^{c}	7.09^{e}	4.87^{e}	3.36^{f}
	T_8	0.046^{a}	0.052^{b}	0.18^{NS}	1.02^{ab}	3.86^{b}	5.10^{bc}	8.56^{a}	9.38^{a}	7.95^{b}	7.39^{bc}	7.18^{e}	4.52^{ef}	3.56^{ef}
	T_9	0.032^{ab}	0.042^{b}	0.05^{NS}	0.86^{b}	3.56^{b}	5.71^{ab}	8.59^{a}	7.89^{cd}	7.56^{b}	7.39^{bc}	6.34^{f}	3.56^{g}	3.26^{fg}
	CD	0.016	0.136	0.36	0.404	0.382	0.573	0.405	0.33	0.99	0.72	0.50	0.50	0.35

4.3 YIELD ATTRIBUTES

4.3.1 Number of panicles per m^2

Among all the treatments variety Vaisakh transplanted on January 1st recorded significantly highest number of panicles per plant (357.00), whereas highest number of panicles observed in October 30th transplanted crop (347.00) in case of Aathira. Number of panicles per plant has significantly varied by the date of planting and the variety (Table 13).

During the first crop season, number of panicles per plant was high for variety Aathira compared to Vaisakh. But in third crop season, the number of panicles per plant was more in Vaisakh compared to Aathira.

4.3.2 Number of filled grains per panicle

Number of filled grains per panicle has varied significantly with changes in dates of planting and the impact was different for different varieties (Table 14). The highest number of filled grains per panicle was observed in June 30th planted crop of Vaisakh (147.3) and it was on par with the June 15th (129.8), October 1st (132.0), October 15th (136.6), October 30th (139.9) planted crops of Vaisakh and June 15th (141.7), October 15th (137.1), October 30th (131.1) planted crops of variety Aathira. Lowest panicle number was observed in January 30th transplanted crop of Aathira (99.73).

4.3.4 Grain yield

It can be observed from Table 13, that both the varieties performed differently with changes in the weather factors. The highest yield of Vaisakh was recorded by the crop planted on January 1st (6.30 t ha^{-1}), whereas in Aathira crop planted on October 30th (5.86 t ha^{-1}) recorded the highest yield. Here we can observe that both the varieties were performing differently with the change in the environment. In the first season, yield of Aathira was high compared to Vaisakh. In third crop season, variety Vaisakh performed better. During the second crop season, the performance of both the varieties was on par.

Table 13.Yield components

Treatment	Grain yield (t ha^{-1})		Straw yield (t ha^{-1})		Harvest index (%)		Number of Filled grains Panicle^{-1}		Number of panicles m^{-2}	
	Aathira	Vaisakh	Aathira	Vaisakh	Aathira	Vaisakh	Aathira	Vaisakh	Aathira	Vaisakh
T1	5.39^{c}	4.74^{d}	7.86^{a}	6.70^{bc}	40.69^{cd}	41. 44^{cd}	120.9^{ab}	102.7^{bc}	315.00^{g}	282.00^{n}
T2	5.03^{cd}	4.82^{d}	7.86^{a}	7.03^{b}	39.05^{cd}	40.68^{cd}	141.7^{a}	129.8^{a}	298.00^{j}	291.00^{k}
T3	5.34^{c}	5.01^{cd}	7.53^{ab}	7.80^{a}	41.67^{cd}	39.13^{cd}	127.2^{ab}	147.3^{a}	310.00^{h}	298.00^{j}
T4	5.20^{c}	5.40^{c}	6.73^{bc}	6.40^{bc}	43.63^{bc}	45.76^{b}	121.3^{ab}	132.0^{a}	316.00^{f}	323.00^{e}
T5	5.42^{c}	5.46^{c}	7.06^{b}	6.40^{bc}	43.45^{bc}	46.04^{b}	137.1^{a}	136.6^{a}	306.00^{i}	325.00^{d}
T6	5.86^{b}	5.50^{c}	6.90^{bc}	6.80^{bc}	45.95^{b}	44.71^{bc}	131.1^{a}	139.9^{a}	347.00^{b}	341.05^{c}
T7	5.26^{c}	6.30^{a}	7.53^{ab}	6.50^{bc}	41.11^{bc}	49.12^{a}	85.80^{c}	116.6^{ab}	306.00^{i}	357.00^{a}
T8	4.99^{cd}	4.93^{cd}	6.33^{c}	6.80^{bc}	44.12^{bc}	42.02^{c}	110.0^{b}	109.3^{b}	289.00^{l}	286.00^{m}
T9	4.93^{cd}	4.74^{d}	6.30^{c}	6.90^{bc}	43.93^{bc}	45.02^{b}	99.73^{bc}	109.2^{b}	273.00^{p}	275.00^{o}
CD	0.38		0.60		2.89		18.04		-	

4.3.5 Straw yield

The highest straw yield has recorded by the variety Aathira transplanted during June 1st (7.86 t ha^{-1}) that was on par with June 15th and June 30th transplanted crop of Vaisakh (7.80 t ha^{-1}). Lowest straw yield was observed in Aathira transplanted on January 30th (6.30 t ha^{-1}) which was on par with the January 15th crop (6.33 t ha^{-1}) (Table 13).

4.3.6 Harvest Index (%)

The highest harvest index was observed in January 1st planted crop of Vaisakh (49.12). The lowest harvest index was observed in June 15th transplanted crop. The low harvest index values were observed in the first crop season in both the varieties. The harvest index values were high in the second season compared to other two seasons. Harvest index values are significantly changing with both the season and variety (Table 13).

4.4 CROP WEATHER RELATIONSHIPS

Simple linear correlations between important morphological, yield attributes and mean weekly weather parameters like maximum temperature, minimum temperature, mean temperature and temperature range, relative humidity (morning, afternoon, mean and difference between morning and afternoon relative humidity), wind speed, bright sunshine, were carried out.

4.4.1 Weather and morphology of rice

Correlation between leaf area index and different weather parameters has found out and presented in the Table 14 for both the varieties. In the variety Aathira LAI had a significant positive correlation with morning relative humidity (0.763), afternoon relative humidity (0.841) and rainfall (0.785), whereas maximum temperature (-0.891), sunshine hours (-0.821) and evaporation (-0.739) showed a significant negative correlation with LAI. In the case of Vaisakh LAI has shown significant correlation with maximum temperature (-0.737), sunshine hours (-0.719) afternoon relative humidity (0.699) and rainfall (0.802) (Table 14).

4.4.2. Phenology of rice

Duration for different phenological events has given in the table 15 and 16. Based on the phenological events, the duration taken for different biotic events is classified into transplanting to active tillering, transplanting to panicle initiation, transplanting to flowering and flowering to physiological maturity. It has been observed from the Table 15 and 16 that the days taken to attain active tillering from planting has varied widely. Correlation between different weather parameters and duration from planting to active tillering was done and presented in the Table 17. There was significant positive correlation with morning relative humidity (0.936) and afternoon relative humidity (0.973) and rainfall (0.887) whereas maximum temperature (-0.991), sunshine hours (0.956), evaporation (-0.866) and wind (-0.883) has showed significant negative correlation in case of Aathira. In case of Vaisakh there is a significant positive correlation with morning relative humidity (0.937), afternoon relative humidity (0.971) and rainfall (0.909), whereas maximum temperature (-0.968), wind speed (-0.902), sunshine hours (0.964) and evaporation (-0.813), had a significant negative correlation with duration of vegetative phase (Table 17).

Table 14. Correlation between LAI and different weather parameters

Weather parameter	Aathira	Vaisakh
Maximum temperature	-0.891**	-0.737*
RH I	0.763*	NS
RH II	0.841**	0.699*
Wind	NS	NS
Rainfall	0.785*	0.802**
BSH	-0.821**	-0.719*
Evaporation	-0.739*	NS

Table 15. Duration of phenological events in Aathira

Treatment	Duration (days)					
	Transplanting-Active tillering	Transplanting-Panicle initiation	Transplanting -Booting	Transplanting -Heading	Transplanting -Flowering	Transplanting-Physiological Maturity
T_1	43	51	67	73	75	103
T_2	43	50	66	73	75	103
T_3	43	51	67	73	75	103
T_4	39	47	63	69	71	97
T_5	39	48	64	69	71	97
T_6	38	46	62	68	70	95
T_7	35	43	59	65	67	93
T_8	35	42	57	64	66	91
T_9	33	40	56	63	65	90

Table 16. Duration for phenological events in Vaisakh

Treatment	Duration (Days)					
	Transplanting-Active tillering	Transplanting-Panicle initiation	Transplanting -Booting	Transplanting -Heading	Transplanting -Flowering	Transplanting –Physiological Maturity
T_1	36	42	57	65	67	98
T_2	36	41	56	64	66	98
T_3	37	43	58	64	66	98
T_4	32	37	52	60	62	92
T_5	30	36	51	58	60	87
T_6	31	36	51	58	60	88
T_7	28	34	49	56	58	85
T_8	25	31	46	54	56	82
T_9	27	33	48	54	56	82

Table 17. Correlation between duration of vegetative stage and different weather parameters

Weather parameter	Aathira	Vaisakh
Maximum temperature	-0.991**	-0.968**
RH I	0.936**	0.937**
RH II	0.973**	0.971**
Wind	-0.883**	-0.902**
Rainfall	0.887**	0.909**
BSH	-0.956**	-0.964**
Evaporation	-0.866**	-0.813**

4.4.3 Weather and yield characters

4.4.3.1 *Grain yield*

The Grain yield of both Aathira and Vaisakh was mainly influenced by minimum temperature. In Aathira minimum temperature during Panicle initiation to flowering stage (-0.840) had negatively influenced the grain yield, whereas in the variety Vaisakh minimum temperature (-0.772) during active tillering to panicle initiation and panicle initiation to flowering (-0.830), influenced the grain yield (Table18).

4.4.3.2 *Harvest index*

In variety Aathira there was no correlation between Harvest index and weather parameters, whereas in variety Vaisakh there was significant negative correlation with minimum temperature during active tillering to panicle initiation (-0.818) and panicle initiation to flowering (-0.881) (Table19).

4.4.3.3 *Number of Filled grains per panicle*

Number of Filled grains per panicle in the variety Aathira during active tillering to panicle initiation number of filled grains has got significant negative correlation with evaporation

(-0.814) and daily temperature range (-0.687). Only evaporation (-0.768) has significant correlation during panicle initiation to flowering, during flowering to physiological maturity maximum temperature (-0.790) and afternoon relative humidity (0.692) has significant correlation.

In case of variety Vaisakh number of filled grains per panicle has shown significant negative correlation with wind speed (-0.748) and evaporation (-0.698) during active tillering to panicle initiation, evaporation (-0.702) during panicle initiation to flowering, minimum temperature (-0.834) and evaporation (-0.766) during flowering to physiological maturity (Table 20).

From the above results it was very clear that impact of weather parameters on growth and development of rice varies significantly with varieties.

Table 18. Correlation between Grain yield and weather during different phenophases

Weather parameter	Aathira				Vaisakh			
	TP-AT	AT-PI	PI-FI	FL-PM	TP-AT	AT-PI	PI-FI	FL-PM
T_{max}	NS	NS	NS	NS	NS	NS	NS	NS
T_{min}	NS	NS	-0.840^{**}	NS	NS	-0.772^{*}	-0.830^{**}	NS
RH-I	NS	NS	NS	NS	NS	NS	NS	NS
RH-II	NS	NS	NS	NS	NS	NS	NS	NS
Wind speed	NS	NS	NS	NS	NS	NS	NS	NS
Rainfall	NS	NS	NS	NS	NS	NS	NS	NS
BSH	NS	NS	NS	NS	NS	NS	NS	NS
Evaporation	NS	NS	NS	NS	NS	NS	NS	NS

Note: TP-transplanting, AT-active tillering, PI- panicle initiation, FL-flowering, PM- Physiological maturity

Table 19. Correlation between HI and weather during different phenophases

Weather parameter	Aathira			Vaisakh		
	AT-PI	PI-FI	FL-PM	AT-PI	PI-FI	FL-PM
T_{max}	NS	NS	NS	NS	NS	NS
T_{min}	NS	NS	NS	-0.818**	-0.881**	NS
RH-I	NS	NS	NS	NS	NS	NS
RH-II	NS	NS	NS	NS	NS	NS
Wind speed	NS	NS	NS	NS	NS	NS
Rainfall	NS	NS	NS	NS	NS	NS
BSH	NS	NS	NS	NS	NS	NS
Evaporation	NS	NS	NS	NS	NS	NS

Note: TP-transplanting, AT-active tillering, PI- panicle initiation, FL-flowering, PM- Physiological maturity

Table 20. Correlation between filled grains and weather during different phenophases

Weather parameter	Aathira			Vaisakh		
	AT-PI	PI-FI	FL-PM	AT-PI	PI-FI	FL-PM
T_{max}	NS	NS	-0.790*	NS	NS	NS
T_{min}	NS	NS	NS	NS	NS	-0.834**
RH-I	NS	NS	NS	NS	NS	NS
RH-II	NS	NS	0.692*	NS	NS	NS
Wind speed	NS	NS	NS	-0.748*	NS	NS
Rainfall	NS	NS	NS	NS	NS	NS
BSH	NS	NS	NS	NS	NS	NS
Evaporation	-0.814**	-0.768*	NS	-0.698*	-0.702*	-0.766*

Note: TP-transplanting, AT-active tillering, PI- panicle initiation, FL-flowering, PM- Physiological maturity

4.5 MULTIPLE REGRESSION MODELS DEVELOPED

Stepwise regression analysis was carried out to select the critical variables, which contributed to yield, morphological characters and phenological variables.

Among all the weather parameters minimum temperature has greatest influence in determining the yield and yield attributes in both the varieties. Multiple regression equations were developed based on minimum temperature for estimation of grain yield.

4.5.1 Grain yield

4.5.1.1 Aathira

Grain yield (t ha^{-1}) = 8.593-0.144 (T min) (R^2= 0.609)

Where,

T min= Minimum temperature from Panicle initiation to flowering (°C)

4.5.1.2 Vaisakh

Grain yield (t ha^{-1}) = 14.506 - 0.203 (T min) (R^2= 0.754)

Where,

T min= Minimum temperature from Panicle initiation to flowering (°C)

4.5.2 Maximum Leaf Area Index

4.5.2.1 Aathira

LAI = 15.743 - 0.219 (T max) (R^2= 0.922)

Where,

T max= Maximum temperature from Panicle initiation to flowering (°C)

4.5.2.2 Vaisakh

LAI= 8.234 - 0.021 (T max) (R^2= 0.733)

Where,

T max = Maximum temperature during Panicle initiation to flowering (°C)

4.5.3 Duration (Transplanting to Physiological maturity)

4.5.3.1 Aathira

Duration = 135.436–1.174 (T max) (R^2= 0.855)

Where,

T max= Maximum temperature from Panicle initiation to flowering (°C)

4.5.3.2 Vaisakh

Duration = 141.029 –1.554 (T max) (R^2= 0.882)

Where,

T max= Maximum temperature during Panicle initiation to flowering (°C)

4.6 DSSAT MODEL VALIDATION

Three dates of transplanting in three seasons (*Virippu*, *Mundakan* and *Puncha*) has been raised for both the varieties for validating CERES –Rice (DSSAT 4.5). The Genetic coefficients for both the varieties were developed and presented in the Table 21.

Table 21. Genetic coefficients of Aathira and Vaisakh

Variety	Genetic co-efficients							
	P1	P2R	P5	P20	G1	G2	G3	G4
Aathira	895.0	5.0	270.0	10.8	46.0	0.0222	0.98	0.90
Vaisakh	630.0	1.0	270.0	10.8	54.0	0.0200	1.00	1.00

The observed and simulated yields of Aathira were presented in the Fig. 7. Maximum yield observed was 5.8 t ha^{-1} during the Oct 30^{th} planting. Lowest yield observed was 4.9 t ha^{-1}on Jan 30^{th} planting. RMSE for Aathira prediction is 515.6 kg and R^2 value is 0.64 (Table 22).

Table 22. RMSE and R^2 for DSSAT prediction

Variety	RMSE	R^2
Aathira	515.60	0.64
Vaisakh	377.75	0.82

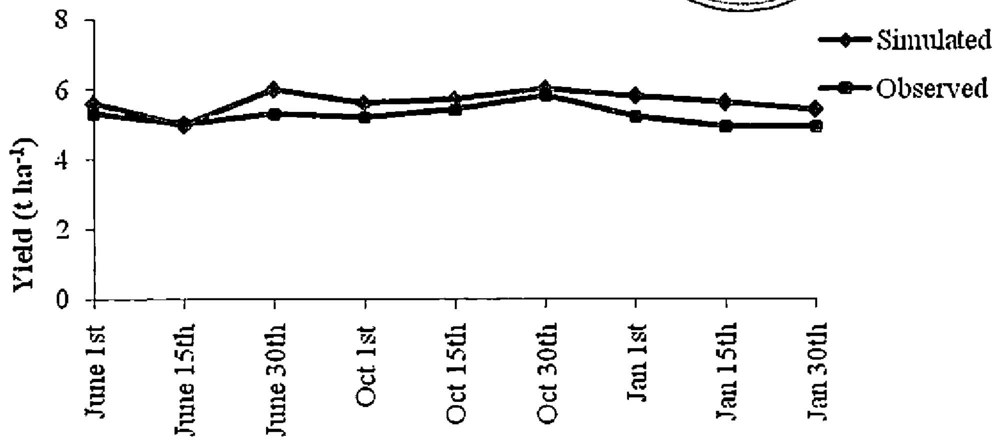

Fig 7. Observed and simulated yields of Aathira

The observed and simulated yields of Vaisakh has presented in the Fig 8. Maximum yield observed is 6.3 t ha^{-1} on Jan 1^{st} planting. Lowest yield observed is 4.7 t ha^{-1}, on Jan 15^{th} planting. RMSE for Vaisakh prediction is 377.75 kg and R^2 value is 0.82 (Table 22).

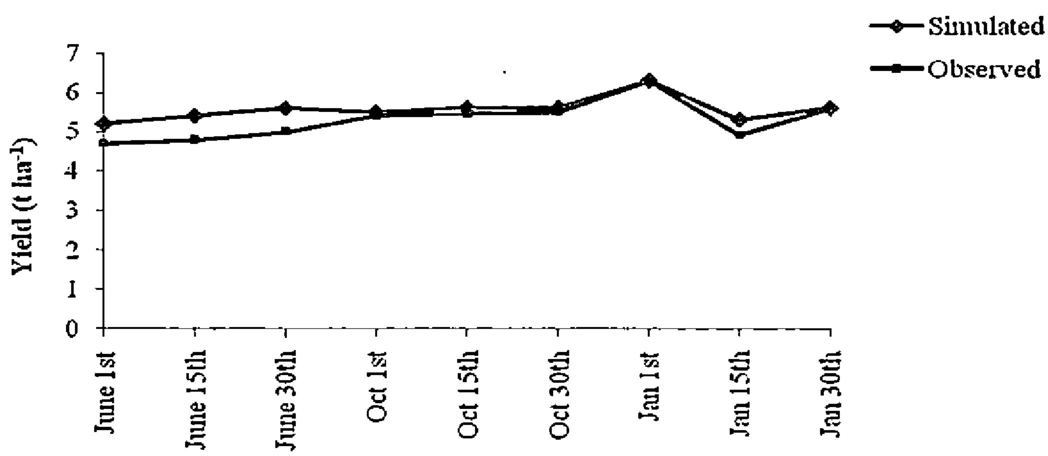

Fig 8. Observed and simulated yields of Vaisakh

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 9 to 20.

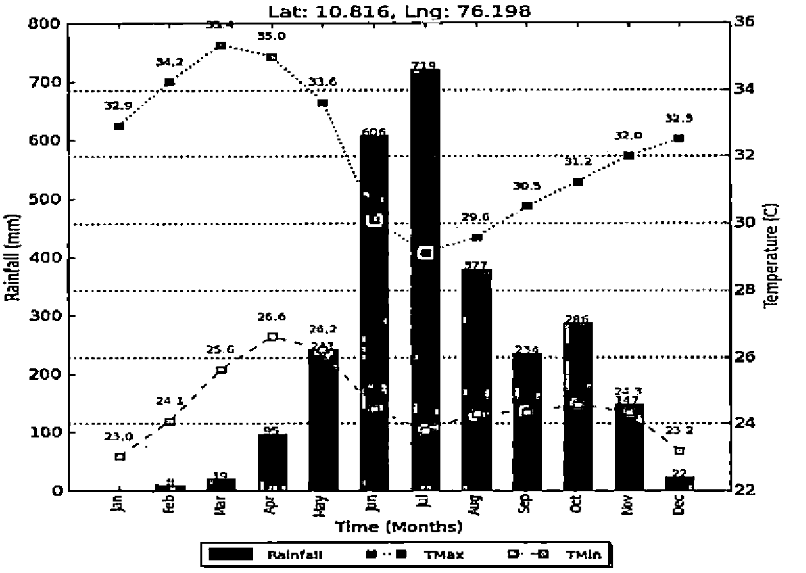

Fig 9. Climate of Pattambi in 2030s under RCP 2.6

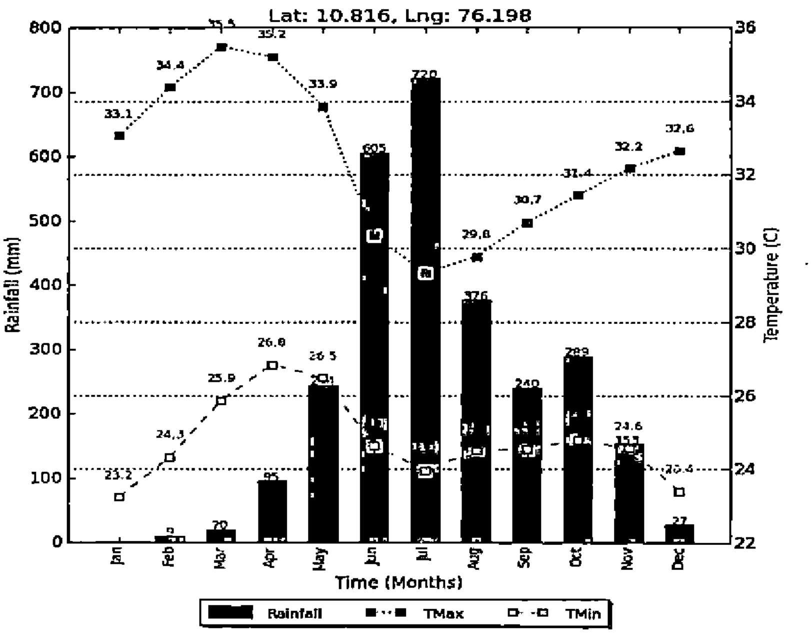

Fig 10. Climate of Pattambi in 2050s under RCP 2.6

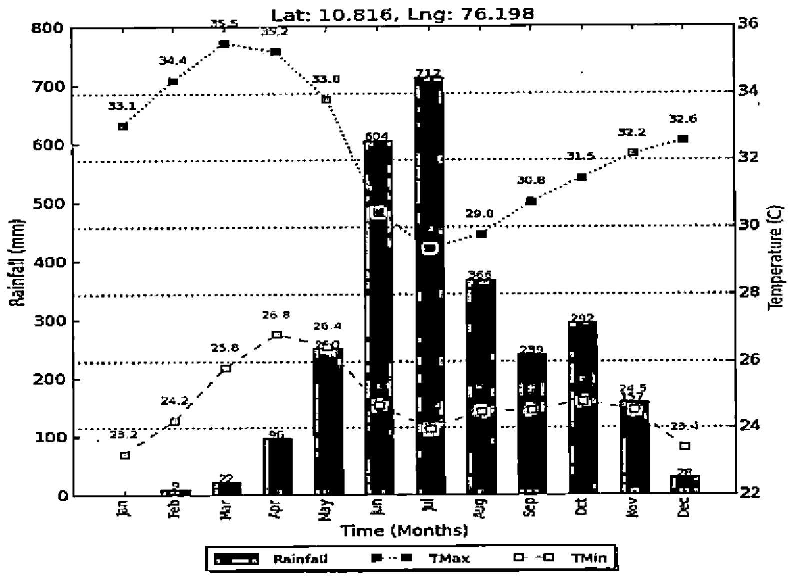

Fig 11. Climate of Pattambi in 2080s under RCP 2.6

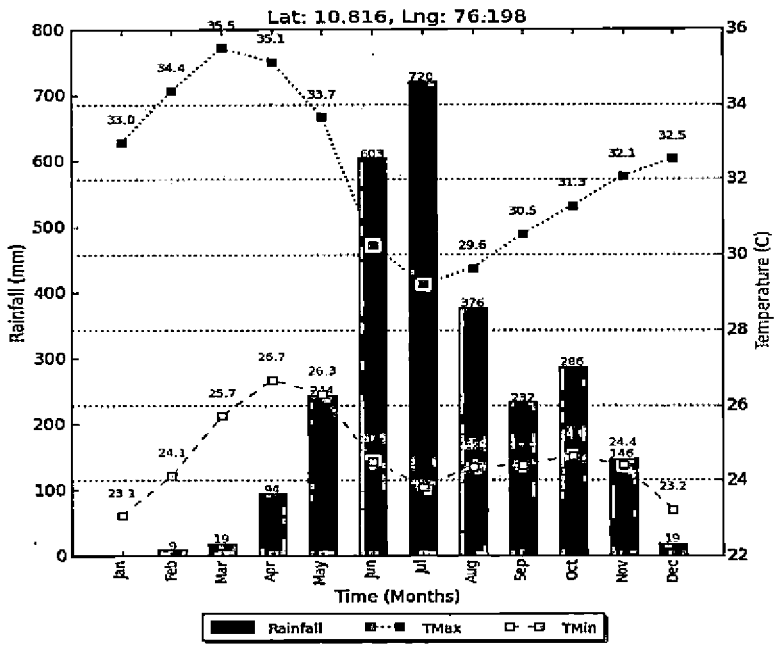

Fig 12. Climate of Pattambi in 2030s under RCP 4.5

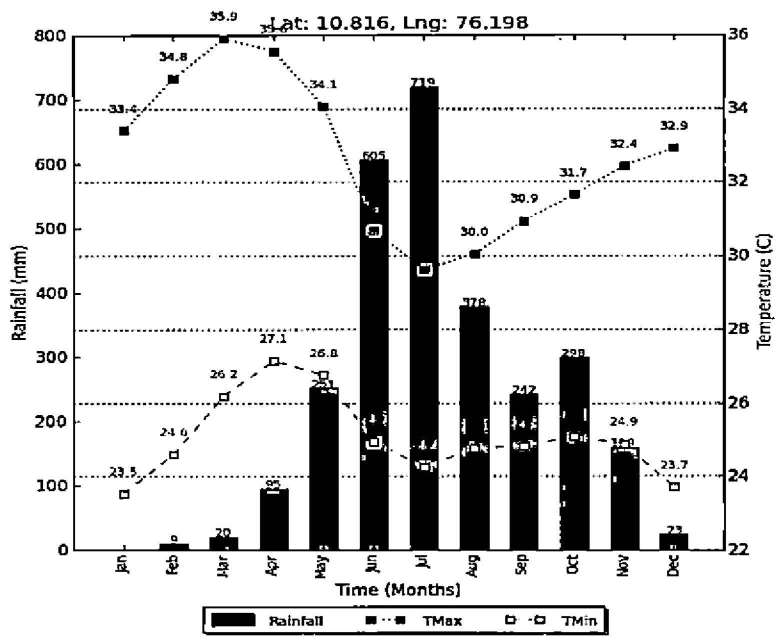

Fig 13. Climate of Pattambi in 2050s under RCP 4.5

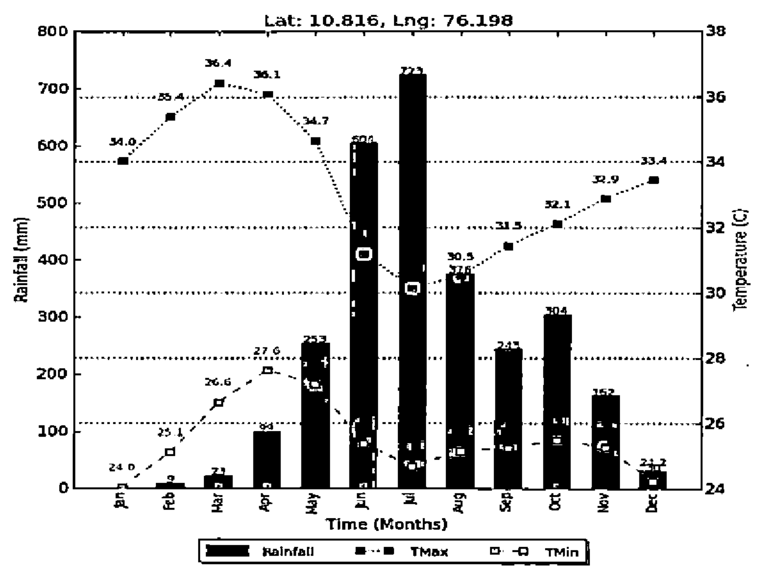

Fig 14. Climate of Pattambi in 2080s under RCP 4.5

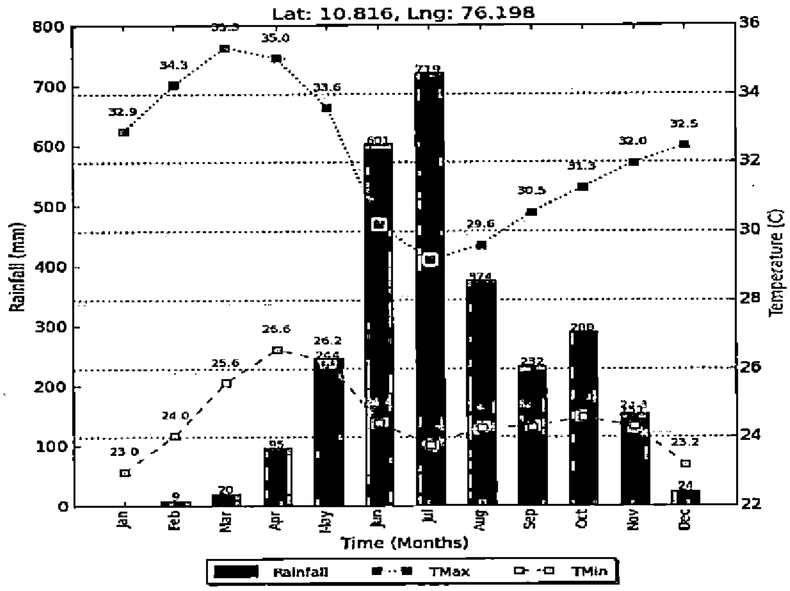

Fig 15. Climate of Pattambi in 2030 under RCP 6.0

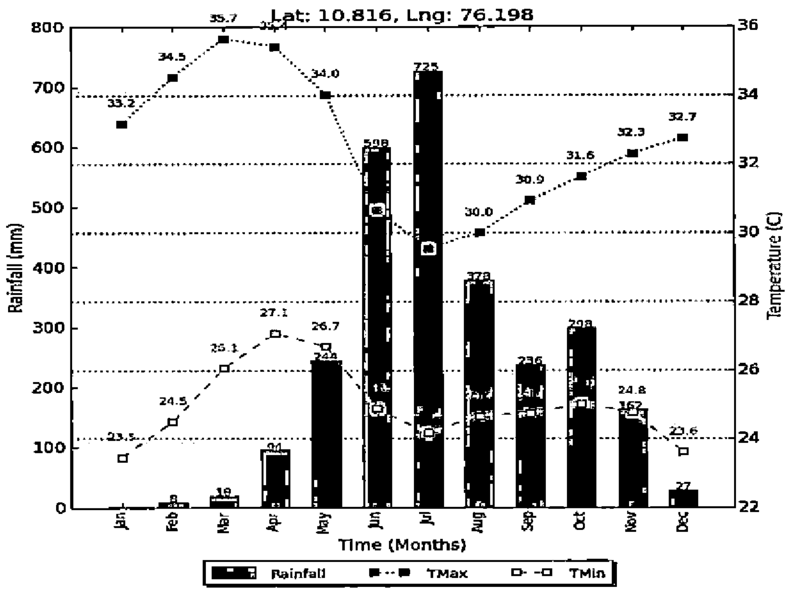

Fig 16. Climate of Pattambi in 2050s under RCP 6.0

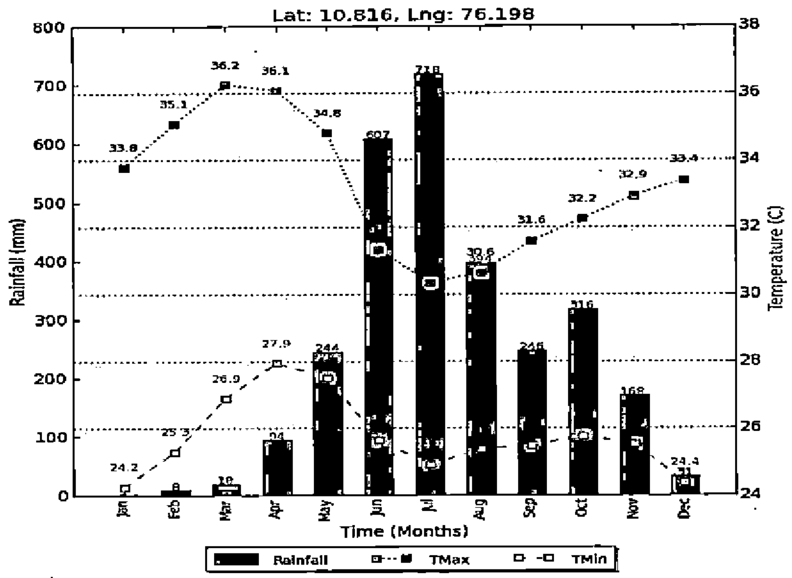

Fig 17. Climate of Pattambi in 2080s under RCP 6.0

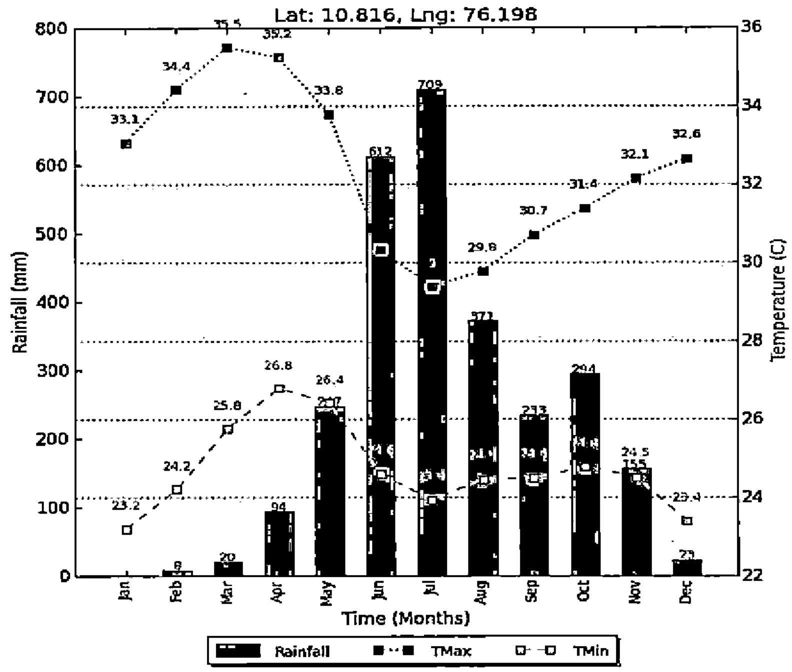

Fig 18. Climate of Pattambi in 2030s under RCP 8.5

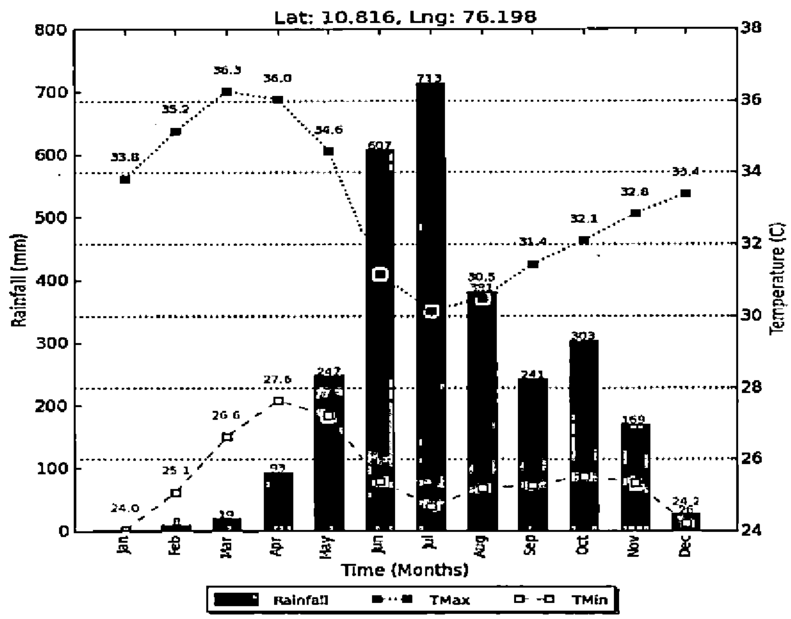

Fig 19. Climate of Pattambi in 2050s under RCP 8.5

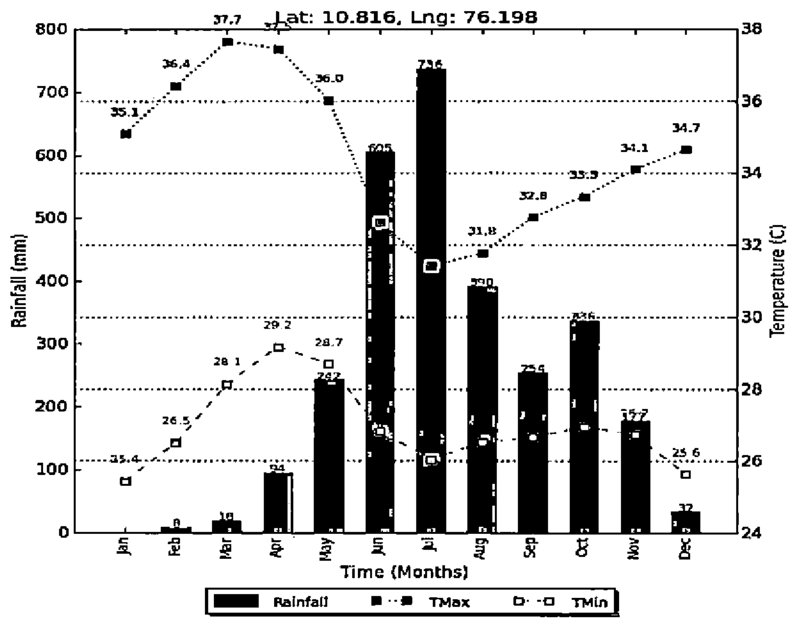

Fig 20. Climate of Pattambi in 2080s under RCP 8.5

4.7.1 RCP 2.6

As per the projections based on RCP 2.6, there will not be any change in the first crop season yield (5.7 t ha^{-1}) in the variety Aathira during 2030s, 2050s and 2080s, whereas during the second crop season yield reduction will be in the tune of 29 per cent, 29 per cent and 26 per cent respectively for the periods 2030s, 2050s and 2080s. During the third crop season, yield will be reduced by 28 per cent, 14 per cent and 12 per cent for the periods 2030s, 2050s and 2080s respectively (Table 22).

Table 22. Per cent change in the yield of Aathira under RCP 2.6

Season	Present yield (t ha^{-1})	Per cent change in the yield (yield t ha^{-1})		
		2030s	2050s	2080s
1st Season	5.70	0.0 (5.7)	0.0 (5.7)	0.0 (5.7)
2nd Season	5.70	-29 (4.0)	-29 (4.0)	-26 (4.2)
3rd Season	5.60	-28 (4.0)	-14 (4.8)	-12 (4.9)

The grain yield of variety Vaisakh the first crop season will be reduced by 24 per cent, 20 per cent and 16 per cent during the periods 2030s, 2050s and 2080s respectively. During the second crop season, yield may be reduced by 36 per cent in 2030s, 32 per cent in 2050s and 25 per cent in 2080s. During the third crop season yield will be reduced by 12 per cent, 21 per cent and 10 per cent for the periods 2030s, 2050s and 2080s respectively (Table 23).

Table 23. Per cent change in the yield of Vaisakh under RCP 2.6

Treatment	Present yield (t ha^{-1})	Per cent change in the yield (yield t ha^{-1})		
		2030	2050	2080
1st Season	5.40	-24 (4.7)	-20 (4.3)	-16 (4.5)
2nd Season	5.50	-36 (3.5)	-32 (3.7)	-25 (4.1)
3rd Season	5.70	-12 (5.0)	-21 (4.5)	-10 (5.1)

4.7.2 RCP 4.5

The yield of Aathira as per the RCP 4.5 will not change by 2030s in first crop season. But by 2050s, it will decrease by 7 per cent and it will further reduce by 22 per cent in 2080s. In the second crop season, yield reduction will be in the tune of 35, 38 and 43 per cent by 2030s, 2050s and 2080s respectively. During the third crop season, yield may be reduced by 26 per cent by 2030s and 2050s, whereas by 2080s, yield reduction will be 23 per cent (Table 24).

Table 24. Per cent change in the yield of Aathira under RCP 4.5

Season	present (t ha^{-1})	Per cent change in the yield (yield t ha^{-1})		
		2030	2050	2080
1st Season	5.70	0.0 (5.7)	-7.0 (5.3)	-22 (4.4)
2nd Season	5.70	-35 (3.7)	-38 (3.5)	-43 (3.2)
3rd Season	5.60	-26 (4.1)	-26 (4.1)	-23 (4.3)

The yield of Vaisakh in the first crop season will be reduced by 16 per cent, 20 per cent and 20 per cent by 2030s, 2050 and 2080s respectively. During the second crop season yield will be reduced by 21 per cent, 40 per cent and 47 per cent for the periods 2030s, 2050s and 2080s respectively. During the third crop season, the yield reduction will be 21 per cent for the periods 2030s, 2050s and 2080s respectively (Table 25).

Table 25. Per cent change in the yield of Vaisakh under RCP 4.5

Season	Present yield (t ha^{-1})	Per cent change in the yield (yield t ha^{-1})		
		2030	2050	2080
1st Season	5.40	-16 (4.5)	-20 (4.3)	-20 (4.3)
2nd Season	5.50	-21 (4.5)	-40 (3.3)	-47 (2.9)
3rd Season	5.70	-21 (4.5)	-21 (4.5)	-21 (4.5)

4.7.3 RCP 6.0

During the first crop season yield of Aathira will remain 5.7 t $ha^{-1}$for the period 2030s, whereas there will be decline in the yield 10 per cent by 2050s and 24 per cent by 2080s. During the second crop season yield will be reduced by 33 per cent, 38 per cent and 42 per cent for the periods 2030s, 2050s and 2080s respectively. Yield will be reduced by 16 per cent, 24 per cent and 29 per cent for the periods 2030s, 2050s and 2080s respectively during the third crop season (Table 26).

Table 26. Percent change in the yield of Aathira under RCP 6.0

Treatment	Present yield (t ha^{-1})	Per cent change in the yield (yield t ha^{-1})		
		2030	2050	2080
1st Season	5.7	0.0 (5.7)	-10(5.1)	-24 (4.3)
2nd Season	5.7	-33 (3.8)	-38 (3.5)	-42 (3.3)
3rd Season	5.6	-16 (4.7)	-24 (4.3)	-29 (4.0)

Yield of Vaisakh in first crop season will be reduced by 20 per cent, 22 per cent and 25 per cent for the periods 2030s, 2050s and 2080s respectively. During the second crop season yield will be reduced by 30 per cent, 32 per cent and 38 per cent for the periods 2030s, 2050s and 2080s respectively. Yield will be reduced by 12 per cent, 22 per cent and 24 per cent for the periods 2030s, 2050s and 2080s respectively during the third crop season (Table 27).

Table 27. Per cent change in the yield of Vaisakh under RCP 6.0

Season	Present yield (t ha^{-1})	Per cent change in the yield (yield t ha^{-1})		
		2030	2050	2080
1st Season	5.40	-20 (4.5)	-22 (4.2)	-25 (4.0)
2nd Season	5.50	-30 (3.8)	-32 (3.7)	-38 (4.0)
3rd Season	5.70	-12 (5.0)	-22 (4.4)	-24 (4.3)

4.7.4 RCP 8.5

Yield of Aathira in first crop season will not be changed (5.7 t ha^{-1}) for the periods 2030s, whereas a reduction of 20 per cent and 28 per cent is forecasted for the periods 2050s and 2080s. During the second crop season yield will be reduced by 38 per cent, 40 per cent and 45 per cent for the periods 2030s, 2050s and 2080s respectively. Yield will be reduced by 35 per cent, 37 per cent and 42 per cent in the periods 2030s, 2050s and 2080s respectively during the third crop season (Table 28).

Table 28. Per cent change in the yield of Aathira under RCP 8.5

Season	present yield (t ha^{-1})	Per cent change in the yield (yield t ha^{-1})		
		2030	2050	2080
1st Season	5.70	0 (5.7)	-20 (4.3)	-28 (4.1)
2nd Season	5.70	-38 (3.5)	-40 (3.3)	-45 (3.1)
3rd Season	5.60	-35 (3.6)	-37 (3.5)	-42 (3.2)

Yield of Vaisakh in the first crop season will be reduced by 20, 29 per cent and 38 per cent in the periods 2030s, 2050s and 2080srespectively. The second crop season yield will be reduced by 36 per cent, 41 per cent and 50 per cent in the periods 2030s, 2050s and 2080srespectively. Yields will be reduced by 28 per cent, 35 per cent and 38 per cent in the periods 2030s, 2050s and 2080s respectively during the third crop season (Table 29).

Table 29. Per cent change in the yield of Vaisakh under RCP 8.5

Season	present yield (t ha^{-1})	Per cent change in the yield (yield t ha^{-1})		
		2030	2050	2080
1st Season	5.40	-20 (4.3)	-29 (3.8))	-38 (3.3)
2nd Season	5.50	-36 (3.5)	-41 (3.2)	-50 (2.7)
3rd Season	5.70	-28 (4.1)	-35 (3.7)	-38 (3.5)

Discussion

5. DISCUSSION

This study was taken up to study the crop weather relationships in rice, validating the DSSAT model and to predict the impact of climate change on the rice production by 2030, 2050 and 2080. The results presented in the previous chapter are discussed here under.

5.1 BIOMETRIC OBSERVATIONS

5.1.1 Plant height

The results have showed that the plant height was significantly influenced by time of planting (Fig. 21) and variety. It showed a gradual decreasing trend from first crop season to third crop season. This is in agreement with findings of Misra and Khan (1973), Majid and Ahmed (1975), Lathif (1982), Sunil (2000) and Kovi *et al.*, (2011).

The night temperature has shown significant negative correlation with plant height from Panicle initiation to physiological maturity. It indicates that rice plant requires moderate night temperatures (22.0°C) for proper growth. High night temperature will increase the respiration and accelerates the spending of photosynthates there by leads to reduction in different growth parameters. Lin (1976) has also reported the same results.

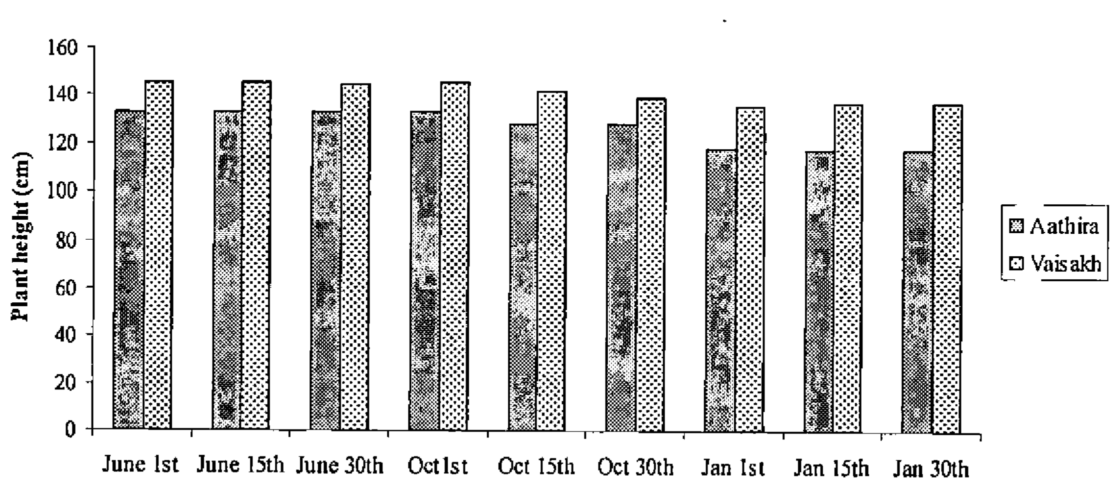

Fig.21 Effect of time of planting and variety on plant height

5.1.2 Biomass

The results showed that the biomass per plant at different stages varied significantly with time of planting and variety (Fig. 22). But in both the varieties, the crops transplanted during the second crop season recorded significantly higher biomass. The maximum temperature (28.0°C to 32.0°C) and relative humidity (80-90%) during entire crop growth period due to rain fall favoured the high biomass per plant. This is supported by findings of Hirai *et al.*, (1993) and Sreedharan (1975).

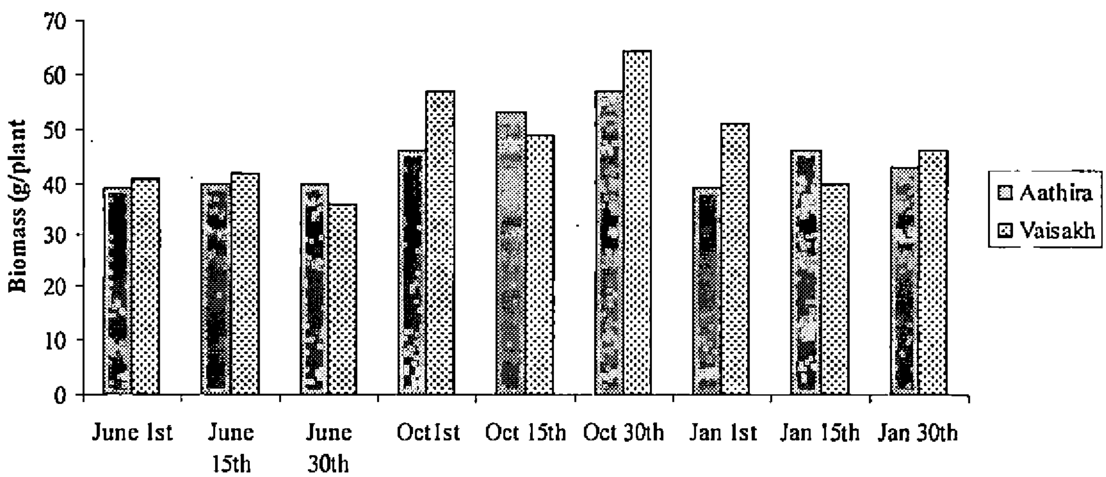

Fig.22 Effect of time of planting and variety on Biomass

5.1.3 Number of tillers

The effect of time of sowing on tiller production was significant. The tiller number was more in first crop season in both the varieties. Tiller number has reduced from first to third crop season. High minimum temperature of 24.0°C and above throughout the crop growth period resulted in the decrease of number of tillers. This is probably due to the fact that high minimum temperature will increase the respiration and reduces the carbohydrate per plant leading to low tiller production. This is in confirmation with the findings of Peng *et al.,* (2004).

5.1.4 Leaf Area Index

There was a significant effect of planting time and variety on leaf area index. Lowest leaf area index (3.10) was observed in third season (Jan 15th). This is due to lower relative humidity during third crop season. These results are in confirmation with the findings of Basu *et al.*, (2014) and Aschonitis (2014).

Maximum LAI was found in first crop season in both the varieties in the crops transplanted during June 15th (Aathira-9.36, Vaisakh-9.96). Lowest LAI was recorded during third crop season (3.10). This is due to high relative humidity (80-90%), low light intensity and temperature range during the transplanting to heading. These results are in conformation with the findings of Janardhan *et al.*, (1980).

5.2 YIELD ATTRIBUTES

5.2.1 Number of panicles m^{-2}

Vaisakh has recorded highest number of panicles per square meter (357.00) in the third crop season (Jan1st). Both the varieties in third season have shown the reduction in panicle number with delay in planting date. The numbers of panicles per hill were influenced mainly by the weather conditions at the active tillering stage. Maximum temperature during this period had a negative relationship with panicle number. This view was supported by the work of Matsushima (1966) and Kovi *et al.*, (2011).

5.2.2 Number of filled grains per panicle

Highest number of filled grains per panicle was observed in June 30th crop of Vaisakh (147.3) and it is on par with the June 15th (141.7) transplanted crop of Aathira. High maximum temperature during the reproductive period might be the reason for lesser number of filled grains in third season crop. This is in agreement with the findings of Yoshida (1978) and Kovi *et al.*, (2011). The first season crops transplanted during the June had overall lowest number of filled grains per panicle where as in third crop season Aathira had less number of filled grains.

5.2.3 Grain yield

Maximum yield has observed in variety Vaisakh transplanted on January 1st (6.30 t ha^{-1}) i.e summer crop. The summer crop is physiologically advantageous due to high photo-period, leading to higher productivity. Dry matter partitioning is more efficient in the temperature tolerant varieties and it may be the reason for high yield in summer crop. This is in agreement with the findings of Talukdar and Beka (2005). But after that there is a sharp decline in the yield. The increase in the night temperature has shown significant negative correlation from panicle initiation to flowering. The increase in the night temperature will increase the respiration there by leads to the reduction of carbohydrates available to transfer to sink. This may be the reason for yield reduction. These results are in conformation with the findings of Peng *et al.*, (2004) and Nagarajan *et al.*, (2010).

Highest yield in Aathira was observed in Oct 30th transplanted crop (5.86 t ha^{-1}). The increase in yield may be due to low minimum temperature during ripening stage. Similar observations were made by Nagato and Ebata (1966). But in third crop season yield is considerably less. Aathira also has shown significant negative correlation with minimum temperature from panicle initiation to the flowering. These results are in conformation with the findings of Peng *et al.*, (2004) and Nagarajan *et al.*, (2010). Grain yield was varied with the genotype.

5.2.4 Straw yield

The maximum straw yield has observed in the variety Vaisakh transplanted during June 1st (7.86 t ha^{-1}). It is on par with the June 30th transplanted crop of Vaisakh (7.80 t ha^{-1}). Lowest straw yield was observed in January 30th transplanted crop of Aathira (6.30 t ha^{-1}). Crops taken during June (first season crops) experienced high relative humidity and low temperature range compared to third crop season. This is the reason for reduction in the straw yield. This is in conformity with the findings of Sreelatha (1989) and Sunil (2000).

5.2.4 Harvest Index (%)

The highest harvest index value was observed in January 1st planted crop of Vaisakh (49.12). This is in agreement with the findings of Talukdar and Beka (2005). October 1st, 15th and 30th planted crops of Vaisakh (45.76, 46.04 and 44.71) and Aathira (43.63, 43.45 and 45.95) has recorded good harvest index. This is due to the moderate temperatures (30.0-33.0°C) experienced throughout the growing period. This is in agreement with the findings of Krishnakumar (1986).

5.3 CROP WEATHER RELATIONSHIPS

Each crop species will have an optimum range of temperature, below and above of which a disturbance is induced in the metabolic processes. The trend of temperature was always on higher side particularly during summer season. Progressive increase in night temperature must have impaired the different morpho-physiological processes and enzymatic behaviour controlled by thermal mechanism.

In case of Aathira increase in 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). Regression equation has developed for the prediction of the yield as,

Grain yield (Aathira) = 8.593 - 0.144 (T min) (R^2= 0.609)

Where,

T min= Minimum temperature from Panicle initiation to flowering (°C)

In case of Vaisakh also increase in 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). Wind has positive influence on the yield and sunshine has negative influence (Matsui *et al.*, 2001). Regression equation has developed for the prediction of the yield as,

Grain yield = 14.506 - 0.203 (T min) (R^2= 0.754)

Where,

Grain yield in (t ha^{-1})

T min = Minimum temperature from Panicle initiation to flowering (°C)

5.4 DSSAT MODEL VALIDATION

The observed and simulated yields of Aathira were in good agreement (Fig. 23). Maximum yield observed was 5.8 t ha^{-1} during the Oct 30th planting. Lowest yield observed is 4.9 t ha^{-1}on Jan 30th planting. RMSE for Aathira prediction is 515.6 kg and R^2 value is 0.644. Similar results were also reported by Timsina and Humphreys (2006).

The observed and simulated yields of Vaisakh were in good agreement (Fig.24). Maximum yield observed is 6.3 t ha^{-1} on Jan 1st planting. Lowest yield observed is 4.7 t ha^{-1} on Jan 15th planting. RMSE for Vaisakh prediction is 377.75 kg and R^2 value is 0.824.Similar results were also reported by Timsina and Humphreys (2006). The model is satisfactorily predicting the yields of Aathira and Vaisakh in all the seasons.

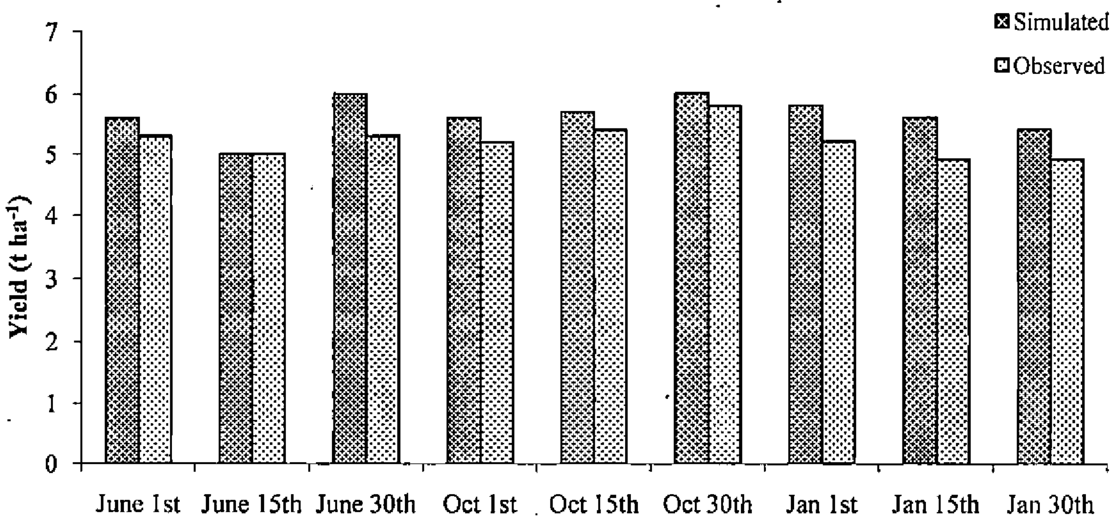

Fig. 23 Observed and simulated yields of Aathira

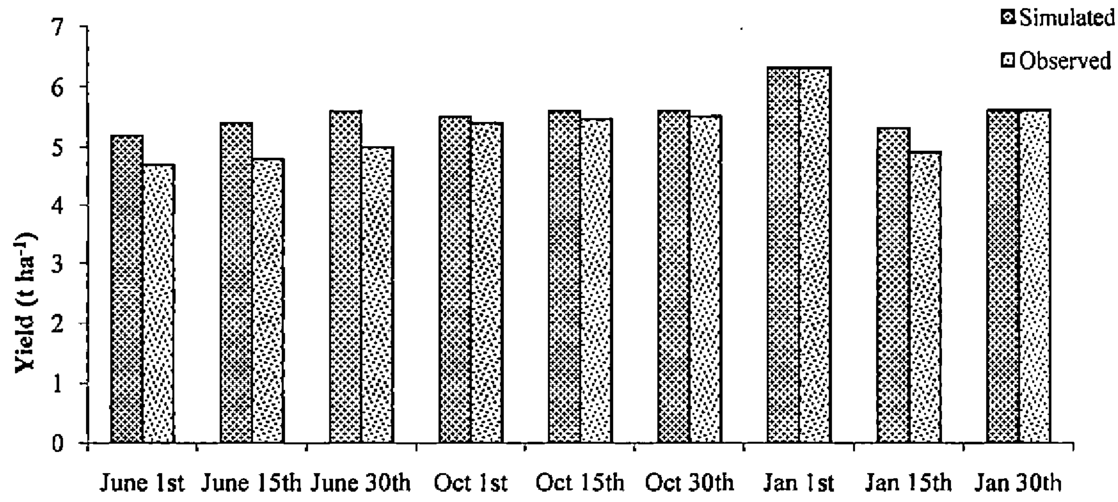

Fig. 24 Observed and simulated yields of Vaisakh

5.5 CLIMATE CHANGE IMPACT ON RICE PRODUCTION

5.5.1 RCP 2.6

As per the projections under RCP 2.6, in the first crop season yield of Aathira will not change during 2030s, 2050s and 2080s (Fig. 25). According to the projected climatic conditions, the minimum temperature (Fig. 27) will be reduced by 0.6°C and maximum temperature (Fig. 28) will remain same during the flowering stage during the first crop season. It is also forecasted that, an increase in the rainfall by 671 mm (Fig. 29). So, climatic conditions as per the RCP 2.6 scenario are optimum (24.0-33.0°C) for growth and development of rice. This may be the reason for stable yield in the first crop season. In the other seasons, the yield got reduced significantly particularly during the second season (Fig. 25). The reasons may be, during the second crop season, there will be an increase of minimum temperature by 1.5°C (Fig. 27) and maximum temperature by 1.3°C but the amount of rainfall will be reduced by 100mm (Fig. 29). It is interesting to note that, during the third crop season, the yield reduction will be comparatively low (12 per cent) compared to second crop season (28 per cent). This can be due to increase in the rainfall (Fig. 29) during third crop season.

Vaisakh has shown 24 per cent decrease in the yield by 2030, 20 per cent by 2050 and 16 per cent by 2080 (Fig. 26) during the first crop season. As the Vaisakh is an upland variety, increase in the amount of rainfall (Fig. 29) (671mm) may be results in low yields during the first crop season. In second crop season, yield has shown reduction of 36 per cent, 32 per cent and 25 per cent in 2030s, 2050s and 2080s respectively. This can be due to increase in the minimum temperature (1.5°C) (Fig. 27) and maximum temperature (1.3°C) (Fig. 28) coupled with reduction in rainfall by 100mm (Fig. 29). In the third crop season, yield reduction will be 12 per cent, 21 per cent and 10 per cent in 2030s, 2050s and 2080s respectively which is very less compared to the other crop seasons. This can be mainly due to increase in the rainfall (Fig. 29) during third crop season. These results are in confirmation with Saseendran *et al.*, (2000) Peng *et al.*, (2004), Wassman *et al.*, (2009) Barnwal *et al.*, (2013) Auffahammer *et al.*, (2012). The change in genotype has significant influence on the yield. This was confirmed by Osbornea *et al.*, (2013).

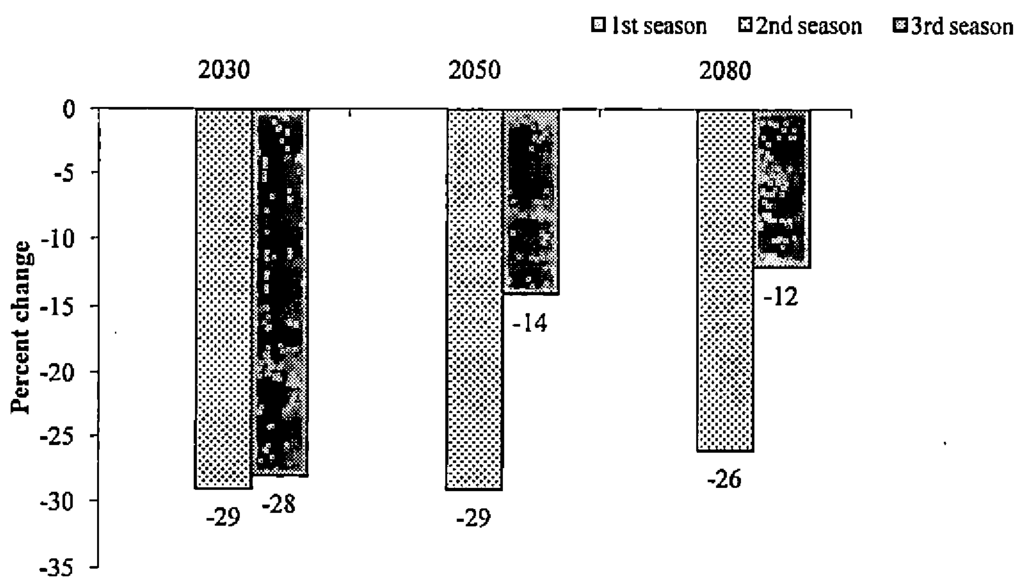

Fig. 25 Percent change in yield of Aathira in RCP 2.6

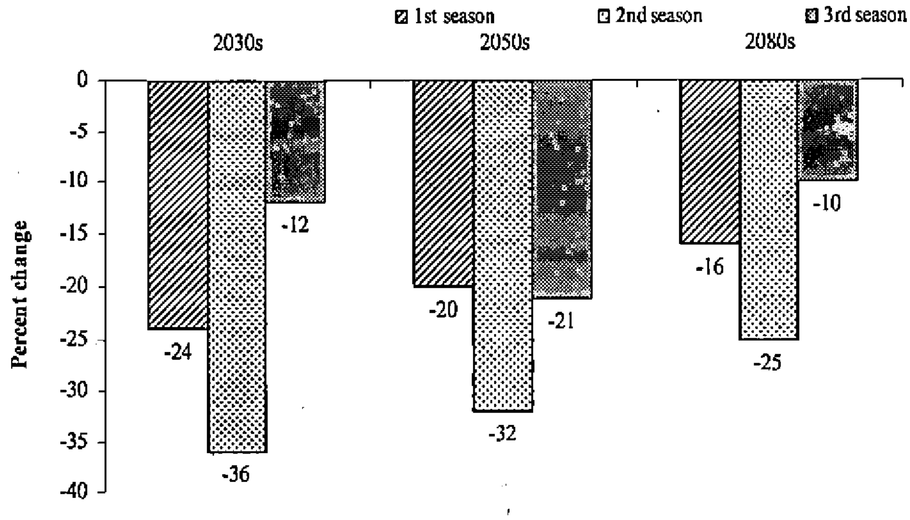

Fig. 26 Percent change in yield of Vaisakh in RCP 2.6

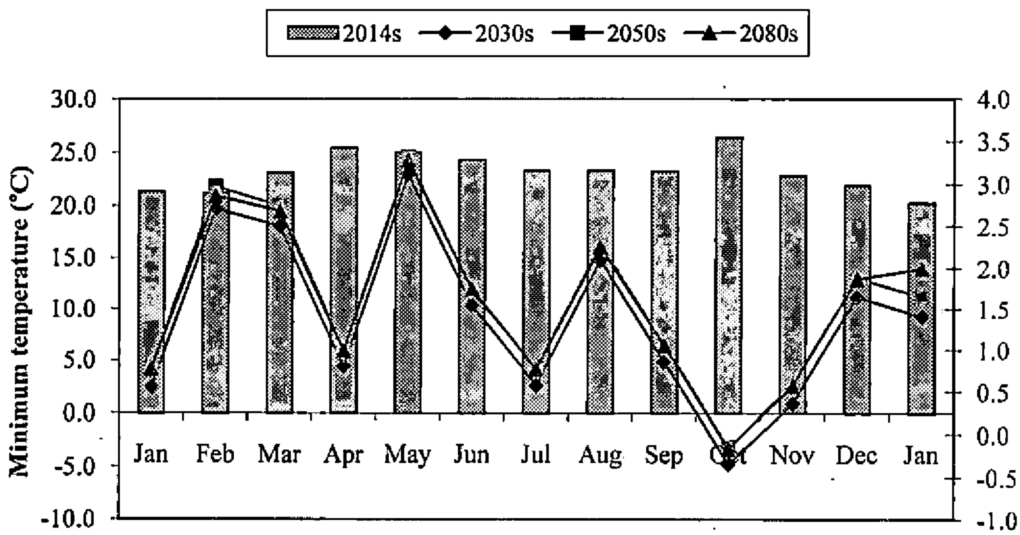

Fig. 27 Projected changes in monthly mean minimum temperature as per RCP 2.6scenario

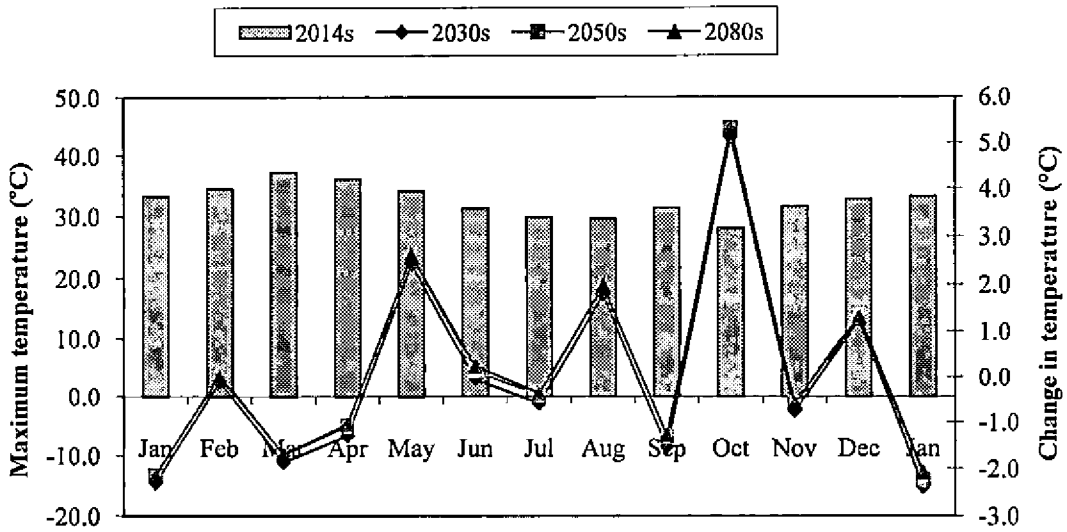

Fig. 28 Projected changes in monthly mean maximum temperature as per RCP 2.6 scenario

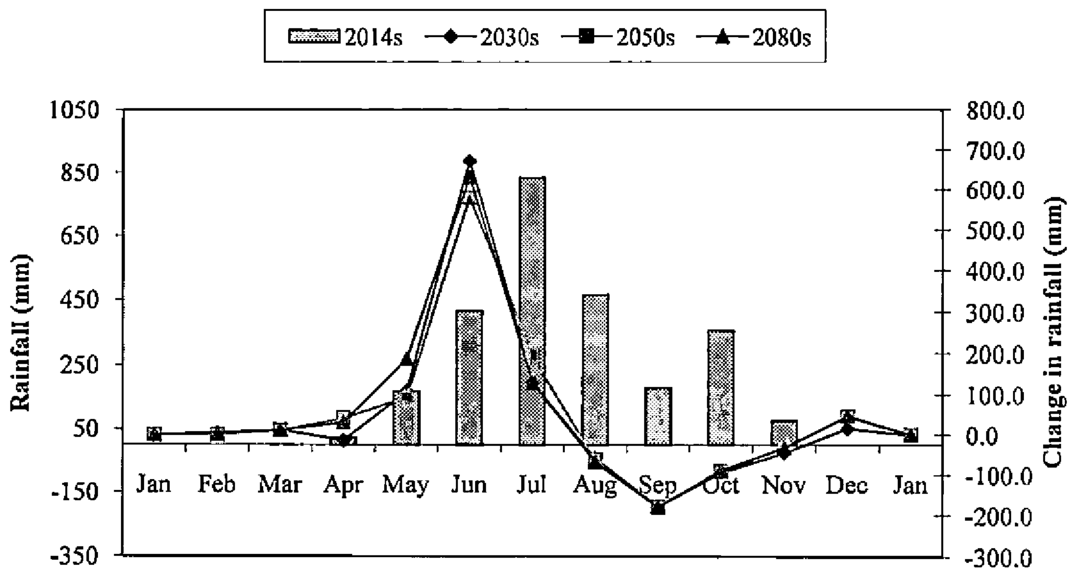

Fig. 29 Projected changes in monthly mean rainfall as per RCP 2.6 scenario

5.5.2 RCP 4.5

In the first crop season yield of Aathira will not change by 2030s (Fig. 30). By 2030s the maximum temperature is decreasing 0.4°C (Fig.33) and minimum temperature (Fig. 32) will increase 0.7°C and this little increase will be compensated by increase in the rainfall (674mm)

(Fig. 34). During the 2050s the yield will decrease by 7 per cent and by 2080s it will decrease by 22 per cent. This is due to increase in the minimum temperature (1.5°C) beyond the optimum temperature (24°C) during the flowering period (Fig. 33). In the second crop season, yield will be reduced by 35 per cent, 38 per cent and 43 per cent by 2030s, 2050s and 2080s respectively. This can be due to increase in the minimum temperature (Fig. 32) during the flowering and grain filling period of the second crop season which will increase the respiration thereby reduces the yield (Peng *et al.,* 2004). During the third crop season, yield will be reduced by 26 per cent, 26 per cent and 23 per cent by 2030s, 2050s and 2080s respectively. This can be due to increase in minimum temperature 2.2°C (Fig. 32) and decrease in the rainfall (100mm) in the flowering and grain filling period. These results are in confirmation with Wassman *et al.,* (2009) Barnwal *et al.,* (2013) Auffahammer *et al.,* (2012).

Vaisakh has shown reduction during 2030s (16 per cent), 2050s (20 per cent) and 2080s (20 per cent) in the first crop season (Fig.31). This can be because of the fact that being a upland variety, excess rainfall during the crop growth period reduced the grain yield in variety Vaisakh. Due to increase in the minimum temperature, by 1.9°C in 2030s and 2050s and 2.7°C in 2080s (Fig. 33) during the flowering and grain filling period, the yield will be reduced in the second crop season (Peng *et al.,* 2004).In the third crop season yield has shown a reduction of 33 per cent, 21 per cent and 18 per cent by 2030s, 2050s and 2080s respectively (Fig. 32). This can be due to increase in minimum temperature 2.2°C (Fig. 32) in the flowering and grain filling period of the third crop season and reduction in rainfall by 100mm (Fig. 33).These results are in confirmation with Wassman *et al.,* (2009) Barnwal *et al.,* (2013) Auffahammer *et al.,* (2012).

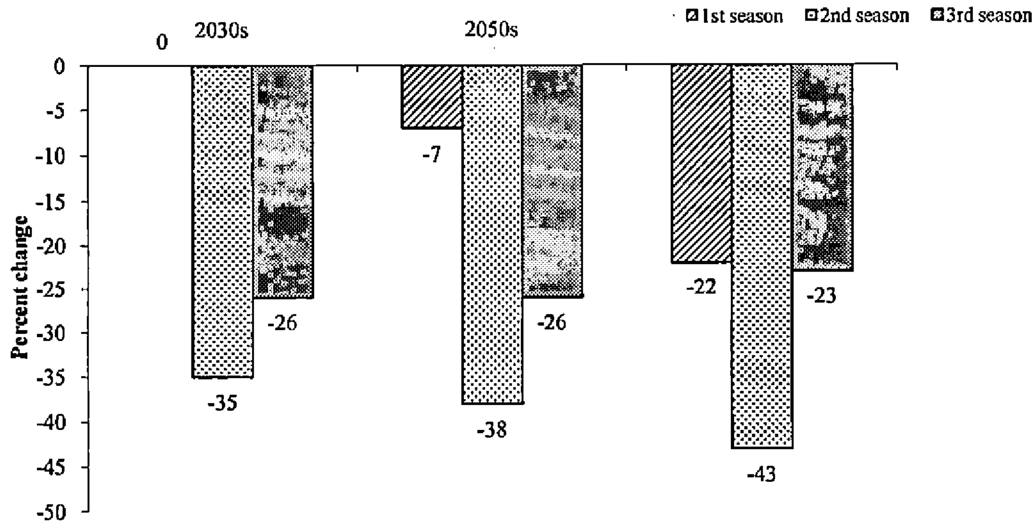

Fig. 30 Percent change in yield of Aathira in RCP 4.5

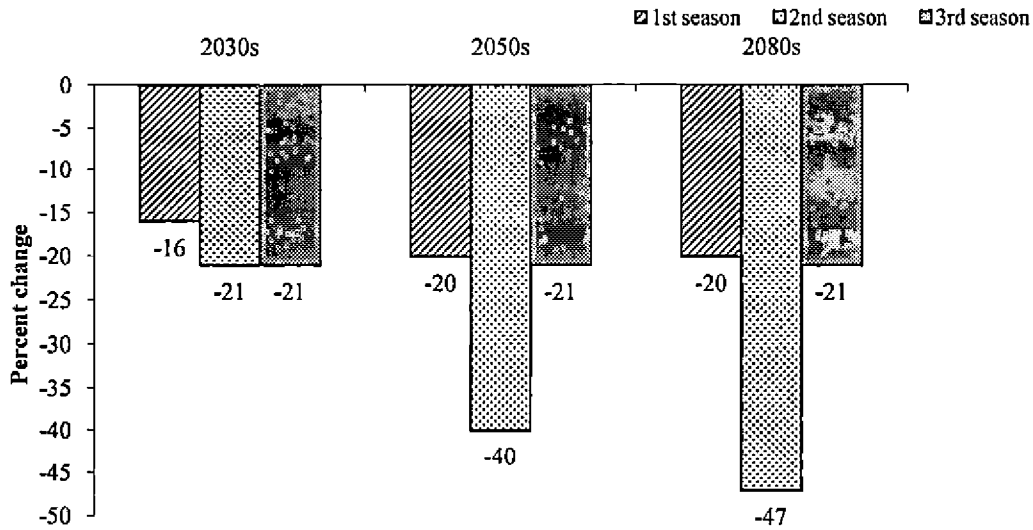

Fig. 31 Percent change in yield of Vaisakh in RCP 4.5

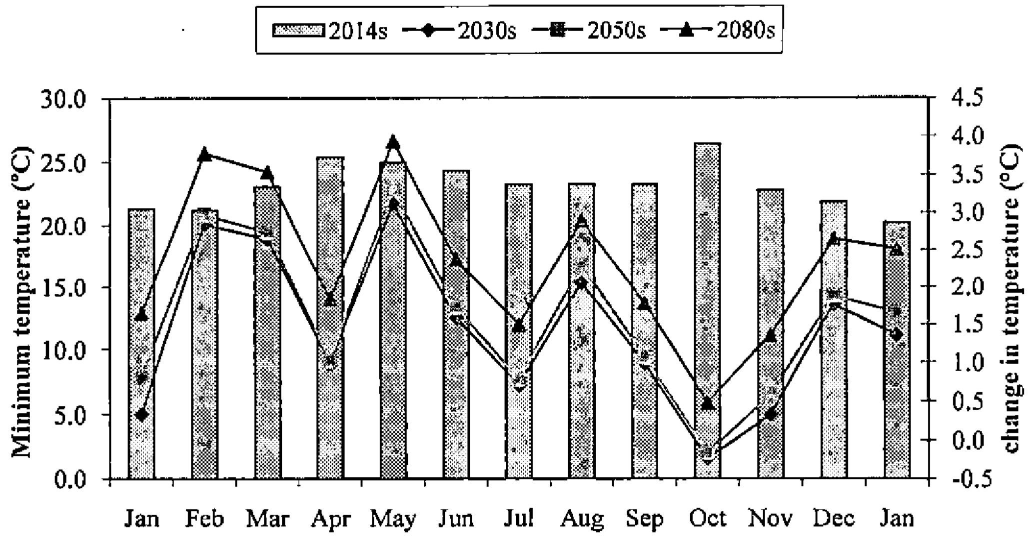

Fig. 32 Projected changes in monthly mean minimum temperature as per RCP 4.5 scenario

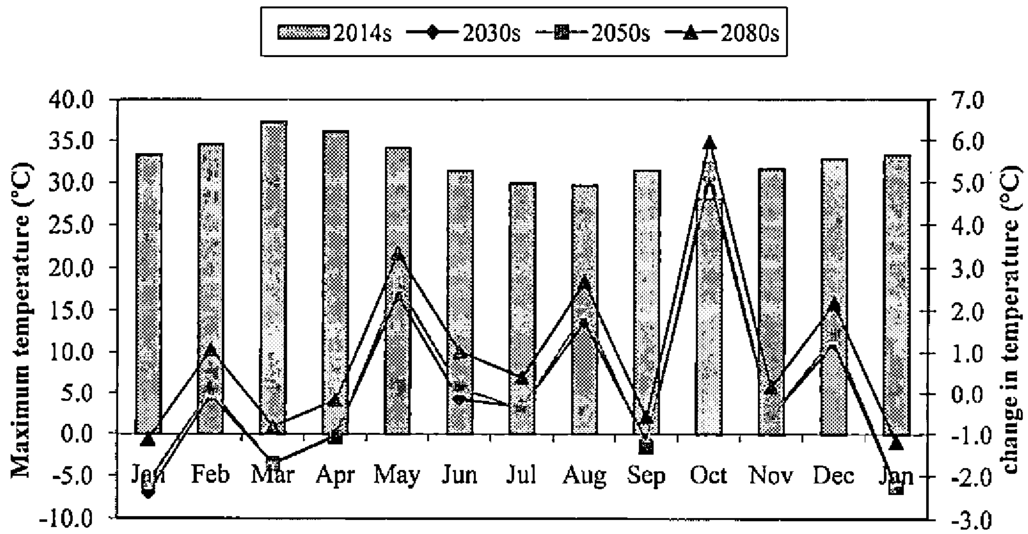

Fig. 33 Projected changes in monthly mean maximum temperature as per RCP 4.5 scenario

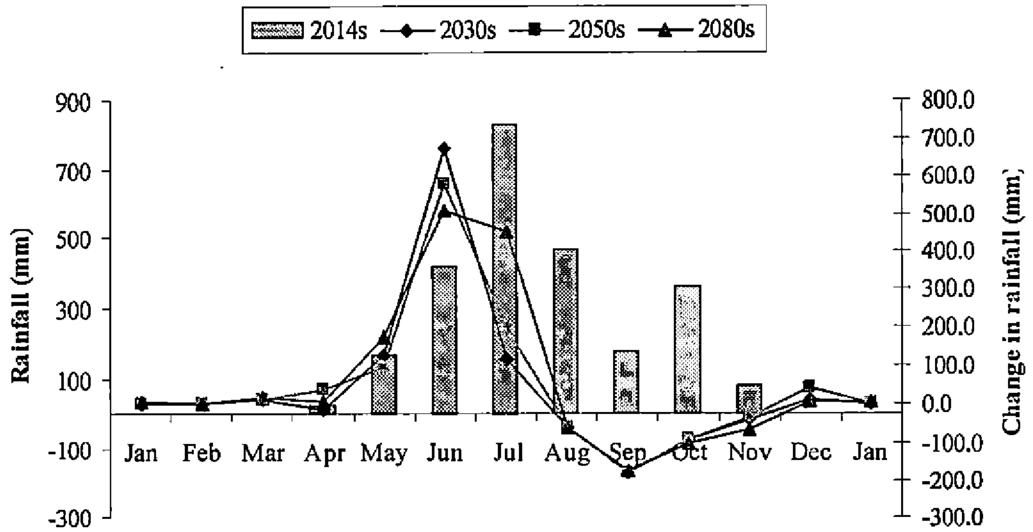

Fig. 34 Projected changes in monthly mean rainfall as per RCP 4.5 scenario

5.5.3 RCP 6.0

The grain yield of variety Aathira will not change during the first crop season in 2030s (Fig. 35). This is mainly because of slight increase in the minimum temperature (0.6°C) (Fig. 36). By 2050s the yield will be decreased by 10 per cent because of increase in the minimum temperature by 1.0°C, during critical crop growth stages. In 2080s, yield will be decreased by 24 per cent. This can be due to increase in the minimum temperature (1.7°C) during the critical growth stages. In the second crop season, yield has shown a reduction of 33 per cent, 38 per cent and 42 per cent by 2030s, 2050s and 2080s respectively (Fig. 35). During that period, the minimum temperature is increasing by 1.7°C, 1.9°C and 2.5°C by 2030s, 2050s and by 2080s which will increase the respiration losses (Peng *et al.,* 2004). Reduction in rainfall (100mm) may also contribute to the yield loss. In the third crop season, yield has shown a reduction of 16 per cent, 24 per cent and 29 per cent by 2030s, 2050s and 2080s, respectively (Fig. 35). This yield loss is due to increase in the minimum temperature by 2.7°C, 3.1°C and 3.7°C (Fig. 37) in 2030s 2050s and 2080s during the flowering stage of the crop. These results are in confirmation with Saseendran *et al.,* (2000) Peng *et al.,* (2004), Wassmann *et al.,* (2009) Barnwal *et al.,* (2013) Auffahammer *et al.,* (2012).

In the first crop seasons, the grain yield of Vaisakh will be reduced by 20 per cent, 22 per cent and 25 per cent by 2030s, 2050s and 2080s respectively (Fig. 36). This is mainly due to high rainfall (Fig. 39) (612mm increase) and increase in the minimum temperature (Fig. 37). In the second crop season, yield has shown a reduction of 30 per cent, 32 per cent and 38 per cent by 2030s, 2050s and 2080s respectively (Fig. 36). During that period, the minimum temperature is increasing by 1.7°C, 1.9°C and 2.5°C by 2030s, 2050s and by 2080s which will increase the respiration losses (Peng *et al.,* 2004). Reduction in rainfall (100mm) may also contribute to the yield loss. In the third crop season, yield has shown a reduction of 12 per cent, 22 per cent and 24 per cent by 2030s, 2050s and 2080s respectively (Fig. 36). This yield loss is less compared to first two seasons. This is because of increase in the rainfall. These results are in confirmation with Saseendran *et al.,* (2000) Peng *et al.,* (2004), Wassman *et al.,* (2009). Each variety has different response to changing conditions as reported by Osbornea *et al.,* (2013).

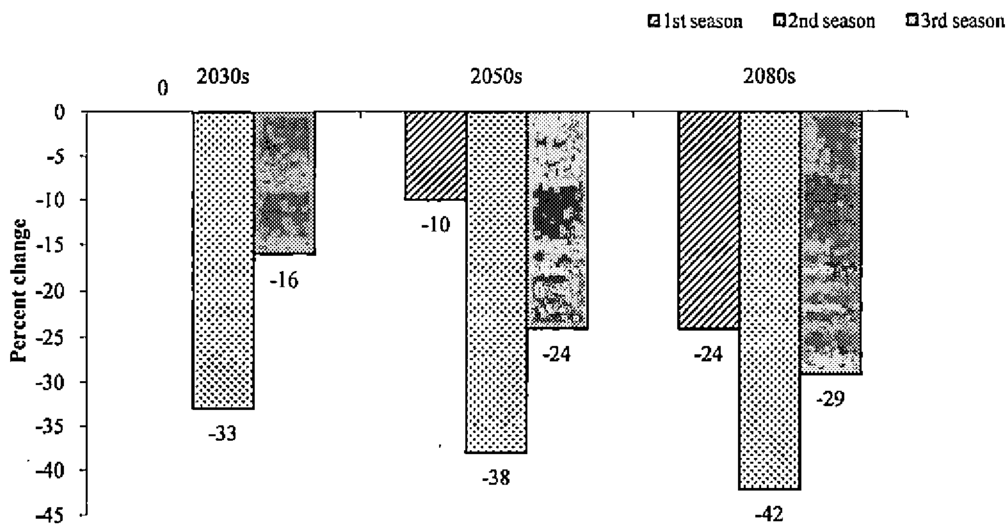

Fig. 35 Percent change in yield of Aathira in RCP 6.0

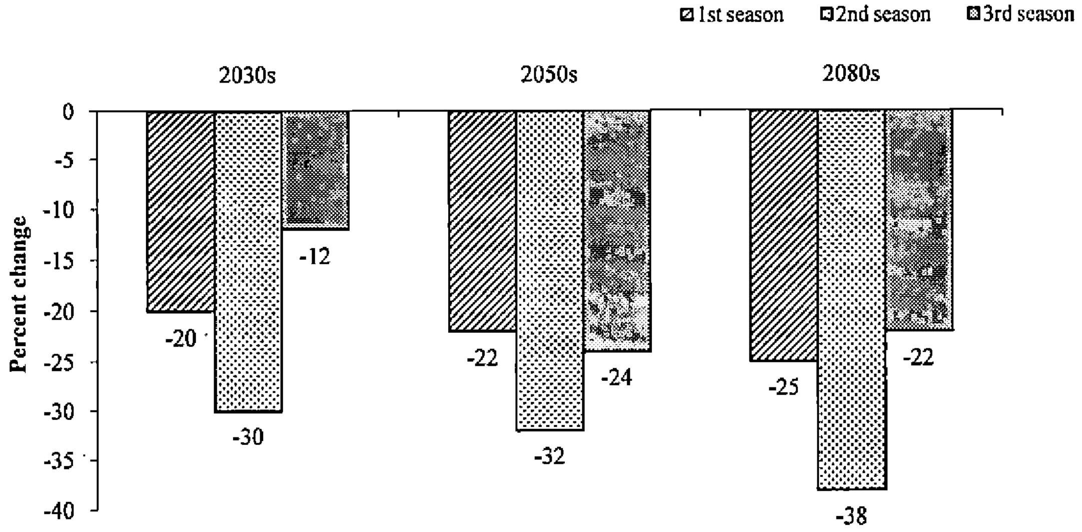

Fig. 36 Percent change in yield of Vaisakh in RCP 6.0

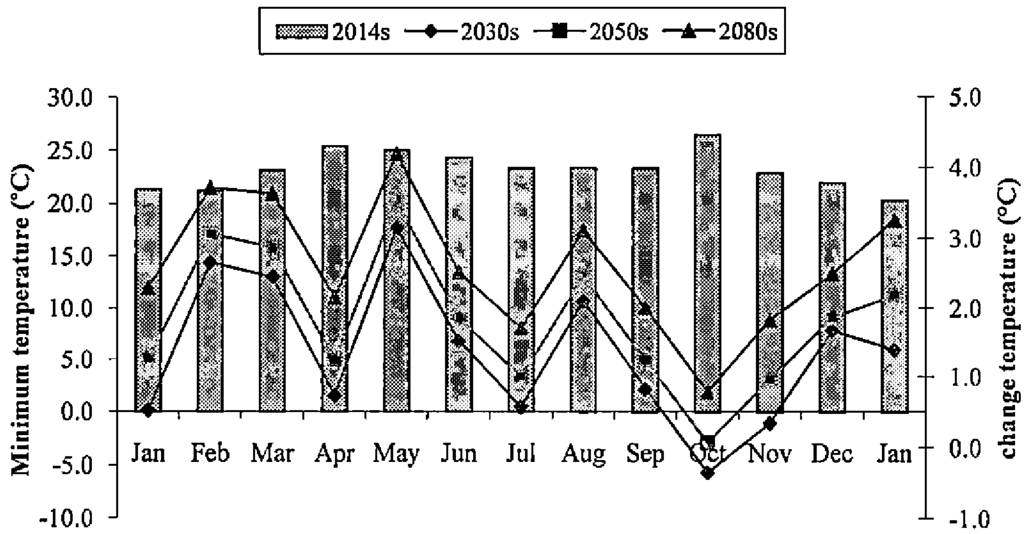

Fig. 37 Projected changes in monthly mean minimum temperature as per RCP 6.0 scenario

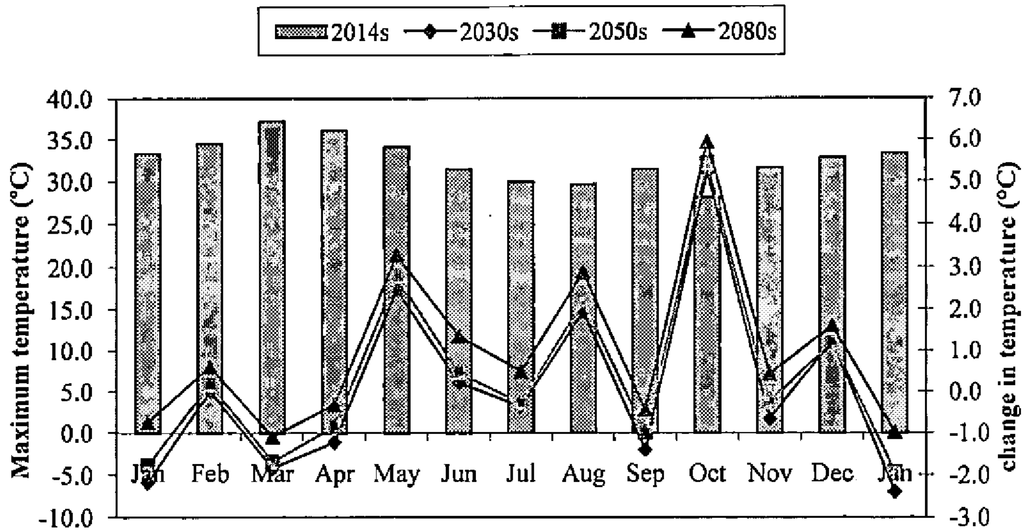

Fig. 38 Projected changes in monthly mean Maximum temperature as per RCP 6.0 scenario

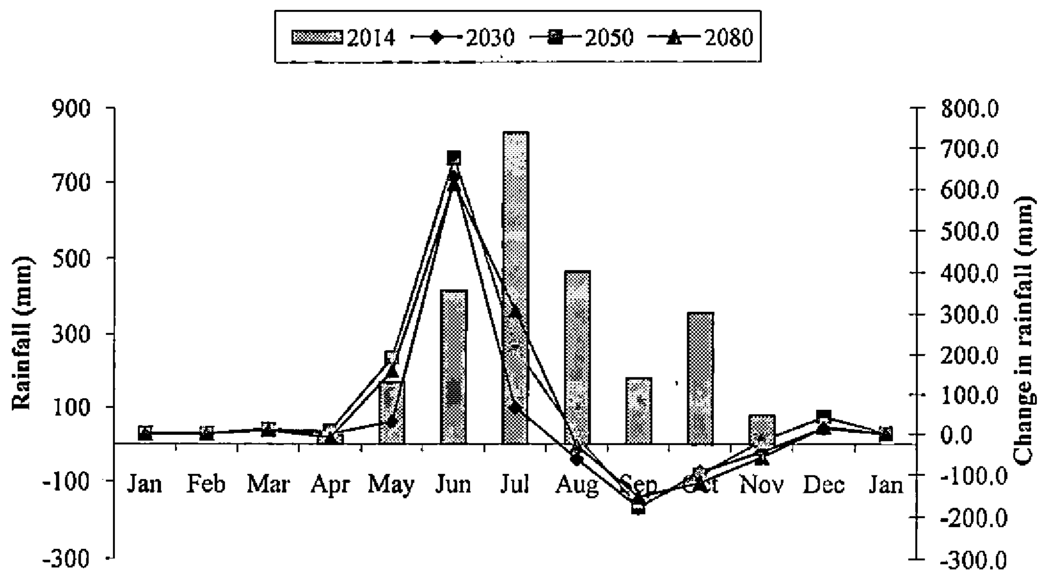

Fig. 39 Projected changes in monthly mean rainfall as per RCP 6.0 scenario

5.5.3 RCP 8.5

Due to the slight increase in the minimum temperature (Fig. 42) during 2030s in the first crop season, Aathira yield will be remains 5.7 t ha^{-1}.But during the second season, an yield reduction of 38 per cent, 40 per cent and 45 per cent by 2030s, 2050s and 2080s respectively (Fig. 40) will be expected. During this season the minimum temperature (Fig. 42) will increase by 0.7°C by 2030s, 2.2°C by 2050s and 3.3°C by 2080 in the flowering and grain filling period of the crop which will result in poor yields. During the third season, yield will show a reduction of 35 per cent, 37 per cent and 42 per cent by 2030s, 2050s and 2080s respectively. In the third season, minimum temperature (Fig. 42) will increase by 2.2°C in 2030s, 2050s and 5.1°C by 2080s, during the flowering stage which will increase the respiration losses and leads to yield reduction (Peng *et al.,* 2004). These results are in confirmation with Saseendran *et al.,* (2000) Peng *et al.,* (2004), Wassman *et al.,* (2009) Barnwal *et al.,* (2013) Auffahammer *et al.,* (2012).

Vaisakh yield in the first crop season will be reduced by 20, 29 per cent and 38 per cent in the periods 2030s, 2050s and 2080srespectively (Fig. 42). This can be due to increase in the rain fall by 781mm (Fig. 44) during the first crop season. The second crop season yield will be reduced by 36 per cent, 41 per cent and 50 per cent in the periods 2030s, 2050s and 2080srespectively (Fig. 42). During this season the minimum temperature (Fig. 42) will increase by 0.7°C by 2030s, 2.2°C by 2050s and 3.3°C by 2080s in the flowering and grain filling period of the crop which will result in poor yields. Yields will be reduced by 28 per cent, 35 per cent and 38 per cent in the periods 2030s, 2050s and 2080s respectively during the third crop season (Fig.41). In this season, minimum temperature (Fig. 42) is increasing by 2.2°C in 2030s, 2050s and by 2080s, it is increasing by 5.1°C during the flowering stage which will increase the respiration losses and leads to yield reduction (Peng *et al.,* 2004).These results are in confirmation with Saseendran *et al.,* (2000) Peng *et al.,* (2004). Each variety has different response to changing conditions as reported by Osbornea *et al.,* (2013).

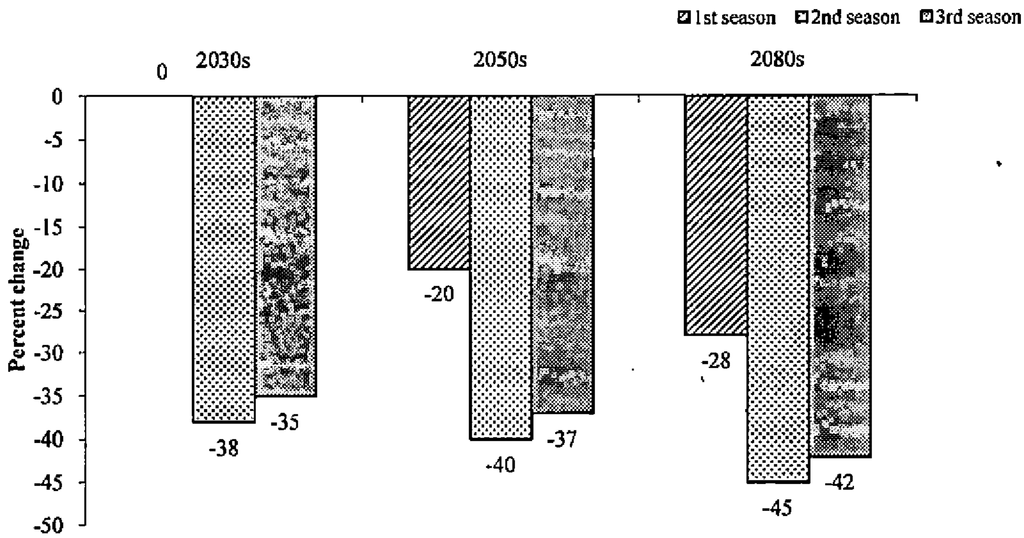

Fig. 40 Percent change in yield of Aathira in RCP 8.5

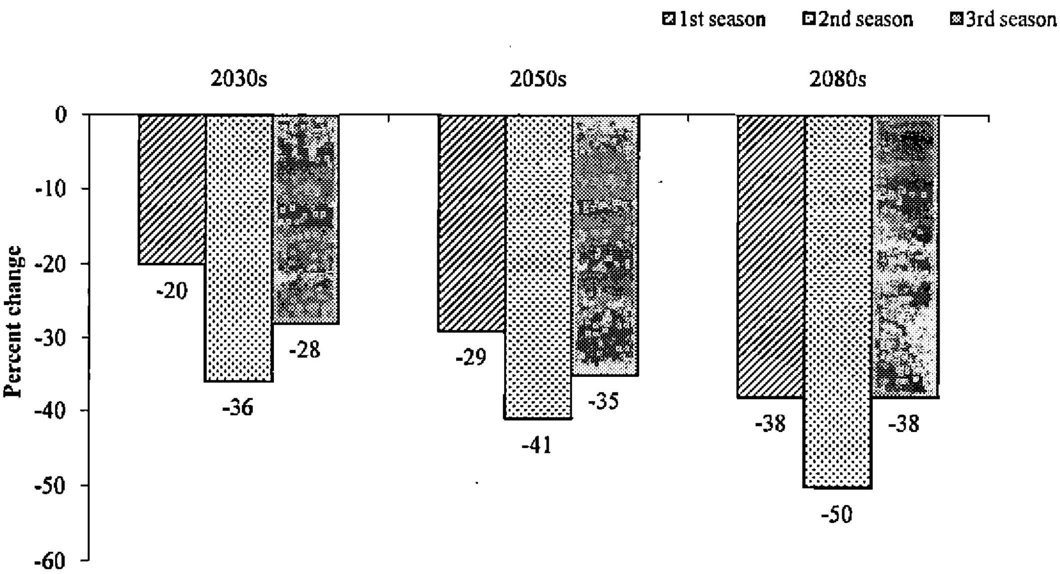

Fig. 41 Percent change in yield of Vaisakh in RCP 8.5

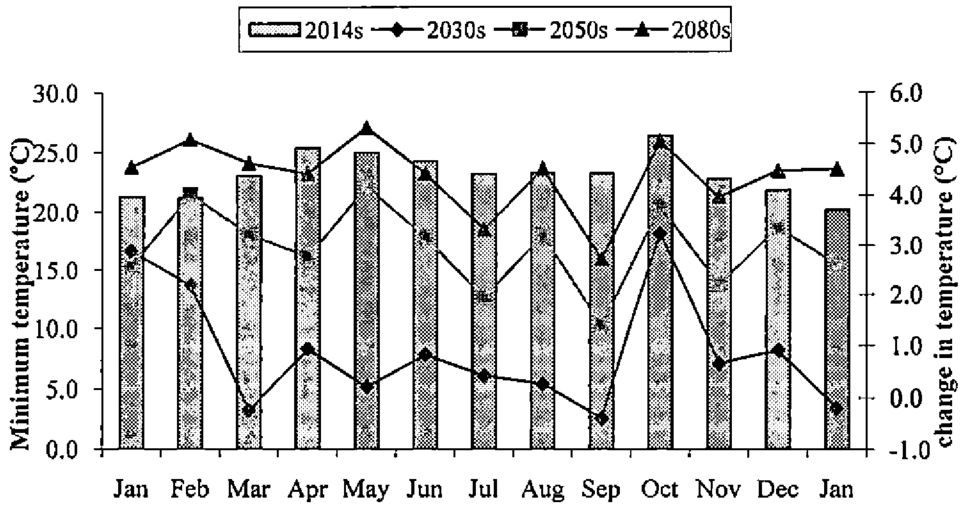

Fig. 42 Projected changes in monthly mean minimum temperature as per RCP 8.5 scenario

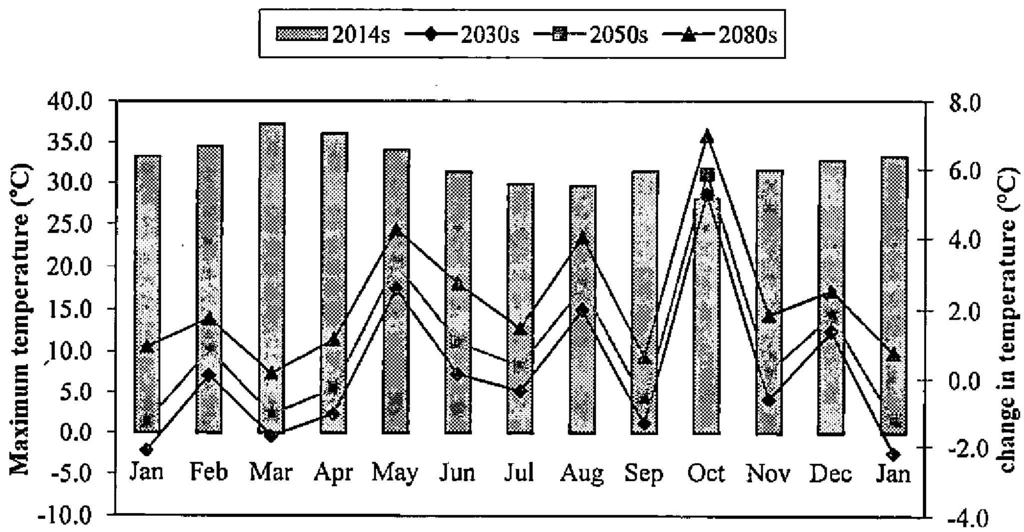

Fig. 43 Projected changes in monthly mean maximum temperature as per RCP 8.5 scenario

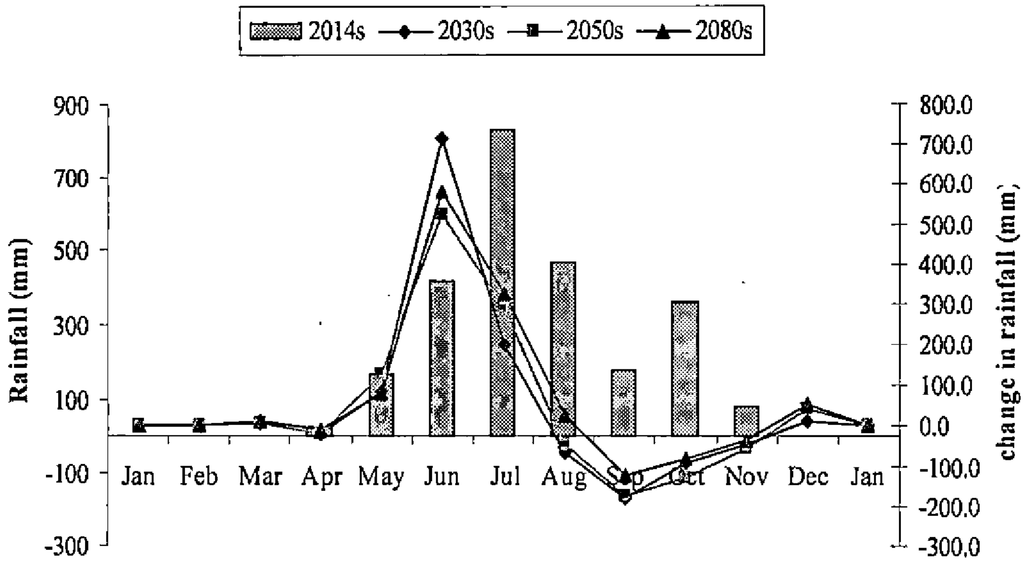

Fig. 44 Projected changes in monthly mean rainfall as per RCP 8.5 scenario

The results of the model simulation showing a clear evidence for a decrease of rice yield with projected climate change. The results also show that the effect of minimum temperature would drastically reduce the yield. The increasing atmospheric CO_2 concentration is likely to have some positive effect on yield, but the effect is not significant compared to the negative impact of rise in temperature.

The most alarming finding of the study is the huge reduction in yield during the second crop season, which is considered as the major rice growing season of Kerala. In RCP 4.5, which is the most likely scenario for India, the yield reduction will be 35 per cent, 38 per cent and 43 per cent during 2030s, 2050s and 2080s respectively in case of variety Aathira, the yield reduction will be 21 per cent, 40 per cent and 47 per cent during 2030s, 2050s and 2080s respectively in case of variety Vaisakh. Both the upland (Vaisakh) and lowland (Aathira) varieties recorded decline in yield during second crop season.

The major reason contributing to reduction in yield were higher temperature and decrease in the rainfall (100mm). Higher temperatures shorten the growing period and reduce the time available for photosynthetic accumulation. The increase in temperature can also decrease the yield due to spikelet sterility and higher respiration losses.

5.6 COMPARISION OF PERFORMANCES OF AATHIRA AND VAISAKH UNDER DIFFERENT CLIMATIC CHANGE SCENARIOS

The simulation analysis as per the projected climatic scenarios for the periods 2030s, 2050s and 2080s indicate that among the two varieties, variety Aathira will perform better in the first crop season. There is no reduction in the yield of Aathira under all the climate change scenarios (RCP 2.6, 4.5, 6.0 and 8.5) during the first crop season up to 2030. The will remain same even in 2050s and 2080s under RCP 2.6. In RCP 4.5, which is the most likely scenario for India, the yield reduction will be 7 per cent and 22 per cent during 2050s and 2080s respectively. Even in the RCP 8.5 scenario, it will show a yield reduction of only 20 per cent by 2050s and 28 per cent by 2080s.

Vaisakh, an upland variety, tolerant to temperature and drought, has better performance under third crop season. During the third crop season, Vaisakh yield will be reduced by 12 per cent, 21 per cent and 10 per cent only for the periods 2030s, 2050s and 2080s respectively in RCP 2.6. In RCP 4.5, the yield reduction will be only 21 per cent for the periods 2030s, 2050s and 2080s. Under the RCP 6.0 projections, yield will be reduced by only 12 per cent, 24 per cent and 22 per cent for the periods 2030s, 2050s and 2080s respectivelyduring the third crop season. Even in the RCP 8.5 scenario, yield will be reduced by only 28 per cent, 35 per cent and 38 per cent in the periods 2030s, 2050s and 2080s respectively. The yield of both the varieties decreased considerably during the second crop season.

Summary

6. Summary

An experiment was conducted at Regional Agricultural Research Station, Pattambi to study the crop-weather relationship in rice, to validate the DSSAT model and to study the impact of climate change on rice production by the periods 2030s 2050s and 2080s under different climate change scenarios of IPCC 2013 report, with two varieties, Aathira and Vaisakh.

The observations on morphological, phenological and yield attributes were recorded at different stages of development of the crop. The observations on weather factors were recorded daily to workout crop weather relationship. DSSAT model was validated and impact of climate change on rice production was studied.

The salient finding are summarised as follows:

1. Variety and time of planting has significantly influenced the plant height. Highest plant height observed in Aathira was 133 cm and Vaisakh was 145.33 cm. June 1st planting has recorded highest plant height in both the varieties.
2. The highest biomass accumulation was recorded in variety Vaisakh planted on 15th Oct (54.40g).
3. In Vaisakh maximum number of tillers per plant was observed (22.33) in the crop transplanted during June 15th, whereas in case of Aathira crops planted during June 1st (20) and June 30th (20) was recorded the maximum number of tillers
4. The maximum LAI recorded by the variety Vaisakh was 9.96 by June 15th transplanted crop. Whereas Aathira recorded a maximum LAI of 9.36 by the crop planted on June 15th.
5. Vaisakh transplanted on January 1st recorded the highest number of panicles per plant (357.00). Highest number of panicles observed in June 30th transplanted crop (340.66) in case of Aathira.
6. The highest number of filled grains per panicle was observed in June 30th planted crop of Vaisakh (147.3) and the June 15th planted (141.7) crop of variety Aathira.
7. The highest yield of Vaisakh was recorded by the crop planted on January 1st (6.30 t ha^{-1}). Whereas in Aathira crop planted on Oct 30th (5.86 t ha^{-1}) recorded the highest yield.
8. The highest harvest index was observed in January 1st planted crop of Vaisakh (49.12). The lowest harvest index was observed in June 15th transplanted crop.

9. Vaisakh transplanted on January 1st recorded the highest number of panicles per plant (357.00). Highest number of panicles observed in June 30th transplanted crop (340.66) in case of Aathira.
10. The highest number of filled grains per panicle was observed in June 30th planted crop of Vaisakh (147.3) and it was on par with the June 15th planted (141.7) crop of variety Aathira.
11. The highest straw yield has recorded by the variety Aathira transplanted during June 1st (7.86 t ha^{-1}).
12. In both the varieties minimum temperature above 24°C in the panicle initiation to flowering stage has reduced the yields. Maximum temperature above 32°C during tillering stage will negatively influence the biomass accumulation.
13. Multiple regression equations was predicted the grain yield, leaf area index and duration with good accuracy in both the varieties.
14. DSSAT model was validated and it was given good RMSE values for both the varieties (Aathira 515.6 kg ha^{-1}, Vaisakh 377.75 kg ha^{-1}).
15. The simulation analysis as per the projected climatic scenarios for the periods 2030s, 2050s and 2080s indicate that among the two varieties, variety Aathira will perform better in the first crop season.
16. Vaisakh, an upland variety, tolerant to temperature and drought, the performance is better under third crop season.
17. The results also showed that the effect of minimum temperature would drastically reduce the yield. The increasing atmospheric CO_2 concentration is likely to have some positive effect on yield, but the effect is not significant compared to the negative impact of rise in temperature.
18. The most alarming finding of the study is the huge reduction in yield during the second crop season, which is considered as the major rice growing season of Kerala.

19. In RCP 4.5, which is the most likely scenario for India, the yield reduction will be 35 per cent, 38 per cent and 43 per cent during 2030s, 2050s and 2080s respectively in case of variety Aathira, the yield reduction will be 21 per cent, 40 per cent and 47 per cent during 2030s, 2050s and 2080s respectively in case of variety Vaisakh, during the second crop season.

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IMPACT OF CLIMATE CHANGE ON RICE PRODUCTION

By

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ABSTRACT OF THE THESIS

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Abstract of the thesis

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% of the population is exposed to a great danger, as the country is one of the most vulnerable countries to climate change. Climatic changes are already exerting a considerable drag on yield growth (Lobell *et al.*, 2011). Future impacts of climate change on rice yield in India would likely be larger than the historical ones (Auffhammer *et al.*, 2012).

Objectives of the study were development of crop weather relationships for the selected rice varieties and assessment of possible change in yield due to climate change. The studies were conducted during 2014-15 at RARS, Pattambi in two varieties (Aathira and Vaisakh) with nine dates of planting.

The results of the study showed the effect of weather parameters on biometric characters varied significantly with variety and time of planting. Both the varieties recorded the maximum plant height (Aathira is 133 cm and Vaisakh is 145.33 cm) when planted on June 1st and maximum LAI during June 15th. The highest grain yield of variety Vaisakh was recorded by the crop planted on January 1st (6.30 t ha^{-1}). Whereas in Aathira crop planted on Oct 30th (5.86 t ha^{-1}) recorded the highest yield.

In both the varieties minimum temperature above 24.0°C in the panicle initiation to flowering stage has reduced the yields. Maximum temperature above 32.0°C during tillering stage will negatively influence the biomass accumulation. Multiple Regression equations were developed for predicting grain yield, leaf area index and duration.

DSSAT model was validated and it was given good RMSE values for both the varieties (Aathira 515.6 kg ha^{-1}, Vaisakh 377.75 kg ha^{-1}). The simulation analysis as per the projected climatic scenarios for the periods 2030s, 2050s and 2080s indicate that

among the two varieties, variety Aathira will perform better in the first crop season. Vaisakh, an upland variety, tolerant to temperature and drought, the performance is better under third crop season. The most alarming finding of the study is the huge reduction in yield during the second crop season, which is considered as the major rice growing season of Kerala. In RCP 4.5, which is the most likely scenario for India, the yield reduction will be 35 per cent, 38 per cent and 43 per cent during 2030s, 2050s and 2080s respectively in case of variety Aathira, the yield reduction will be 21 per cent, 40 per cent and 47 per cent during 2030s, 2050s and 2080s respectively for Vaisakh, during the second crop season.

Appendices

Appendix I-Pests and diseases observed in different dates of planting

Planting dates	Pests				Diseases		
	Leaf folder	Rice bug	Stem borer	Case worm	Brown spot	Sheath blight	BLB
June 1st	✓	✓	✓			✓	
June 15th	✓	✓	✓			✓	
June 30th	✓	✓	✓			✓	
October 1st	✓	✓	✓	✓		✓	
October 15th	✓	✓	✓	✓		✓	
October 30th	✓	✓	✓	✓	✓	✓	
January1st	✓	✓	✓	✓	✓	✓	✓
January 15th	✓	✓	✓	✓	✓	✓	✓
Januray 30th	✓	✓	✓	✓	✓	✓	✓