ASSESSMENT OF RICE (*Oryza sativa* L.) PRODUCTION UNDER CLIMATE CHANGE SCENARIOS

By

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(2015-11-108)

THESIS

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DECLARATION

I hereby declare that this thesis entitled **"Assessment of rice (*Oryza sativa* L.) production under climate change scenarios"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **"Assessment of rice (*Oryza sativa* L.) production under climate change scenarios"** is a bonafide record of research work done independently by **Mr. Jasti Venkata Satish (2015-11-108)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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We, the undersigned members of the advisory committee of **Mr. Jasti Venkata Satish (2015-11-108)**, a candidate for the degree of **Master of Science in Agriculture** with major field in Agricultural Meteorology, agree that this thesis entitled **"Assessment of rice (*Oryza sativa* L.) production under climate change scenarios"** may be submitted by **Mr. Jasti Venkata Satish** in partial fulfillment of the requirement for the degree.

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Introduction

1. INTRODUCTION

Agriculture is sensitive to short term changes in weather and to seasonal, annual and long term variations in climate. Climate change will have decisive impact on crop production, and the prediction of this climate change emerged as a major research priority during the past decade. Numerous estimates for the impending decade projects that continuous rise of anthropogenic forcing leads to increase in green-house gas (GHG) concentrations, is expected to alter regional temperature and precipitation patterns, also contributing to higher risk of extreme weather events and climate irregularity (IPCC, 2013), with obvious implications on crops (Porter and Semenov, 2005). Predictions of central Asia shows that by the end of the twenty first century temperatures are likely to increase by 3^0-4^0 C, and the atmospheric CO_2 concentration will increase from the current 380ppm to 485-1000ppm. Under such scenarios crop yields are likely to decrease by as much as 30% in the region even when the direct positive Physiological effects of increased CO_2 are accounted (Parry *et al.,* 2007). A numerous investigators reported that in event of climate change, irrigation agriculture would be severely affected due to increased crop water requirement and decreased water resources availability especially in arid and semi-arid regions of world including India.

Since rice is the staple food of India, it is essential to identify the impacts of climate change on rice yield to increase the country's rice production. Rice is adapted to a greater range of climatic conditions than any other single cereal species, as such, cultivated land range from lowland, flood plains, and deltas to hills and mountains. In India, more than half of the annual rice crop continues to be grown during the summer monsoon season (*kharif*). During the last 45 years there was a steady reduction in area under paddy in Kerala. Climatic factors such as temperature, rainfall, atmospheric CO_2 and solar radiation are important parameters for rice production.

Under climate change scenarios, plant response to elevated CO_2 alone without change in temperature and precipitation was found to be positive, which will directly depend on photosynthesis pathway of plant species, water and nutrient availability. Rice being a C_3 crop, its photosynthesis, yield and biomass are expected to increase under elevated CO_2 in absence of temperature increase (Razzaque *et al.,* 2011). But under the elevated CO_2 and temperature, the positive effect of CO_2 is nullified by temperature rise (Krishnan *et al.,* 2007). Thus, climate change and its impact is a major constraint in cultivation of rice crop by farmers, and therefore, adaptations based on future simulated grain yields can provide valuable inputs to sustain the yield.

The CERES-Rice (Crop Environment Resource Synthesis) of DSSAT v4.6 (Decision Support System for Agro-Technology Transfer) is process-oriented, management level model of rice crop growth and development, respectively (Jones *et al.,* 2003), which can be used to simulate the phenology, crop growth and yield and biomass partitioning of plants. The simulation processes of model is dynamic, mechanistic and process based, which are affected by environmental and cultivar specific factors. These tools can reduce the need for expensive and time consuming field trails and could be used to analyze the yield gaps in various crops including rice (Pathak and Wassmann, 2005).

Since all the crop models are limited limitations of the real system, they all have extensive field validation to assess whether they are structurally sound and, as well, to assess the limitations of validity. Only after extensive experimental validation, a crop model can become an actual working tool capable of providing guidance on the practical management of agricultural systems. After proper validation, models may be used to predict the effects of changes in environment and management of crop yield. In this background, the present investigation was carried out to assess the impact of climate change on rice production using crop simulation technique and evaluate the potential of cultivars and planting times, with the following objectives.

1. Determine the crop weather relationships

2. Validate the CERES-Rice model for varieties Jyothi and Kanchana

3. Identify the changes of rice yields and growth under climate change scenarios

Review of Literature

2. REVIEW OF LITERATURE

In general, the productivity of Rice crop can be influenced by environmental conditions such as solar radiation, temperature and water availability during crop growth and development (Fageria, 2007)

2.1 EFFECT OF WEATHER PARAMETERS ON GROWTH AND YIELD OF RICE

Choudhary and Wardlaw (1978) reported that the size of grain is more stable at night temperature than wheat. Rao (1978) studied the influence of weather on rice yield using regression equation for the productivity of rice in Kenya. The mean temperature showed a positive influence on rice yield while radiation showed a negative influence on rice yield.

According to Vishwambharan *et al.* (1989) poor yield of rice due to high sterility of spikelets was caused by high wind speed especially during flowering and maturity stages.

Hirai *et al.* (1993) studied the effect of relative humidity on dry matter production and nitrogen absorption at various temperature levels. The rice plants were grown for 4 days under 60 and 90% relative humidity at 12 h day and 12 h night temperatures of 24/20, 28/24, 32/28 and 36/32 °C. The plants grown under 90% relative humidity with 24/20 and 28/24°C increases the dry matter in leaves and roots than that of plants grown under 60% relative humidity. They concluded that the dry matter accumulation was affected by humidity and temperature.

Increased daily average and maximum temperatures shorten length of grain filling phase and reduce the seed setting rate in rice (Fu *et al.* 2008)

Kaladevi *et al.* (1999) conducted a study during 1997-98 in Tamil Nadu to understand the effect of agrometeorological parameters such as maximum and minimum temperature, relative humidity, solar radiation, wind speed, evaporation and total rainfall on the yield of *Rabi* rice under three transplanting dates (15^{th} October, 1st November and 15th November). They reported that higher dry matter production is contributed by lower minimum temperature.

Lalitha *et al.* (2000) reported that the temperature plays a major role in tillering duration in lowland rice varieties in Andhra Pradesh. They reported that the duration of tillering period was controlled mainly by temperature prevailed during the tillering stage. Daily mean temperature more than 26 °C during tillering reduces the duration to 5 weeks after planting whereas, the temperature between 22.9 to 25.8 °C increases the duration of tillering up to 8 weeks.

Gupta *et al.* (2000) studied the effect of rainfall, number of rainy days and length of rainy season with productivity of rice in Jabalpur. They reported that the weather variables like quantum of rainfall, length of rainy season and number of rainy days were significantly correlated with rice yields. They concluded that for obtaining higher productivity of rainfed rice either surplus rain water be efficiently used to overcome moisture stress during reproductive phase or to minimize the risk of moisture stress during grain filling stage and selection of short duration varieties gave better water use efficiency and are drought tolerant.

Abeysiriwardena *et al.* (2002) reported that the complete grain sterility in rice is associated with relative humidity of 85-90% at heading stage along with day or night temperature of 35/30°C.

Nigam and Mishra (2003) studied the correlation between weather parameters and rice yield in the tarai region of Pantnagar. They noticed that the effect of weather variables varies with time of transplanting. They reported that the number of sunshine hours showed significant correlation with rice yield. The weather variables like minimum temperature, maximum and minimum relative humidity and rainfall showed positive correlation with yield, whereas the number of rainy days, wind velocity, and evaporation showed positive correlation with yield. Timely transplanting showed significant correlation between number of sunshine hours and maximum temperature with yield, whereas number of sunshine hours showed significant correlation in later transplanted crops.

Peng *et al.* (2004) reported that the yield of dry season rice crops in the Philippine decreased by 15% for each 1° C increase in mean temperature in the growing season.

Goswami *et al*. (2006) studied the effect of weather parameters on phenology, growth and yield of rice and wheat. They reported that the relationship of two or more weather parameters and grain yield of crops can be used to predict the actual harvesting of crops.

According to Wahid *et al*. (2007) reported that the high temperature effect rice growth stages and the growth stage at which is exposed to more heat causes damages to crop. Low and high temperature during vegetative and reproductive stage may cause poor tillering, less productive tillers and poor seed setting in rice crop.

According to Weerakoon *et al*. (2008) increased relative humidity along with high temperature reduced the pollen shedding on stigma while high relative humidity along with low air temperature does not show such reduction in pollen shedding. They suggest that the high relative humidity along with high temperature causes spikelet sterility.

Yan *et al*. (2010) reported that the high relative humidity at flowering stage at increased temperature affect the spikelet fertility.

According to Shah *et al*. (2011) high temperature during booting and flowering stages of rice leads to complete sterility and humidity also plays a vital role in spikelet sterility at increased temperature. Soleymani and Shahrajabian (2011) reported that the temperature and humidity was not favorable for grain development in rice and showed highest number of tillers, number of grains, 1000 grain weight and grain yield and harvest index in rice planted on 25th May.

Auffhammer *et al*. (2011) studied the effect of climate change and monsoon in India. The study conducted during the *kharif* season and the data confirms that drought and extreme rainfall negatively affected the rice yield. They reported that the rice yield became 1.7 per cent higher on an average of monsoon characteristics and yield received additional boost of nearly 4 per cent without any other meteorological changes.

Singh *et al.* (2012) conducted an experiment in Department of agronomy, Kanpur during *Kharif* season with three dates of planting (15th July, 25th July and 5th August) and three rice varieties (Ashwani, Pant 4 and Mahsoori). They reported that the early transplanting period was favorable for growth and development of rice and also the early transplanted crops produce more biomass.

Bhattacharya and Panda (2013) reported that the 1°C increase in temperature showed decrease in rice yield whereas per mm increase in rainfall showed an increase in rice yield in subtropical region and the increase were recorded as 0.35kg/ha per mm rainfall and decrease were recorded as 152.2kg/ha per degree rise in temperature.

Temperature is the most important factor influencing the rice crop growth, development and yield (Rani and Maragatham, 2013). Temperature influences the duration of each phenological stages and directly affect the yield of rice. They conducted the experiment during the *kharif* season of 2012 under temperature control chamber with 2 to 4°C increased ambient temperature. They reported that the days taken to attain maturity was less under elevated temperature of 4°C (96 days) and 2°C (102 days) than ambient temperature (108 days).

Restrepo and Garces (2013) reported that decrease in solar radiation by 20-50% can reduce the grain yield approximately by 40% in certain periods of the year in profoundly rice producing areas in Colombia.

Sanchez-Reinoso *et al.* (2014) reported high temperature s of low radiation during the reproductive or maturity period shows negatively effect on the capacity of photosynthesis and decline the size of number of spikelets in rice plants.

Naziya (2014) studied the crop weather relationship of two rice varieties (Jyothi and Kanchana) in Department of Agricultural Meteorology, Kerala Agricultural University, Thrissur. She reported that the duration of rice varieties decreases with increase in temperature and bright sunshine hours and the weather parameters like forenoon and afternoon relative humidity, rainfall and rainy days positively influences the crop duration. She also reported that the weather parameters like minimum temperature, forenoon and afternoon relative humidity, rain fall, rainy days, bright sunshine hours and evaporation were higher in early transplanted crops than late transplanted crops.

Pandey *et al.* (2015) studied the joint effect of weather parameters on rice yield in Uttar Pradesh and reported that the most favorable combination of weather variables are rainfall and wind velocity with 82% followed by rainfall and sunshine hours and wind velocity and sunshine hours 63.5 and 53.8 respectively.

Shi *et al.* (2015) studied the extreme heat events on rice yield. The spatial variation of heat stress during post heading was greater during single season rice region than double season rice region.

Yuliawan and Handoko (2016) claimed that temperature rise would make the age of rice the shorter and decrease the rice yields. This research pointed out that irrigated farm having less impact from temperature rise compared with rainfed farm which had the decreasing of rice yield for 11.1% ^{0}C and 14.4% ^{0}C sequentially as well.

2.2 EFFECT OF DATES OF PLANTINGS ON GROWTH AND YIELD OF RICE

Timely transplanting is one of the major objectives of rice production. Rice varieties widely differ in their tillering behavior based on the time of transplanting, season, agrometeorological conditions of locality and varietal characteristics. The time of transplanting is a critical component for the better crop production.

Choudhary and Sodhi (1979) studied the effect of weather factor on growth of rice variety Taichung Native-I from 15th May to 30th April and transplanted after 14 to 21 days at Kharagpur. They reported that the growth duration varied with air temperature and increased in proportion to the length of time the experienced low temperature during vegetative growth and flowering.

Roy and Biswas (1980) reported that the effect of date of sowing on the yield of boro rice cultivar. Early transplanted rice cultivars gave highest value of seedling height, plant dry matter content, number of tillers per plant and crop duration decreased with delayed sowing and decreasing night temperature. Low temperature reduced seedling leaf emergence by up to 30 days.

Ramdoss and Subramanian (1980) studied the effect of weather parameters during the last 45 days of crop growth on rice yield at Coimbatore. They reported that rice yield were positively affected by maximum temperature and number of sunshine hours and negatively affects straw yield.

Agarwal *et al.* (1983) reported the joint effects of climate variables on rice yield at different stages of crop growth in Raipur district. Above average maximum temperature along with rise in humidity during active vegetative phase showed beneficial effect on rice yield and showed detrimental effects on other growth stages.

According to Reddy and Reddy (1986) early transplanted rice gave higher paddy yields than later transplanted rice cultivars. Delay in planting affects the duration of rice in Nellore variety, but the number of days taken for production was increased. Harvest index increased in the crops transplanted in early planted crops than later transplanted crops.

Maity and Mahapatra (1988) reported that the highest yield was obtained from rice varieties planted on 5 to 10th January and 20 to 25th December and the yield was 3.7 and 2.6 t ha^{-1} in 1985 and 1986 respectively. High temperature during late and early transplanting reduced the rice yield.

According to Shi and Shen (1990) high humidity and low temperature affect the spikelet fertility in 12 Indica rice varieties in China. High relative humidity along with decreased temperature reduces the spikelet fertility and relative humidity was the most significant weather parameter affecting spikelet fertility followed by mean temperature at 3 days after heading.

Reddy and Reddy (1992) reported that the early transplanted rice variety Surekha produces more productive tillers per unit area than later planted rice cultivar.

Early transplanted rice variety received less amount of solar radiation which leads to mortality of rice.

Begum *et al.* (2000) observed that time of anthesis; maturity and duration of two varieties of rice were altered by date of transplanting with 10 dates of transplanting with 10 dates of sowing, starting with 1st July, 1994 and ending with 28th March, 1995 at 30 days interval.

Biswas and Salokhe (2001) reported that the 1000 grain weight was significantly affected by sowing date. Early sown rice variety (20^{th} June) produced heavier grains while minimum grain weight was observed by crop sown on 20^{th} July.

Safdar *et al.* (2006) studied the effect of transplanting dates and number of seedlings per hill under high temperature on productivity of rice in Dera Ismail Khan district of North West Frontier Province (NWFP), Pakistan. Four dates of planting (20^{th} and 27^{th} June and 4^{th} and 11^{th} July) were selected for the study and they reported that the June 20^{th} planted crop gave higher grain yield and net return with one seedling per hill. They concluded that the timely planting require 1 seedling per hill or 4 seedlings per hill to compensate the yield gap in late planted rice varieties.

Khakwani *et al.* (2006) studied the effect of date of planting on yield and yield components. Highest yield were obtained in early transplanted rice cultivars while later transplanted crops were heavily infested by stem borer causes reduced yield to larger extent at Agricultural research station, Dera during 2003.

Effect of planting dates on growth and some agronomic characters by early seeding and late seeding and indicated that transplanting date affected the performance of these traits significantly (Vange and Obi 2006).

Chahal *et al.* (2007) studied the influence of transplanting dates in yield, evapotranspiration and water productivity of rice wheat system in Punjab. They reported that the yield of rice is significantly influenced by temperature and the shifting of transplanting dates of rice from higher to lower evaporative demand shows increase in rice production. Long term analysis showed that the weather conditions are favourable for growth and production in late transplanted rice.

Akram *et al.* (2007) reported the effect of different planting dates from July 1 to 30 with 10 days interval on six rice varieties. They reported that the number of tillers, grains per spike, plant height, 1000 grain weight and sterility were significantly affected.

According to Nahar *et al.* (2009) the grain weight of Aman rice was influenced by transplanting dates. Early transplanted rice provided the highest result whereas 30th September transplanted rice provided the lowest result for both the cultivars.

According to Ali and Khalifa (2009) sowing dates are important factor for increasing grain yield and it is closely related to the growth duration. They conducted the experiment in Egypt in 2008 for the physiological evaluation of four hybrid rice varieties under six different sowing dates. They reported that the variety H1 gave highest values than other hybrid varieties due to higher activity of rice plants on early growth stage.

Khalifa (2009) conducted a field experiment at the experimental farm of Rice Research and Training Centre (RRTC), Egypt in 2008. Six dates of planting with four hybrid rice were selected for the study. The dates of planting were 10th April, 20th April, 1st May, 10th May, 20th May and 1st June. The result showed that the early planting date was best for the growth and development of rice. The crops sown on April 20th gave highest value of number of tillers, plant height, root length at panicle initiation and heading stages. Number of filled grains per panicles was also influenced by different sowing dates. April 10th sowing recorded highest number of grains per panicle and June 1st recorded the lowest value. They also find out the April 20th sowing gave highest value of 1000 grain weight, number of panicles and grain yield. They concluded that the late planting reduces the plant properties and there by reduces the grain yield.

Akbar *et al*. (2010) studied the effect of sowing dates on yield of direct seeded fine rice. Six dates of sowing were selected for this study and the results showed that the yield components showed significant responses to different sowing dates of rice crops.

Bashir *et al*. (2010) conducted field experiment for understanding the effect of different sowing dates on yield and yield components of direct seeded coarse rice. They selected six dates of plantings for the study such as 31st May, 10th June, 30th June, 10th July and 20th July. They reported that the crops sown on 20th June provide maximum grain yield and net return. 20th June also gave maximum number of productive tillering number of kernals per panicle and 1000 grain weight.

Buddhaboon *et al*. (2011) reported that crops which are cultivated during dry season showed an increase in biomass and yield were affected by the interaction between planting dates and variety. The experiment was carried out at the deep water area of Thailand. Four dates of plantings *viz*. 19th May, 2nd June, 16th July and 23rd July with three rice varieties viz. Chai Nat 1 (CNT 1), Pathum Thani 1 (PTT 1) and Pitsanulok 2 (PSL 2) were selected for the field experiment. They reported highest average grain yield (3898 kg h-1) in variety PSL2 which were planted from June 19 to July 23.

Ali *et al.* (2012) reported that the effect of different sowing dates on growth and yield of five new rice varieties, Sakha 106, Sakha105,G.Z.7576,G.Z.9057 and G.Z.9362 under five dates of sowing viz. April 1st, April 10th, April 20th , May 1st and May 10th . The result showed that the variety which is sown during April 1st gave highest value of maximum tillering, panicle initiation and flowering dates. They also reported that the variety Sakha is superior to other varieties.

Safdar *et al.* (2013) studied growth and yield of medium grain rice varieties under five different sowing dates. Results showed that the rice yield and number of grains per panicle increased with delay in sowing time up to 16th May (third date of planting) and number of days for flowering, tillers per hill and plant height decreased with delay in sowing. They also reported that the difference in yield response to different sowing dates was due to differential tolerance to temperature stress at vegetative and reproductive growth stages.

Sandhu *et al.* (2013) reported that early transplanted rice varieties accumulated more heat units to attain physiological maturity.

Khan and Rahman (2014) studied the effect of different transplanting dates on yield and yield components of rice in the hilly areas of Swat valley. They conducted the experiment during the summer season of 2007 at Agricultural Research Institute (North) Mingora Swat Pakistan. Six rice cultivars (ILLABONG- 2, PR- 2881, YUNLIN-2, IRI-384, GZ-5830 and JP-5) were tested on four different transplanting dates (24th May, 9th June, 24th June and 9th July). He reported that planting dates independently showed highly significant differences for days to 50 per cent flowering, days to maturity, plant height, tillers per hill except that 1000 grain weight was non-significant. Interaction between cultivars and planting dates was significant for days to 50 per cent flowering, days to maturity and plant height while non significant for tillers per hill.

Fayaz *et al.* (2015) conducted a field experiment to determine the effect of different sowing dates and spacing on the growth and yield of scented rice variety Pusa sugandh-3 under temperate conditions of Kashmir during *kharif* seasons of 2013 and 2014. They reported that the growth parameters like plant height, number of tillers per hill, dry matter production were higher in early sown crops (10th April, 15th meteorological week) with average grain yield of 48.01 q ha^{-1} and straw yield of 77.26 q ha^{-1} compared to other treatments.

Vysakh (2015) studied the crop weather relationship in rice to validate the CERES (Crop Environment Resource Synthesis) –Rice model and to calibrate the genetic coefficients of rice, in the Department of Agricultural Meteorology, Kerala Agricultural University, Thrissur. The field experiment was conducted at the Agricultural Research Station, Mannuthy during the *Kharif* season of 2014. Two rice varieties Jyothi and Kanchana with five dates of planting (5th June, 20th June, 5th July, 20th July and 5th August) were selected for the experiment. He reported that the maximum temperature showed an increasing trend towards late transplanting and weather parameters like minimum temperature, forenoon and afternoon relative humidity, rainfall and rainy days were found to be higher in early transplanting dates compared to the late transplanting. Highest yield in Jyothi were observed in June 5th planting while Kanchana recorded highest yield in June 20th planted crops. He also reported that the different growth indices showed an increasing trend in early planted crops while delayed planting showed a decreasing trend.

2.3 EFFECT OF THERMAL INDICES ON PHENOLOGY AND YIELD OF RICE

Sandhu *et al.* (2013) reported that the early transplanted rice variety accumulate more heat units compared to late transplanted rice varieties. Two varieties (PR 115 and PR 118) were selected for the study the effect of heat units under five dates of planting. Variety PR 115 showed maximum GDD when it was transplanted on D5 and GDD for other dates of planting was 9-10 lower than D5. In case of variety PR118, the maximum GDD were accumulated during D1 date of transplanting and other dates of transplanting showed 1.2 to 4.2 decrease in GDD than D1 date of planting. He also reported that both the rice varieties accumulate maximum PTU and HTU during D1 date of transplanting.

Praveen *et al.* (2013) studied the effect of heat units on yield of three rice varieties such as Mahamaya, Karma Mahsuri and MTU-1010 under three dates of planting (10^{th}, 20^{th} and 30^{th} June). The experiment was conducted during *Kharif* season of 2012 at Raipur. They reported that the cumulative growing degree day at maturity stage was higher for June 10^{th} planting and it was 2410°C, 2365°C and 2161°C for Karma Mahsuri, Mahamaya and MTU-1010 respectively. They also reported that early transplanted crops recorded maximum growing degree days than late planted crops and heliothermal units and photothermal units also follow the same trend.

Bhat *et al.* (2015) studied the relationship between rice yield and different growth indices. The experiment was carried out during 2012 and 2013 at Shalimar. Two varieties were selected for the study as Jhelum and SR-2. The results showed that the variety SR-2 recorded high yield, growing degree days (GDD), helio thermal units (HTU) and heat use efficiency (HUE).

Mote *et al.* (2015) observed the thermal requirements for attainment of phenophases of rice cultivars under variable weather conditions at college farm of

Navsari Agricultural University, Gujarat during *Kharif* season of the year 2012. Three dates of planting *viz.* 12th July, 27th July and 11th August was selected to study the requirement of total GDD for three rice cultivars (Jaya, Gurjari and GNR-2). They reported that the first dates of planting recorded highest grain yield due to more GDD during early plantings. They concluded that the total GDD were decreased with delay in transplanting.

Khavse *et al.* (2015) studied the yield and heat unit requirement of rice with three genotypes under three sowing dates at research and instructional farm of Indhira Gandhi Agricultural University, Raipur. They conducted the experiment during *kharif* season of 2012. Rice varieties like Mahamaya, Karma Mashuri and MTU-1010 were selected for the experiment. They observed that higher yield were recorded for Karma Mashuri with higher growing degree day at maturity stage (2410°C) followed by Mahamaya (2365 °C) and MTU -1010 (2161°C). They also reported that the early sown variety showed maximum growing degree, photo thermal and helio thermal units than late sown crops.

Zhang *et al.* (2016) reported that the impacts of extreme temperature on field crops in Southern China from 1981 to 2009 at 120 national agro-meteorological experiment stations were used. They studied the changes in accumulated thermal index (growing degree day), high temperature stress index (> 35 °C high temperature degree day) and cold stress index (< 20°C cold degree day) and their impacts on rice yield were further analyzed by using multivariable analysis. They concluded that rice yield was generally more sensitive to high temperature stress than cold temperature stress and the rice yield were increased by 5.83%, 1.71%, 8.73% and 3.49% due to increased GDD whereas decreased by 0.14%, 0.32%, 0.34% and 0.14% due to increase in HDD, whereas increased by 1.61%, 0.26%, 0.16% and 0.01% due to decrease in CDD during past three decades for early rice, late rice and single rice in western part and single rice in other parts of the middle and lower reaches of Yangtze River. The amount of decreased solar radiation also reduced the rice yield by 0.96%, 0.13%, 9.34% and 6.02%. They concluded that the overall impacts of climate on yield were determined by the positive impacts of increased GDD and negative impacts of decreased solar radiation.

2.4 WEATHR INFLUENCES ON THE INCIDENCE OF PEST AND DISEASES

Climate change, global warming and increased variability, will require improved analysis that can be used to assess risks associated with already existing and newly developed pest management strategies and techniques and to gage the impact of these techniques on productivity and profitability.

Tripathi *et al.* (1997) studied the occurrence of blast in rice and reported that the maximum percentage of occurrence was noticed in the second fortnight of October followed by first fortnight of November. Maximum and minimum temperature varied between 18.1 and 16.6 °C and relative humidity 40-90%.

Singh *et al*. (1986) reported that the sheath rot of rice was an important disease in rainfed lowland rice especially in delayed plantings. The occurrence of sheath rot was found to be higher in 50 days old seedlings. They concluded that the photoperiod sensitive tall varieties showed more resistant than photoperiod insensitive ones.

Yang and Chu (1988) studied the influence of low temperature on pest and disease occurrence in rice. They noticed that low temperature is favourable for the occurrence of moulting in nymphs of brown plant hopper and developed as adults within 1-2 days. They concluded that the temperature around 10 °C was crucial for the survival and development of pest and disease.

According to Agrawal and Mehta (2007) weather based models can be used for the forewarning of important pest and diseases in rice, mustard, pigeon pea, sugarcane, groundnut, mango, potato and cotton at various locations using regression techniques.

According to Gautam *et al.* (2013) climate change affect the agriculture due to increase in the global temperature at the rate of 0.74°C during the last 100 years and atmospheric CO_2 concentration increased from 280ppm in 1750 to 400ppm in 2013. Such changes affect the reproduction, spread and severity of many plant pathogens.

They reported that the elevated temperature and CO_2 concentration affect the perception of late blight of potato (*Phytophthora infestans*) and important diseases of rice namely blast (*Pyricularia oryzae*) and sheath blight (*Rhizoctonia solani*).

2.5 CLIMATE CHANGE IMPACT ON RICE CULTIVATION

Presently, most of the rice production takes place in the regions where temperatures are already above the optimum temperatures for crop growth (day time maximum 28^0 C and night time minimum 22^0 C) (Krishnan *et al*., 2011)

Krishnan *et al.* (2007) reported that every 1^0 C rise in temperature declines rice yield by 7.2% at the current CO_2 concentration (380ppm), but increase in CO_2 enrichment up to 700ppm will lead to an average increase of yield about 31% in India.

It is estimated that each 1^0 C increase in the daytime maximum temperature and night time minimum temperatures with in the 28^0-21^0 C to 34^0-27^0 C range decrease rice yields by 7%-8% (Baker *et al.,* 1992).

The climate in central Asia in continental and arid, with long, cold, dry winters and short, hot summers. Under this climatic conditions, rice cultivation is possible only for 140 days during the period May-October (Christmann *et al.,* 2009)

2.6 CLIMATE CHANGE SCENARIOS

Simulation studies on different seeding dates with different growth duration rice varieties can contribute to identifying the optimal seeding date and appropriate rice variety for specific geographical region under both current and predicted climate change scenarios (Krishnan *et al.* 2011).

Rajwade *et al.* (2015) reported that grain yield of rice was simulated for the base period (1969-1999) and future periods 2020, 2050 and 2080 under A2 and B2 scenarios of HadCM3 Global Climate Model. Under A2 and B2 scenarios, the yield of rice declined from base period to the future periods 2020, 2050 and 2080.

Satapathy *et al.* (2014) simulated the possible climate change impacts using HadCM3 data and found a continuous decline in the rice grain yield for the years 2020, 2050 and 2080 with increasing temperature >0.8^0 C.

Candradijaya *et al.* (2014) confirms that for rice varieties Ciherang, Mekongga, Inpari 4 and Inpari 10, yield reduction to occur in the near future, to the extent variable across the GCMs. At the heighest estimation, rice yields decreases by 32% and 31.81%, in comparision to baseline, for near future under RCP8.5 and RCP4.5, respectively. The reduction is sensitive to difference in farming practices of the local farmers, particularly in planting time and scheduling of irrigation. The shift in planting time to better match rainfall pattern and improved irrigation reduce the yield reduction by 16.16% and 15.18%, respectively.

According to Jalota *et al.* (2013) yields of rice in years 2027, 2030, 2043 and 2047 in Mid-century and 2078, 2082, 2088 and 2097 in End-century were much lower than the current average yield and concluded that on shifting the date of planting from June 20 to June 27and July 5 to July 11 by 7 days increment under these years showed improvement in yields. The improvement was 3, 11 and 12% in Mid-century and 3, 14, 18% in End-century.

Lamsal *et al.* (2013) developed eight different climate scenarios by making maximum and minimum temperature (± 4°C), CO_2 (±20ppm), solar radiation (± 1MJ m^{-1} day^{-1}) using interactive sensitivity analysis mode in DSSAT in Nepal. They reported that temperature (±4°C), CO_2 (+20ppm) with change in solar radiation (±1 MJ m^{-1} day^{-1}) affect the yield in rice varieties viz. Prithivi, Masuli and Sugandha by increase in yield by 62, 41 and 41 per cent under decrease in climatic scenarios while decreased the yield by 80, 46, 40 per cent under increased climatic scenarios.

Swain and Thomas (2010) reported 7 to 27 % decline in rice yield under Global Climate Model scenarios at different locations in India.

The global mean temperature at the end of 21st century is expected to increase over 1.5 ^{0}C compared to 1850 to 1900 for all RCP scenarios except for RCP 2.6 with non-uniform increase over the different regions (IPCC 2013), expected to have substantial impact on food grain production of developing countries located in tropical and sub-tropical latitude (Mall *et al.* 2006).

According to Dias *et al.* (2016) simulation results, under climate change scenario RCP 8.5 rice yields of both varieties At362 and Bg 357 will be decreased in mid-centuries than the present yield. Average yield reduction varies from 1500 to 2000 kg/ha with increasing temperatures and decreasing rainfall.

Yang *et al.* (2017) reported that medium duration variety Maize FAO-500 growth cycle length is projected to decline from 124 days (baseline) to 123 (-1%, RCP 4.5) or 119 days (-4%, RCP 8.5) in the 2030s, to 119 (-4%, RCP 4.5) or to 114 days (-8%, RCP 8.5) for 2050s, and to 117 days (-6%, RCP 4.5) or to 109 days (-12%, RCP 8.5) for 2070s.

2.7 CROP SIMULATION MODELS

Ritchie *et al.* (1986) developed the CERES-Rice model and estimated the yields for rainfed and irrigated rice crops. The model initially handled phasic development or growth stages as influenced by plant genetics, weather and other environmental factors: biomass production and its partitioning, root system dynamics, effect of soil water deficit and N deficiency on photosynthesis partitioning in plant system.

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

Jand *et al.* (1994) tested CERES –Rice model in Punjab using three dates transplanting viz. 13th June, 27th June and 13th July and two varieties. They concluded that the prediction made by the model for yield and yield components varied from 8.34 to 10.9 percent of the observed yield.

Crop simulation models provide us with an opportunity of building scenarios of agricultural production in changed climates. The CERES models have been extensively using for assessment of the impact of climate change on agricultural crop production (Rao and Sinha, 1994).

Saseendran *et al*. (1998) calibrated the CERES-Rice model and evaluated the model for the agroclimatic conditions of the state of Kerala in India. They conducted the experiment during virippu season (June to September) using different dates of planting under rainfed conditions. They developed genetic coefficients for the rice variety Jaya and used for the model evaluation studies. The model was found to be predicted the flowering date within an error of four days, crop maturity within an error of two days and also predicted the grain yield with an error of 3 per cent for all transplanting dates and straw yield prediction with an error of 27 percent. The model predicted the phenological stages of crop fairly well. They concluded that the accuracy of prediction in grain yield showed the ability of the model to stimulate the growth of the rice variety Jaya in the agro climatic zones of Kerala.

Mahmood (1998) used YIELD and CERES-Rice models to estimate the productivity of boro rice in Bangladesh. He observed that the productivity of boro rice was higher in prediction form the model YIELD than prediction from CERES Rice model. He also reported that the model YIELD predicted shorted growing season than CERES-Rice model under normal and abnormal thermal conditions.

Singh *et al.* (2007) calibrated and validated the data from field experiment conducted using CERES-Rice model version 4.0 during the rainy season of 2004 and 2005 at Shalimar, Srinagar, India. They used six rice varieties and each variety was transplanted on 25th May, 10th June and 25th June. Data from 25th transplanted crops were used for model calibration and developed genetic coefficients for rice varieties. They found that the predicted and observed dates of phenological events showed a close relation with the root mean square error and mean absolute error. They reported that the predicted and the observed yield were also very close with a RMSE of 0.63Mh ha^{-1}, MAE of 0.58Mg ha^{-1}. They concluded that the model can be effectively used in the temperate regions of Kashmir to increase crop productivity and optimize crop management practices.

Basak *et al.* (2008) studied the effect of climate change on yield of two boro rice varieties (BR3 and BR14) using CERES-rice model. The yield of rice varieties were simulated for twelve locations of Bangladesh because the genetic coefficients of these varieties are available in the DSSAT modelling system. They reported that the model predicted the significant reduction in yield of BR 3and BR 14 due to climate change and the predicted yield reduction was 20% and 50% for both the varieties for the years 2050 and 2070. They concluded that DSSAT modeling system is useful for the assessment of impacts of climate change and management practices on different varieties of rice and other crops.

Mariappan *et al.* (2008) evaluated the rice yields during the period of 1979 to 1998 using CERES-Rice model and simulate the seasonal yield variability and yield prediction during a period of 1999 to 2001 of Chengalpattu district of Tamil Nadu. They used yield deviation from single linear technology trends along with year wise variations in simulated yields during the periods of 1979 to 1998. They reported that the CERES-Rice model simulate the pattern of weather induced yield variability in Chengalpattu district over a period of 19 years.

Timsina *et al.* (2008) studied the increasing yield and water productivity of wheat in Punjab, India using DSSAT-CSM-CERES-Wheat model. They evaluated the model using 13 independent data sets on phenology, biomass, yield and yield components of wheat. Three experiments were conducted and the experiment 1 and 2 involved rice- wheat cropping systems, while experiment 3 involved maize-wheat and soybean-wheat cropping systems. The results showed that the predicted number of days to anthesis and maturity with low RMSE and good D-index.

Basak *et al.* (2010) used the DSSAT modelling system for studying the effect of climate change on yield of two boro rice varieties (BR3 and BR 14) for the years 2008, 2030, 2050 and 2070 and simulated for 12 locations of Bangladesh. The model predicted significant reduction in yield in both the varieties due to climate change and the predicted yield reduction was 20 and 59 per cent for the years 2050 and 2070. They reported that the increased temperature and solar radiation reduces the physiological maturity of rice varieties.

According to Ahmad *et al.* (2012) the CSM-CERES-Rice model was an effective tool for determining best suitable combination of plant density and N levels of rice variety Basmati- 385 which is growing under irrigated semiarid environments in Pakistan. The data collected from experiments conducted in Faisalabad, Punjab and Pakistan during 2000 and 2001 were used for evaluation of crop simulation model. The cultivar coefficients of Basmati -385 were compared with simulated and experimental data using CSM-CERES-Rice model and it also predicted the number of days took for transplanting to anthesis and physiological maturity with a difference of one day between simulated and experimental data. They concluded that the CSM-CERES-Rice model can be used to identify the optimum management practices for a specific region and a specific crop. They also reported that a few year experimental data along with long term weather data were needed for the model evaluation management scenario analysis.

Oteng-Darko *et al.* (2012) simulated the rice yields under different climatic change scenarios in Ghana using data from the Annum Valley Irrigation Project. Eighteen years (1989-2006) data were used to run the model. The model was sensitive to climatic parameters like temperature, CO_2 concentration, solar radiation and rainfall and various effects on rice. They reported that the increase or decrease in temperature by 4 °C from the maximum and minimum, decreased rice yields by 34% as compared to base scenario of 2006.

Akinbile (2013) used CERES –rice model to simulate the growth and yield of a new rice variety (NERICA-2) in Nigeria provided with full (100% ET), medium (75% ET), average (50% ET) and low (25% ET) irrigation treatments. He compared the parameters such as plant height, root depth, canopy shading, Leaf area index, biomass and grain yield with simulated values from the CERES- rice model. He reported that the model predicts parameters like biomass yield (13.74 t ha^{-1}), total yield (16.47) and grain yield (2.63 t ha^{-1}) gave slightly higher value than observed values of 8.17 t ha^{-1}, 10.58 t ha^{-1} and 2.41 t ha^{-1}. Increases or decreases of temperature by 4 °C from the maximum or minimum, decreased rice yields by 34% as compared to base scenario of 2006.

Azdawiyah *et al.* (2015) studied the effect of planting dates on rice production in MADA area, Malaysia. Decision Support System for Agro technology Transfer were used for the simulation of rice production with effect of planting dates for both off-season and main season. Yield productivity was simulated in DSSAT based on the projections of daily weather data. They reported that the forecasted average seasonal daily maximum temperature showed an increasing trend with a highest value of 33. 98°C for off-season in the year 2046, while the lowest value of 30.03 °C for the main season.

Singh *et al.* (2016) studied the yield gap in rice using CERES-rice model of climate variability for different agro climatic zones of India. The experiment was conducted during the *kharif* season at Jorhat, Kalyani, Ranchi and Bhagalpur. The CERES-rice model was calibrated for genetic coefficients of rice and the result was found to be positive with a rate of change of 26, 36.9, 57.6 and 3.7 kg $ha^{-1}year^{-1}$ at Jorhat, Kalyani, Ranchi and Bhagalpur. They also reported that delayed sowing in these districts resulted in a decrease in rice yield at the rate of 35.3, 1.9, 48.6 and 17.1 kg ha^{-1} $day^{-1.}$

Vijayalakshmi *et al.* (2016) evaluated the CERES-Rice model under various plant densities in southern Telangana zone of Telangana state in India. The experiment was conducted during the *kharif* season of 2013 at the college farm of Telangana state agricultural university, Hyderabad with three plant densities (1, 3 and 5) and four age of seedlings (15, 25, 35 and 45 days old). They reported that the number of days to heading was closer to the observed data with RMSV of 2 days, CRM of 2.2 and NRMSE of 3 per cent and for attaining physiological maturity 3 days difference was noticed between observed and simulated values with RMSE of 3 days, NRMSE of 3 and CRM of -2.5 percent. They concluded that the model can be used as a research tool for variable agro-environments of Telangana state.

Materials and Methods

3. MATERIALS AND METHODS

The study on "Assessment of rice (*Oryza sativa* L.) production under climate change scenarios" was conducted at the Department of Agricultural Meteorology, College of Horticulture, Vellanikkara, Thrissur during 2016-17. The details of the experiments conducted and the methods are in the following sections.

3.1. DETAILS OF FIELD EXPERIMENT

3.1.1. Field Location

The field experiments were conducted during the period from May 2016 to November 2016 at Agricultural Research Station, Mannuthy, Kerala Agricultural University, Thrissur. The station is located at 10^0 32' N latitude and 76^0 20' E longitudes at an altitude of 22m above the mean sea level.

3.1.2. Soil Characteristics

The soil of the study site was sandy clay loam in texture. The physical properties of the soil are presented in Table 3.1.

Table 3.1. Physical properties of soil in the experimental field

Sl. No.	Particulars	Value (%)
1	Coarse sand	27.6
2	Fine sand	24.2
3	Silt	22.2
4	Clay	26.0

3.1.3. Climate and Weather

The experimental area was influenced by a typical warm humid tropical climatic condition and benefited by both southwest and northeast monsoons. The experimental area received maximum amount of rainfall during the months of July and August. The mean maximum and minimum temperatures of the location recorded were 32.6 °C and 23.3 °C respectively. The average annual sunshine recorded for the location is 5.8 h day^{-1}. The recorded mean annual relative humidity was 81.5% with forenoon and afternoon relative humidity of 87.6% and 59.9% respectively. The total annual rainfall is 1751.6mm. The average annual wind speed of the experimental field was 2.5 km h^{-1}. Table 3.2 shows the details of weekly weather parameters during the experimental period.

3.1.4. **Season**

The field experiment was conducted during *Kharif* season from May 2016 to November 2016.

3.2. EXPERIMENTAL MATERIALS AND METHODS

3.2.1. Variety

The most popular rice varieties among the farmers of Kerala namely Jyothi and Kanchana were selected for the study. The selected rice varieties are of short duration with 110-125 days for Jyothi and 105- 110 days for Kanchana.

Jyothi is grown in a wide range of field conditions in Kerala with wide adaptability in all the three seasons. It was developed from the cross between short duration improved local strain PTB 10 and the high yielding genotype IR8. The variety Kanchana was developed from the cross between IR36 and Pavizham.

3.2.2. Design and Layout

The experiment was laid out under split plot design, replicated four times with five dates of planting at 15 days interval from 5^{th} June to 5^{th} August as main plot treatments and two rice varieties, Jyothi and Kanchana as sub plot treatments. The varieties were planted at a spacing of 15 cm x10 cm in four replications and there were

Table.3.2. Weekly weather parameters during the experimental period in 2016

Week No.	Tmax (°C)	Tmin (°C)	VPD I (mmHg)	VPD II (mmHg)	RH I (%)	RH II (%)	WS (kmh^{-1})	BSS (h)	RF (mm)	RD	Epan (mm)
20	32.1	23.5	22.5	25.0	94.6	73.6	1.4	2.8	157.9	4.0	2.4
21	33.0	24.6	25.7	24.4	90.9	67.9	1.6	5.3	35.9	1.0	3.2
22	31.3	22.6	23.0	23.7	93.3	79.4	1.4	3.3	148.4	5.0	2.4
23	29.8	22.9	23.1	22.9	96.1	89.1	0.9	1.5	220.6	6.0	2.2
24	30.8	22.0	22.5	23.8	95.0	79.4	1.4	2.2	94.6	5.0	2.4
25	29.8	20.7	23.4	23.6	93.4	81.4	1.5	2.4	72.7	4.0	2.1
26	28.7	20.9	22.9	24.4	96.7	82.9	1.1	0.3	147.4	5.0	1.8
27	29.9	21.5	23.5	23.2	96.3	80.1	1.6	2.8	58.5	5.0	2.2
28	29.2	20.8	22.7	22.8	96.1	81.0	1.1	0.6	214.8	6.0	2.5
29	30.4	21.2	22.1	22.8	95.3	70.9	1.4	3.0	25.5	3.0	2.6
30	30.1	22.5	22.1	21.6	97.0	71.7	1.7	2.8	88.4	5.0	2.8
31	30.3	23.1	22.7	21.9	96.1	71.6	1.9	4.0	51.2	4.0	2.9
32	30.3	22.7	22.6	22.8	95.1	69.7	1.6	5.1	51.2	6.0	2.7
33	30.0	23.4	23.2	23.2	95.6	73.4	2.3	4.2	55.4	6.0	3.0
34	30.9	23.8	22.8	23.0	95.7	67.4	1.7	6.1	18.7	2.0	3.0
35	30.2	23.3	23.3	22.3	94.6	71.1	1.6	3.4	16.3	3.0	2.6
36	30.0	22.8	23.0	23.4	94.0	65.6	1.2	3.8	12.0	1.0	2.5
37	30.8	24.1	22.9	21.6	95.4	66.3	2.0	6.5	10.2	1.0	3.3
38	30.6	23.4	23.1	22.9	95.1	66.9	2.2	6.5	40.8	4.0	3.4
39	29.9	24.0	23.1	23.9	95.0	74.7	1.9	3.7	18.9	3.0	2.7
40	31.5	22.5	22.6	23.1	93.0	63.4	1.5	9.1	0.0	0.0	3.3
41	31.1	23.1	22.5	23.8	91.3	68.4	1.2	5.7	14.5	1.0	3.0
42	32.1	23.2	23.3	22.9	94.3	70.0	0.7	4.2	0.6	0.0	2.6
43	31.1	22.2	22.4	22.6	94.3	68.7	0.7	3.1	3.5	1.0	2.4
44	32.0	22.4	22.2	22.6	94.0	69.6	0.9	4.5	18.7	2.0	2.4
45	32.3	21.3	21.8	22.7	87.7	52.6	1.0	6.3	2.9	0.0	2.9
Mean	30.7	22.6	20.5	22.1	94.5	72.2	1.4	4.0	1579.6	83.0	2.7

Tmax-Maximum temperature RH I- Forenoon relative humidity RD- Rainy days
Tmin-Minimum temperature RH II- Afternoon relative humidity RF- Rainfall
BSS- Bright sunshine hours Epan- Pan Evaporation WS-Wind speed
VP I-Forenoon vapour pressure VP II- Afternoon vapour pressure

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total of 40 plots each having 5x4 m^2 area. The layout is provided in Fig.3.1.

3.2.3. Treatments

The experiment had main plot treatments and subplot treatments. Five dates of planting were selected as main plot treatments which included 5th June, 20th June, 5th July, 20th July and 5th August during 2015. The rice varieties Jyothi and Kanchana were selected as subplot treatments. The different treatments in the experiment are described in Table.3.3.

Table.3.3. Treatments used in the experiment

Main plot treatments	**Subplot treatments**
Planting time	Variety
5th June	Jyothi
	Kanchana
20th June	Jyothi
	Kanchana
5th July	Jyothi
	Kanchana
20th July	Jyothi
	Kanchana
5th August	Jyothi
	Kanchana

	D3	D2	D4	D5	D1
R1	J	K	J	K	J
	K	J	K	J	K
	D1	D5	D3	D4	D2
R2	K	K	J	K	K
	J	J	K	J	J
	D4	D1	D3	D5	D2
R3	K	J	K	J	J
	J	K	J	K	K
	D3	D2	D1	D4	D5
R4	J	K	K	J	J
	K	J	J	K	K

D1- June 5th D2- June 20th D3- July 5th D4- July 20th D5- August 5th

J- Jyothi and K- Kanchana

Fig : 3.1. Layout of experiment in split plot design

3.3. CROP MANAGEMENT

3.3.1. Nursery management

Nurseries were prepared earlier to each date of transplanting and eighteen days old seedlings were transplanted with 2-3 seedlings per hill. Adequate irrigation and drainage and plant protection measures were provided.

3.3.2. Land preparation and planting

The recommendations of package of practices (KAU, 2012) given by Kerala Agricultural University were followed for the planting of Jyothi and Kanchana rice varieties. Plough the field thoroughly and levelled for transplanting the seedlings. Forty plots were prepared according to the layout of experiment.

3.3.3. Application of manures and fertilizers

Farmyard manure was incorporated into the field at the rate of 5000 kg ha^{-1} during land preparation. Fertilizers like urea, rock phosphate and murate of potash were used to supply adequate amount of nutrients such as 70 N, 35 P_2O_5 and 45 K_2O kg ha^{-1}. The entire dose of P_2O_5, half dose of N and K_2O were applied as basal dose while remaining amount of fertilizers top dressed at 30 days after transplanting.

3.3.4. After cultivation

The herbicide Lontax at the rate of 1 kg ha^{-1} were applied to the field for controlling weeds. The plots were hand weeded twice, first at 30 days after transplanting and second at 45 days after transplanting. The recommended plant protection measures were taken to control pest and diseases.

3.4. Observations

Observations on growth and yield parameters for Jyothi and Kanchana for each replication were recorded from randomly selected plants from unit area after leaving the border plants. The observations were taken at different growth stages of rice varieties.

Plate I. Land preparation

Plate II. Transplanting

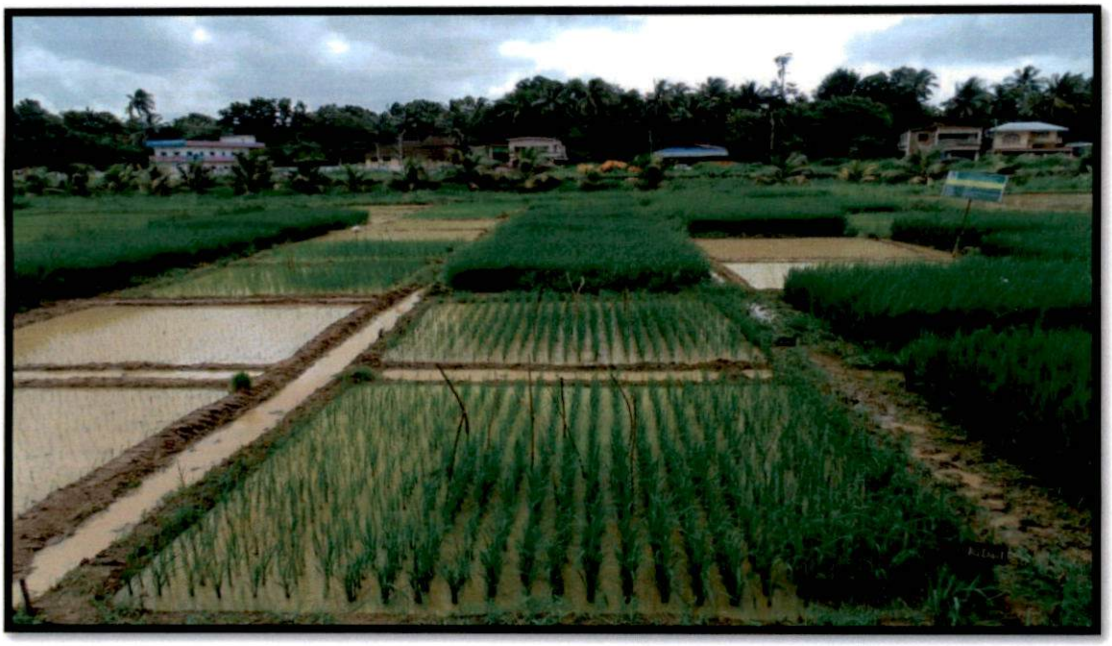

Plate III. General view of experimental plot

Plate IV. Harvest

Plate V. Threshing

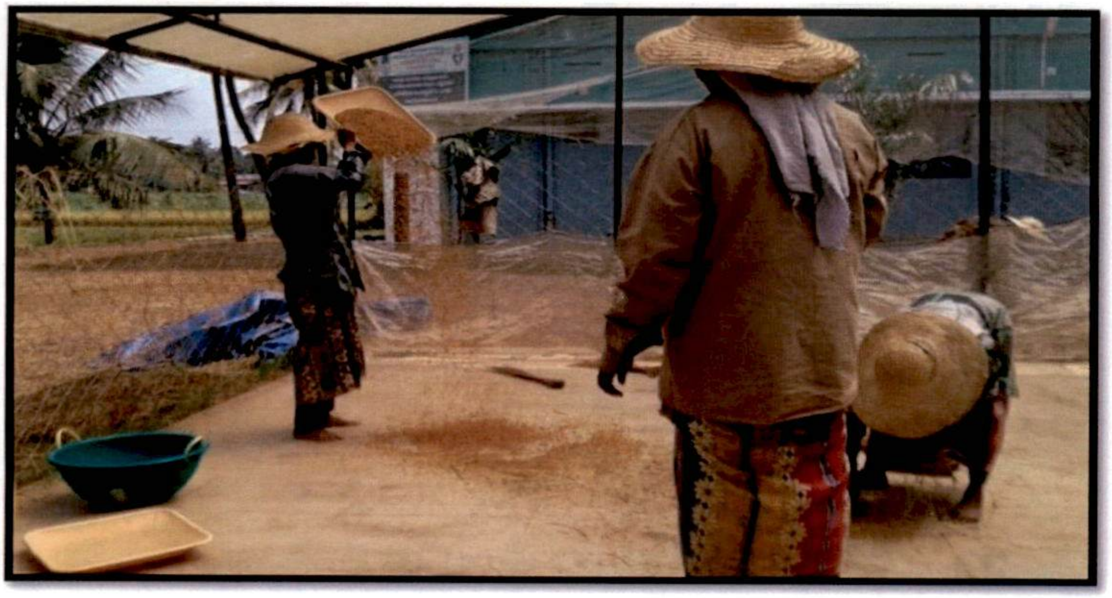

Plate VI. Winnowing

3.4.1. Biometric observations

3.4.1.1. Plant height

The plant height of each variety were recorded at weekly intervals. The height was measured in cm from the bottom of the culm to tip of the leaf.

3.4.1.2. Leaf area

Leaf area of each variety was recorded at fortnight interval in cm^2. The leaf area was measured using leaf area meter.

3.4.1.3. Biomass

The dry matter accumulation or biomass production was recorded at 15 days interval from transplanting. Two sample hills were selected randomly from the experimental field and uprooted from the sampling row. The samples were first sun dried followed by oven dried to a temperature of $80^{\circ}C$ to a constant weight and the biomasses were recorded as grams per plant.

3.4.1.4. Number of panicles per unit area

Number of panicles per plant was recorded randomly from 5 plants.

3.4.1.5. Number of spikelets per panicle

Number of spikelets from panicle was recorded from 5 plants.

3.4.1.6. Number of filled grains per panicle

The number of filled grains per panicle from 5 plants was recorded at the time of harvest.

3.4.1.7. Thousand grain weight

Thousand grain weights or test weight from each plot were counted and recorded in grams.

3.4.1.8. Grain yield

The grain from each plot was dried to 14 per cent moisture, and was cleaned, winnowed, weighed and expressed in kg ha^{-1}.

3.4.1.9. Straw yield

The straw from each plot were dried, weighed and expressed as kg ha^{-1}.

3.4.2. Phenological Observations

3.4.2.1. Days for active tillering

Days from transplanting to active tillering was counted and listed in days.

3.4.2.2. Days for panicle initiation

Number of days for panicle initiation was calculated from transplanting and listed in days

3.4.2.3. Days for booting

Number of days taken for booting was calculated from transplanting and listed in days.

3.4.2.4. Days for heading

Days taken for heading were calculated from transplanting in both the varieties and listed in days.

3.4.2.5. Days for 50 per cent flowering

Number of days taken for 50% flowering was calculated from transplanting and listed in days.

3.4.2.6. Days for physiological maturity

Number of days taken for physiological maturity was calculated from transplanting and expressed in days.

3.4.3. Physiological observations

3.4.3.1. Leaf Area Index (LAI)

Leaf Area Index = (Total leaf area of plant)/(Land area occupied by plant)

Leaf area index (LAI) was suggested by Williams (1946). The leaf area was calculated at 15 days interval from transplanting to harvest using leaf area meter from randomly selected plants.

3.4.4. Soil analysis

Soil samples were collected before planting from 5 cm and 15 cm depth. The samples were dried separately powdered well in a mortar and respective samples were analyzed for pH, EC, available nitrogen, available phosphorous, available potassium and organic carbon content. The results of chemical analysis are presented in Table 3.4.

3.4.5. Weather Data

The daily weather data on maximum temperature, minimum temperature, bright sunshine hours, rainfall, number of rainy days, relative humidity, evaporation and wind speed were taken during the study period was collected from the meteorological observatory. The different weather parameters used in the study are described in Table 3.5.

Table 3.4. Chemical properties of soil

SI. No	Parameter	Sampling depth in cm	
		0-5	5-15
1	pH	5.5	5.4
2	Electrical conductivity (ds m^{-2})	0.10	0.10
4	Available phosphorous (kg ha^{-1})	150.48	148.18
5	Available potassium (kg ha^{-1})	420	347.20
6	Organic carbon (%)	0.89	0.79

Table 3.5. Weather parameters used in the experiment

SI. No.	**Weather parameter**	**Unit**
1	Maximum temperature (Tmax)	^{0}C
2	Minimum temperature (Tmin)	^{0}C
3	Relative humidity (RH) Forenoon relative humidity (RHI) Afternoon relative humidity (RHII)	%
4	Rainfall (RF)	mm
5	Rainy days (RD)	days
6	Bright sunshine hours (BSS)	h
7	Forenoon vapour pressure deficit (VPDI) Afternoon vapour pressure deficit (VPDII)	mm Hg
8	Wind speed (WS)	km hr^{-1}
9	Evaporation (Ep)	mm
10	Growing degree day (GDD)	^{0}C day

3.6. HEAT UNITS

3.6.1. Growing Degree Days (GDD)

The growing degree days (GDD) were calculated for the entire crop growing period and used to relate the effect of GDD with crop duration as well as grain yield. The formula for calculating GDD was given below. The growing degree days were calculated using Peterson (1965) equation. The base or threshold temperature used in the calculation of GDD is assumed as 10 °C for rice. (Islam and Sikder, 2011).

$$\mathrm{GDD} = \sum_{i=0}^{n} \frac{\mathrm{Tmax} + \mathrm{Tmin}}{2} - \mathrm{Tb}$$

Where,

n- Number of days from sowing date till the last date of harvesting

Tmax- Maximum temperature (°C)

Tmin- Minimum temperature (°C)

Tb - Base temperature (minimum threshold temperature)

3.6.2. Helio thermal Unit (HTU)

Helio thermal units for rice were calculated during each phenophases of crop and correlated with growth and yield parameters. The Helio thermal units were calculated using the formula given by Rajput (1980). The calculated Helio thermal unit is expressed in °C day h.

$$\mathrm{HTU} = \sum_{i=0}^{n} \mathrm{GDD\ X\ BSS}$$

Where, GDD = Growing Degree Days

BSS = Actual bright sunshine hours

3.6.3. Photo thermal Units (PTU)

The effect of maximum possible sunshine hours on the crop were studied by calculating photothermal units in °C day h. The photothermal units were calculated using the equation given by Wilsie (1962).

$$PTU = \sum_{i=0}^{n} GDD \text{ X } L$$

Where, L is the maximum possible sunshine hours

The maximum possible sunshine hours were calculated using Smithsonian table.

3.7. STATISTICAL ANALYSIS

The standard procedure for split plot design was given by Fisher (1947). Analysis of variance was performed to test the significant difference between dates of planting (main plot treatments), varieties (sub-plot treatments) and their interaction. When the ANOVA revealed significance for the above, pair wise comparison were made using the following critical differences.

a) Critical difference for the comparison of two main plot treatments (dates of planting)

$$C_1 = t_1 \text{ x } SE_1$$

Where, t_1 = t value at degrees of freedom for main plot error

SE_1 = standard error of difference between two main plot treatment means

$$SE_1 = \sqrt{\frac{2 \times E_1}{rb}}$$

Where, E_1 = error mean square value of main plot treatment in ANOVA

r = number of replications

b = number of sub plot treatments

b) Critical difference for the comparison of two subplot treatments (varieties)

$CD_2 = t_2 \times SE_2$

Where, t_2 = t value at degrees of freedom for sub plot error

SE_2= Standard error of difference between two sub plot treatments

$$SE_2 = \sqrt{\frac{2 \times E_2}{ra}}$$

Where, E_2=Error mean square value of sub plot treatments in ANOVA

r = Number of replications

a = Number of main plot treatments

c) Critical difference value for the comparison of two main plot treatment means at the same or different levels of sub plot treatment

$CD_3 = t_1 \times SE_3$

Where, t_1 = t value at degrees of freedom for main plot error

SE_3= Standard two main plot treatment means at the same or different levels of sub plot treatment

$$SE_3 = \sqrt{\frac{2(b-1)E_2 + E_1}{rb}}$$

E_1= Error mean square value of main plot treatment in ANOVA

E_2= Error mean square value of sub plot treatments in ANOVA

r = Number of replications

b = Number of sub plot treatments

Correlation was carried out to study the influence of weather parameters on biometric and phenological characters of rice. Weekly weather parameters were also calculated during different growth stages and correlated with yield characters. Microsoft excel, SPSS and MSTAT-C were used for various analysis.

3.8. CROP SIMULATION MODEL

The crop growth simulation model uses large quantum of information with respect to interaction of soil- plant-atmosphere continuum and predicts numerous parameters of crop production. The crop simulation model for a particular crop or variety under a given environment, the crop growth and production is influenced by weather parameters, fertilizers, irrigation and soil parameters can be generated. The crop growth simulation models can generate information on different crop management and cultural practices *viz.* age of seedlings, optimum plant population, spacing, time of fertilizer application and its dose, number of irrigations required during the crop season. Decision Support System for Agro Technology Transfer (DSSAT) and its different crop simulation models can be used for the assessment of impact of climate variability and climate change in on-farm and precision management. Daily weather data, soil surface and profile information and crop management are the input requirement of a crop simulation model. DSSAT provide crop specific file which contains the crop genetic information and variety or cultivar information is given by the user in another data file and it combines crop, soil and weather data with crop simulation models. DSSAT used for evaluation of crop model output with experimental data and compare the simulated outcomes with observed results. DSSAT v. 4.6 includes different application programmes for seasonal, spatial, sequence and crop rotation analysis for the assessment of economic risks, environmental impacts, climate variability, climate change, soil carbon sequestration and precision management.

3.8.1. CERES-Rice model

Crop Estimation through Resource and Environment Synthesis (CERES) model (Ritchie and Otter, 1985; Ritchie, 1986 and Godwin *et al.,* 1990) is considered as the basis for simulating the effect of cultivar, plant density, weather, soil water and nitrogen on growth and yield. CERES- Rice model is a part of Decision Support System for Agro-technology Transfer and it has a common input and output data format (Tsuji *et al.,* 1994). Hunt and Boote (1994) provide the minimum data set for the operation and calibration of the CERES-Rice model.

3.8.1.1. Input files

The input and experimental data files required for the CERES-Rice model are given in Table 3.6.

3.8.1.2. Output files

The output files are helpful for users to select information needed for a particular application. The output file for CERES-Rice model is given in Table 3.7.

3.8.2. Running the crop model

Once all the desired files were created carefully the model was run for all the treatments.

3.8.3. Model Calibration and Evaluation

Model calibration is the adjustment of parameters for comparing simulated values with observed values. The genetic coefficients in CERES-Rice model were derived by adjusting the relevant coefficients to attain the possible match between simulated and observed number of days taken for the occurrence of phenological events. Calibration of genetic coefficients of CERES-Rice model require minimum crop performance data set of planting date, plant density, row spacing, amount of fertilizer application, irrigation data, panicle initiation date, physiological maturity date, harvesting date, harvesting method, grain yield/m^2 and leaf area in 5 growth stages were collected. Model performance was evaluated using the statistical parameters such as Normalized Root Mean Square Error (RMSE) and D-stat index (Willmott *et al.* 1985) as common tools to test the goodness-of-fit of simulation models.

Table 3.6. Input files of CERES-Rice model

Internal file name		External description	Name
Experiment	FILEX	Experiment details file for a specific experiment (e.g., rice at JVVK): Contains data on treatments, field conditions, crop management and simulation controls	JVVK1601.RIX
Weather and soil	FILEW	Weather data, daily, for a specific (e.g.,JVVS) station and time period (e.g., for one year)	JVVK1601.WTH
	FILES	Soil profile data for a group of experimental sites in general (e.g.,SOIL.SOL) or for a specific institute (e.g., JVSCLAYLOM.SOL)	SOIL.SOL
Crop and cultivar	FILEC	Cultivar/variety coefficients for a particular crop species and model; e.g., rice for the 'CERES' model, version 046	RICER046.CUL[1]
	FILEE	Ecotype specific coefficients for a particular crop species and model; e.g., rice for the 'CERES' model, version 046	RICER046.ECO[1]
	FILEG	Crop (species) specific coefficients for a particular model; e.g., rice for the 'CERES' model, version 046	RICERO46.SPE[1]
Experiment data files	FILEA	Average values of performance data for a rice experiment. (Used for comparison with summary model results.)	JVVK1601.RIA
	FILET	Time course data (averages) for a rice experiment. (Used for graphical comparison of measured and simulated time course results.)	JVVK1601.RIX

These names reflect a standard naming convention in which the first two spaces are for the crop code, the next three characters are for the model name, and the final three are for model version.

Table 3.7. Output files of CERES-Rice model

Internal file name	External description	File name
OUTO	Overview of inputs and major crop and soil variables.	OVERVIEW.OUT
OUTS	Summary information: crop and soil input and output variables; one line for each crop cycle or model run.	SUMMARY.OUT
SEVAL	Evaluation output file (simulated vs. observed)	EVALUATE.OUT
OUTWTH	Daily weather	Weather. OUT
OUTM	Daily management operations output file	MgmtOps. OUT
ERRORO	Error messages	ERROR.OUT
OUTINFO	Information output file	INFO.OUT
OUTWARN	Warning messages	WARNING.OUT

3.8.4. Scenario

Scenario is a picture of a phenomenon, sequence of events (or) situation, based on certain assumptions and factors (variables) and it is used in estimating the probable effects of one or more variables.

3.8.4.1. RCPs (Representative Concentration Pathway)

Representative Concentration Pathways (RCPs) are four greenhouse gas concentration (not emissions) trajectories adopted by the IPCC (2014) for its fifth Assessment Report (AR5). It supersedes Special Report on Emissions Scenarios (SRES) projections published in 2000.

The pathways are used for climate modeling and research. They describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. The four RCPs are RCP2.6, RCP4.5, RCP6, and RCP8.5 are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values given in the Table. 3.8.

Table. 3.8. Types of RCPs and their radiative forces

	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
Type	Low	Intermediate	Intermediate	High
Radiative forces	2.6 to 3 Wm^{-2}	4.5 Wm^{-2}	6.0 Wm^{-2}	8.5 Wm^{-2}
CO_2 concentrations peaks	2050s (421 ppm)	2040s (538 ppm)	2060s (670 ppm)	2100s (936 ppm)
References	Van Vuuren *et al.* (2006-2007) – IMAGE	Clarke *et al.* (2007) – MiniCAM	Fujino *et al.* (2006) and Hijioka et al. (2008) – AIM	Riahi *et al.* (2007)– MESSAGE

3.8.5. Climate change scenarios used for crop yield simulation

Climate change influences rice crop mainly through increased atmospheric CO_2, temperature, and change in rainfall. The Climate Change Agriculture and Food Security (CCAFS) Institute under the CGIAR system has hosted a web site for providing the downscaled projection data on point basis (http://gismap.ciat.cgiar.org/MarkSimGCM/), through Mark Sim™ DSSAT weather file generator. This generator converts the downscaled weather data from global climate models (GCMs) to DSSAT weather input file format.

GCMs (*viz* GFDL CM3, CCSM4 and Had CM2) were used to project or represent changes in average monthly rainfall, minimum and maximum monthly temperature data for two time slices, these are 2041-2070 (Mid-century) 2071-2099

(End-century). Observed climate data for 30 years (1983-2013) was collected, as a reference from local observatory located closest to the study area that is Vellanikkara station. The 30 years period was chosen, considering that this is minimum period needed to define a climate. The performance of selected GCM, was measured by comparing the simulated climate generated by each model with observed climate. It is assumed that those models that generated simulated climate for baseline period close to observed climate will produce more accurate regional climate projections. In this study, the general circulation model GFDL CM3 was used to generated the potential range of future climate and estimate the possible range of climate change impacts on rice yields.

In an attempt to cover the influence of future greenhouse gas emission and the corresponding socio economic development, the recent climate change scenarios adopted by IPCC (AR5) was used. The scenarios is known as Representation Concentration Pathway (RCPs). The pathways are used for climate modelling and research. They describe four possible climate futures, all of which are possible depending on how much greenhouse gases are emitted in the years to come.

The four RCPs, RCP 2.6, RCP 4.5, RCP 6 and RCP 8.5, each specifies radiation forcing and associated concentrations of atmospheric constituents involved over a period of 1850-2100 (Moss *et al.,* 2010). Among this four scenarios, two scenarios are chosen for this study. The first is RCP 8.5 that represents a future with no policy changes to reduce emissions and it can be comparable with SRES scenario of A1F1, second is RCP 4.5 represent a future with relatively ambitious emission reduction with stabilized radiative forcing achieved shortly after 2100. The RCP 4.5 is comparable to SRES scenario of B1.

3.8.6. Bias Correction of Predicted Data

Even though the model GFDL-CM3 showed a good ability to simulate the present climate over the basin, the presence of uncertainties on the future climate because of systematic bias needs to be corrected. The method reported by Leander and Buishand (2007) was used for bias correction of future data.

Precipitation

The daily precipitation P is transformed to a corrected value P^* using

$$P^* = aP^b$$

Where a and b are constant

The constants a and b in the equation used was found out by the following procedure.

Determination of the parameter `b' was done iteratively, so that the coefficient of variation of the daily precipitation values predicted by the model matches the coefficient of variation of the observed daily precipitation. After evaluating the parameter 'b', the transformed intermediate daily precipitation values were calculated and based on that the parameter a was determined such that the mean of the transformed daily values of precipitation matched with the observed mean. The parameter 'a' depends on 'b', but parameter b depends only on the coefficient of variation and is independent of the value of parameter 'a'. The bias correction coefficients 'a' and 'b' obtained for different months are plotted and the values of the coefficients are given in Appendix-II-page ii. The rainfall data of the best performing model, GFDL-CM3 was compared with the bias corrected data and found an almost perfect match with the observed data.

Temperature

Correction for temperature involves shifting and scaling to adjust the mean and the variance. The corrected daily temperature T^* is given by:

$$T^* = \overline{T}_{obs} + \frac{\sigma(T_{obs})}{\sigma(T_{mod})}(T_{mod} - \overline{T}_{obs}) + (\overline{T}_{obs} - T_{mod})$$

Where T_{mod} is the uncorrected daily temperature from GFDL-CM3 model and T_{Obs} is the observed daily temperature. The average over the considered.

In the simplest formulations of bias correction, only the changes in a specific statistical aspect (mean value or the variance) of the computed field are used. Leander and Buishand (2007) found that a relatively simple non-linear correction,

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adjusting both the biases in the mean and its variability, leads to better reproduction of observed extreme daily and multi-daily precipitation amounts than the commonly used linear scaling correction. This power law transformation method which corrects for the coefficient of variation (CV) and the mean of the precipitation values was used in this study to correct for bias in precipitation data. The most important statistics (coefficient of variation, mean and standard deviation of the model data) were matched with corresponding quantities computed from the observed values.

Results

4. RESULTS

The results obtained from the study "Assessment of rice (*Oryza sativa* L.) production under climate change scenarios" are presented below.

4.1. PHENOPHASES OF RICE CROP

Phenology is the study of relationship between the dates of first occurrence of biological events in their annual cycle with seasonal climatic changes. The factors like environmental and crop genotypes shows a significant effect on different developmental stages of rice.

In this current study, the phenophases of rice crop was divided into six development stages based on their morphological characters and are denoted by P1 to P6. The phenophases of rice crop include:

1. **P1**- Transplanting to active tillering
2. **P2**- Active tillering to panicle initiation
3. **P3**- Panicle initiation to booting
4. **P4**- Booting to heading
5. **P5**- Heading to 50% flowering
6. **P6**- 50% flowering to physiological maturity

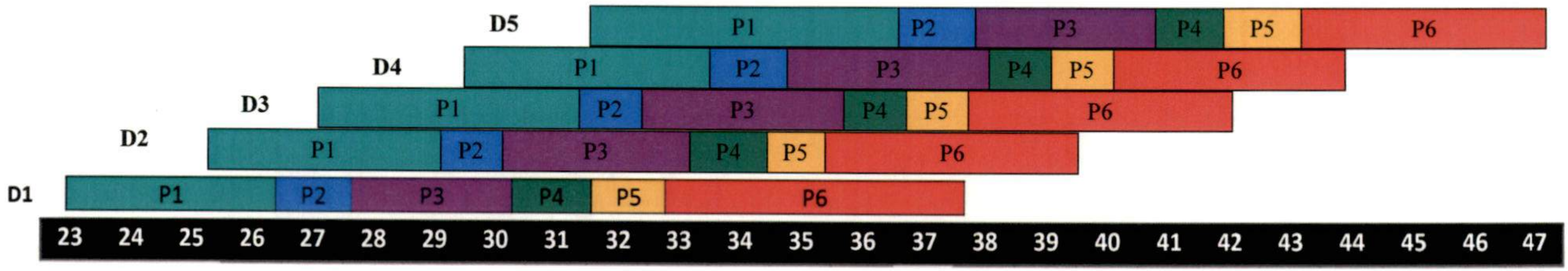
All these phenophases are comes under different growth periods such as vegetative period, reproductive period and ripening period. The developmental stage from transplanting to panicle initiation (P1& P2) comes under the vegetative period, panicle initiation to 50% flowering stage (P3-P5) comes under reproductive period and flowering to physiological maturity (P6) under ripening period. The rice varieties Jyothi and Kanchana showed variations in occurrence of their duration of phenophases for five dates of planting (5th June- 5th August) during the *kharif* season in 2016. The variations in duration of different growth stages for both the varieties are displayed in the phenological calendar (Fig. 4.1 a & b). The phenophases of crops were drawn against standard meteorological weeks. Late transplanting in both Jyothi and Kanchana shows a decrease in their crop duration.

4.2. WEATHER PARAMETERS PREVAILED DURING CROP GROWTH PERIOD

Different weather parameters prevailed during the entire crop period was recorded. The weather parameters like maximum and minimum temperature, forenoon and afternoon relative humidity (RH), rainfall (RF), bright sunshine hours (BSS), number of rainy days (RD), evaporation (Ep), vapour pressure deficit (VPD) and wind speed (WS) recorded daily and converted to weekly observations. The weather parameters were averaged against standard meteorological weeks which correspond to different phenophases of crop growth. The recorded weather displayed graphically. The growth indices like growing degree days (GDD), helio thermal units (HTU) and photo thermal units (PTU) were worked out for each growth stage.

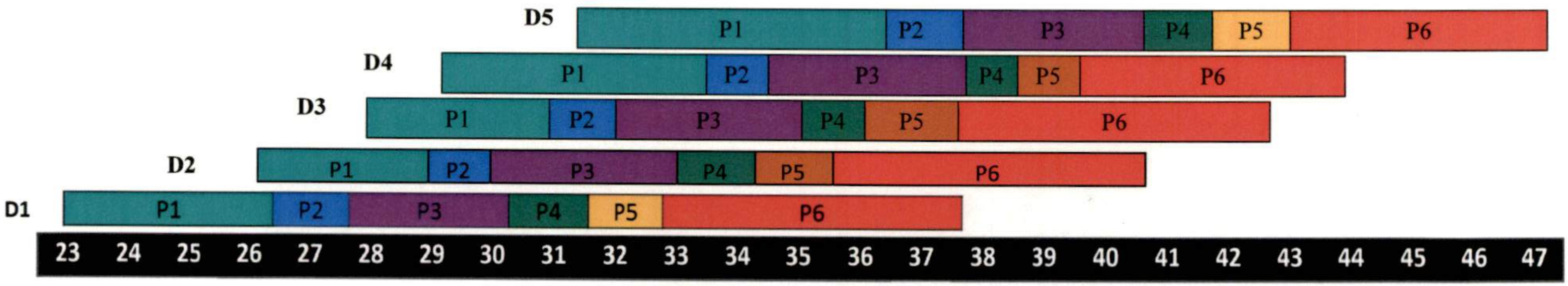
4.2.1. Air temperature

The temperature observed during the crop period was displayed graphically on weekly basis in Fig. 4.2. The maximum temperature (Tmax), minimum temperature (Tmin), weekly mean temperature and diurnal range temperature (DTR) were recorded. Late transplanted crop experiences more maximum and minimum temperature than early transplanted crops and recorded maximum temperature during 21st week (33.0°C) and minimum temperature experienced during 25th week (20.7°C).



Standard meteorological weeks

Fig. 4.1.a. Phenological calendar of Jyothi (2016)



Standard meteorological weeks

Fig. 4.1.b. Phenological calendar of Kanchana (2016)

P1- Transplanting to active tillering
P2- Active tillering to panicle initiation
P3- Panicle initiation to booting
P4-Booting to heading
P5- Heading to 50% flowering
P6- 50% flowering to physiological maturity

D1- June 5th transplanting
D2-June 20th transplanting
D3- July 5th transplanting
D4- July 20th transplanting
D5- August 5th transplanting

4.2.2. Relative humidity

Relative humidity (forenoon and afternoon) were recorded for entire crop growing period and were represented graphically against standard meteorological weeks. The forenoon relative humidity (RHI) and afternoon relative humidity (RHII) prevailed during the crop period was studied and it was given in the Fig. 4.3. The forenoon relative humidity was highest during 26th and 30th week (97%) and showed a decreasing trend towards delayed date of transplanting. The lowest forenoon relative humidity was observed on 45th week (88%). Afternoon relative humidity also showed variations and decreasing trend towards delayed transplanting. Highest afternoon relative humidity was recorded during 23rd week (89%) and lowest afternoon relative humidity was recorded on 45th week (53%).

4.2.3. Rainfall and rainy days

The weekly total rainfall and number of rainy days were calculated for the entire crop growing period and for different growth stages of the crop. The rainfall and rainy days are displayed over standard meteorological weeks in Fig. 4.4. The highest rainfall of 220.6mm obtained in 23rd week. The amount of rainfall showed decline in trend towards delayed date of transplanting. The amount of rainfall observed during the entire crop period was 1579.6 mm. The total number of rainy days for entire crop period was 83 days. The number of rainy days reduced towards delayed transplanting.

4.2.4. Vapour pressure deficit (VPD)

The dry bulb and wet bulb thermometers readings was taken for calculating the vapour pressure deficit (mm Hg) for the entire crop period. The forenoon and afternoon vapour pressure for the entire crop period was displayed in Fig. 4.5. The forenoon and afternoon vapour pressure deficit showed a decline in trend towards delayed date of transplanting. The highest and lowest forenoon vapour pressure deficit were recorded on 21st and 45th weeks and their values were 25.7 mm Hg and 20.5 mm Hg

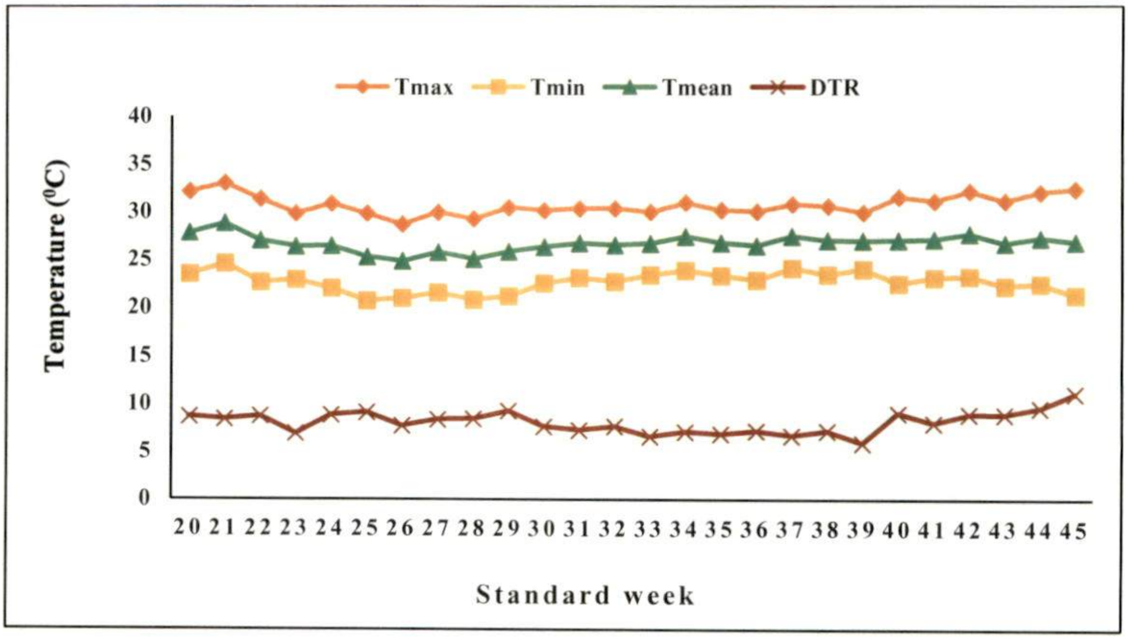


Fig.4.2. Weekly Tmax, Tmin, Tmean and DTR temperatures (°C) during the crop period

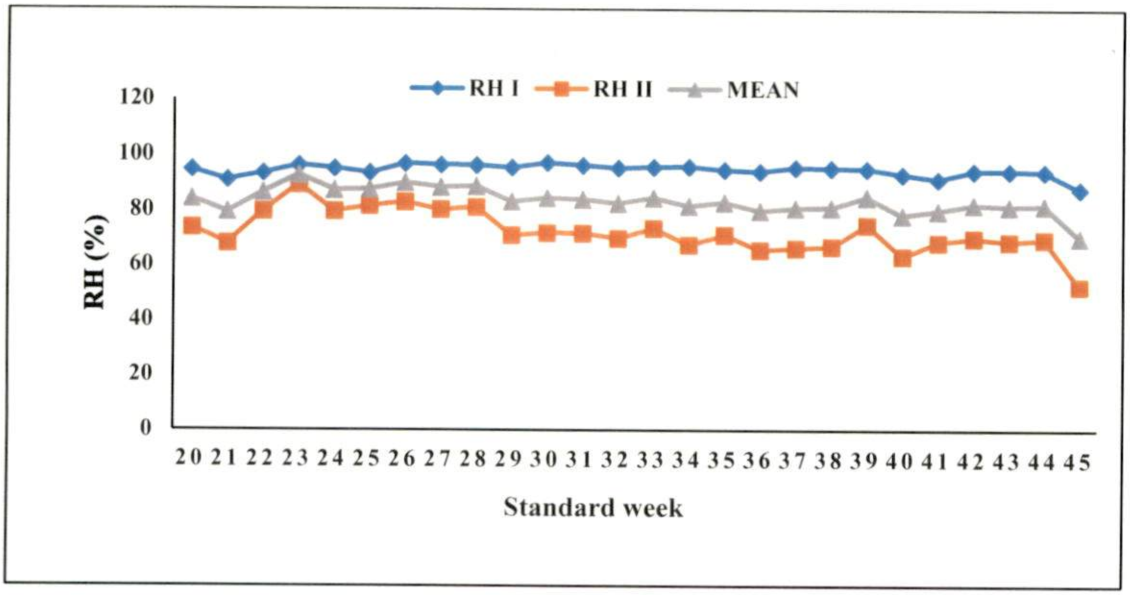


Fig.4.3. Weekly relative humidity (%) during the crop period

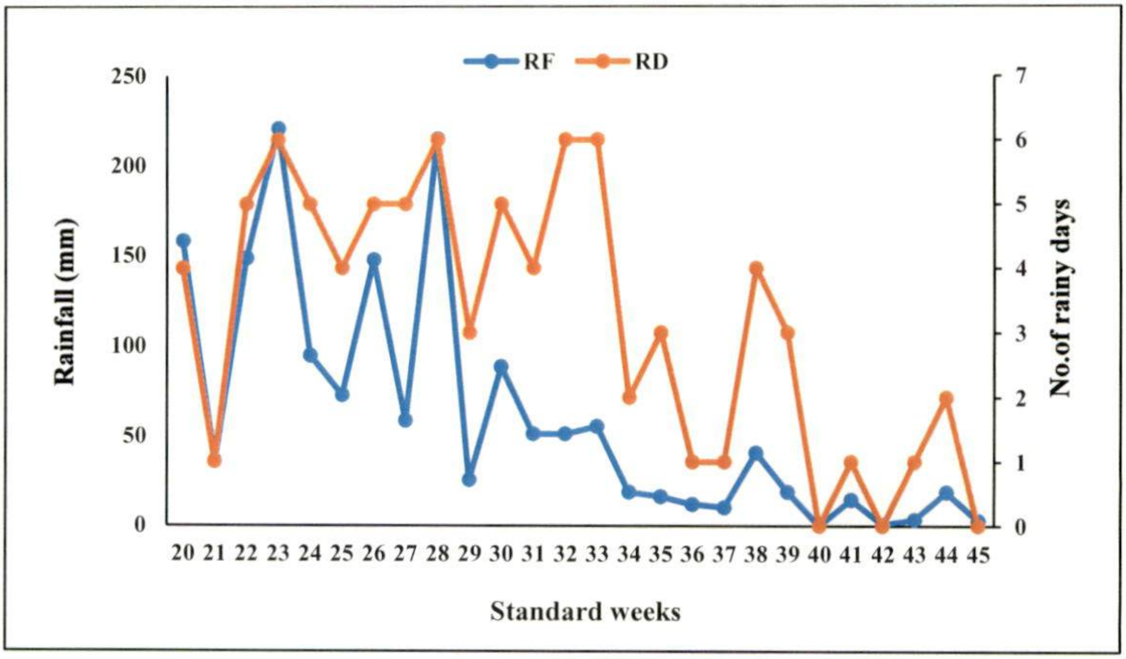


Fig.4.4. Weekly total rainfall (mm) and number of rainy days during the crop period

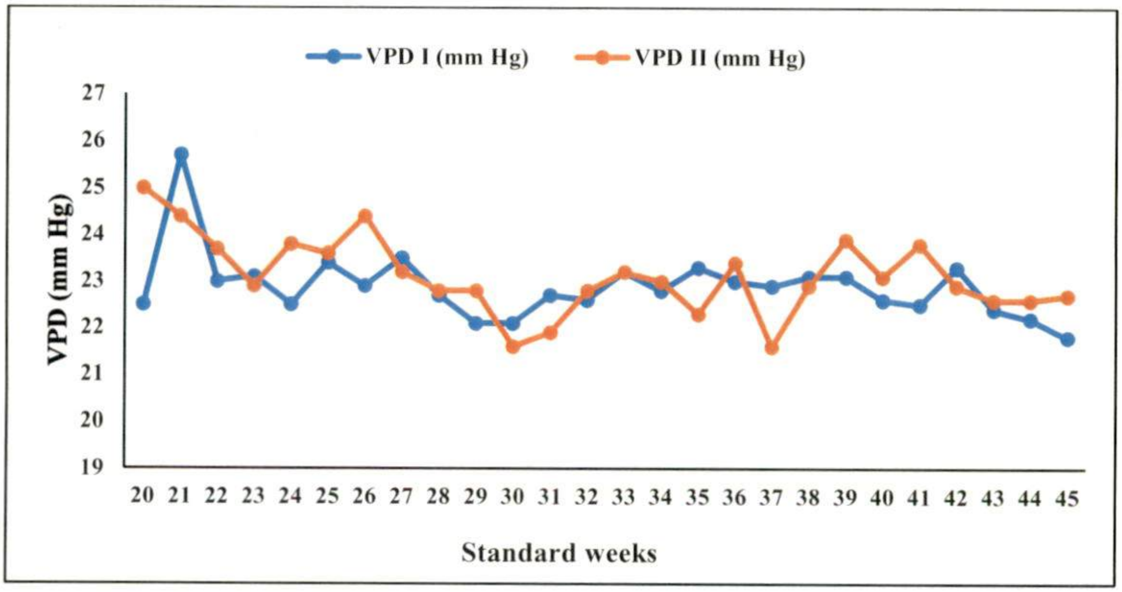


Fig.4.5. Weekly vapour pressure deficit (mm Hg) during the crop period

respectively. The highest and lowest values of afternoon vapour pressure deficit recorded were 25.0 mm Hg and 21.6 mm Hg and it was on 20th and 30th & 37th weeks, respectively.

4.2.5. Bright sunshine hours (BSS) and Pan evaporation (Ep)

The bright sunshine hours and pan evaporation for the entire crop season were recorded and displayed in Fig. 4.6. Delayed transplanting showed rising trend for both bright sunshine hours and pan evaporation. The bright sunshine was found to be highest on 40th week and the observed value was 9.1 h. The lowest value of BSS was recorded on 26th week and the observed value was 0.3 h, respectively. Bright sunshine hours showed undulations during the entire crop growing period.

4.2.6. Wind speed (WS)

The wind speed observed during the different crop growth period was recorded and displayed graphically in Fig.4.7. The wind speed showed a decline in trend towards delayed dates of planting. It could be noted that the early transplanted crops experienced fluctuations in wind speed and, a mild fluctuation are observed in the middle of standard meteorological weeks. The highest wind speed (2.3 km h^{-1}) was recorded on 33rd week and lowest (0.7 km h^{-1}) on 42nd week.

4.3. WEATHER PARAMETERS DURING DIFFERENT PHENOPHASES

The weather parameters experienced during different phenophases of crop growth and development were presented below.

4.3.1. Weather during transplanting (T) to active tillering stage (AT)

The weather experienced during transplanting (T) to active tillering (AT) stages of Jyothi and Kanchana at different date of transplanting were displayed in Table. 4.1.

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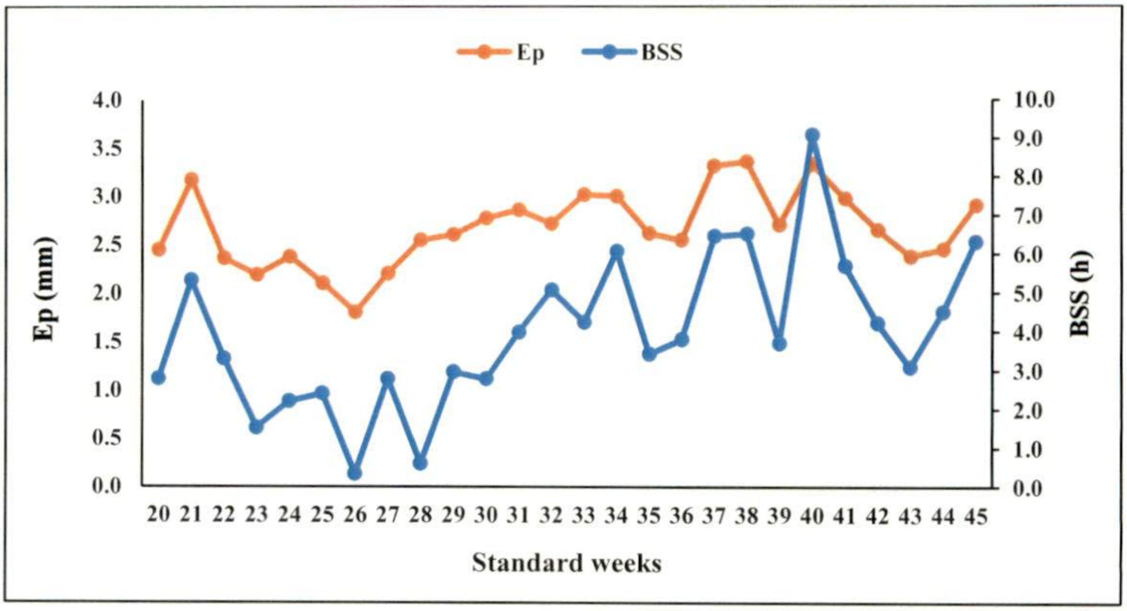

Fig. 4.6. Weekly bright sunshine hours (h) and evaporation (mm) during the crop

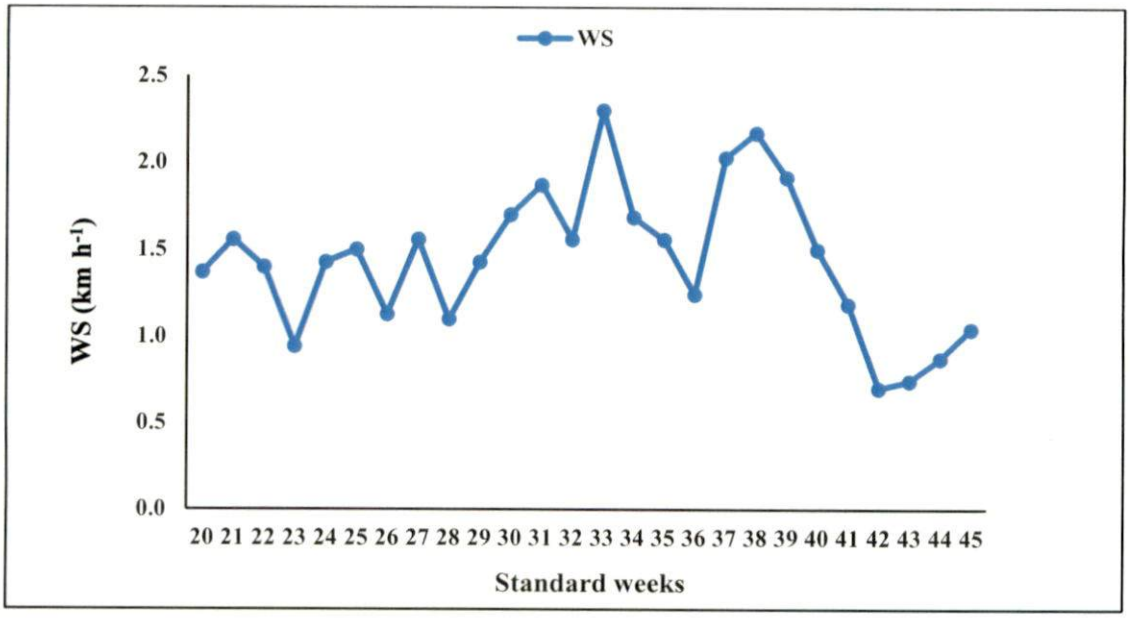

Fig.4.7. Weekly wind speed (km h^{-1}) during the crop period

Table. 4.1. Weather parameters experienced during transplanting to active tillering stages of rice varieties at different dates of planting

Weather parameters	Date of transplanting									
	D1		D2		D3		D4		D5	
	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana
Tmax (°C)	29.7	29.7	29.3	29.3	29.8	29.7	30.2	30.3	30.4	30.4
Tmin (°C)	21.6	21.6	20.9	20.9	21.6	21.6	22.6	22.6	23.2	23.2
Tmean (°C)	25.6	25.7	25.1	25.1	25.7	25.7	26.4	26.5	26.8	26.8
DTR (°C)	8.1	8.1	8.4	8.4	8.2	8.1	7.6	7.7	7.1	7.2
RH I (%)	95.0	96	96	96	96	96	96	96	95.0	95
RH II (%)	83.0	82	82	82	75	75	72	72	71.0	70
RH mean (%)	89.0	89.0	89.0	89.0	85.5	85.5	84.0	84.0	83.0	82.5
VP I (mm Hg)	22.7	22.7	22	22	22.6	22.6	23	23	22.7	22.7
VP II (mm Hg)	23.0	23.0	22.9	22.9	22.9	22.9	22.5	22.6	22.1	22.1
RF (mm)	467.5	467.5	495.4	495.4	386.1	375.4	209.2	205.9	160.8	155.4
RD (days)	19	19	21	21	19	18	18	17	17	16
BSS (h)	1.5	1.6	1.6	1.6	2	1.9	3.8	3.9	4.9	5.1
WS (km h^{-1})	1.2	1.2	1.3	1.3	1.4	1.4	1.7	1.7	1.8	1.8
Ep (mm)	2.1	2.1	2.1	2.1	2.5	2.5	2.7	2.8	2.9	2.9

D1- 5th June D2- 20th June D3- 5th July D4- 20th July D5- 5th August

4.3.1.1. Temperature (Maximum, minimum, mean and diurnal temperature)

The temperature during transplanting to active tillering stages of experimental period experiences highest maximum temperature during August 5th transplanted crops for both Jyothi and Kanchana (30.4 °C). The lowest minimum temperature were observed during June 20th transplanted crops and the recorded highest minimum temperature was 23.2 °C for Jyothi and Kanchana. The observed maximum and minimum temperature observed for Jyothi and Kanchana were 29.3 °C to 30.4 °C and 20.9 °C to 23.2 °C respectively. The mean temperature ranges between 25.1 °C to 26.8 °C for Jyothi and Kanchana. The diurnal temperature range recorded for Jyothi was 7.1 °C to 8.4 °C and Kanchana was 7.2 °C to 8.4 °C.

4.3.1.2. Relative humidity (forenoon relative humidity (RH I), afternoon relative humidity (RH II) and mean relative humidity (RH mean))

The relative humidity range experienced during transplanting to active tillering stage of Jyothi was 95% to 96 % (RH I) and 70% to 83% (RH II). The transplantation during 20th June, 5th July and 20th July recorded highest (96 %) and lowest (95%) forenoon relative humidity for August 5th transplanted one. The afternoon relative humidity reaches its highest during first date of planting (5th June) and lowest during fifth date of planting (5th August). The mean relative humidity was highest (89%) during first and second date of planting and lowest (82.5%) during fifth date of transplanting. The variety Kanchana experiences highest forenoon relative humidity (96%) during 1st, 2nd, 3rd and 4th transplanting and lowest forenoon relative humidity (95%) during 5th transplanting and 1st planting in the case of Jyothi. The range of mean relative humidity during transplanting to active tillering of Jyothi was 83% to 89% and 82.5% to 89% in the case of Kanchana.

4.3.1.3. Vapour pressure deficit (forenoon and afternoon vapour pressure deficit (VPD I & VPD II))

The vapour pressure deficit during the experimental period was taken as forenoon vapour pressure deficit (VPD I) and afternoon vapour pressure deficit (VPD II). The recorded vapour pressure deficit range for Jyothi and Kanchana was 22.0 to 23.0 mm Hg. The highest forenoon vapour pressure deficits for both varieties were recorded during July 20th transplanting. The rice varieties experiences highest afternoon vapour pressure deficit during June 5th planting (23.0 mm Hg) and lowest afternoon relative humidity (22.1 mm Hg) during 5th date of planting (August 5th).

4.3.1.4. Rainfall (RF) and rainy days (RD)

Rice varieties Jyothi and Kanchana from transplanting to active tillering stage received highest rainfall during second date of planting (June 20th) while lowest rainfall received during fifth date of planting (August 5th). The highest rainfall of 495.4 mm was recorded for the second date of planting for both Jyothi and Kanchana whereas the lowest rainfall recorded for Jyothi was 160.8 mm and for Kanchana was 155.4 mm for the last date of Planting. Transplanting to active tillering, the varieties Jyothi and Kanchana got maximum number of rainy days during second date of transplanting (21 RD). For Jyothi and Kanchana the minimum rainy days (RD) were observed during the last date of planting.

4.3.1.5. Bright sunshine hours (BSS)

The bright sunshine hours recorded for Jyothi was 1.5 h to 4.9 h and for Kanchana it was 1.6 h to 5.1 h. The highest sunshine hours recorded during August 5th transplanting and lowest during June 5th transplanting for both varieties. The recorded highest sunshine hours for Jyothi were 4.9 h and in the case of Kanchana it was 5.1 h.

4.3.1.6. Wind speed (WS)

The wind speed increases towards delayed transplanting for both the varieties. High wind speed occurs during fifth date of transplanting. The recorded wind speed for Jyothi and Kanchana was 1.8 km h^{-1}. The lowest recorded wind speed was 1.2 km h^{-1} on first date of planting.

4.3.1.7. Pan evaporation (Ep)

Evaporation occurred during transplanting to active tillering stage was 2.9 mm and it was recorded on August 5^{th} transplanting for Jyothi and Kanchana. The recorded range of evaporation for Jyothi and Kanchana was 2.1 to 2.9 mm respectively.

4.3.2. Weather during Transplanting (TP) to Panicle initiation (PI)

The weather prevailed during transplanting to panicle initiation was presented in the Table. 4.2.

4.3.2.1. Temperature (Tmax, Tmin, Tmean and DTR)

During transplanting to panicle initiation stage there was an increasing trend in temperature towards the fourth date of transplanting and there was a slight decline in temperature during last date of transplanting. The maximum temperature range recorded for Jyothi was 29.7 °C to 30.4 °C. The maximum temperature was found to be highest during fourth date of transplanting for both varieties. The temperature range recorded for Kanchana was 29.5 °C to 30.4 °C.

In case of minimum temperature Jyothi and Kanchana recorded an increasing trend towards the last date of planting. The minimum temperature range for Jyothi and Kanchana are 21.2 °C to 23.1 °C and 21.1 °C to 23.2 °C, respectively. Diurnal temperature range showed a decline in trend towards delayed date of transplanting and it ranges from 7.1 °C to 8.6 °C for Jyothi and 7.0 °C to 8.0 °C for Kanchana.

Table. 4.2. Weather parameters experienced during transplanting to panicle initiation

Weather parameters	Date of transplanting									
	D1		D2		D3		D4		D5	
	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana
Tmax (°C)	29.7	29.5	29.8	29.7	30.0	30.0	30.4	30.4	30.2	30.1
Tmin (°C)	21.5	21.4	21.2	21.1	22.3	22.3	23.1	23.1	23.1	23.2
Tmean (°C)	25.6	25.5	25.5	25.4	26.2	26.1	26.8	26.7	26.6	26.6
DTR (°C)	8.2	8.1	8.6	8.6	7.7	7.7	7.3	7.3	7.1	7.0
RH I (%)	95.7	96.0	95.9	96.0	96.2	96.0	95.7	95.5	94.8	95.0
RH II (%)	82.1	83.0	77.0	77.0	73.3	73.0	71.0	71.0	68.9	69.5
RH mean (%)	88.9	89.5	86.4	86.5	84.7	84.5	83.4	83.3	81.8	82.3
VP I (mm Hg)	22.6	22.5	22.1	22.1	22.7	22.6	23.0	23.0	22.2	22.3
VP II (mm Hg)	23.3	23.4	22.9	22.9	22.5	22.5	22.4	22.4	21.4	21.6
RF (mm)	565.4	614.5	584.4	584.4	458.1	458.6	276.6	272.0	176.9	176.7
RD (days)	25	26	24	25	25	25	24	23	19	19
BSS (h)	2.0	1.6	1.9	1.9	3.0	3.0	4.9	4.7	4.0	3.9
WS (km h^{-1})	1.4	1.3	1.4	1.4	1.6	1.6	1.9	1.9	1.5	1.5
Ep (mm)	2.2	2.2	2.4	2.4	2.6	2.6	3.0	3.0	2.7	2.7

D1- 5th June D2- 20th June D3- 5th July D4- 20th July D5- 5th August

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4.3.2.2. Relative humidity (RH I, RH II and RH mean)

Both Jyothi and Kanchana experienced an increasing trend in forenoon relative humidity and decreasing trend in afternoon and mean relative humidity. Forenoon relative humidity was recorded highest (96.2 percent) during the third date of planting for both varieties. The afternoon relative humidity was recorded highest (82.1 percent) for Jyothi and (83.0 percent) for Kanchana during the first date of planting. Mean relative humidity was recorded highest (88.9 percent) for Jyothi and (89.5 percent) for Kanchana during the first date of planting.

4.3.2.3. Vapour pressure deficit (VPD I and VPD II)

Forenoon vapour pressure deficit was recorded low for delayed transplanting in both Jyothi and Kanchana. The forenoon vapour pressure deficit range for Jyothi and Kanchana was 22.1 to 23.0 mm Hg. The afternoon vapour pressure deficit shows a declining trend towards the last date of planting for Jyothi and Kanchana and afternoon vapour pressure deficit range for Jyothi was 21.4 to 23.3 mm Hg and for Kanchana it was 21.6 to 23.4 mm Hg.

4.3.2.4. Rainfall (RF) and rainy days (RD)

During transplanting to panicle initiation the amount of rainfall received showed decreasing trend towards the delayed date of planting and highest amount of rainfall received by Jyothi during second date of planting and Kanchana during the first date of planting. The recorded highest amount of rainfall for Jyothi and Kanchana was 574.6 mm and 614.5 mm respectively. For both varieties the lowest amount of rainfall received on delayed planting and the observed rainfall was 176.9 mm and 176.7 mm, respectively.

The number of rainy days showed decreasing trend towards delayed planting. For both varieties highest rainy days 25 days for Jyothi and 26 days for Kanchana was recorded during the first date of planting and lowest rainy days 19 days for both varieties Jyothi and Kanchana was recorded during the last date of planting.

4.3.2.5. Bright sunshine hours (BSS)

There was an increasing trend in bright sunshine hours towards the delayed planting in both Jyothi and Kanchana. The varieties Jyothi and Kanchana received more sunshine hours (4.9 h and 4.7 h) during fourth date of planting. The observed sunshine hours range was 2.0 h to 4.9 h (Jyothi) and 1.6 h to 4.7 h (Kanchana).

4.3.2.6. Wind speed (km h^{-1})

Both Jyothi and Kanchana experienced highest wind speed (1.9 km h^{-1}) during the fourth date of planting. Wind speed range experienced during the phenological stage 1.3 km h^{-1} to 1.9 km h^{-1} for Jyothi and Kanchana respectively.

4.3.2.7. Pan evaporation (Ep)

The rate of evaporation was highest (3.0 mm) during the fourth date of planting for both Jyothi and Kanchana. The rate of evaporation ranges from 2.2 to 3.0 mm for both the varieties.

4.3.3. Weather prevailed during Transplanting (TP) to Booting (B)

The weather prevailed during transplanting to booting stage showed increasing trend towards delayed transplanting for both varieties and it was given in Table. 4.3.

4.3.3.1. Temperature (Tmax, Tmin, Tmean and DTR)

Transplanting to booting stage of Jyothi and Kanchana experienced a maximum temperature of 30.3 °C and minimum temperature of 21.5 °C. Both the varieties experienced highest maximum temperature during fourth and fifth date of planting and lowest minimum temperature recorded during first date of planting. The observed

Table. 4.3. Weather prevailed during transplanting to booting

Weather parameters	Date of transplanting									
	D1		D2		D3		D4		D5	
	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana
Tmax (°C)	29.8	29.8	30.0	30.0	30.2	30.2	30.3	30.3	30.3	30.3
Tmin (°C)	21.6	21.5	22.1	22.1	22.8	22.8	23.2	23.2	23.4	23.4
Tmean (°C)	25.7	25.7	26.1	26.0	26.5	26.5	26.8	26.7	26.8	26.8
DTR(°C)	8.3	8.3	7.9	8.0	7.4	7.4	7.1	7.1	6.9	6.9
RH I (%)	95.9	96.0	95.9	96.0	95.6	95.5	94.9	95.3	95.4	95.0
RH II (%)	77.6	78.0	74.0	74.0	71.6	72.0	69.5	69.5	68.4	68.8
RH mean (%)	86.7	87.0	85.0	85.0	83.6	83.8	82.2	82.4	81.9	81.9
VP I (mm Hg)	22.6	22.6	22.7	22.7	22.7	22.7	22.4	22.6	22.6	22.6
VP II (mm Hg)	23.0	23.0	22.5	22.5	22.3	22.3	21.8	21.8	21.6	21.5
RF (mm)	859.9	857.9	711.3	708.7	551.6	553.5	305.1	305.1	246.8	246.8
RD (days)	39	39	39	38	35	35	28	28	27	27
BSS (h)	2.1	2.0	3.2	3.1	4.2	4.2	4.6	4.4	5.0	4.9
WS (km h^{-1})	1.4	1.3	1.5	1.5	1.7	1.7	1.7	1.7	1.8	1.8
Ep (mm)	2.4	2.4	2.6	2.5	2.8	2.8	2.8	2.8	2.9	2.9

D1- 5th June D2- 20th June D3- 5th July D4- 20th July D5- 5th August

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maximum and minimum temperature range for Jyothi was 29.8 °C to 30.3 °C and 21.6 °C to 23.4 °C. The highest diurnal temperature 8.3 °C was experienced during first date of planting for both varieties and lowest diurnal temperature 6.9 °C was experienced during 5th date of planting.

4.3.3.2. Relative humidity (RH I, RH II and RH mean)

Highest forenoon relative humidity recorded on first and second date of planting for Jyothi (95.9%) and Kanchana (96.0%). Whereas, afternoon relative humidity recorded highest during the first date of planting for Jyothi (77.6%) and Kanchana (78%). Relative humidity showed a decreasing trend towards the delayed date of planting. The range of mean relative humidity experienced during this growth period was 81.9% to 87% for both the varieties.

4.3.3.3. Vapour pressure deficit (VPD I and VPD II)

The forenoon vapour pressure deficit was highest during second and third date of planting for both varieties (22.7 mm Hg). The range of forenoon relative humidity was 22.4 mm Hg to 22.7 mm Hg for Jyothi and 22.6 mm Hg to 22.7 mm Hg in case of Kanchana. The variety Jyothi and Kanchana recorded highest afternoon vapour pressure deficit 23.0 mm Hg on first date of planting. The lowest afternoon vapour pressure deficit recorded for Jyothi and Kanchana was 21.6 mm Hg and 21.5 mm Hg during the last date of planting, respectively.

4.3.3.4. Rainfall (RF) and rainy days (RD)

The amount of rainfall received shows a decreasing trend towards the last date of planting for both the varieties. Both Jyothi and Kanchana received highest rainfall 859.9 mm and 857.9 mm rainfall respectively. The lowest rainfall 246.8 mm for both Jyothi and Kanchana was recorded during the fifth date of planting. For the crop period transplanting

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to booting the highest number of rainy days recorded during the first date of planting for both Jyothi (39 days) and Kanchana (39 days).

4.3.3.5. Bright sunshine hours (BSS)

The bright sunshine hours recorded during the period of transplanting to booting shows an increasing trend towards the delayed date of planting. The maximum bright sunshine hours recorded for Jyothi (5.0 h) and Kanchana (4.9 h) during the last date of transplanting. The minimum bright sunshine hours recorded for Jyothi (2.1 h) and Kanchana (2.0 h) during the first date of planting. The range of bright sunshine hours for Jyothi and Kanchana was 2.1 h to 5.0 h and 2.0 h to 4.9 h, respectively.

4.3.3.6. Wind speed (WS)

There was an increasing trend of wind speed observed towards the delayed date of transplanting. The highest wind speed 1.8 km h^{-1} recorded for Jyothi and Kanchana was during the last date of transplanting and lowest wind speed 1.4 km h^{-1} for Jyothi and 1.3 km h^{-1} for Kanchana was recorded during the first date of planting.

4.3.3.7. Pan evaporation (Ep)

The rate of evaporation recorded during the crop period from transplanting to booting stage for Jyothi and Kanchana was 2.4 mm to 2.9 mm and the highest rate of evaporation of 2.9 mm for both Jyothi and Kanchana observed during fifth date of planting.

4.3.4. Weather prevailed during Transplanting (TP) to Heading (H)

The weather during transplanting to heading stages of Jyothi and Kanchana were presented on Table 4.4.

Table. 4.4. Weather prevailed during transplanting to heading

Weather parameters	Date of transplanting									
	D1		D2		D3		D4		D5	
	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana
Tmax (°C)	29.9	29.9	30.1	30.1	30.0	29.9	30.4	30.4	30.4	30.4
Tmin (°C)	22.0	22.0	22.6	22.5	23.0	23.0	23.3	23.5	23.4	23.4
Tmean (°C)	26.0	26.0	26.3	26.3	26.5	26.4	26.9	26.9	26.9	26.9
DTR (°C)	7.9	7.9	7.5	7.6	7.0	6.9	7.1	7.0	7.0	7.0
RH I (%)	96.2	96.3	95.6	95.7	95.5	95.3	95.3	95.5	94.5	94.3
RH II (%)	75.6	76.0	72.8	73.0	72.1	72.0	69.1	69.0	68.8	69.2
RH mean (%)	85.9	86.2	84.2	84.3	83.8	83.7	82.2	82.3	81.6	81.8
VP I (mm Hg)	22.6	22.6	22.8	22.7	22.5	22.4	23.0	22.9	23.1	23.1
VP II (mm Hg)	22.7	22.8	22.5	22.4	22.1	22.1	21.7	21.8	21.8	21.8
RF (mm)	912.6	912.6	763.8	763.8	574.4	574.4	330.4	330.7	246.8	246.8
RD (days)	43	43	44	44	39	39	31	31	27	27
BSS (h)	2.6	2.5	3.9	4.0	3.3	3.0	5.0	5.2	5.3	5.2
WS (km h^{-1})	1.5	1.5	1.7	1.8	1.5	1.5	1.7	1.8	1.7	1.7
Ep (mm)	2.5	2.5	2.7	2.7	2.6	2.5	2.9	2.9	2.9	2.9

D1- 5th June D2- 20th June D3- 5th July D4- 20th July D5- 5th August

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4.3.4.1. Temperature (Tmax, Tmin, Tmean and DTR)

The delayed date of planting shows a highest maximum temperature of 30.4 °C for both Jyothi and Kanchana during fourth and fifth date of planting and mean temperature of Jyothi and Kanchana ranges from 26 °C to 26.9 °C. The diurnal temperature 7.9 °C recorded highest during first date of planting for both Jyothi and Kanchana. The lowest diurnal temperature 7.0 °C for Jyothi and 6.9 °C for Kanchana was recorded during the third date of planting.

4.3.4.2. Relative humidity (RH I, RH II and RH mean)

The highest forenoon relative humidity 96.2% for Jyothi and 96.3% for Kanchana was observed during the first date of transplanting and there was a decreasing trend observed towards the delayed date of transplanting. Highest afternoon relative humidity 75.6% for Jyothi and 76% for Kanchana observed during the first date of planting and followed a decreasing trend towards the delayed date of planting. Mean relative humidity of 85.9% for Jyothi and 86.2% for Kanchana was recorded highest during the first date of planting.

4.3.4.3. Vapour pressure deficit (VPD I and VPD II)

Increasing trend of vapour pressure deficit was recorded during transplanting to booting stage of both varieties towards delayed planting. The highest forenoon vapour pressure deficit was recorded during the delayed date of planting and it was 23.1 mm Hg for both Jyothi and Kanchana. The afternoon vapour pressure deficit showed decreasing trend and recorded highest VPD II 22.7 mm Hg for Jyothi and 22.8 mm Hg for Kanchana during the first transplanted crops.

4.3.4.4. Rainfall (RF) and Rainy days (RD)

Highest amount of rainfall 912.6 mm for Jyothi and Kanchana was observed during the first date of planting and lowest rainfall was recorded during the fifth date of planting that was 246.8 mm for both Jyothi and Kanchana. There was a declining trend of rainfall observed towards the delayed date of transplanting. Highest number of rainy days 43 was recorded during the first date of planting and there was a declining trend of rainy days was observed towards the delayed date of planting.

4.3.4.5. Bright sunshine hours (BSS)

Bright sunshine hours for Jyothi and Kanchana showed highest on last date of planting (5.3 h and 5.2 h). The range of bright sunshine hours observed for Jyothi and Kanchana was 2.6 h to 5.3 h and 2.5 h to 5.2 h, respectively.

4.3.4.6. Wind speed (WS)

Highest wind speed for both varieties Jyothi and Kanchana was recorded 1.7 km h^{-1} and 1.8 km h^{-1} respectively, during second and fourth date of planting and lowest wind speed 1.5 km h^{-1} was observed for both varieties during the first and third date of planting.

4.3.4.7. Pan evaporation (Ep)

Highest evaporation rate 2.9 mm was recorded on fourth and fifth date of planting for both varieties and lowest evaporation rate 2.5 mm was observed during first date of planting. The recorded range was 2.5 mm to 2.9 mm for Jyothi and Kanchana, respectively.

4.3.5. Weather prevailed during Transplanting (TP) to 50% flowering (F)

The weather conditions experienced during transplanting to 50% flowering stages of Jyothi and Kanchana was presented on Table. 4.5.

Table. 4.5. Weather prevailed during transplanting to 50% flowering

	Date of transplanting									
Weather parameters	D1		D2		D3		D4		D5	
	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana
Tmax (°C)	30.1	30.0	30.3	30.4	30.2	30.0	30.5	30.5	30.7	30.7
Tmin (°C)	22.2	22.2	22.8	22.8	22.9	23.0	23.4	23.3	23.2	23.2
Tmean (°C)	26.1	26.1	26.6	26.6	26.5	26.5	26.9	26.9	26.9	27.0
DTR (°C)	7.9	7.9	7.5	7.6	7.3	7.0	7.1	7.1	7.6	7.5
RH I (%)	96.0	96.0	95.9	95.5	95.2	95.5	95.2	95.4	94.2	94.0
RH II (%)	73.8	74.0	71.5	71.8	70.2	69.8	68.5	68.3	67.3	67.4
RH mean (%)	84.9	85.0	83.7	83.6	82.7	82.6	81.9	81.8	80.8	80.7
VP I (mm Hg)	22.5	22.6	22.8	22.7	22.3	22.5	22.9	22.8	22.8	22.8
VP II (mm Hg)	22.5	22.5	22.3	22.4	21.5	21.7	21.5	21.6	21.6	21.6
RF (mm)	952.3	952.3	782.2	780.2	574.8	574.8	356.1	337.2	246.8	246.8
RD (days)	47	47	46	46	39	39	33	32	27	27
BSS (h)	3.2	3.0	4.3	4.4	4.1	3.1	5.5	5.5	6.2	6.1
WS (km h^{-1})	1.5	1.5	1.7	1.8	1.6	1.5	1.9	1.9	1.7	1.6
Ep (mm)	2.6	2.6	2.8	2.8	2.7	2.5	3.1	2.9	3.0	2.9

D1- 5th June D2- 20th June D3- 5th July D4- 20th July D5- 5th August

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4.3.5.1 Temperature (Tmax, Tmin, Tmean and DTR)

During transplanting to 50% flowering, there was an increasing trend observed in maximum temperature towards the delayed date of planting. Maximum temperature range of Jyothi and Kanchana was 30.1 °C to 30.7 °C and 30.0 °C to 30.7 °C, respectively. Minimum temperature range observed was 22.2 °C to 23.2 °C for both varieties Jyothi and Kanchana and mean temperature range exists between 26.1 °C to 26.9 °C for Jyothi and 26.1 °C to 27 °C for Kanchana. Diurnal temperature ranges from 7.1 to 7.9 °C for Jyothi and 7.0 °C to 7.9 °C in case of Kanchana.

4.3.5.2. Relative humidity (RH I, RH II and RH mean)

The relative humidity range during transplanting to 50% flowering was 94.2% to 96.0%, 67.3% to 73.8% and 80.8% to 84.9% (RH I, RH II and RH mean) for Jyothi and 94.0% to 96.0%, 67.4% to 74% and 80.7% to 85.0% for Kanchana (RH I, RH II and RH mean). The first date of planting recorded highest forenoon, afternoon and mean relative humidity for Jyothi and Kanchana respectively.

4.3.5.3. Vapour pressure deficit (VPD I and VPD II)

The forenoon vapour pressure deficit 22.8 mm Hg for Jyothi and Kanchana was recorded highest during the delayed date of planting and lowest vapour pressure deficit 2.5 mm Hg for Jyothi and 2.6 mm Hg for Kanchana was observed during the first date of planting. Observed vapour pressure deficit range for forenoon relative humidity was 22.5 mm Hg to 22.8 mm Hg for both the varieties. Whereas, in case of afternoon vapour pressure deficit it was 21.6 mm Hg to 22.5 mm Hg for both the varieties.

4.3.5.4. Rainfall and rainy days (RF and RD)

Early transplanted rice varieties Jyothi and Kanchana received heavy rainfall of 952.3 mm on June 5th and it reduced on delayed planting and the lowest amount of rainfall received during transplanting to 50% flowering was 246.8 mm for both Jyothi and Kanchana. Number of rainy days received maximum of 47 days for Jyothi and Kanchana during the first date of planting. The lowest rainy days of 27 days for both Jyothi and Kanchana was recorded during the last date of planting.

4.3.5.5. Bright sunshine hours (BSS)

The bright sunshine hours received during transplanting to 50% flowering stage showed increasing trend towards the delayed date of planting for both varieties and 6.2 h and 6.1 h was the highest sunshine hours recorded during last date of planting for Jyothi and Kanchana on that period. The range was noticed as 3.2 h to 6.2 h for Jyothi and 3.0 h to 6.1 h for Kanchana.

4.3.5.6. Wind speed (WS)

High wind speed 1.9 km h^{-1} observed during the fourth date of planting for both Jyothi and Kanchana. The wind speed range recorded was 1.5 km h^{-1} to 1.9 km h^{-1} for both the varieties, respectively.

4.3.5.7. Pan evaporation (Ep)

The evaporation rate recorded for Jyothi and Kanchana was 2.6 mm to 3.1 mm and 2.6 to 2.9 mm respectively. The highest rate of evaporation was found on fourth date of planting for Jyothi and last date of planting for Kanchana.

4.3.6. Weather prevailed during Transplanting (T) to Physiological maturity (PM)

The weather conditions during transplanting to physiological maturity were given in the Table. 4.6.

Table. 4.6. Weather prevailed during transplanting to physiological maturity

Weather parameters	Date of transplanting									
	D1		D2		D3		D4		D5	
	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana
Tmax (°C)	30.1	30.1	30.3	30.3	30.3	30.1	30.6	30.6	30.9	30.9
Tmin(°C)	22.4	22.4	23.0	22.9	22.9	23.1	23.3	23.3	23.0	23.1
Tmean(°C)	26.3	26.2	26.6	26.6	26.6	26.6	26.9	26.9	27.0	27.0
DTR(°C)	7.7	7.7	7.4	7.4	7.3	7.1	7.3	7.3	7.9	7.9
RH I (%)	95.8	95.8	95.7	95.4	95.0	95.2	95.0	95.1	94.0	93.8
RH II (%)	72.8	73.0	71.0	71.2	69.6	69.4	68.6	68.4	67.1	67.1
RH mean (%)	84.3	84.4	83.3	83.3	82.3	82.3	81.8	81.8	80.5	80.5
VP I (mm Hg)	22.5	22.6	22.7	22.6	22.4	22.5	22.9	22.8	22.6	22.6
VP II (mm Hg)	22.3	22.4	22.1	22.2	21.5	21.7	21.7	21.7	21.7	21.7
RF (mm)	1068.9	1059.5	880.4	878.6	645.4	645.4	393.4	393.4	287.0	287.0
RD (days)	61	59	58	58	47	47	38	38	31	31
BSS (h)	3.6	3.4	4.3	4.5	4.6	3.8	5.4	5.5	5.9	5.8
WS (km h^{-1})	1.6	1.5	1.7	1.8	1.6	1.5	1.8	1.7	1.5	1.4
Ep (mm)	2.6	2.6	2.8	2.8	2.8	2.7	3.0	2.9	2.9	2.9

D1- 5th June D2- 20th June D3- 5th July D4- 20th July D5- 5th August

4.3.6.1. Temperature (Tmax, Tmin, Tmean and DTR)

Highest maximum temperature prevailed during the last date of planting for Jyothi and Kanchana was 30.9 °C and lowest minimum temperature was 22.4 °C during the first date of planting. The mean temperature was found maximum on delayed date of planting (27.0 °C) for both Jyothi and Kanchana. Highest diurnal temperatures 7.9 °C for both Jyothi and Kanchana was recorded on last date of planting and lowest diurnal temperatures 7.3 °C for Jyothi and 7.1 °C for Kanchana was recorded during the third date of planting.

4.3.6.2. Relative humidity (RH I, RH II and RH mean)

The relative humidity from transplanting to physiological maturity experienced decreasing trend towards delayed date of planting. From the Table. 4.6 it was noticed that the early planted crops (June 5^{th}) experiences highest relative humidity and it decreased on delayed planting (August 5^{th}). The range of RH I, RH II and RH mean was 94.0% to 95.8%, 67.1% to 72.8% and 81.8% to 84.3% for Jyothi and 93.8% to 95.8%, 67.1% to 73.0% and 80.5% to 84.4% for Kanchana.

4.3.6.3. Vapour pressure deficit (VPI and VP II)

Transplanting to physiological maturity period of Jyothi and Kanchana experiences forenoon vapour pressure deficit range of 22.5 to 22.9 mm Hg and 22.6 to 22.8 mm Hg respectively. Highest forenoon vapour pressure deficit 22.9 and 22.8 mm Hg for Jyothi and Kanchana was experienced during the fourth date of planting. Highest afternoon relative humidity of 22.3 and 22.4 mm Hg for Jyothi and Kanchana was experienced during the first date of planting and lowest 21.5 mm Hg for Jyothi whereas 21.7 mm Hg for Kanchana recorded during the third and fifth date of planting.

4.3.6.4. Rainfall and rainy days (RF and RD)

First transplanted rice varieties Jyothi and Kanchana received heavy rainfall of 1068.9 mm and 1059.5 mm, respectively on June 5 and it shows declining trend towards delayed planting and the lowest amount of rainfall received during transplanting to physiological maturity was 287.0 mm for both varieties Jyothi and Kanchana. Number of rainy days recorded maximum of 61 days for Jyothi and 59 days for Kanchana during the early date of planting.

4.3.6.5. Bright sunshine hours (BSS)

There was an increasing trend observed towards the delayed date of planting during the period from planting to physiological maturity. The maximum BSS was recorded on delayed date of planting and lowest on third and second date of planting. The observed range of BSS was 3.6 h to 5.9 h for Jyothi and 3.4 h to 5.8 h for Kanchana.

4.3.6.6. Wind speed (WS)

Highest wind speed (1.8 km h^{-1}) was recorded during the second and fourth date of planting for Jyothi and Kanchana and lowest wind speed (1.5 km h^{-1}) recorded during the first date of planting for both the varieties.

4.3.6.7. Pan evaporation (Ep)

The rate of evaporation of 3.0 mm and 2.9 mm was recorded highest during the fourth date of planting for both Jyothi and Kanchana and lowest rate of 2.6 mm during the first date of planting for both the varieties.

4.4. PHENOLOGICAL OBSERVATIONS

The phenological observations were recorded for every planting. The recorded duration for the completion of each growth stages *viz.* active tillering, panicle initiation, booting, heading, 50% flowering and physiological maturity for both the rice varieties (Jyothi and Kanchana) were given in the Table. 4.7.

4.4.1. Number of days taken for Active tillering

The varieties Jyothi and Kanchana took 27 and 28 days for active tillering, respectively for June 5^{th} transplanting. Whereas, 27 and 26 days for August 5^{th} transplanted crops. In case of Kanchana number of days taken for active tillering showed a decreasing trend towards delayed transplanting. Jyothi recorded highest number of active tillering days of 28 during the third date of planting.

4.4.2. Number of days taken for Panicle initiation

The varieties Jyothi and Kanchana transplanted on June 20^{th} took highest number of days for the completion of panicle initiation stage. Both Jyothi and Kanchana took 37 days for the completion of panicle initiation stage. Jyothi took more number of days for completion of panicle initiation stage during fourth and fifth date of planting compared to Kanchana.

4.4.3. Number of days taken for Booting

The number of days taken for booting followed a decreasing trend towards the delayed date of transplanting for both the varieties. The number of days for booting reduced during last date of planting. Number of days taken for the completion of booting stage for Jyothi and Kanchana ranges from 54-57 days.

4.4.4. Number of days taken for Heading

Number of days from planting to heading ranges from 60-64 days for Jyothi and 60- 63 days for Kanchana. It was observed that Jyothi and Kanchana took 63 days for the completion of heading stage during the first date of planting. For second and third planted crops it took 64 and 63 days for Jyothi and 63-62 days for Kanchana, respectively. It was

Table 4.7. Duration of different phenophases during crop growth and development

	Date of transplanting									
Phenophases	D1 (5^{th} June)		D2 (20^{th} June)		D3 (5^{th} July)		D4 (20^{th} July)		D5 (5^{th} August)	
	J	K	J	K	J	K	J	K	J	K
Active tillering	27	28	27	27	28	27	27	26	27	26
Panicle initiation	35	36	37	37	36	36	37	35	36	35
Booting	57	56	56	57	56	57	57	54	54	54
Heading	63	63	64	63	63	62	62	61	60	60
50% flowering	67	67	67	66	66	65	66	64	64	63
Physiological maturity	103	102	102	102	100	99	101	99	99	98

J - Jyothi K- Kanchana

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found that for first four plantings Jyothi took more number of days for heading stage than Kanchana and in fifth date of planting kanchana took more days than Jyothi.

4.4.5. Number of days taken for 50% Flowering

Number of days taken for 50% flowering for Jyothi was 64 to 67 days. Whereas, Kanchana took only 63 to 67 days. There was a decreasing trend observed towards the delayed date of planting. From the above Table 4.7 it was observed that the June 5th transplanted crop took almost same days (67 days) for both Jyothi and Kanchana for 50% flowering.

4.4.6. Number of days taken for Physiological maturity

The number of days for physiological maturity varied for both the varieties in different dates of planting. June 5th planted crops took highest number of days of 103 days for Jyothi and 102 days for Kanchana for attaining physiological maturity. Delayed planting took less number of days for the completion of physiological maturity for both Jyothi and Kanchana. When compared to Kanchana, variety Jyothi took more number of days for physiological maturity.

4.5. STATISTICAL ANALYSIS OF PLANT CHARACTERISTICS

Statistical analysis were performed for biometric observations such as plant height, leaf area, dry matter accumulation at weekly intervals, number of filled grains per panicle, number of spikelets per panicle, number of filled grains per panicle, 1000 grain weight, grain yield, straw yield and physiological observations. The results of analysis of covariance were presented given below.

4.5.1. Biometric observations

4.5.1.1. Plant height at weekly intervals

Analysis of variance was done for weekly plant height observations from 1st week after transplanting to 12th week for both the varieties Jyothi and Kanchana. The results of variance analysis performed on plant height at weekly intervals for varieties Jyothi and Kanchana are given in Appendix-II-page.iii. From the variance analysis, it was found that there was no significant difference observed between the date of planting and planting height during the 1st, 3rd, 6th, 9th, 10th,11th and 12th weeks after transplanting for both the varieties of rice. Date of planting had significant influence on 2nd, 4th, 5th and 7th weeks after planting in both Jyothi and Kanchana. Among all the five plantings, June 5th planting found to be superior to all other plantings, except for 8th, 9th, 10th and 11th weeks, July 20th planting was superior. Plant height observations at weekly intervals from first week after transplanting to 12th week before harvest corresponding to five dates of planting from June 5th to August 5th from both rice varieties were provided in Table. 4.8.

A comparison was drawn between Jyothi and Kanchana for the plant height at weekly intervals and results are displayed in Table 4.9. It was found that variety Jyothi recorded significantly highest plant height when compared to Kanchana for all the dates of planting.

4.5.1.2. Dry matter accumulation at 15 days interval

Analysis of variance was performed for dry matter accumulation at fortnight intervals and the results are presented in appendix-II- page. iv. Accumulation of dry matter at fortnight intervals for five dates of planting was displayed in Table. 4.10. From the variance of analysis, it was observed that there was a significant difference between the dry matter accumulation and different dates of planting. Among all the dates of plantings, first date of planting, June 5th showed a highest dry matter accumulation and

Table 4.8. Effect of dates of planting on plant height at weekly intervals

Date of plantings	Weekly plant height											
	Week 1			Week 2			Week 3			Week 4		
	J	K	Mean	J	K	Mean	J	K	Mean	J	K	Mean
D1	22.5	19.7	21.1	33.8^{a}	24.2^{b}	29.0^{b}	49.7^{a}	33.7^{c}	41.7	63.0^{a}	48.1^{cd}	55.5^{ab}
D2	20.2	19.2	19.7	32.2^{a}	32.2^{a}	32.2^{ab}	45.0^{ab}	38.7^{abc}	41.8	63.5^{a}	51.7^{bc}	57.6^{a}
D3	23.7	19.5	21.6	28.5^{ab}	32.3^{a}	30.4^{ab}	36.2^{d}	37.7^{bc}	37.0	58.9^{b}	46.7^{d}	52.8^{b}
D4	23.6	21.2	22.4	33.7^{a}	32.2^{a}	33.0^{a}	42.0^{bc}	43.2^{a}	42.6	60.0^{ab}	56.5^{a}	58.2^{a}
D5	22.2	21.7	22.0	27.7^{b}	28.2^{ab}	27.9^{b}	39.7^{cd}	40.0^{ab}	39.9	58.9^{b}	54.7^{ab}	56.8^{a}
CD	NS		NS	4.2		3.4	5.2		NS	3.6		3.0

Date of plantings	Weekly plant height											
	Week 5			Week 6			Week 7			Week 8		
	J	K	Mean	J	K	Mean	J	K	Mean	J	K	Mean
D1	76.7^{a}	66.2^{a}	71.5^{a}	86.5	74.7	80.6^{a}	92.6^{a}	84.7^{a}	88.6^{a}	99.8^{b}	95.5^{ab}	97.6^{b}
D2	71.5^{ab}	59.0^{b}	65.2^{bc}	73.7	66.5	70.1^{c}	89.0^{ab}	89.0^{a}	89.0^{a}	94.7^{c}	96.5^{a}	95.6^{bc}
D3	70.8^{b}	56.7^{b}	63.8^{c}	75.3	65.2	70.3^{c}	82.0^{c}	78.0^{b}	80.0^{b}	92.2^{c}	98.0^{a}	95.1^{bc}
D4	70.1^{b}	67.2^{a}	68.6^{ab}	83.7	75.2	79.5^{a}	91.5^{a}	86.2^{a}	88.8^{a}	104.7^{a}	97.7^{a}	101.2^{a}
D5	68.7^{b}	67.0^{a}	67.8^{abc}	76.0	74.7	75.3^{b}	86.7^{b}	76.2^{b}	81.5^{b}	96.2^{bc}	91.7^{b}	94.0^{c}
CD	5.2		4.6	NS		3.2	4.6		3.7	4.1		2.9

Date of plantings	Weekly plant height											
	Week 9			Week 10			Week 11			Week 12		
	J	K	Mean	J	K	Mean	J	K	Mean	J	K	Mean
D1	104.5	104.5	104.5	114.6	105.7	110.1	114.2	107.0	110.6[b]	123.6[a]	115.5[a]	119.6
D2	104.5	104.2	104.3	114.7	108.9	111.8	115.7	115.5	115.6[a]	121.0[ab]	119.5[a]	120.2
D3	107.5	102.0	104.7	114.2	105.5	109.9	115.7	116.2	116.0[a]	118.7[c]	118.5[a]	118.6
D4	110.4	103.7	107.1	116.0	111.2	113.6	118.7	117.9	118.3[a]	122.6[ab]	119.7[a]	121.1
D5	108.2	100.6	104.4	114.0	108.2	111.1	115.7	116.3	116.0[a]	119.1[bc]	117.9[a]	118.5
CD	NS		NS	NS		NS	NS		3.3	4.4		NS

Table. 4.9. Comparison between varieties with respect to plant height (cm) at weekly intervals

Variety	Plant height											
	week											
	1	2	3	4	5	6	7	8	9	10	11	12
Jyothi	22.4[a]	31.2	42.5[a]	60.8[a]	71.6[a]	79.0[a]	88.3[a]	97.5	107.0[a]	114.7[a]	116.0	120.6[a]
Kanchana	20.3[b]	29.8	38.7[b]	51.5[b]	63.2[b]	71.3[b]	82.8[b]	95.9	103.0[b]	107.9[b]	114.6	118.2[b]
CD	1.3	NS	1.6	1.3	1.4	2.4	1.7	NS	2.5	2.5	NS	1.1

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Table.4.10. Effect of dates of planting on dry matter accumulation (kg ha^{-1}) at 15 days interval

Date of plantings	Dry matter accumulation at 15 days interval								
	15 DAT			30 DAT			45 DAT		
	J	K	Mean	J	K	Mean	J	K	Mean
D1	501.5^{b}	526.2^{a}	513.8^{a}	3,180.0^{a}	2,846.2^{c}	3,013.1^{ab}	7,170.0	6,891.2^{b}	7,030.6^{a}
D2	542.7^{a}	547.5^{a}	545.1^{a}	3,116.2^{a}	3,115.0^{a}	3,115.6^{a}	6,097.5	6,602.5^{c}	6,350.0^{c}
D3	529.7^{a}	394.2^{c}	462.0^{b}	2,872.2^{b}	2,951.2^{bc}	2,911.7^{ab}	5,137.7	7,112.0^{a}	6,124.8^{d}
D4	450.5^{c}	457.5^{b}	454.0^{b}	2,976.7^{b}	2,625.0^{d}	2,800.8^{b}	6,680.2	6,614.7^{c}	6,647.5^{b}
D5	402.7^{d}	468.7^{b}	435.7^{b}	2,701.5^{c}	2,988.5^{b}	2,845.0^{b}	6,907.5	6,680.0^{c}	6,793.7^{b}
CD	24.5		34.8	124.8		227.2	137.7		194.6

Date of plantings	Dry matter accumulation at 15 days interval								
	60DAT			75 DAT			90 DAT		
	J	K	Mean	J	K	Mean	J	K	Mean
D1	11,999.7^{b}	12,202.5^{a}	12,101.1^{a}	15,693.2^{a}	15,675.0^{a}	15,684.1^{a}	13,906.7^{a}	13,427.5^{b}	13,667.1^{b}
D2	11,195.7^{d}	12,312.5^{a}	11,754.1^{b}	14,921.0^{b}	14,603.7^{b}	14,762.3^{b}	13,849.2^{a}	13,907.5^{a}	13,878.3^{a}
D3	10,273.7^{e}	11,507.2^{b}	10,890.5^{e}	14,821.5^{b}	14,246.2^{c}	14,533.8^{c}	13,527.0^{c}	13,096.2^{c}	13,311.6^{c}
D4	12,391.5^{a}	10,230.7^{d}	11,311.1^{d}	14,882.7^{b}	13,461.0^{e}	14,171.8^{d}	13,457.5^{c}	12,073.2^{e}	12,765.3^{d}
D5	11,789.5^{c}	11,362.7^{c}	11,576.1^{c}	14,893.7^{b}	13,615.5^{d}	14,254.6^{d}	13,672.2^{b}	12,882.0^{d}	13,277.1^{c}
CD	110.7		137.8	104.2		138.5	104.9		129.1

highest dry matter accumulation for both the varieties was recorded at 75 days after transplanting. The highest dry matter accumulation of 15,639.2 for Jyothi and 15,675 for Kanchana was observed 75 days after transplanting (Table 4.11.). The lowest dry matter accumulation was recorded on third and fifth date of plantings in most of the observations from 15 days after planting to 90 days after planting.

4.5.1.3. Yield and yield parameters

Analysis of variance (ANOVA) was performed on yield and the various yield attributes are presented in Appendix II-page.v.

The effect of date of planting on yield and yield parameters such as panicles per unit area, spikelets per panicle, filled grains per panicle and 1000 grain weight were presented in Table.4.12. The date of planting had significant effect on yield, panicles per unit area, spikelets per panicle. Among yield observations, June 20^{th} planting found to be superior and it was on par with the June 5^{th} date of planting. The date of planting had significant effect on the number of spikelets per panicle and June 5^{th} planting found superior and on par with June 20^{th} date of planting and July 20^{th} date of planting. The planting date had significant influence on the number of panicles per unit area, June 5^{th} planting recorded highest panicle per unit area and it was on par with 20^{th} date of planting. The date of planting had no significant influence on number of filled grains per panicle and 1000 grain weight.

Comparison between varieties and yield parameters were given in Table. 4.13. In case of yield, spikelets per panicle, number of filled grains per panicle and 1000 grain weight had no significant interaction with varieties except panicles per unit area.

4.5.1.4. Leaf area at 15 days interval

Analysis of variance (ANOVA) was performed and the results for leaf area are presented in Appendix II-page.iv. High significant influence of dates of planting was

Table.4.11. Comparison between varieties with respect to dry matter accumulation (kg ha^{-1})

Varieties	15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT
Jyothi	485.4	2,969.3	6,398.6[a]	11,530.0	15,042.4[a]	13,682.5[a]
Kanchana	478.8	2,905.2	6,780.1[b]	11,523.1	14,320.3[b]	13,077.3[b]
CD	NS	NS	87.0	NS	57.7	47.6

Table. 4.12. Effect of dates of planting on yield and yield parameters

Date of planting	Yield (Kg ha)			Number of panicles per unit area			Number of spikelets per panicle			Number of filled grains per panicle			1000 grain weight (g)		
	J	K	Mean	J	K	Mean	J	K	Mean	J	K	Mean	J	K	Mean
D1	5700.0	5450.0	5575.0^{ab}	376.3	448.0	412.2^{a}	77.2^{a}	77.7^{a}	77.4^{a}	83.7	84.5	84.1	29.1	28.9	29.0
D2	5782.0	6155.0	5968.7^{a}	396.3	410.3	403.3^{ab}	73.8^{a}	75.9^{a}	74.8^{a}	90.2	85.2	87.7	29.0	28.9	28.9
D3	4475.0	3385.0	3930.0^{c}	343.3	335.0	339.1^{d}	50.5^{c}	48.7^{c}	49.6^{c}	55.2	57.5	56.3	28.6	29.2	28.9
D4	4092.5	4265.0	4178.7^{bc}	370.1	395.3	382.7^{bc}	69.2^{ab}	67.9^{ab}	68.5^{ab}	79.7	80.2	80.0	28.8	28.1	28.4
D5	3717.5	3830.0	3773.7^{c}	375.2	356.7	365.9^{c}	59.0^{bc}	58.1^{bc}	58.6^{bc}	72.2	78.5	75.3	28.8	28.5	28.6
CD	NS		1485.0	NS		29	13.1		13.1	NS		NS	NS		NS

Table.4.13. Comparison between varieties and yield attributes

Varieties	Yield (kg ha^{-1})	Panicles per unit area	Spikelets per panicle	Number of filled grains	1000 grain weight (g)
Jyothi	4753.5	372.2^{a}	65.9	76.2	28.8
Kanchana	4617.0	389.1^{b}	65.7	77.2	28.7
CD	NS	15	NS	NS	NS

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observed in both varieties. The leaf area at 15 days interval for different dates of planting was displayed in Table 4.14. During 15 days after transplanting, June 20th date of planting showed superiority among all the dates of planting. During 30 days after transplanting, July 5th date of planting showed superiority and found on par with July 20th date planting. There was no significant influence of date of planting on leaf area at 45 days and 75 days after transplanting. The highest leaf area was recorded during the 60 days (Table 4.15) after transplanting for the both the varieties. During 90 days after planting, July 20th recorded higher leaf area.

4.5.1.5. Leaf area index at 15 days interval

The leaf area index at 15 days interval for different dates of planting was displayed in Table 4.16. During 15 days after transplanting, June 20th date of planting showed superiority among all the dates of planting. During 30 days after transplanting, July 5th date of planting showed higher leaf area index and found on par with July 20th date planting. There was no significant influence of date of planting on leaf area at 45 days and 75 days after transplanting. The highest leaf area index was recorded during the 60 days (Table 4.17) after transplanting for the both varieties. During 90 days after transplanting, July 20th recorded highest leaf area index which was on par with June 5th and June 20th planting.

Table.4.14. Effect of date of planting on leaf area at 15 days interval

DOP	Leaf area at 15 days interval								
	15 DAT			30 DAT			45 DAT		
	J	K	Mean	J	K	Mean	J	K	Mean
D1	24.0^{ab}	22.1^{b}	23.0	232.8	316.6	274.7^{b}	766.3	719.2	742.7
D2	24.8^{ab}	41.7^{a}	33.3	248.1	258.0	253.1^{b}	670.9	698.3	684.6
D3	21.2^{b}	31.9^{ab}	26.5	305.4	373.4	339.4^{a}	715.9	698.9	707.4
D4	34.4^{ab}	19.9^{b}	27.1	323.6	330.7	327.2^{a}	686.9	631.2	659.0
D5	36.7^{a}	22.4^{b}	29.5	250.3	266.7	258.5^{b}	608.6	669	638.8
CD	15.4		NS	NS		43.6	NS		NS

DOP	Leaf area at 15 days interval								
	60 DAT			75 DAT			90 DAT		
	J	K	Mean	J	K	Mean	J	K	Mean
D1	969.1	826.1	897.6^{b}	821.9	743.5	782.7	674.9	567.7	621.3^{ab}
D2	1037.4	1013.7	1025.5^{a}	833.1	862.1	847.6	620.1	630.2	625.2^{ab}
D3	858.1	749.5	803.8^{c}	742.2	671.4	706.8	515.1	493.7	504.4^{c}
D4	1035.3	806.3	920.8^{b}	913	793.1	853	667.5	613.9	640.7^{a}
D5	902.2	819.6	860.9^{b}	809.9	767.5	788.7	605.6	583.1	594.3^{b}
CD	NS		104.8	NS		NS	NS		38.4

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Table.4.15. Comparison between varieties with respect to leaf area at 15 days interval

Varieties	15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT
Jyothi	28.2	272.1^{b}	689.7	960.4^{a}	824.0^{a}	616.6^{a}
Kanchana	27.6	309.1^{a}	683.3	843.0^{b}	767.5^{b}	577.7^{b}
CD	NS	36.8	NS	70.1	41.4	27.3

Table. 4.16. Comparison between effect of date of planting on leaf area index at 15 days interval

Date of planting	Leaf area index at 15 days interval								
	15 DAT			30 DAT			45 DAT		
	J	K	Mean	J	K	Mean	J	K	Mean
D1	0.1^{ab}	0.1^{b}	0.1	1.5	2.1	1.8^{b}	5.1	4.7	4.9
D2	0.1^{ab}	0.2^{a}	0.2	1.6	1.7	1.6^{b}	4.4	4.6	4.5
D3	0.1^{b}	0.2^{ab}	0.1	2.0	2.4	2.2^{a}	4.7	4.6	4.7
D4	0.2^{ab}	0.1^{b}	0.1	2.1	2.2	2.1^{a}	4.5	4.2	4.3
D5	0.2^{a}	0.1^{b}	0.1	1.6	1.7	1.7^{b}	4.0	4.4	4.2
CD	0.1		NS	NS		0.2	NS		NS

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Date of planting	Leaf area index at 15 days interval								
	60 DAT			75 DAT			90 DAT		
	J	K	Mean	J	K	Mean	J	K	Mean
D1	6.4	5.5	5.9^{b}	5.5	4.9	5.2	4.5	3.7	4.1^{ab}
D2	6.9	6.9	6.9^{a}	6.4	5.7	6.4	4.1	4.2	4.1^{ab}
D3	5.7	4.9	5.3^{c}	4.9	4.4	4.7	3.4	3.2	3.3^{c}
D4	6.9	5.3	6.1^{b}	5.3	5.2	5.3	4.4	4.0	4.2^{a}
D5	6.0	5.4	5.7^{b}	5.4	5.1	5.2	4.0	3.8	3.9^{b}
CD	NS		0.7	NS		NS	NS		0.2

Table.4.17. Comparison between varieties with respect to leaf area index at 15 days interval

Varieties	15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT
Jyothi	0.1	1.8^{b}	4.6	6.4^{a}	5.6^{a}	4.1^{a}
Kanchana	0.1	2.0^{a}	4.5	5.6^{b}	5.1^{b}	3.8^{b}
CD	NS	0.2	NS	0.4	0.4	0.1

4. 6. Crop weather relationships

The correlation between weather elements with yield and yield contributing parameters of Jyothi and Kanchana were worked out for different phenophases of crop growth. Correlation between weather and duration of different phenophases of both Jyothi and Kanchana also worked out individually.

4. 6. 1. Influence of weather parameters on crop duration

The correlation between weather elements and duration of different phenological stages of rice variety Jyothi was presented in the Table. 4.18.

4. 6. 1. 1. Transplanting to active tillering (P1)

There was no significant correlation between duration and weather variables of transplanting to active tillering period.

4. 6. 1. 2. Active tillering to panicle initiation (P2)

During active tillering to panicle initiation stage, the weather variables like maximum temperature and evaporation positively influenced the duration. Whereas, afternoon relative humidity and rainy days had a negative impact on duration of active tillering to panicle initiation.

4. 6. 1. 3. Panicle initiation to booting (P3)

Weather variables like diurnal temperature range, afternoon relative humidity, afternoon vapour pressure and rainfall had positive correlation, while variables like maximum and minimum temperatures, bright sunshine hours, wind speed and evaporation had significant negative effect on panicle initiation to booting period in Jyothi.

Table 4. 18. Correlation between weather and phenophase duration of Jyothi

CROP STAGE	Tmax	Tmin	DTR	RH1	RH2	VP1	VP2	RF	RD	BSS	WS	Ep
P1	-0.107	-0.231	0.334	0.408	-0.160	.010	0.303	0.070	-0.221	-0.277	-0.198	0.061
P2	0.701**	0.147	0.091	-0.280	-0.526*	-0.059	-0.164	-0.290	-0.589**	.0296	0.149	0.649**
P3	-0.719**	-0.878**	0.869**	-0.113	0.715**	-0.438	0.494*	0.731**	0.324	-0.875**	-0.812**	-0.798**
P4	-0.550*	0.038	-0.587**	-0.180	0.513*	-0.590**	0.557*	0.401	0.469*	-0.292	0.130	-0.283
P5	0.037	-0.199	0.163	-0.448*	-0.008	-0.170	0.405	0.400	0.327	0.363	0.187	0.157
P6	-0.170	0.082	-0.135	0.423	0.500*	-0.287	0.097	0.465*	0.489*	-0.740**	0.000	-0.389
P7	0.497*	0.185	-0.017	0.111	-0.491*	-0.058	-0.230	-0.215	-0.171	0.389	0.514*	0.637**
P8	-0.853**	-0.753**	0.202	0.875**	0.977**	-0.534*	0.517*	0.930**	0.872**	-0.964**	-0.462*	-0.909**
P9	-0.170	0.082	-0.135	0.423	0.500*	-0.287	0.097	0.465*	0.489*	-0.740**	0.000	-0.389

*- Significant at 5% level **- Significant at 1% level

P1- Transplanting to active tillering
P2- Active tillering to panicle initiation
P3- Panicle initiation to booting
P4- Booting to heading
P5- Heading to 50% flowering
P6-50% flowering to physiological maturity
P7- Vegetative period
P8- Reproductive period
P9- Ripening period

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4. 6. 1. 4. Booting to heading (P4)

Afternoon relative humidity, afternoon vapour pressure deficit and rainy days were positively correlated, while, maximum temperature, diurnal temperature range and morning vapour pressure deficit were negatively correlated with the booting to heading period.

4. 6. 1. 5. Heading to 50% flowering (P5)

Morning relative humidity had negative significant effect on heading to 50% flowering stage in Jyothi.

4. 6. 1. 6. Flowering to physiological maturity (P6)

The duration from flowering to physiological maturity of rice variety Jyothi showed a negative correlation with bright sunshine hours. The weather variables such as afternoon relative humidity, rainfall and rainy days showed positive correlation.

4. 6. 1. 7. Vegetative period (P7)

Significant positive correlation was observed with maximum temperature, wind speed and evaporation and negative correlation was observed with afternoon relative humidity.

4. 6. 1. 8. Reproductive period (P8)

Weather variables like morning relative humidity, afternoon relative humidity, afternoon vapour pressure deficit, rainfall and rainy days are positively correlated with the reproductive period, whereas, maximum and minimum temperatures, morning vapour pressure deficit, bright sunshine hours, wind speed and evaporation showed a negative correlation.

4. 6. 1. 9. Ripening period (P9)

During the ripening period, Jyothi variety showed a significant negative correlation with bright sunshine hours and positive correlation with the afternoon relative humidity, rainfall and rainy days.

4. 6. 2. Influence of weather during different phenophases on yield of Jyothi

Correlation between weather and yield of Jyothi was worked out and presented in Table 4.19.

4. 6. 2. 1. Transplanting to active tillering (P1)

The weather elements like diurnal temperature range, afternoon relative humidity, afternoon vapour pressure deficit, rainfall and rainy days during transplanting to active tillering stage showed significant positive correlation with yield and maximum and minimum temperature, bright sunshine hours, wind speed and evaporation showed negative correlation with the yield.

4. 6. 2. 2. Active tillering to panicle initiation (P2)

Active tillering to panicle initiation stage of Jyothi showed significant positive correlation with diurnal temperature range, morning and afternoon relative humidity, afternoon vapour pressure deficit and rainfall, whereas minimum temperature had negative correlation with the yield.

4. 6. 2. 3. Panicle initiation to booting (P3)

Diurnal temperature range, afternoon relative humidity, afternoon vapour pressure deficit, rainfall and rainy days during panicle initiation to booting had significant positive correlation with yield, whereas minimum temperature and bright sunshine showed a negative correlation.

Table 4. 19. Correlation between weather and yield of Jyothi

YIELD	Tmax	Tmin	DTR	RH1	RH2	VP1	VP2	RF	RD	BSS	WS	Ep
P1	-0.597**	-0.578**	0.548*	0.028	0.646**	-0.429	0.550*	0.632**	0.578**	-0.581**	-0.604**	-0.646**
P2	-0.342	-0.599**	0.610**	0.528*	0.497*	0.089	0.572**	0.563**	0.278	-0.413	-0.038	-0.228
P3	-0.339	-0.498*	0.513*	0.309	0.592**	0.211	0.515*	0.493*	0.554*	-0.458*	-0.376	-0.426
P4	-0.253	-0.309	-0.085	0.359	0.244	-0.354	0.281	0.625**	0.565**	-0.123	0.335	-0.011
P5	-0.263	0.278	-0.352	0.573**	0.542*	0.318	0.347	0.402	0.467*	-0.607**	-0.143	-0.504*
P6	-0.602**	0.558*	-0.586**	0.622**	0.448*	0.207	-0.451*	0.621**	0.635**	-0.135	0.540*	0.306
P7	-0.575**	-0.634**	0.632**	0.336	0.603**	-0.182	0.572**	0.630**	0.525*	-0.586**	-0.428	-0.533*
P8	-0.362	-0.254	0.008	0.612**	0.588**	-0.065	0.481*	0.543*	0.643**	-0.497*	-0.078	-0.433
P9	-0.602**	0.558*	-0.586**	0.622**	0.448*	0.207	-0.451*	0.621**	0.635**	-0.135	0.540*	0.306

*- Significant at 5% level **- Significant at 1% level

P1- Transplanting to active tillering
P2- Active tillering to panicle initiation
P3- Panicle initiation to booting
P4- Booting to heading
P5- Heading to 50% flowering
P6-50% flowering to physiological maturity
P7- Vegetative period
P8- Reproductive period
P9- Ripening period

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4. 6. 2. 4. Booting to heading (P4)

In variety Jyothi, weather variables rainfall and rainy days during booting to heading had positive correlation with yield.

4. 6. 2. 5. Heading to 50% flowering (P5)

Heading to 50% flowering stage of Jyothi showed a significant positive correlation with morning and afternoon relative humidity and rainy days, whereas yield was negatively correlated with bright sunshine hours and evaporation.

4. 6. 2. 6. Flowering to physiological maturity (P6)

The weather parameters like minimum temperature, morning and afternoon relative humidity, rainfall and rainy days had significant positive correlation with yield and minimum temperatures, afternoon vapour pressure deficit, diurnal temperature range and wind speed showed negative correlation with the yield.

4. 6. 2. 7. Vegetative period (P7)

Diurnal temperature range, afternoon relative humidity, afternoon vapour deficit, rainfall and rainy days are positively correlated with the yield and maximum and minimum temperatures, bright sunshine hours and evaporation are negatively correlated with the vegetative period.

4. 6. 2. 8. Reproductive period (P8)

Rice variety Jyothi shows a positive correlation with morning and afternoon relative humidity, afternoon vapour pressure, rainfall and rainy days during reproductive period, whereas significant negative correlation was observed with bright sunshine hours.

4. 6. 2. 9. Ripening period (P9)

Maximum temperatures, afternoon vapour pressure deficit, diurnal temperature range and wind speed have negative correlation with the yield and minimum temperature, morning and afternoon relative humidity, rainfall, rainy days have significantly positive correlation with the yield during ripening period.

4. 6. 3. Influence of weather during different phenophases on yield of Kanchana

Correlation between weather and phenophase duration of Kanchana was worked out and presented in Table 4.20.

4. 6. 3. 1. Transplanting to active tillering (P1)

In Kanchana the weather variables such as diurnal temperature range, morning and afternoon relative humidity, afternoon vapour pressure, rainfall and rainy days during transplanting to active tillering period showed positive correlation, whereas maximum and minimum temperatures, bright sunshine hours, wind speed and evaporation showed negative correlation with duration of transplanting to active tillering stage in Kanchana.

4. 6. 3. 2. Active tillering to panicle initiation (P2)

Variables as maximum temperature shows positive correlation, whereas, afternoon relative humidity, rainfall and rainy days are negatively correlated with the duration.

4. 6. 3. 3. Panicle initiation to booting (P3)

There was a positive correlation present with afternoon relative humidity, morning and afternoon vapour pressure deficit and rainy days during panicle initiation to booting period and there was no negative correlation.

Table 4. 20. Correlation between weather and phenophase duration of Kanchana

CROP STAGE	Tmax	Tmin	DTR	RH1	RH2	VP1	VP2	RF	RD	BSS	WS	Ep
P1	-0.727**	-0.727**	0.709**	0.535*	0.867**	-0.325	0.813**	0.871**	0.652**	-0.858**	-0.947**	-0.888**
P2	0.661**	0.032	0.276	0.000	-0.691**	0.000	-0.333	-0.453*	-0.584**	0.135	0.097	0.423
P3	0.378	-0.166	0.284	0.218	0.717**	0.451*	0.679**	0.351	0.543*	-0.040	0.194	0.127
P4	0.724**	0.346	0.601**	0.564**	-0.464*	0.463*	0.386	0.378	0.218	0.635**	0.630**	0.702**
P5	-0.440	-0.464*	-0.089	0.102	0.520*	0.294	0.338	0.819**	0.772**	-0.359	-0.075	-0.309
P6	-0.232	0.178	-0.211	0.423	0.290	-0.189	0.000	0.356	0.368	-0.847**	-0.085	-0.389
P7	-0.745**	-0.934**	0.962**	0.802**	0.617**	-0.623**	0.640**	0.867**	0.706**	-0.839**	-0.649**	-0.709**
P8	-0.831**	-0.836**	0.296	0.864**	0.739**	-0.370	0.484*	0.893**	0.659**	-.814**	-.190	-.730**
P9	-0.232	0.178	-0.211	0.423	0.290	-0.189	0.000	0.356	0.368	-0.847**	-0.085	-0.389

*- Significant at 5% level **- Significant at 1% level

P1- Transplanting to active tillering
P2- Active tillering to panicle initiation
P3- Panicle initiation to booting
P4- Booting to heading
P5- Heading to 50% flowering
P6-50% flowering to physiological maturity
P7- Vegetative period
P8- Reproductive period
P9- Ripening period

4. 6. 3. 4. Booting to heading (P4)

Weather variables like maximum temperature, diurnal temperature range, morning relative humidity, morning vapour pressure deficit, bright sunshine hours, evaporation are positively correlated with the duration and variable relative humidity negatively effect on the duration.

4. 6. 3. 5. Heading to 50% flowering (P5)

Afternoon relative humidity, rainfall, rainy days influences the duration of heading to 50% flowering, they showed a positive correlation with duration, and minimum temperature shows a negative correlation with duration.

4. 6. 3. 6. 50% flowering to physiological maturity (P6)

The duration from 50% flowering to physiological maturity was negatively influenced by bright sunshine hours.

4. 6. 3. 7. Vegetative period (P7)

Diurnal temperature, morning and afternoon relative humidity, afternoon vapour pressure, rainfall and rainy days are positively correlated with the duration. Whereas maximum and minimum temperatures, morning vapour pressure, bright sunshine hours, wind speed and evaporation are negatively correlated with the duration.

4. 6. 3. 8. Reproductive period (P8)

Variables like morning and afternoon relative humidity, afternoon vapour pressure deficit, rainfall and rainy days shows a positive effect on the duration and maximum and minimum temperature, bright sunshine hours and evaporation showed a significantly negative effect on reproductive period.

4. 6. 3. 9. Ripening period (P9)

Ripening period was negatively influenced by bright sunshine hours.

4.6.4. Correlation between weather and yield of Kanchana

Correlation between weather and yield of Kanchana was displayed in Table 4.21.

4. 6. 4. 1. Transplanting to active tillering (P1)

The grain yield showed significant positive correlation with diurnal temperature range, afternoon relative humidity, rainfall and rainy days. Whereas, maximum and minimum temperature, morning vapour pressure, wind speed and evaporation shows a negative correlation with the yield.

4. 6. 4. 2. Active tillering to panicle initiation (P2)

Among the weather variables studied, diurnal temperature range and afternoon vapour pressure showed a positive correlation with the yield. Whereas, minimum temperature and bright sunshine hours shows negative correlation with yield.

4. 6. 4. 3. Panicle initiation to booting (P3)

Morning relative humidity, rainfall and rainy days during the panicle initiation to booting period shows a significantly positive correlation with the yield. Whereas, maximum and minimum temperatures, bright sunshine hours and evaporation showed negative correlation with the yield.

4. 6. 4. 4. Booting to heading (P4)

Weather variables like afternoon vapour pressure deficit, rainfall, rainy days and wind speed are positively correlated with the yield during booting to heading stage in Kanchana variety.

Table 4. 21. Correlation between weather and yield of Kanchana

YIELD	Tmax	Tmin	DTR	RH1	RH2	VP1	VP2	RF	RD	BSS	WS	Ep
P1	-0.506*	-0.498*	0.478*	0.298	0.654**	-0.487*	0.377	0.546*	0.648**	-0.417	-0.484*	-0.614**
P2	-0.261	-0.659**	0.683**	0.352	0.394	-0.217	0.550*	0.436	-0.104	-0.472*	-0.251	-0.178
P3	-0.488*	-0.470*	0.438	0.732**	0.396	0.351	0.363	0.481*	0.577**	-0.515*	-0.382	-0.528*
P4	0.187	-0.136	0.351	0.329	0.146	0.014	0.498*	0.661**	0.487*	0.271	0.624**	0.406
P5	0.016	0.284	-0.150	0.053	0.702**	0.112	0.738**	0.656**	0.677**	-0.079	0.192	0.313
P6	-0.518*	0.464*	-0.498*	0.638**	0.476*	0.031	-0.273	0.618**	0.623**	-0.537*	0.295	-0.087
P7	-0.517*	-0.624**	0.634**	0.364	0.559*	-0.411	0.518*	0.538*	0.379	-0.537*	-0.436	-0.480*
P8	-0.144	-0.308	0.227	0.446*	0.348	0.286	0.400	0.536*	0.590**	-0.156	0.457*	0.071
P9	-0.518*	0.464*	-0.498*	0.638**	0.476*	0.031	-0.273	0.618**	0.623**	-0.537*	0.295	-0.087

*- Significant at 5% level **- Significant at 1% level

P1- Transplanting to active tillering
P2- Active tillering to panicle initiation
P3- Panicle initiation to booting
P4- Booting to heading
P5- Heading to 50% flowering
P6-50% flowering to physiological maturity
P7- Vegetative period
P8- Reproductive period
P9- Ripening period

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4. 6. 4. 5. Heading to 50% flowering (P5)

The weather parameters afternoon relative humidity, afternoon vapour pressure, rainfall and rainy days are positively correlated with the yield.

4. 6. 4. 6. 50% flowering to physiological maturity (P6)

The weather parameters such as morning and afternoon relative humidity, rainfall and rainy days showed a significant positive influence on yield and maximum temperature, diurnal temperature range and bright sunshine hours showed a negative influence on yield during flowering to physiological maturity stage.

4. 6. 4. 7. Vegetative period (P7)

Weather parameters diurnal temperature, afternoon relative humidity, afternoon vapour pressure and rainfall are positively correlated with the yield. Whereas, maximum and minimum temperatures, bright sunshine hours and evaporation are negatively correlated with the yield.

4. 6. 4. 8. Reproductive period (P8)

Weather variables such as morning relative humidity, rainfall, rainy days and wind speed are positively significant with yield.

4. 6. 4. 9. Ripening period (P9)

Weather variables such as morning and afternoon relative humidity, rainfall and rainy days showed a significant positive influence on yield and maximum temperature, diurnal temperature range and bright sunshine hours showed a negative influence on yield.

4.7. Heat units prevailed during the crop period

The heat units required during the entire crop period was recorded over standard meteorological weeks. The heat units required for the entire crop season was presented in Table. 4.22.

4.7.1.1. Weekly accumulated growing degree days

The accumulated growing degree days required for Jyothi and Kanchana was given in Fig.4.8. The highest and lowest accumulated growing degree days recorded on 42^{nd} and 26^{th} week respectively. The recorded highest and lowest accumulated GDD was 123.6 day °C and 103.6 day °C.

4.7.1.2 Weekly accumulated helio thermal unit

The accumulated helio thermal units required for the entire crop season was presented in Fig.4.9. The accumulated HTU showed fluctuations in their entire crop period. The highest (1079.8 day °C h) and lowest (34.0 day °C h) accumulated heliothermal units were recorded on 40^{th} and 26^{th} week, respectively.

4.7.1.3. Weekly accumulated photo thermal unit

The accumulated photo thermal unit during the entire crop season was given in the Fig.4.10. Accumulated photo thermal units were recorded highest (1482.4 day °C h) on 34^{th} week and lowest (1300.3 day °C h) on 26^{th} week.

4.7.2. The heat units prevailed during different phenophases of Jyothi and Kanchana

The heat units accumulated during each phenophases of Jyothi and Kanchana were also worked out individually.

Table 4.22. Weekly heat units during the crop growing season

Week No.	GDD(day ^{0}C)	HTU(day ^{0}C)	PTU(day ^{0}C)
23	114.5	175.0	1432.2
24	114.8	254.3	1442.4
25	106.7	257.7	1344.4
26	103.6	34.0	1300.3
27	110.1	306.7	1376.4
28	105.1	63.1	1308.7
29	110.5	328.3	1370.7
30	114.1	317.9	1409.9
31	116.8	465.5	1438.0
32	115.4	585.5	1416.0
33	116.6	494.9	1425.5
34	121.7	739.2	1482.4
35	117.1	401.7	1421.2
36	115.0	437.0	1390.1
37	122.0	787.8	1469.3
38	118.9	774.5	1426.8
39	118.6	438.8	1418.0
40	118.8	1079.8	1415.8
41	119.6	680.0	1419.4
42	123.6	520.9	1461.5
43	116.5	359.5	1372.3
44	120.4	542.0	1413.4
45	117.5	740.3	1373.4
Total	2658.3	10784.5	32328.2

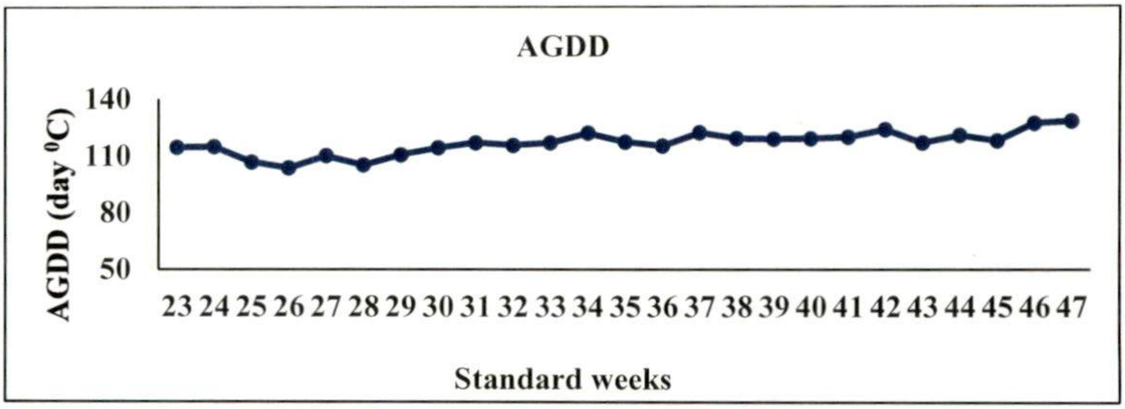

Fig. 4.8. Weekly growing degree days (day ^{0}C) for entire crop period

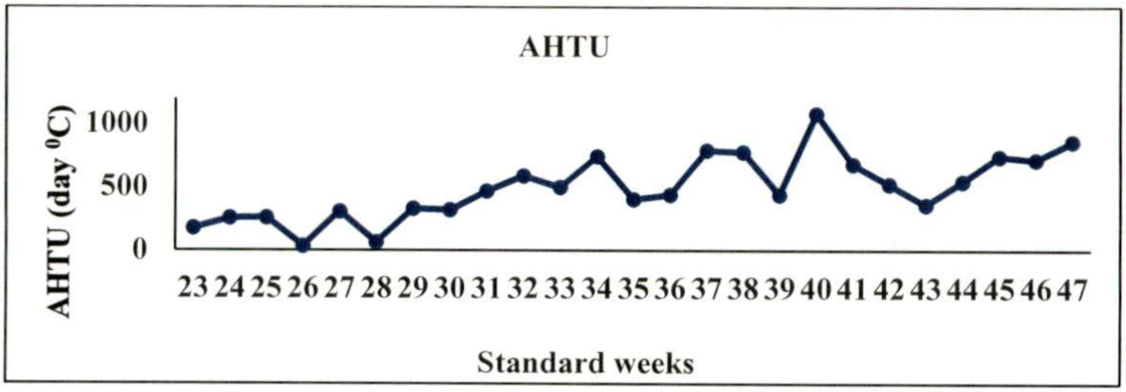

Fig. 4.9. Weekly helio thermal units (day ^{0}C) for entire crop period

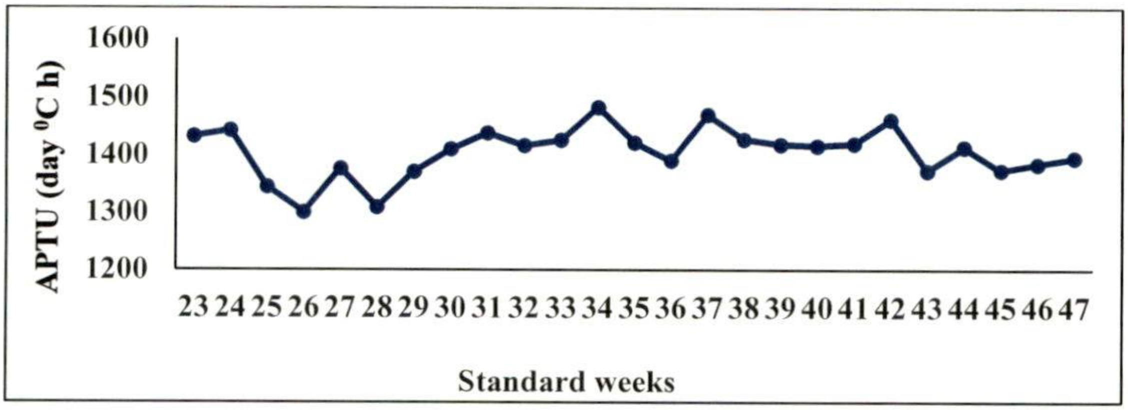

Fig. 4.10. Weekly photo thermal units (day ^{0}C) for entire crop period

4.7.2.1. Heat units required during transplanting to active tillering

The heat units required during transplanting to active tillering stage of Jyothi and Kanchana at different date of transplanting was given in the Table 4.23.

4.7.2.1.1. Accumulated growing degree days (GDD)

The accumulated growing degree day (GDD) during transplanting to active tillering stage of Jyothi was recorded highest on fifth date of planting and first date of planting in Kanchana, the recorded value of accumulated GDD was 453.8 day °C and 439.1 day °C respectively. The second date of planted crops recorded lowest accumulated GDD (409.4 day °C) for Jyothi and Kanchana. The recorded range of accumulated GDD was 409.4 to 453.8 day °C and 409.4 to 439.1 day °C for Jyothi and Kanchana, respectively.

4.7.2.1.2. Accumulated helio thermal unit (HTU)

The delayed transplanting showed an increase in accumulated helio thermal units for Jyothi and Kanchana. The recorded range of HTU for both rice varieties was 644.6 (D1) to 2262.2 (D5) day °C h and 699.8 (D1) to 2260.6 (D5) day °C h respectively. The rice variety Jyothi and Kanchana recorded highest accumulated HTU on fifth date of planting (2260.6 day °C h) followed by fourth date of planting (1728.5 day °C h). Accumulated helio thermal unit was found to be lowest on first date of plantings for both Jyothi and Kanchana.

4.7.2.1.3. Accumulated photo thermal units (PTU)

The variety Jyothi recorded highest (5539.7 day °C h) accumulated PTU on fifth date of planting and lowest (5123.3 day °C h) on second date of planting. The accumulated PTU for Jyothi was 5304.5, 5123.3, 5472.5, 5478.9 and 5539.7 day °C h for D1, D2, D3, D4 and D5 respectively.

Table. 4.23. Heat units experienced during transplanting to active tillering stage of rice varieties at different dates of planting

Date of planting	Jyothi			Kanchana		
	GDD (day ^{0}C)	HTU (day ^{0}C)	PTU (day ^{0}C)	GDD (day ^{0}C)	HTU (day ^{0}C)	PTU (day ^{0}C)
D1	422.5	644.6	5304.5	439.1	760.5	5511.8
D2	409.4	699.8	5123.3	409.4	699.8	5123.3
D3	441.1	947.3	5472.5	424.2	862.6	5263.7
D4	445.1	1728.5	5478.9	428.5	1728.5	5276.0
D5	453.8	2262.2	5539.7	438.2	2260.6	5350.5

GDD- Growing degree days HTU- Helio thermal units PTU- Photo thermal units

D1- 5th June D2- 20th June D3- 5th July D4- 20th July D5- 5th August

The variety Kanchana recorded highest accumulated PTU on first date of planting and lowest on second date of planting. The observed values of accumulated photo thermal units for Kanchana was 5511.8, 5123.3, 5263.7, 5276.0 and 5350.5 day °C h for D1, D2, D3, D4 and D5 respectively.

4.7.2.2. Heat units required during active tillering to panicle initiation

The accumulated growing degree days required during active tillering to panicle initiation was given in the Table.4.24.

4.7.2.2.1. Accumulated growing degree day (GDD)

Accumulated growing degree day was highest in fourth date of planting in Jyothi and Kanchana. The recorded highest value of GDD was 121.4 day °C and 136.5 day °C for Jyothi and Kanchana respectively. The lowest value of GDD for Jyothi and Kanchana was 110.1 and 124.3 day °C respectively. For both Jyothi and Kanchana, the first date of planting recorded lowest value of accumulated GDD.

4.7.2.2.2. Accumulated helio thermal units (HTU)

The accumulated HTU was highest (797.0 and 838.1 day °C h) on fourth date of plantings in Jyothi and Kanchana. The accumulated HTU was found to be lowest (273.1 and 318.8 day °C h) on second date of plantings for Jyothi and first date of planting for Kanchana.

4.7.2.2.3. Accumulated photo thermal units (PTU)

The highest (1954.8 day °C h) and lowest (1627.0 day °C h) values of accumulated PTU were recorded on second and third date of planting for Jyothi. The variety Kanchana recorded highest (1954.7 day °C h) and lowest (1528.9 day °C h) accumulated PTU on second and first date of planting respectively

Table. 4.24. Heat units experienced during active tillering to panicle initiation stage of rice varieties at different dates of planting

Date of planting	Jyothi			Kanchana		
	GDD (day ^{0}C)	HTU (day ^{0}C)	PTU (day ^{0}C)	GDD (day ^{0}C)	HTU (day ^{0}C)	PTU (day ^{0}C)
D1	110.1	317.4	1553.6	124.3	318.8	1528.9
D2	111.1	273.1	1954.8	126.8	346.6	1954.7
D3	116.1	451.6	1627.0	132.4	523.3	1835.7
D4	121.4	797.0	2084.7	136.5	838.1	1867.9
D5	115.0	436.1	1794.7	132.7	392.2	1793.8

GDD- Growing degree days HTU- Helio thermal units PTU- Photo thermal units

D1- 5th June D2- 20th June D3- 5th July D4- 20th July D5- 5th August

4.7.2.2.3. Accumulated photo thermal units (PTU)

The highest (1954.8 day ˚C h) and lowest (1627.0 day ˚C h) values of accumulated PTU were recorded on second and third date of planting for Jyothi. The variety Kanchana recorded highest (1954.7 day ˚C h) and lowest (1528.9 day ˚C h) accumulated PTU on second and first date of planting respectively.

4.7.2.3. Heat units required during panicle initiation to booting

The accumulated growing degree days required during panicle initiation to booting was given in the Table.4.25

4.7.2.3.1 Accumulated growing degree days (GDD)

The highest accumulated GDD was recorded on first (346.7 day ° C) date of planting for Jyothi and third (339.8 day ° C) date of planting for Kanchana. For Jyothi (307.8 day °C) and Kanchana (315.5 day °C), lowest accumulated GDD was recorded on fifth date of planting for Jyothi and first date of planting for Kanchana.

4.7.2.3.2. Accumulated helio thermal unit (HTU)

The delayed transplanting showed an increase in accumulated helio thermal units for Jyothi and Kanchana. The recorded range of HTU for both rice varieties was 799.2 day °C h (D1) to 1867.2 day °C h (D5) and 726.5 day °C h (D1) to 1931.7 day °C h (D4) respectively. The rice varieties Jyothi and Kanchana recorded highest accumulated HTU on 4th date of planting followed by second date of planting (2198.7 day °C h and 1984.3 day °C h). Accumulated helio thermal unit was found to be lowest on first date of plantings for both Jyothi (799.2 day °C h) and Kanchana (726.5 day °C h).

Table. 4.25. Heat units experienced during panicle initiation to booting stage of rice varieties at different dates of planting

Date of planting	Jyothi			Kanchana		
	GDD (day ^{0}C)	HTU (day ^{0}C)	PTU (day ^{0}C)	GDD (day ^{0}C)	HTU (day ^{0}C)	PTU (day ^{0}C)
D1	346.7	799.2	4320.3	315.5	726.5	3938.3
D2	317.4	1455.4	3900.8	334.0	1455.4	4103.7
D3	322.7	1778.0	4138.1	339.8	1873.8	4345.5
D4	319.0	1427.5	4061.5	318.3	1326.5	3854.9
D5	307.8	1867.2	3696.0	323.5	1931.7	3886.1

GDD- Growing degree days HTU- Heliothermal units PTU- Photothermal units

D1- 5th June D2- 20th June D3- 5th July D4- 20th July D5- 5th August

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4.7.2.3.3. Accumulated photo thermal units (PTU)

Accumulated photo thermal units during panicle initiation to booting stage. The highest and lowest values of accumulated PTU were recorded on first and fifth date of planting for Jyothi and third and fourth date of planting for Kanchana. In case of Jyothi the highest and lowest recorded value for accumulated PTU was 4320.3 day °C h and 3696.0 day °C h respectively. In case of Kanchana the highest and lowest recorded value for accumulated PTU was 4345.5 day °C h and 3854.9 day °C h respectively.

4.7.2.4. Heat units required during booting to heading

The accumulated growing degree days required during booting to heading was given in the Table. 4.26.

4.7.2.4.1. Accumulated growing degree day (GDD)

Accumulated growing degree day was highest in second date of planting in Jyothi and fourth date of planting in Kanchana. The recorded highest value of GDD was 102.1 day °C and 121.8 day °C for Jyothi and Kanchana respectively. The lowest value of GDD for Jyothi and Kanchana was 84.7 day °C (D4) and 81.4 day °C (D2) respectively

4.7.2.4.2. Accumulated helio thermal units (HTU)

The accumulated HTU during booting to heading was highest (634.1 day °C h and 798.3 day °C h) on second date of planting for Jyothi and fourth date of planting for Kanchana. The accumulated HTU was found to be lowest (60.2 day °C h and 56.8 day °C h) on third date of planting for both Jyothi and Kanchana.

Table. 4.26. Heat units experienced during booting to heading stage of rice varieties at different dates of planting

Date of planting	Jyothi			Kanchana		
	GDD (day ^{0}C)	HTU (day ^{0}C)	PTU (day ^{0}C)	GDD (day ^{0}C)	HTU (day ^{0}C)	PTU (day ^{0}C)
D1	99.9	397.1	1222.8	116.8	468.3	1421.8
D2	102.1	634.1	1652.4	117.5	583.2	1231.4
D3	98.6	60.2	1400.8	81.4	56.8	985.3
D4	85.9	514.4	1031.8	121.8	798.3	1465.4
D5	84.7	532.6	1220.3	102.3	608.1	1220.3

GDD- Growing degree days HTU- Helio thermal units PTU- Photo thermal units

D1- 5th June D2- 20th June D3- 5th July D4- 20th July D5- 5th August

4.7.2.4.3. Accumulated photo thermal units (PTU)

The highest (1652.4 day °C h) and lowest (1031.8 day °C h) values of accumulated PTU were recorded on second and fourth date of planting for Jyothi. The highest (1465.4 day °C h) accumulated PTU for Kanchana were recorded on fourth date of planting while lowest (985.3 day °C h) accumulated PTU were recorded on third date of planting.

4.7.2.5. Heat units required during heading to 50% flowering

The accumulated growing degree days required during heading to 50% flowering was given in the Table. 4.27.

4.7.2.5.1. Accumulated growing degree days (GDD)

The highest accumulated GDD was recorded on first (65.7 day ° C) date of planting for Jyothi and Kanchana respectively. For Jyothi (49.7 day °C) lowest accumulated GDD was recorded on third date of planting, whereas in Kanchana (50.4 day °C) it was on fourth date of planting.

4.7.2.5.2 Accumulated helio thermal unit (HTU)

The delayed transplanting showed fluctuations in accumulated helio thermal units for Jyothi. The recorded range of HTU for both rice varieties was 240.0 day °C h (D1) to 450.8 day °C h (D5) and 174.9 day °C h (D3) to 451.8 day °C h (D5) day °C h respectively. The rice varieties Jyothi and Kanchana recorded highest accumulated HTU on fifth date of planting.

4.7.2.5.3. Accumulated photo thermal units (PTU)

Accumulated photo thermal units during heading to 50% flowering stage of Jyothi and Kanchana recorded highest and lowest values of accumulated PTU on

Table. 4.27. Heat units experienced during heading to 50% flowering stage of rice varieties at different dates of planting

Date of planting	Jyothi			Kanchana		
	GDD (day ^{0}C)	HTU (day ^{0}C)	PTU (day ^{0}C)	GDD (day ^{0}C)	HTU (day ^{0}C)	PTU (day ^{0}C)
D1	65.7	240.0	853.3	65.7	240.0	816.4
D2	52.2	276.7	635.2	52.5	305.5	638.6
D3	49.7	333.5	600.4	50.7	174.9	612.8
D4	50.9	315.7	609.6	50.4	335.7	604.7
D5	51.4	450.8	611.1	51.8	451.8	616.7

GDD- Growing degree days HTU- Helio thermal units PTU- Photo thermal units

D1- 5th June D2- 20th June D3- 5th July D4- 20th July D5- 5th August

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D1 (853.3 day °C h) and D3 (600.4 day °C h) in Jyothi and D1 (816.4 day °C h) and D4 (604.7 day °C) in Kanchana.

4.7.2.6. Heat units required during 50% flowering to physiological maturity

The accumulated growing degree days required during 50% flowering to physiological maturity was given in the Table. 4.28.

4.7.2.6.1. Accumulated growing degree days (GDD)

The accumulated growing degree day (GDD) during 50% flowering to physiological maturity stage of Jyothi recorded highest accumulated GDD on first (607.2 day ° C) date of planting, whereas in Kanchana it was on fourth date of planting (597.4 day ° C). For Jyothi (577.8day °C) and Kanchana (577.0 day °C), the lowest accumulated GDD was recorded on third date of planting.

4.7.2.6.2. Accumulated helio thermal unit (HTU)

The recorded range of accumulated HTU for Jyothi and Kanchana was 2841.8 day °C h (D2) to 3689.8 day °C h (D3) and 2841.8day °C h (D2) to 3787.2 day °C h (D3) respectively. The rice varieties Jyothi and Kanchana recorded highest accumulated HTU on third date of planting.

4.7.2.6.3. Accumulated photo thermal units (PTU)

The highest (7384.8 day °C h) and lowest (6913.3 day °C h) values of accumulated PTU were recorded on first and third date of planting for Jyothi. The highest (7172.4 day °C h) accumulated PTU for Kanchana were recorded on first date of planting while lowest (6907.2 day °C h) accumulated PTU were recorded on third date of planting.

Table.4.28. Heat units experienced during 50% flowering to physiological maturity stage of rice varieties at different dates of planting

Date of planting	Jyothi			Kanchana		
	GDD (day ^{0}C)	HTU (day ^{0}C)	PTU (day ^{0}C)	GDD (day ^{0}C)	HTU (day ^{0}C)	PTU (day ^{0}C)
D1	607.2	3023.8	7384.8	590.1	2934.9	7172.4
D2	591.3	2841.8	7124.9	591.3	2841.8	7124.9
D3	577.8	3689.8	6913.3	577.0	3787.2	6907.2
D4	597.2	3082.9	7087.0	597.4	3165.2	7097.3
D5	597.7	2859.0	7040.0	597.3	2916.1	7039.0

GDD- Growing degree days HTU- Helio thermal units PTU- Photo thermal units

D1- 5th June D2- 20th June D3- 5th July D4- 20th July D5- 5th August

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4.8. INFLUENCE OF HEAT UNITS ON YIELD OF CROPS

Heat units such as accumulated growing degree days (GDD), helio thermal units (HTU) and photo thermal units (PTU) are correlated with yields of Jyothi and Kanchana for different phenophases and the results were presented in the Table. 4.29.

Table 4.29. Influence of heat units on yield of Jyothi

Phenophase	GDD(day ^{0}C)	HTU(day ^{0}C)	PTU(day ^{0}C)
P1	-0.602**	-0.590**	-.603**
P2	-0.507*	-0.440	-.163
P3	0.419	-0.461*	-.258
P4	0.578**	0.093	.386
P5	0.398	-0.556*	.414
P6	0.134	-0.121	.418
P7	-0.617**	-0.604**	-.513*
P8	0.522*	-0.427	-.112
P9	0.134	-0.121	.418

*- Significant at 5% level **- Significant at 1% level

4.8.1. Influence of heat units on yield of Jyothi at different phenophases

In phenophase P1 (transplanting to active tillering), P2 (active tillering to panicle initiation) and P7 (vegetative stage), the accumulated GDD showed a significantly negative correlation, whereas P4 (panicle initiation to booting) and P6 (50% flowering to physiological maturity) showed a positive correlation with yield. While, in case of accumulated helio thermal units, phenophase P1, P2, P3, P5 and P7 are showing negatively correlation with the yield. Accumulated photo thermal units has negative significant correlation in P1 and P7 stage.

4.8.2. Influence of heat units on yield of Kanchana at different phenophases

In case of Kanchana, accumulated GDD showed a significantly positive correlation with phenophase P7 and P8. Whereas, phenophase P2 was negatively correlated with yield. The accumulated HTU showed a significantly negative correlation with yield during the phenophase P3, P6, P7 and P9. In accumulated PTU phenophase P6 and P9 are showing significantly positive correlation with yield and phenophase P7 showed a significantly negative correlation with yield (Table 4.30).

Table 4.30. Influence of heat units on yield of Kanchana

Phenophase	GDD(day ^{0}C)	HTU(day ^{0}C)	PTU(day ^{0}C)
P1	-0.319	-0.422	-.098
P2	-0.587**	-0.357	-.054
P3	-0.143	-0.504*	-.147
P4	0.555*	0.280	.343
P5	0.377	-0.032	.395
P6	0.200	-0.550*	.638**
P7	0.775**	-0.463*	-.506*
P8	0.752**	-0.302	.016
P9	0.200	-0.550*	.638**

*- Significant at 5% level **- Significant at 1% level

4.9. INFLUENCE OF HEAT UNITS ON THE DURATION OF DIFFERENT GROWTH STAGES

4.9.1. Influence of heat units on the duration of different phenophases of Jyothi

Accumulated growing degree days showed significantly positive correlation with duration in phenophase P3, P4, P6, P8 and P9. Whereas, in HTU phenophase P3, P6, P8 and P9 showed a significantly negative correlation with the duration. In case of PTU phenophase P2, P3, P4, P6, P7 and P9 are showing significant positive correlation with duration (Table 4.31).

Table 4.31. Influence of heat units on phenophases of Jyothi

Phenophase	GDD(day ^{0}C)	HTU(day ^{0}C)	PTU(day ^{0}C)
P1	-0.144	-0.244	.292
P2	0.350	0.366	.971**
P3	0.967**	-0.854**	.544*
P4	0.756**	-0.041	.997**
P5	0.415	0.208	.373
P6	0.962**	-0.681**	.963**
P7	0.114	0.292	.661**
P8	0.991**	-0.950**	.406
P9	0.962**	-0.681**	.963**

*- Significant at 5% level **- Significant at 1% level

4.9.2. Influence of heat units on the duration of different phenophases of Kanchana

In case of Kanchana, phenophases P3, P4, P5, P6, P8 and P9 in accumulated GDD are showing significant positive correlation with the duration and phenophase P7 showing a negative correlation with the duration. In HTU phenophase P1, P6, P7, P8 and P9 are showing significant negative correlation with the duration. Whereas, phenophase P4 was showing significant positive correlation with the duration. In accumulated PTU, phenophases P2, P3, P4, P5, P6 and P9 are positively correlated with duration and P7 was showing significant negative correlation with duration (Table 4.32).

Table 4.32. Influence of heat units on phenophases of kanchana

Phenophase	GDD(day ^{0}C)	HTU(day ^{0}C)	PTU(day ^{0}C)
P1	0.006	-0.843**	.401
P2	0.176	0.046	.937**
P3	0.698**	0.048	.928**
P4	0.888**	0.765**	.996**
P5	0.992**	-0.330	.990**
P6	0.609**	-0.863**	.754**
P7	-0.919**	-0.907**	-.733**
P8	0.508*	-0.961**	-.069
P9	0.609**	-0.863**	.754**

*- Significant at 5% level **- Significant at 1% level

4.10. INCIDENCE OF PEST AND DISEASES

During the crop period, incidence of various pests and diseases were comparatively less. The incidence of pests was more in delayed planting crops compared to early plantings. The different pests noticed in the field during the crop season are Leaf folder (*Cnaphalocrocis medinalis*), Stem borer (*Scirphophaga incertulas*) and Rice bug (*Leptocorisa acuta*). Incidence of diseases was very less compared to pests and the two important diseases noticed in the field were sheath rot (*Sarocladium oryzae*) and sheath blight (*Rhizoctonia solani*) (Table.4.33).

Table 4.33. Pests and diseases observed in different dates of planting

Planting dates	Pests			Diseases	
	Leaf folder	Rice bug	Stem borer	Sheath rot	Sheath blight
June 5th	✓	✓	✓	✓	✓
June 20th	✓	✓	✓	✓	✓
July 5th	✓	✓	✓	✓	✓
July 20th	✓	✓	✓	✓	✓
August 5th	✓	✓	✓	✓	✓

4. 11. CERES- RICE SIMULATION RESULTS

The CERES-Rice model was calibrated with experimental data collected during the 2016 rice crop season. Calibration of genetic coefficients of Jyothi and Kanchana were estimated with the independent data sets of two rice varieties were displayed in Table 4.34.

Table 4. 34. Genetic coefficients of the rice varieties Jyothi and Kanchana

Cultivar trait	Genetic coefficients	Jyothi	Kanchana
Time from seed emergence to the end of juvenile phase	P1	537.0	470.7
Extent to which development is delayed for each hour increase in photoperiod above the longest photoperiod	P2O	18.5	150.0
Extent to which phasic development from vegetative to panicle initiation is delayed for each hour increase in photoperiod above P2O, *i.e.*, 12.5 h	P2R	445.0	445.5
Time starting from grain filling to physiological maturity	P5	10.2	12.3
Maximum spikelet number coefficient	G1	48.5	50.5
Maximum possible single grain size	G2	0.0250	0.0210
Scalar vegetative growth coefficient for tillering relative to IR64	G3	1.10	1.30
Temperature tolerance scalar coefficient	G4	1.10	1.10
Phyllocron interval	PHINT	81.0	76.0

4. 11. 1. Simulates v/s Observed Grain yield

In variety Jyothi , observed grain yield of rice varied from 3817 (D5) to 5782 kg ha^{-1} (D2) for different planting dates while in Kanchana the grain yield varied from 3830 (D5) to 5789 kg ha^{-1} (D2).

The model overestimated the grain yield in all date of plantings of Jyothi and Kanchana. Error percent of CERES-Rice simulated grain yields from those corresponding observed ones during the crop season was presented in Table 4.35.

Table 4.35. Observed and predicted grain yield (kg ha^{-1}) of Jyothi and Kanchana with their percent error

Planting dates	Jyothi			Kanchana		
	Observed	Simulated	Error %	Observed	Simulated	Error %
D1	5700	5753	0.9	5450	5570	2.2
D2	5782	5862	1.3	6155	5721	-7.0
D3	4475	5919	32.2	3385	5561	64.2
D4	4092	5902	44.2	4265	5647	32.4
D5	3817	6327	65.7	3830	5586	45.8
Average	4773.2	5952.6	28.9	4617	5617	27.5

Error percent = [(simulated − observed)/ observed] ∗ 100

4. 11. 2. Simulates V/s Observed Phenological development

In order to get accurate simulation of crop growth and yield, the accurate simulation of phasic development of the crop was crucial. Thus, evaluation of the phasic development was the most important and the first step in any study aimed at assessment of the performance of a simulation crop model. The results obtained from the field observation showed that, phenological observation for both the varieties with respect to different planting dates were found to be different.

4. 11. 2. 1. Days to panicle initiation

A comparison between the model simulated and the field observed duration for panicle initiation with their error percent are presented in Table 4.36. The results showed that, the observed duration of panicle initiation varied from 35 (D5) to 36 (D2 and D4) days in Jyothi, while in Kanchana it was 34 (D5) to 36 (D2) days with respect to different planting dates. Days to panicle initiation as simulated by model were found to be under estimated in all the plantings except D1 it was overestimated in Jyothi. While in Kanchana, simulated values are under estimated in D5 and D4, overestimated in D1, D2 and D3 plantings.

Table 4.36. Observed and simulated duration of panicle initiation of Jyothi and Kanchana with their percent error

Planting dates	Jyothi			Kanchana		
	Observed	Simulated	Error %	Observed	Simulated	Error %
D1	34	35	-2.9	35	38	8.5
D2	36	35	-2.7	36	38	5.5
D3	35	34	-2.8	35	36	2.8
D4	36	32	-11.1	34	33	-2.9
D5	35	32	-8.5	34	31	-8.8
Average	35.2	33.6	-4.4	34.8	35.2	1.0

Error percent = [(simulated − observed)/ observed] * 100

4. 11. 2. 2. Days to anthesis

The results of observed and simulated duration of anthesis for Jyothi and Kanchana were presented in Table 4.37. The observed days to anthesis for Jyothi varied from 63 (D5) to 66 (D2) while Kanchana varied from 62 (D5) to 66 (D1). In Jyothi, duration of anthesis was under estimated in D4 and D5 while overestimated in D1, D2 and D3 plantings. In Kanchana, the duration of anthesis was over estimated in D1, D2, D3 and D4 while the duration was under estimated in D5.

Table 4.37. Observed and predicted anthesis days for rice with their percent error

Planting dates	Jyothi			Kanchana		
	Observed	Simulated	Error %	Observed	Simulated	Error %
D1	66	69	4.5	66	70	6.0
D2	66	67	1.5	65	69	6.1
D3	65	66	1.5	64	67	4.6
D4	65	64	-1.5	63	64	1.5
D5	63	64	1.58	62	61	-1.6
Average	65	66	1.5	64	66.2	3.3

4. 11. 2. 3. Days to physiological maturity

The prediction of days to physiological maturity for Jyothi and Kanchana was given in the Table.4.38. The observed duration for Jyothi and Kanchana varied from 99 (D5 and D3) to 102 (D1) days and 98 (D3, D4 and D5) to 101 (D1 and D2) days respectively. The duration of physiological maturity in Jyothi was under estimated in D1, D2, D4 and D5 whereas D3 simulated value was contemporary to observed value. In case of Kanchana the duration for physiological maturity was found to be overestimated in D1, D2, D3 while under estimated in D5 and D4.

Table 4.38. Observed and simulated maturity days for Jyothi and Kanchana with their percent error

Planting dates	Jyothi			Kanchana		
	Observed	Simulated	Error %	Observed	Simulated	Error %
D1	102	101	-0.9	101	103	1.9
D2	101	100	-0.9	101	102	0.9
D3	99	99	0	98	99	1.0
D4	100	96	-4	98	96	-2.0
D5	99	97	-2.0	98	94	-4.0
Average	100.2	98.6	-1.5	99.2	98.8	-0.4

4. 12. Model performance

Root Mean Square Error (RMSE) and D-stat index for yield and phenophases of two varieties given in Table 4.39.

Table 4.39. RMSE and D-stat index for Jyothi and Kanchana

Variable Name	Jyothi		Kanchana	
	RMSE	d-Stat	RMSE	d-Stat
Yield (kg ha^{-1})	1525.7	0.40	1409.3	0.50
Anthesis day	1.6	0.71	2.9	0.68
Panicle initiation day	2.3	0.13	2.1	0.60
Maturity day	2.0	0.57	2.2	0.77

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4.12.1. Climate change scenarios

Climate change scenarios are used by analysts to make projections of future greenhouse gas (GHG) emissions and to assess future vulnerability to climate change.

4.12.1.1. Projected future climate of the station

IPCC reports a significant change in the worldwide air temperature in the 21st century (IPCC, 2013) and that is going to have an immediate effect on the season and intensity of rainfall across the globe.

Prediction of future climate was essential for doing the climate change impact analysis on rice production. So, for getting reliable future climate data of the region based on the latest CMIP5 dataset, the following procedure was adopted.

4.12.1.2. Prediction and Downscaling of Future Climate Data

A historical run forced by observed atmospheric composition changes, cover much of the industrial period (from the mid-nineteenth century to near present) and also referred to as "twentieth century" simulations was used for comparing with the observed data to assess the reliability of the model.

4.12.1.3. Comparison of Predicted Data to Observed Data

Observed data station on precipitation and temperature during the reference period, and historical data from the 3 regional climate models for the period 1989 to 2005 were compared initially on the basis of graphical representation (Fig. 4.11 a, b, c & d, 4.12 and 4.13 a, b & c). Statistical comparison was also done to ascertain the results of graphical comparison. The results of comparison on the basis of correlation given in Table 4.40. The GFDL-CM3 model was found to be the best on the basis of the statistical analysis done since it showed close correlation with the observed data. Jena *et al*., 2016

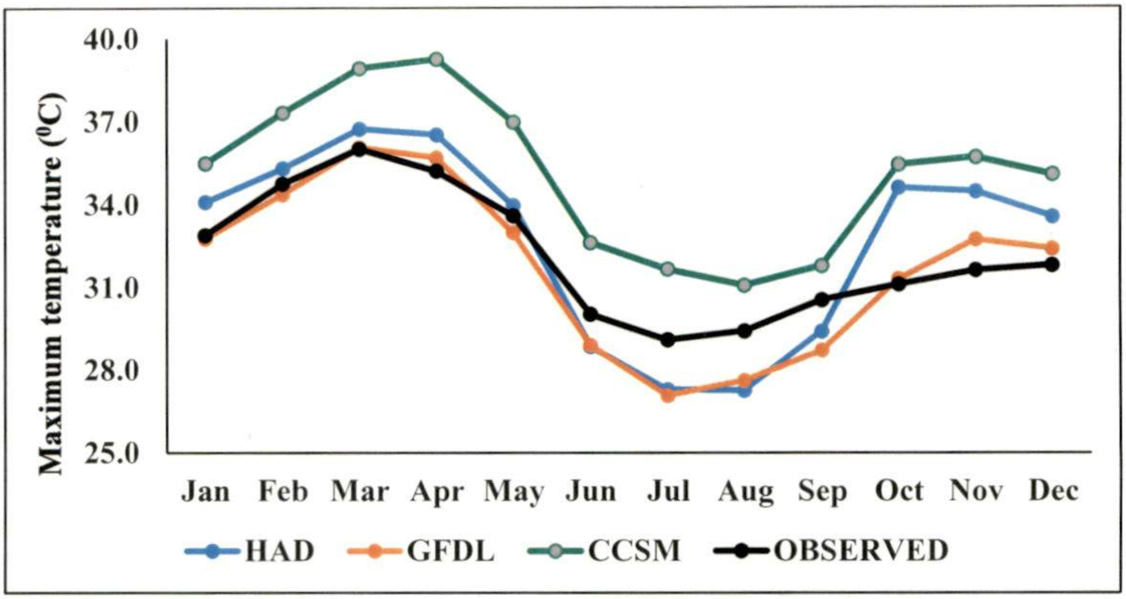

Fig. 4.11(a). Comparison of maximum temperature of different models with observed data

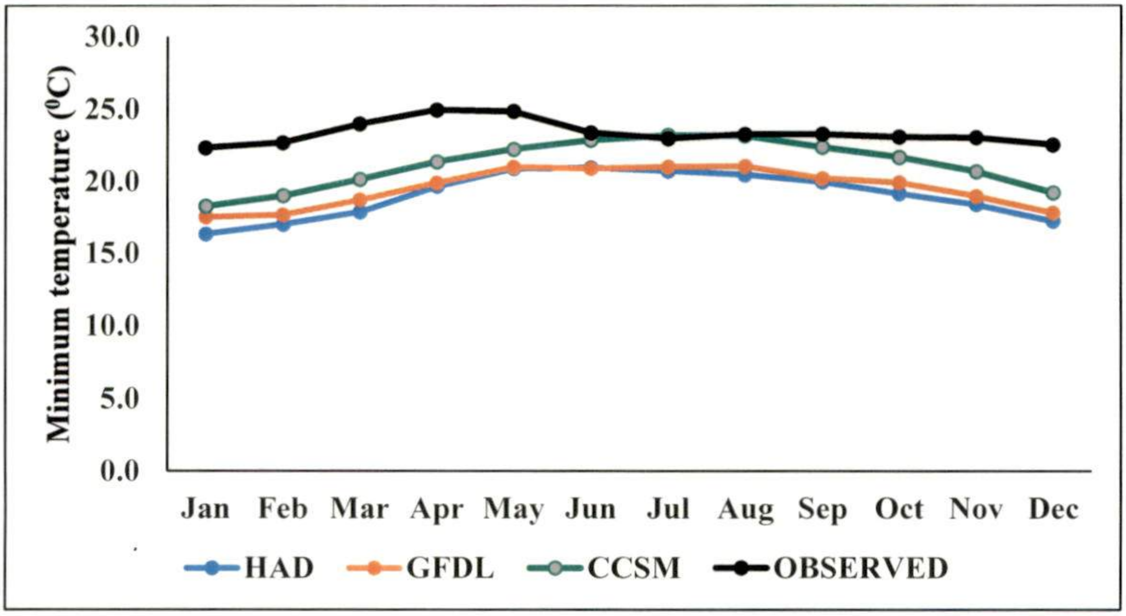

Fig. 4.11(b). Comparison of minimum temperature of different models with observed data

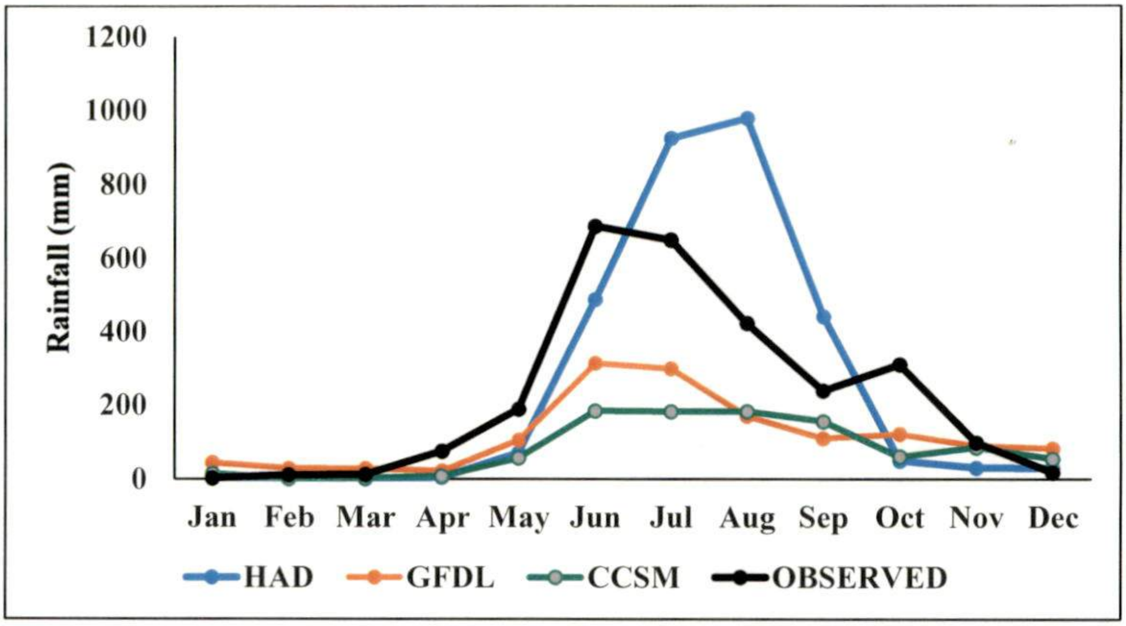

Fig. 4.11(c). Comparison of rainfall (mm) of different models with observed data

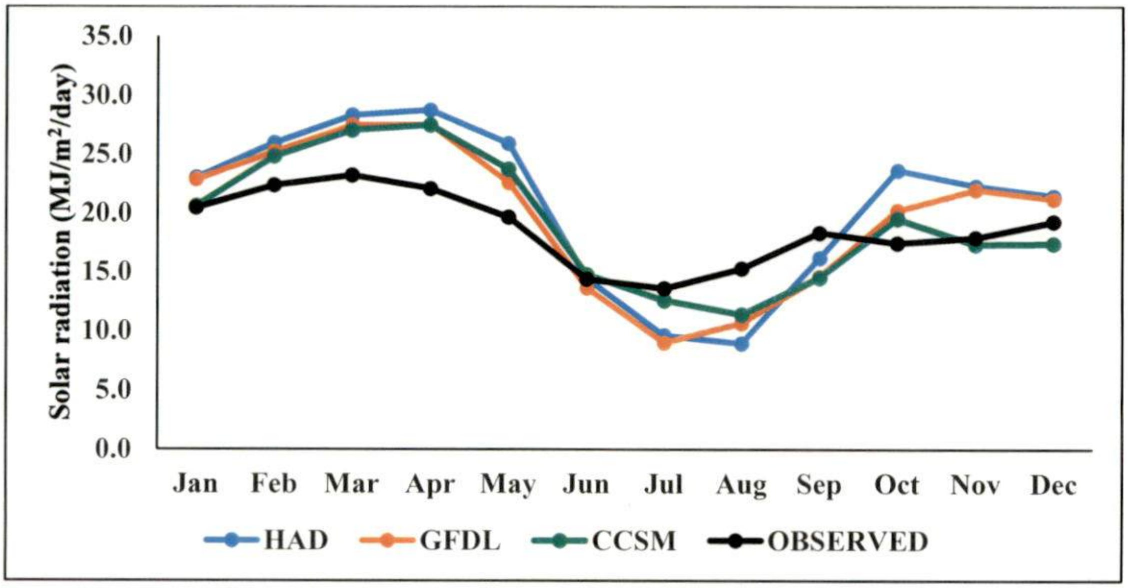

Fig. 4.11(d). Comparison of solar radiation (MJ/m^2/day) of different models with observed data

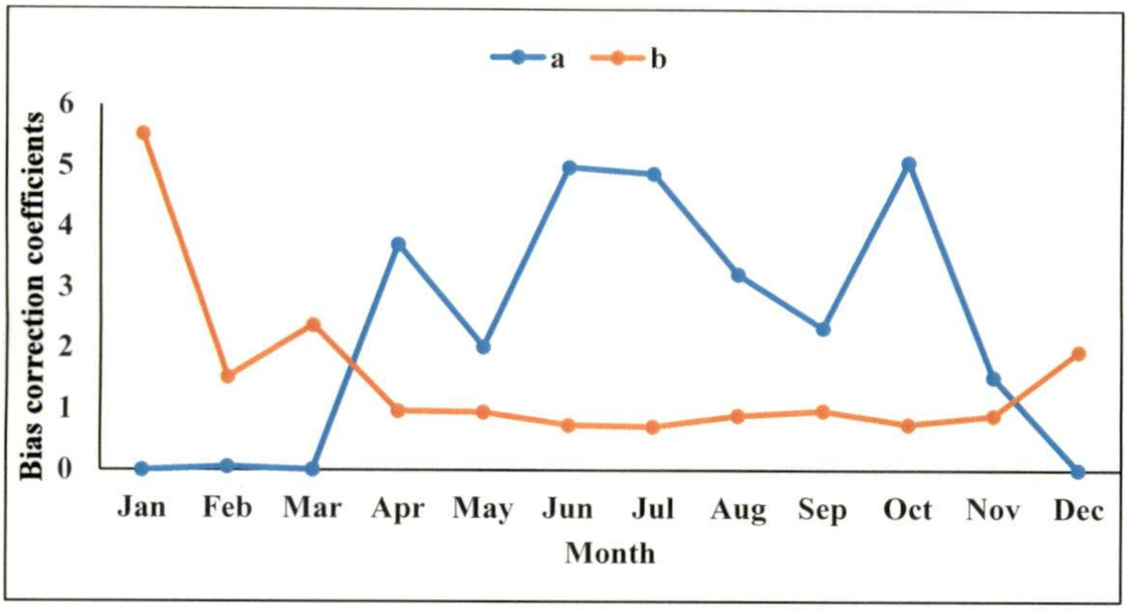

Fig. 4.12. Comparison of monthly transformation coefficients

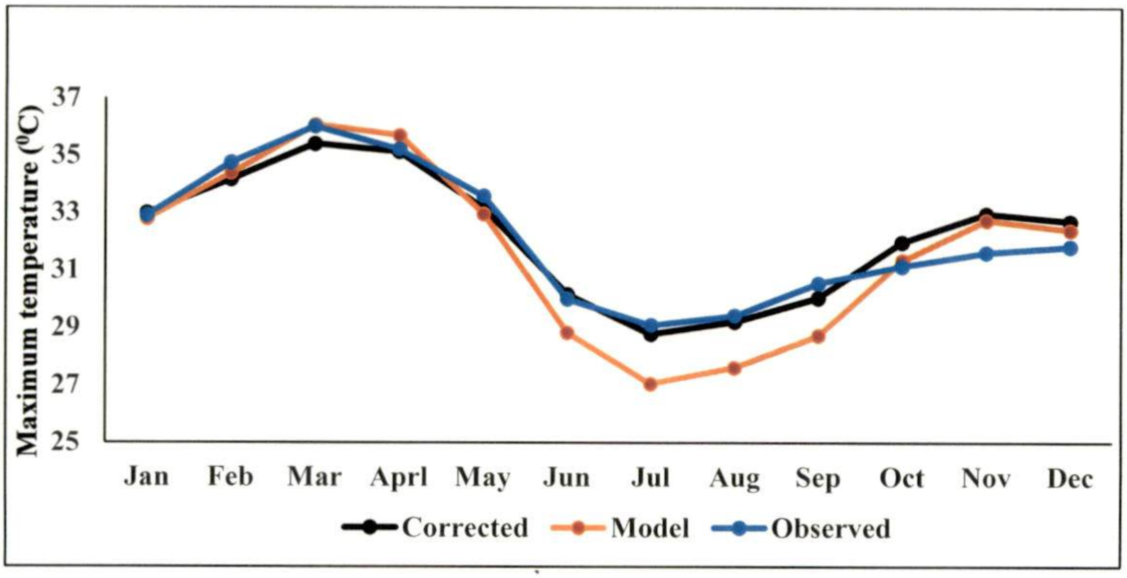

Fig. 4.13(a). Comparison of observed and bias corrected monthly maximum temperature

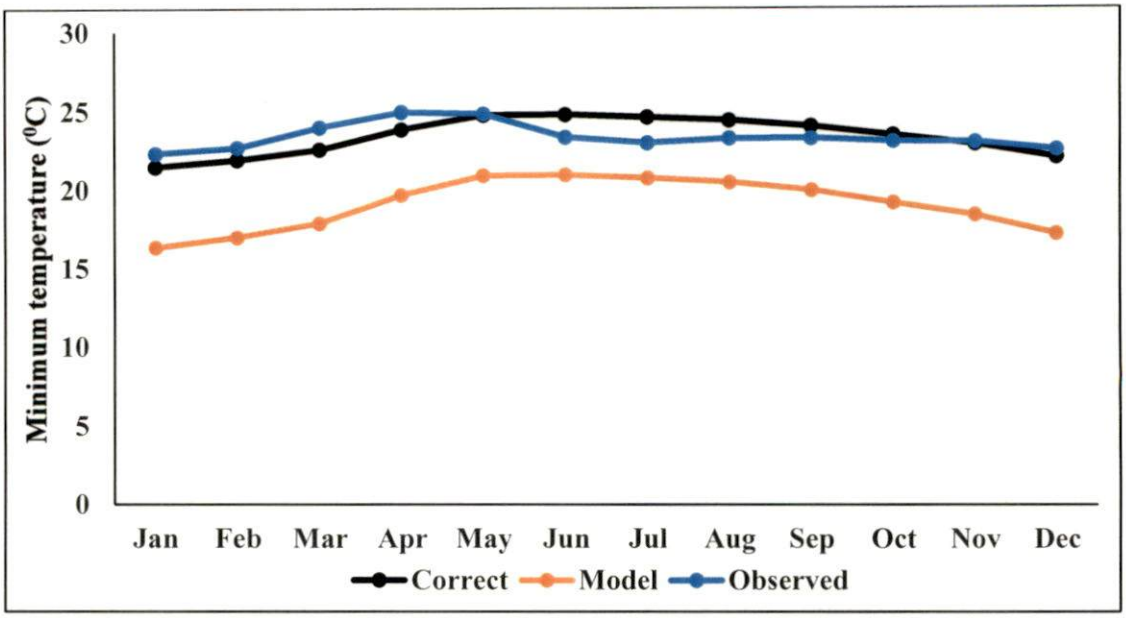

Fig. 4.13(b). Comparison of observed and bias corrected monthly minimum temperature

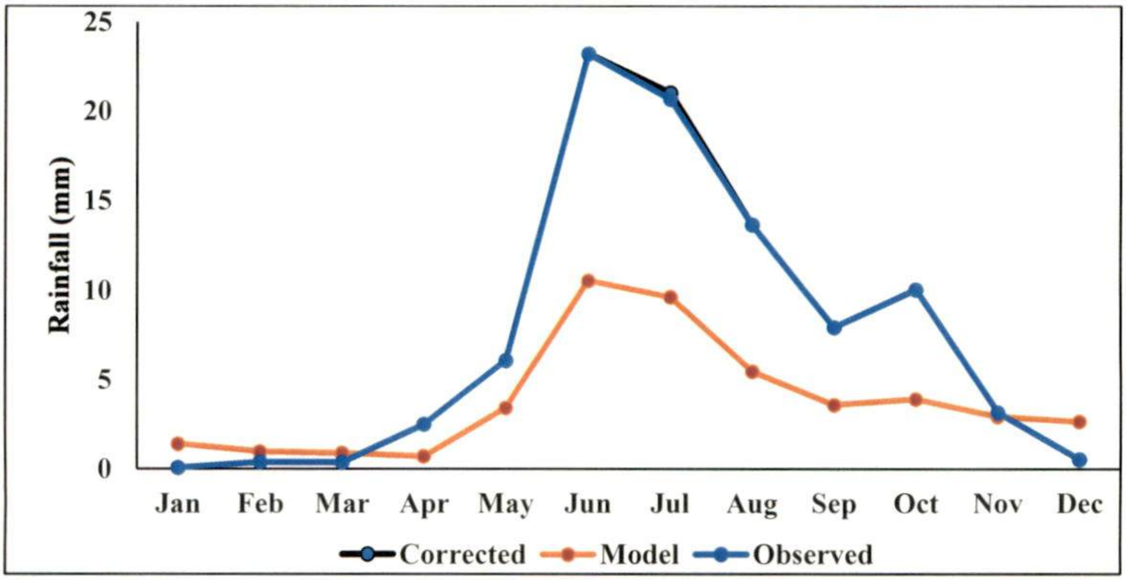

Fig. 4.13(c). Comparison of observed and bias corrected monthly precipitation

have reported that GFDL-CM3 was one of the best models in the CMIP5 dataset which can capture the pattern of Indian rainfall.

Table 4.40. Statistical comparison of model estimates with observed data

	CCSM4	**GFDL-CM3**	**HAD**
Correlation coefficient for maximum temperature	0.91	0.98	0.82
	CCSM4	**GFDL-CM3**	**HAD**
Correlation coefficient for minimum temperature	0.94	0.96	0.88
	CCSM4	**GFDL-CM3**	**HAD**
Correlation coefficient for rainfall	0.45	0.42	0.32
	CCSM4	**GFDL-CM3**	**HAD**
Correlation coefficient for solar radiation	0.90	0.92	0.89

4. 12. 1. 4. Future climate data of Vellanikkara station during the crop period

Weather data for different dates of planting under RCP 4.5 and RCP 8.5 scenarios were displayed in Table 4. 41.

Table 4. 41. Baseline (2016) and projected mean maximum, minimum temperature and rainfall at Vellanikkara during the crop growth period

Date of planting	Weather parameters	2016	RCP 4.5		RCP 8.5	
			2050s	2080s	2050s	2080s
D1	TMAX	30.0	29.9	30.3	30.9	31.8
	TMIN	22.3	25.8	26.1	26.5	27.5
	RAINFALL	1068.9	2079.0	2074.7	2112.5	2206.0
	SRAD	14.1	9.4	9.6	10.2	9.8
D2	TMAX	30.0	29.9	30.2	30.8	31.6
	TMIN	22.5	25.7	26.0	26.4	27.4
	RAINFALL	880.4	1887.7	1855.4	1951.2	1993.0
	SRAD	14.9	9.4	9.5	10.0	9.7
D3	TMAX	30.2	30.1	30.6	31.0	32.8
	TMIN	22.8	25.6	25.9	26.2	27.3
	RAINFALL	645.4	1553.7	1573.2	1580.5	1757.1
	SRAD	16.0	10.5	10.8	11.1	10.6
D4	TMAX	30.6	30.6	31.0	31.6	32.3
	TMIN	23.0	25.5	25.7	26.2	27.4
	RAINFALL	393.6	1338.1	1381.6	1376.2	2291.7
	SRAD	16.4	12.5	12.5	13.2	12.2
D5	TMAX	30.9	31.3	31.8	32.2	33.1
	TMIN	22.9	25.3	25.6	26.1	27.3
	RAINFALL	287	1226.7	1197.4	1243.7	1515.2
	SRAD	16.7	14.7	14.8	15.1	14.7

4. 13. Impact of climate change on selected rice varieties under RCP 4.5 and RCP 8.5 scenarios

This study was conducted to identify the yield and growth changes of selected two rice varieties Jyothi and Kanchana cultivated at Vellanikkara under the global climate scenarios Representative Concentration pathway (RCP) 4.5 and 8.5. The Decision Support System for Agro technology Transfer (DSSAT) software was used to forecast the rice yield in 2050s and 2080s.

4. 13. 1. Impact on panicle initiation

The days to panicle initiation of base line period (2016) and projected periods (2050s) and (2080s) under RCP 4.5 and 8.5 scenarios for selected rice varieties Jyothi and Kanchana are presented below.

4. 13. 1. 1. RCP 4.5 Scenario

A comparison between the model simulated and the field observed duration for panicle initiation are presented in Table 4.42. The results showed that, the observed duration of panicle initiation varied from 35 (D5) to 36 (D2 and D4) days in Jyothi, while in Kanchana it was 34 (D5) to 36 (D2) days with respect to different planting dates. The days to panicle initiation simulated during projected period (2050s) under RCP 4.5 ranges 31days for all dates of planting in Jyothi, while in Kanchana it was 33 (D1, D2 and D3) to 30 (D5) days. During the projected period (2080s) under RCP 4.5, days to panicle initiation ranges 30(D1, D2, D3, D4 and D5) days for Jyothi. Whereas for Kanchana, days to panicle initiation ranges from 33 (D1 and D2) to 30 (D5) days.

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Table 4. 42. Baseline and projected days to panicle initiation under RCP 4.5

Panicle initiation						
Date of planting		2016	RCP 4.5			
			2050s		2080s	
			Simulated	Days (Error %)	Simulated	Days (Error %)
D1	Jyothi	34	31	-3(-8.1%)	30	-4(-11.7%)
	Kanchana	35	33	-2(-5.7%)	33	-2(-5.7%)
D2	Jyothi	36	31	-5(-13.8%)	30	-5(-16.6%)
	Kanchana	36	33	-3(-8.3%)	33	-3(-8.3%)
D3	Jyothi	35	31	-4(-11.4%)	30	-5(-14.2%)
	Kanchana	35	33	-2(-5.7%)	32	-3(-8.5%)
D4	Jyothi	36	31	-5(-13.8%)	30	-6(-16.6%)
	Kanchana	34	31	-3(-8.8%)	31	-3(-8.8%)
D5	Jyothi	35	31	-4(-11.4%)	30	-5(-14.2%)
	Kanchana	34	30	-4(-11.7%)	30	-4(-11.7%)

4. 13. 1. 2. RCP 8.5 Scenario

The days to panicle initiation simulated during projected period (2050s) under RCP 8.5 (Table 4.43) it was 29 (D1 and D5) days to 30 (D2, D3 and D4) days for Jyothi, while in Kanchana it was 32 (D1 and D2) to 29 (D5) days. During the projected period (2080s) under RCP 8.5, days to panicle initiation was 30 (D1, D2, D3, D4 and D5) days for Jyothi. Whereas for Kanchana, days to panicle initiation ranges from 33 (D1 and D2) to 30 (D5) days.

Table 4. 43. Baseline and projected days to panicle initiation under RCP 8.5

Panicle initiation						
Date of planting		2016	RCP 8.5			
			2050s		2080s	
			Simulated	Days (Error %)	Simulated	Days (Error %)
D1	Jyothi	34	29	-5(-14.7%)	28	-6(-13.6%)
	Kanchana	35	32	-3(-8.57%)	31	-4(-10.6%)
D2	Jyothi	36	30	-6(-16.6%)	29	-7(-12.1%)
	Kanchana	36	32	-4(-11.1%)	31	-5(-9.2%)
D3	Jyothi	35	30	-5(-14.2%)	29	-6(-10.7%)
	Kanchana	35	31	-4(-11.4%)	30	-5(-9.3%)
D4	Jyothi	36	30	-6(-16.6%)	28	-8(-12.3%)
	Kanchana	34	30	-4(-11.7%)	29	-5(-9.5%)
D5	Jyothi	35	29	-6(-17.1%)	28	-7(-7.9%)
	Kanchana	34	29	-5(-14.7%)	28	-8(-9.6%)

4. 13. 2. Impact on days to anthesis

The days to anthesis of base line period (2015) and projected periods (2050s) and (2080s) under RCP 4.5 and 8.5 scenarios for selected rice varieties Jyothi and Kanchana are presented in Table 4.44 and 4.45.

Table 4. 44. Baseline and projected days to anthesis under RCP 4.5

Anthesis						
Date of planting		2016	RCP 4.5			
			2050s		2080s	
			Simulated	Days (Error %)	Simulated	Days (Error %)
D1	Jyothi	66	62	-4(-6.0%)	60	-6(-9.0%)
	Kanchana	66	62	-4(-6.0%)	62	-4(-6.0%)
D2	Jyothi	66	61	-5(-7.5%)	60	-6(-9.0%)
	Kanchana	65	62	-3(-4.6%)	62	-3(-4.6%)
D3	Jyothi	65	61	-5(-6.1%)	60	-5(-7.6%)
	Kanchana	64	62	-2(-3.1%)	61	-3(-4.6%)
D4	Jyothi	65	61	-4(-6.1%)	60	-4(-7.6%)
	Kanchana	63	60	-3(-4.7%)	60	-3(-4.7%)
D5	Jyothi	63	61	-2(-3.1%)	60	-3(-4.7%)
	Kanchana	62	59	-3(-4.8%)	59	-3(-4.8%)

Table 4. 45. Baseline and projected days to anthesis under RCP 8.5

Anthesis						
Date of planting		2016	RCP 8.5			
			2050s		2080s	
			Simulated	Days (Error %)	Simulated	Days (Error %)
D1	Jyothi	66	59	-7(10.6%)	57	-9(-13.6%)
	Kanchana	66	61	-5(-7.5%)	59	-7(-10.6%)
D2	Jyothi	66	60	-6(-9.0%)	58	-8(-12.1%)
	Kanchana	65	61	-4(-6.1%)	59	-6(-9.2%)
D3	Jyothi	65	60	-5(-7.6%)	58	-7(-10.7%)
	Kanchana	64	59	-5(-7.8%)	58	-6(-9.3%)
D4	Jyothi	65	60	-5(-7.6%)	57	-8(-12.3%)
	Kanchana	63	58	-5(-7.9%)	57	-6(-9.5%)
D5	Jyothi	63	59	-4(-6.3%)	58	-5(-7.9%)
	Kanchana	62	58	-4(-6.4%)	56	-8(-9.6%)

4. 13. 2. 1. RCP 4.5 Scenario

The results showed that during base line (2016) period the days to anthesis for Jyothi varied from 63 (D5) to 66 (D2) days while Kanchana varied from 62 (D5) to 66 (D1) days. The days to anthesis simulated during projected period (2050s) under RCP 4.5 ranged between 61 (D2, D3, D4 and D5) to 62 (D1) days for Jyothi, while in Kanchana it was 62 (D1, D2 and D3) to 59 (D5) days. During the projected period (2080s) under RCP 4.5 anthesis days ranges 60 days for all dates of planting in Jyothi. Whereas for Kanchana, days to anthesis ranges from 62 (D1 and D2) to 59 (D5) days.

4. 13. 2. 2. RCP 8.5 Scenario

The days to anthesis simulated during projected period (2050s) under RCP 8.5 ranges between 59 (D1 and D5) to 60 (D2, D3 and D5) days for Jyothi, while in Kanchana it was 61 (D1 and D2) to 58 (D4 and D5) days. During the projected period (2080s) under RCP 8.5 anthesis days are ranges between 57 (D4 and D1) to 58 (D2, D3 and D5) for Jyothi. Whereas for Kanchana, days to anthesis ranges from 59 (D1 and D2) to 56 (D5) days.

4. 13. 3. Impact on days to physiological maturity

The days to physiological maturity of base line period (2016) and projected periods (2050s) and (2080s) under RCP 4.5 and 8.5 scenarios for selected rice varieties Jyothi and Kanchana are presented below.

4. 13. 3. 1. RCP 4.5 Scenario

The results presented in Table 4.46 showed that during base line (2016) period the days to physiological maturity for Jyothi and Kanchana varied from 99 (D5 and D3) to 102 (D1) days and 98 (D3, D4 and D5) to 101 (D1 and D2) days respectively. The days to physiological maturity simulated period (2050s) under RCP 4.5 ranges between 93

(D5) to 92 (D1, D2, D3 and D4) days for Jyothi, while in Kanchana it was 93 (D1, D2 and D3) to 90 (D5) days. During the projected period (2080s) under RCP 4.5, days to physiological maturity ranges between 90 (D1 and D2) to 92 (D5) days for Jyothi. Whereas for Kanchana, days to physiological maturity ranges from 92 (D1 and D2) to 90 (D5) days.

Table 4. 46. Baseline and projected days to Physiological maturity under RCP 4.5

Physiological maturity						
Date of planting		2016	RCP 4.5			
			2050s		2080s	
			Simulated	Days (Error %)	Simulated	Days (Error %)
D1	Jyothi	102	92	-10(-9.8%)	90	-12(-11.7%)
	Kanchana	101	93	-8(-7.9%)	92	-9(-8.9%)
D2	Jyothi	101	92	-9(-8.9%)	90	-11(-10.0%)
	Kanchana	101	93	-8(-7.9%)	92	-9(-8.9%)
D3	Jyothi	99	92	-7(-7.0%)	91	-8(-8.0%)
	Kanchana	98	93	-5(-5.1%)	91	-7(-7.1%)
D4	Jyothi	100	92	-8(-8.0%)	91	-9(-9.0%)
	Kanchana	98	91	-7(-7.1%)	91	-7(-7.1%)
D5	Jyothi	99	93	-6(-6.0%)	92	-7(-7.0%)
	Kanchana	98	90	-8(-8.1%)	90	-8(-8.1%)

4. 13. 3. 2. RCP 8.5 Scenario

The results presented in Table 4.47 showed that days to physiological maturity simulated during projected period (2050s) under RCP 8.5 ranges between 89 (D1, D2, D3 and D4) to 90 (D5) days for Jyothi, while in Kanchana it was 91 (D1 and D2) to 89

(D4 and D5) days. During the projected period (2080s) under RCP 8.5, days to physiological maturity ranges from 87 (D1) to 89 (D5) days for Jyothi. Whereas for Kanchana, days to physiological maturity ranges from 89 (D1 and D2) to 87 (D4 and D5) days.

Table 4. 47. Baseline and projected days to physiological maturity under RCP 8.5

Physiological maturity						
Date of planting		2016	RCP 8.5			
			2050s		2080s	
			Simulated	Days (Error %)	Simulated	Days (Error %)
D1	Jyothi	102	89	-13(-12.7%)	87	-15(-14.7%)
	Kanchana	101	91	-10(-9.9%)	89	-12(-11.8%)
D2	Jyothi	101	90	-11(-10.8%)	88	-13(-12.8%)
	Kanchana	101	91	-10(-9.9%)	89	-12(-11.8%)
D3	Jyothi	99	90	-9(-9.0%)	88	-11(-11.1%)
	Kanchana	98	90	-8(-8.1%)	88	-10(-10.2%)
D4	Jyothi	100	91	-9(-9.0%)	88	-12(-12.0%)
	Kanchana	98	89	-9(-9.1%)	87	-11(-11.2%)
D5	Jyothi	99	90	-9(-9.0%)	89	-10(-10.1%)
	Kanchana	98	89	-9(-9.1%)	87	-11(-11.2%)

4. 13. 4. Impact on grain yield

The days to physiological maturity of base line period (2016) and projected periods (2050s) and (2080s) under RCP 4.5 and 8.5 scenarios for selected rice varieties Jyothi and Kanchana are presented in Table.4.48 and 4.49.

Table 4. 48. Baseline and projected grain yield under RCP 4.5

Grain yield (kg h^{-1})						
Date of planting		2016	RCP 4.5			
			2050s		2080s	
			Simulated	(Error %)	Simulated	(Error %)
D1	Jyothi	5700	5123	-10.1	4956	-13.0
	Kanchana	5450	3897	-28.4	4050	-25.6
D2	Jyothi	5782	5028	-13.0	4965	-14.1
	Kanchana	6155	3896	-36.7	3981	-35.3
D3	Jyothi	4475	5243	17.1	5371	20.0
	Kanchana	3385	4080	20.5	4117	21.6
D4	Jyothi	4092	5620	37.3	5742	40.3
	Kanchana	4265	4281	0.3	4405	3.2
D5	Jyothi	3817	6371	66.9	6598	72.8
	Kanchana	3830	4613	20.4	4932	28.7

4. 13. 4. 1. RCP 4.5 Scenario

In variety Jyothi , observed grain yield of rice varied from 3817 (D5) to 5782 kg ha^{-1} (D2) for different planting dates while in Kanchana the grain yield varied from 3830 (D5) to 5789 kg ha^{-1} (D2). The grain yield simulated during projected period (2050s) under RCP 4.5 ranges between 5028 (D2) to 6371 kg ha^{-1} (D5) for Jyothi. While, in Kanchana it was 3896 (D2) to 4613 kg ha^{-1} (D5). During the projected period (2080s) under RCP 4.5, grain yield ranges between 4956 (D1) to 6598 kg ha^{-1} (D5) for Jyothi. Whereas for Kanchana, grain yield ranges from 3981 (D2) to 4932 kg ha^{-1} (D5).

Table 4. 49. Baseline and projected grain yield under RCP 8.5

Grain yield (kg h^{-1})						
Date of planting		2016	RCP 8.5			
			2050s		2080s	
			Simulated	(Error %)	Simulated	(Error %)
D1	Jyothi	5700	5147	-9.7	4825	-15.3
	Kanchana	5450	4232	-22.3	4480	-17.7
D2	Jyothi	5782	5220	-9.7	4858	-15.9
	Kanchana	6155	4190	-31.9	4381	-28.8
D3	Jyothi	4475	5530	23.5	5041	12.6
	Kanchana	3385	4190	23.7	4455	31.6
D4	Jyothi	4092	5998	46.5	5473	33.7
	Kanchana	4265	4378	2.6	4713	10.5
D5	Jyothi	3817	6431	68.4	6309	65.2
	Kanchana	3830	5069	32.3	5144	34.3

4. 13. 4. 2. RCP 8.5 Scenario

The grain yield simulated during projected period (2050s) under RCP 8.5 ranges between 5147 (D1) to 6431 kg ha^{-1} (D5) for Jyothi, while in Kanchana it was 4190 (D2 and D3) to 5069 kg ha^{-1} (D5). During the projected period (2080s) under RCP 8.5, grain yield ranges from 4825 (D1) to 6309 kg ha^{-1} (D5) for Jyothi. Whereas for Kanchana, grain yield ranges from 4381 (D2) to 5144 kg ha^{-1} (D5).

Discussion

5. DISCUSSION

The present study was taken up with a view to validate the CERES-Rice model for the varieties Jyothi and Kanchana, calibrate their genetic coefficient and to determine the crop weather relationship. The results of the experiments details are discussed below.

5.1. EFFECT OF WEATHER ON GROWTH AND DEVELOPMENT OF RICE

5.1.1. Dry matter accumulation

It was observed that, delay in planting dates significantly reduced the dry matter accumulation in both Jyothi and Kanchana varieties. Early planted crop availed more time to complete its life cycle because of appropriate environmental conditions and hence influenced the dry matter production. In both the varieties, maximum temperature showed a negative influence on dry matter production in delayed plantings while relative humidity and rainfall (Table 5.1) during the early planting periods favoured the high biomass in both the varieties Fig.5.1(a & b). These results were supported by studies of Roy and Biswas (1980), Hirai *et al.,* (1993), Kaladevi *et al.,* (1999) and Singh *et al.,* (2012).

Table 5.1. Correlation coefficients between weather parameters and dry matter accumulation

Variety	Tmax	Tmin	RHI	RHII	RF	Epan
Jyothi	-0.453*	-0.682**	0.508*	0.656**	0.730**	-0.733**
Kanchana	-0.517*	-0.818**	0.362	0.659**	0.749**	-0.535*

5.1.2. Straw yield

Dates of planting had significant influence on straw yield in both Jyothi and Kanchana varieties. Crops taken during early dates received high relative humidity with low temperature during the entire growth period and favoured more straw yield (Fig.5.2). August 5th planted crop which experienced low relative humidity with high temperature

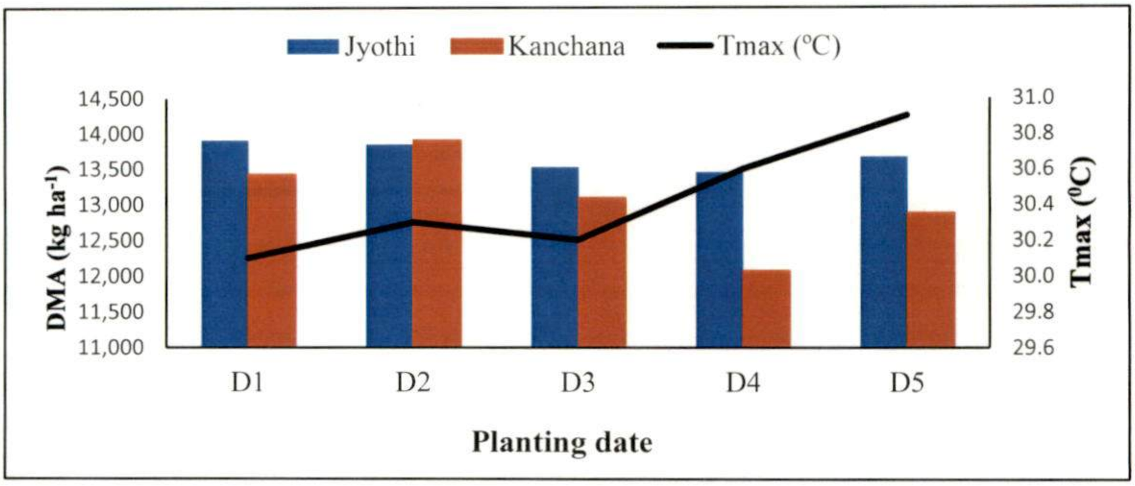

Fig.5.1(a). Influence of maximum temperature on dry matter accumulation (kg ha^{-1}) with respect to different planting dates

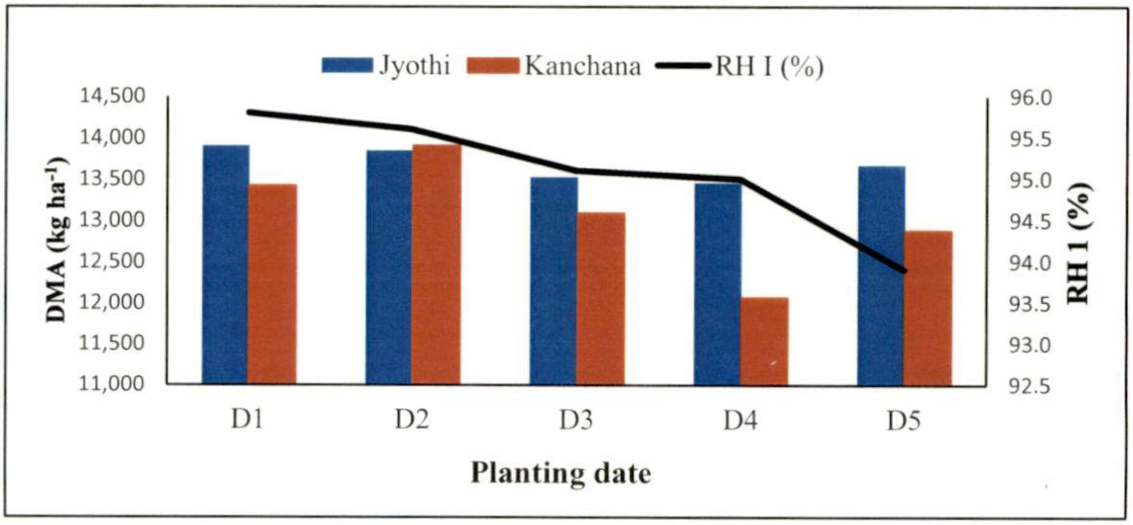

Fig.5.1(b). Influence of forenoon relative humidity on dry matter accumulation (kg ha^{-1}) with respect to different planting dates

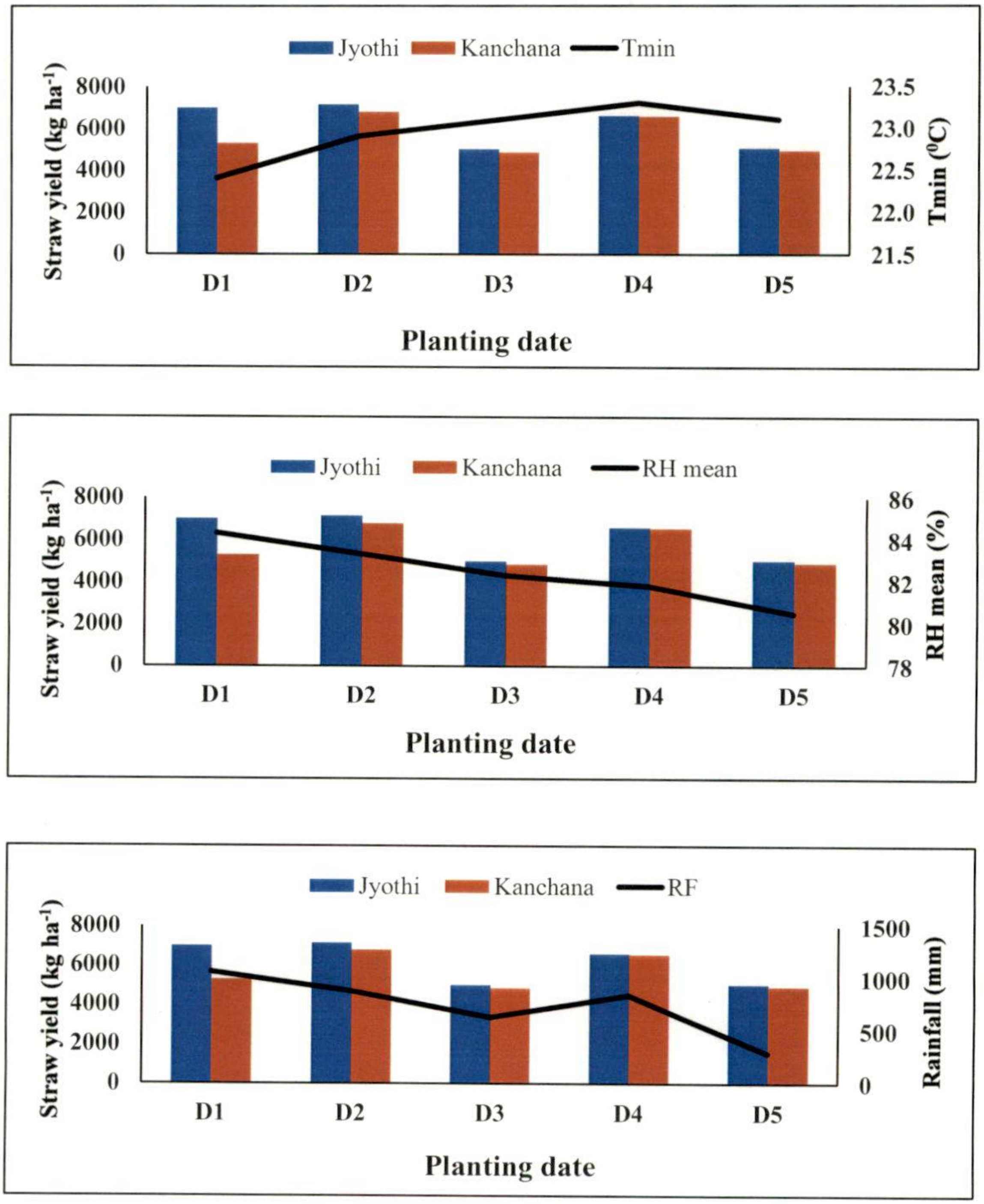

Fig.5.2. Influence of weather parameters on straw yield (kg ha^{-1}) with respect to different planting date

reduced the straw yield compared to June 5th and June 20th planting in both the varieties (Table 5.2). This was in conformity with findings of Ramdoss and Subramaniam (1980) and Sreelatha (1989). The variety Jyothi showed significantly higher straw yield compared to Kanchana.

Table 5.2. Correlation coefficients between weather parameters and straw yield

STRAW	Tmin	DTR	RHI	RHII	RHIII	RF
Jyothi	-0.153	-0.167	0.716**	0.606**	0.638**	0.564**
Kanchana	-0.347	-0.181	0.217	0.104	0.138	0.084

5.1.3. Grain yield

Grain yield was significantly affected by planting date in both the varieties. In both varieties June 5th, June 20th and July 20th gave higher yield compared to other plantings. The high rainfall during the early growth period had positive effect on grain yield in both the varieties (Table 5.3). Number of panicles per unit area, filled grains per panicle and 1000 grain weight contributed the high yield. The reduction in grain yield on late plantings was due to increased temperature at the heading stage which might have induced grain sterility and thus reduced the yield. These results were in agreement with findings of Akram *et al*., (2007), Huda *et al.,* (1975) and Abeysiriwardena *et al.,* (2002). Reduction in grain yield in August 5th planting in Jyothi and Kanchana was due to high temperature and low rainfall during the growth period (Fig.5.3), which was also reported by Wahid *et al*., (2007). In Kanchana, higher yield in August 5th compared to July 5th planting may be due to more number of panicles per m^{-2} in August 5th than July 5th planting.

Table 5.3. Correlation coefficients between weather parameters and grain yield

Yield	Tmax	Tmin	RHI	RHII	RF
Jyothi	-0.557*	-0.39	0.603**	0.609**	0.627**
Kanchana	-0.243	-0.739**	0.436	0.577**	0.570**

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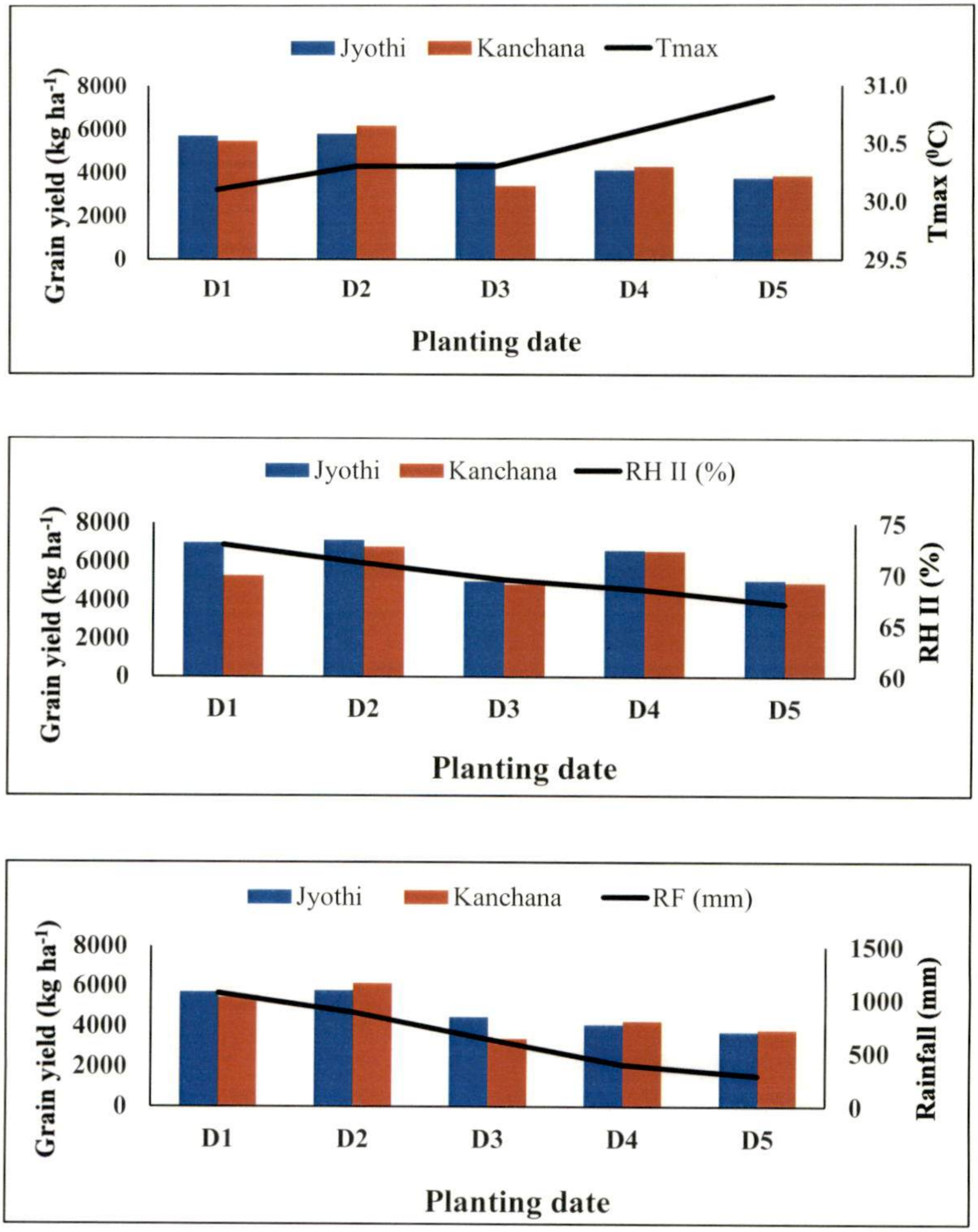

Fig.5.3. Influence of weather parameters on grain yield (kg ha^{-1}) with respect to different planting dates

5.1.4. Leaf area index (LAI)

The rice varieties Jyothi and Kanchana recorded highest value of leaf area index during 60 days after transplanting. Early transplanted crops showed highest value for leaf area index in both varieties (Fig.5.4 and 5.5). Same result was reported by Ahmad *et al.*, (2009). In both varieties, the leaf area index was found to increase and reached its maximum value at 60 days after transplanting and there after it decreased. The decrease in leaf area towards maturity may be due to lesser leaf number as a result of senescence in early formed leaves. This result was in accordance with the findings of Sharma and Haloi (2001).

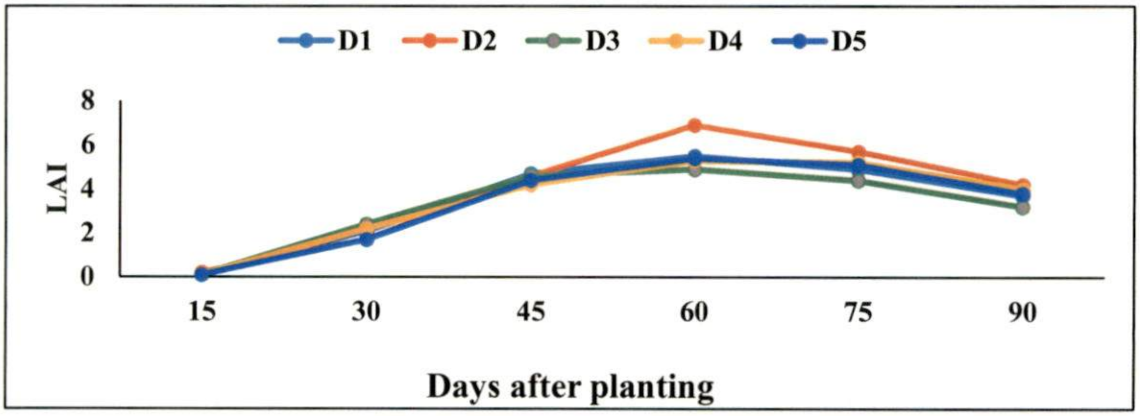

Fig.5.4. Leaf area index (LAI) in Jyothi

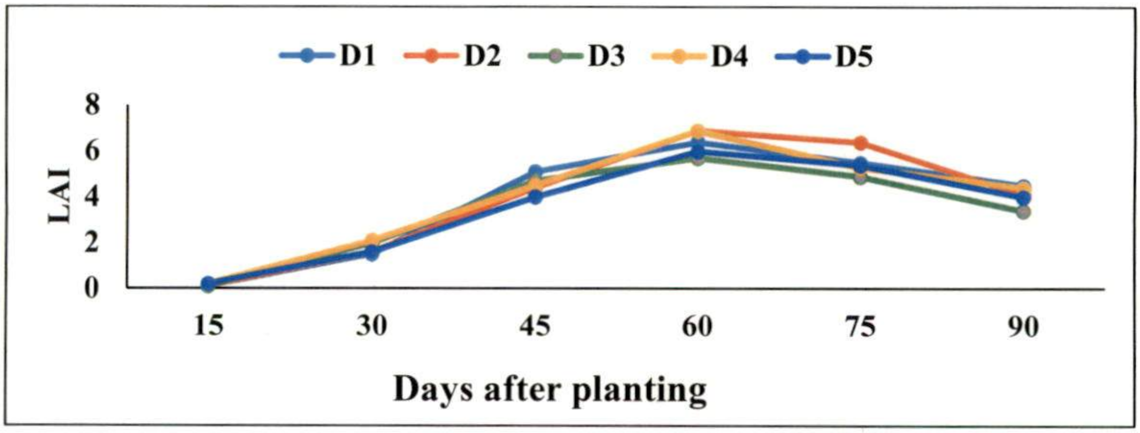

Fig.5.5. Leaf area index (LAI) in Kanchana

5.2. EFFECT OF WEATHER ON THE DURATION OF PHENOLOGICAL STAGES

The duration taken for each growth stage was found to be different for the varieties Jyothi and Kanchana, with respect to different planting dates. Early planted crops took more days to attain maturity compared to late planted crops. Results revealed that days taken to complete life cycle was reduced with delay in planting dates. It might be due to the fact that the weather conditions prevailed during different dates of planting were not the same, even though the season was same. Similar results were reported by Lamsal *et al.,*(2013).

From the correlation analysis, it was identified that maximum temperature during panicle initiation to booting and booting to heading reduced the phenophases in late planting crops, while afternoon relative humidity, afternoon vapour pressure deficit and rainy days during this period shows positive influence on the number of days taken for the phenophases in Jyothi . Minimum temperature during transplanting to active tillering and flowering to physiological maturity decreases the phenophases duration in late planted crops compared to early plantings in Kanchana. Higher afternoon relative humidity and rainy days during transplanting to active tillering, panicle initiation to booting and heading to flowering shows increase in the duration of Kanchana.

It was observed that, days to 50% flowering and physiological maturity was significantly shorter with late planting than early planting. This view was supported by the work of Begum *et al*., (2000). The various phenological stages like active tillering, booting, heading, 50% flowering and physiological maturity taken for the crops with delayed planting was found to be shorter than early planting. This reduction in phenological phases during late planting was attributed to the increase in temperature (Fig.5.6, 5.7 and 5.8). This was in conformity with the findings of Rani and Maragatham (2013).

In order to attain full maturity, environmental conditions like low maximum temperature and high relative humidity was most favourable for early planted crops.

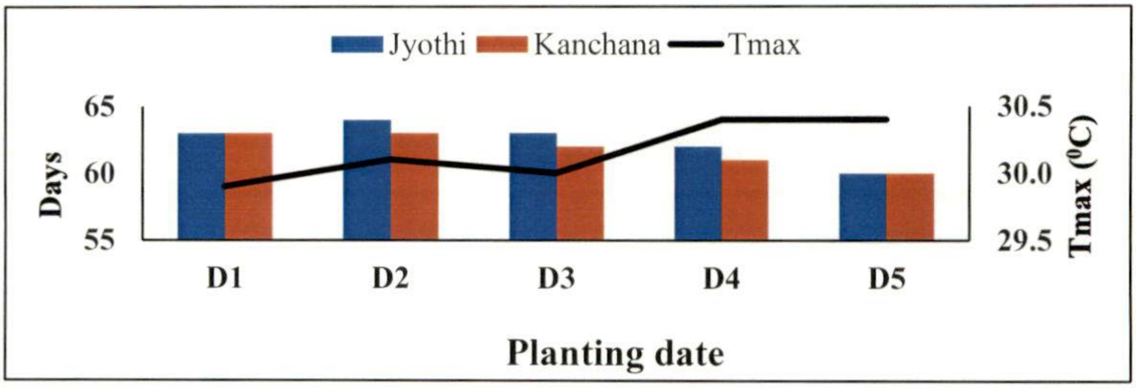

Fig 5.6. Influence of maximum temperature on days taken for heading

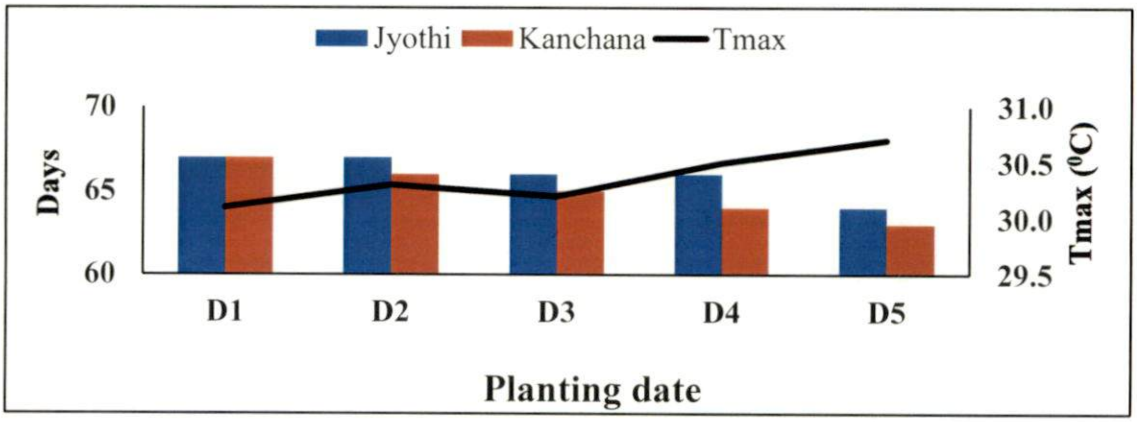

Fig 5.7. Influence of maximum temperature on days taken for flowering

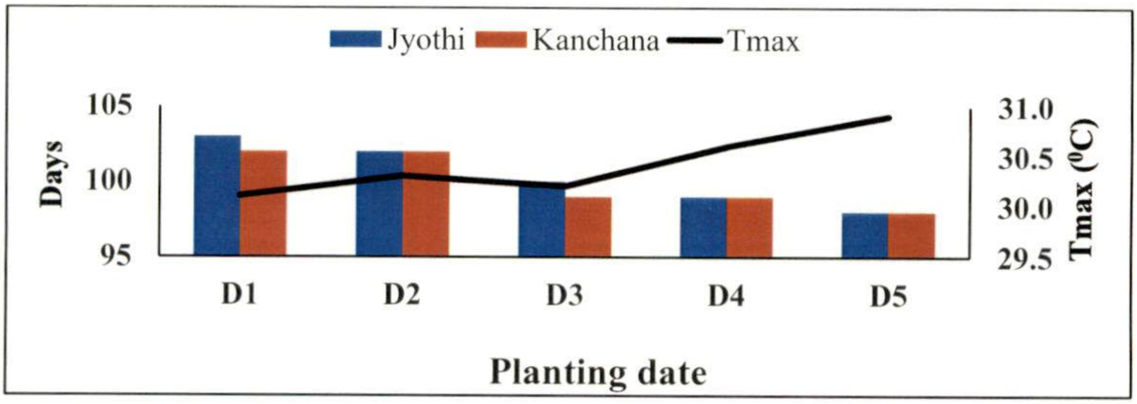

Fig 5.8. Influence of maximum temperature on days taken for physiological maturity

Similar findings were also reported by Soleymani and Shahrajabian (2011). Late planted crops experienced high temperature throughout the growing season, reducing the growth duration.

5.3. EFFECT OF HEAT UNITS ON GROWTH AND DEVELOPMENT OF RICE

5.3.1 Grain yield

The mean grain yield was significantly influenced by dates of planting in Jyothi and Kanchana. The rice varieties Jyothi and Kanchana recorded highest accumulated growing degree days during June 5th planting. Lower grain yields in Jyothi and Kanchana was observed in delayed dates of planting, due to higher accumulation of GDD during transplanting to active tillering in delayed dates of planting (Fig.5.9 and 5.10). This result was in agreement with Sandhu *et al*. (2013).

The delayed transplanting recorded highest HTU in Jyothi and Kanchana. This result was in agreement with Khavse *et al*., (2015). The highest HTU for Jyothi and Kanchana was recorded on August 5th date of planting in both varieties. In Jyothi and Kanchana HTU was found to be increased with delay in transplanting due to more sunshine hours. In Jyothi and Kanchana, increase in HTU with delay in transplanting decreases the yield (Fig.5.11 and 5.12). Highest PTU was observed in June 5th planting for both Jyothi and Kanchana. PTU found decreasing trend during physiological maturity towards the delayed date of planting in both varieties respectively (Fig.5.13 and 5.14).

5.3.2. Phenology

The duration of different phenological stages of rice was influenced by different dates of planting in both Jyothi and Kanchana. The results showed that the early transplanted rice varieties accumulated more heat units to attain physiological maturity. The growing degree days (GDD) showed significant negative correlation with crop duration on vegetative stage (P7), panicle initiation to booting (P4) and active tillering to

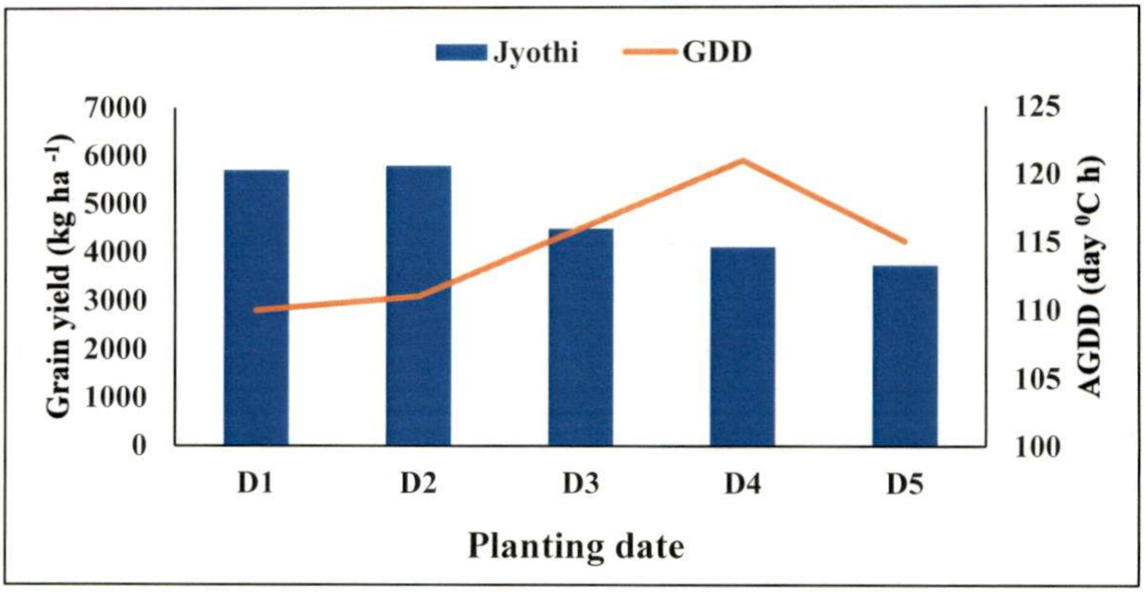

Fig 5.9. Effect of GDD on grain yield (kg ha^{-1}) of Jyothi during active tillering to panicle initiation

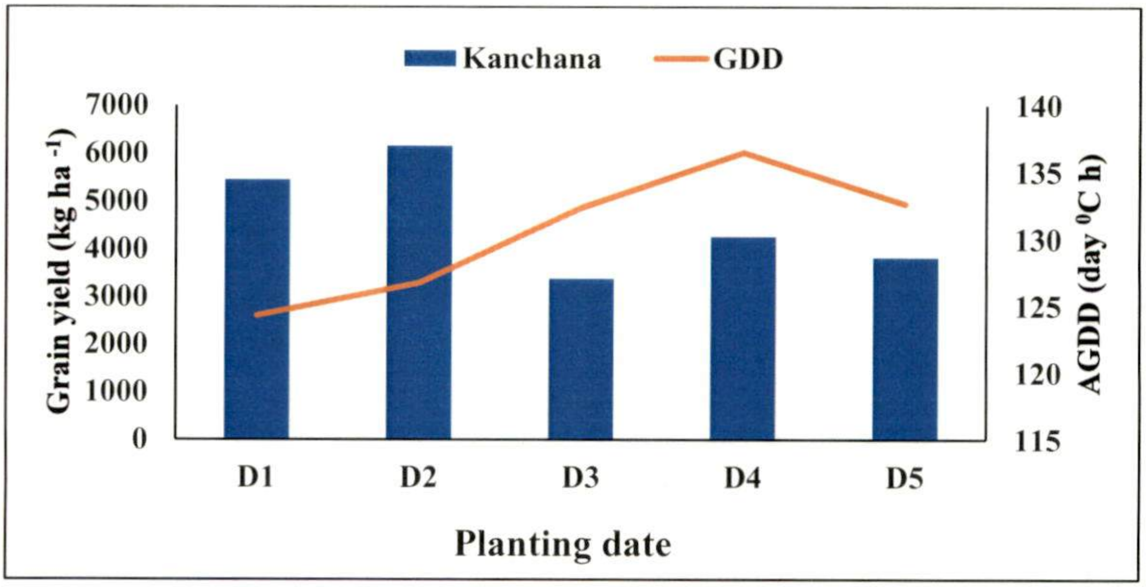

Fig 5.10. Effect of GDD on grain yield (kg ha^{-1}) of Kanchana during active tillering to panicle initiation

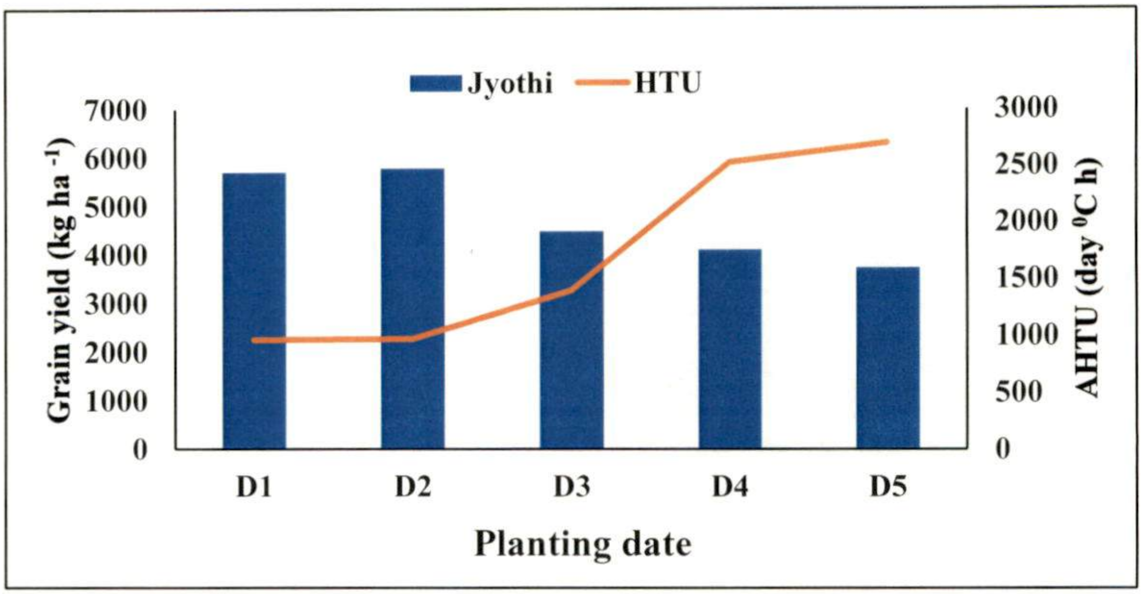

Fig 5.11. Effect of AHTU on grain yield (kg ha^{-1}) of Jyothi during vegetative phase

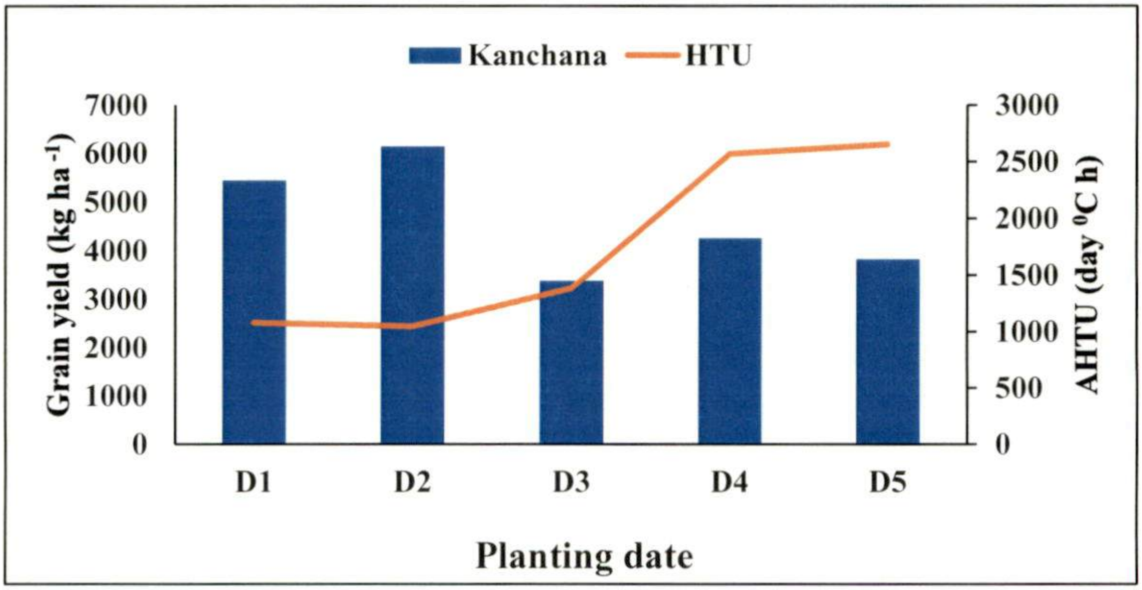

Fig 5.12. Effect of AHTU on grain yield (kg ha^{-1}) of Kanchana during vegetative phase

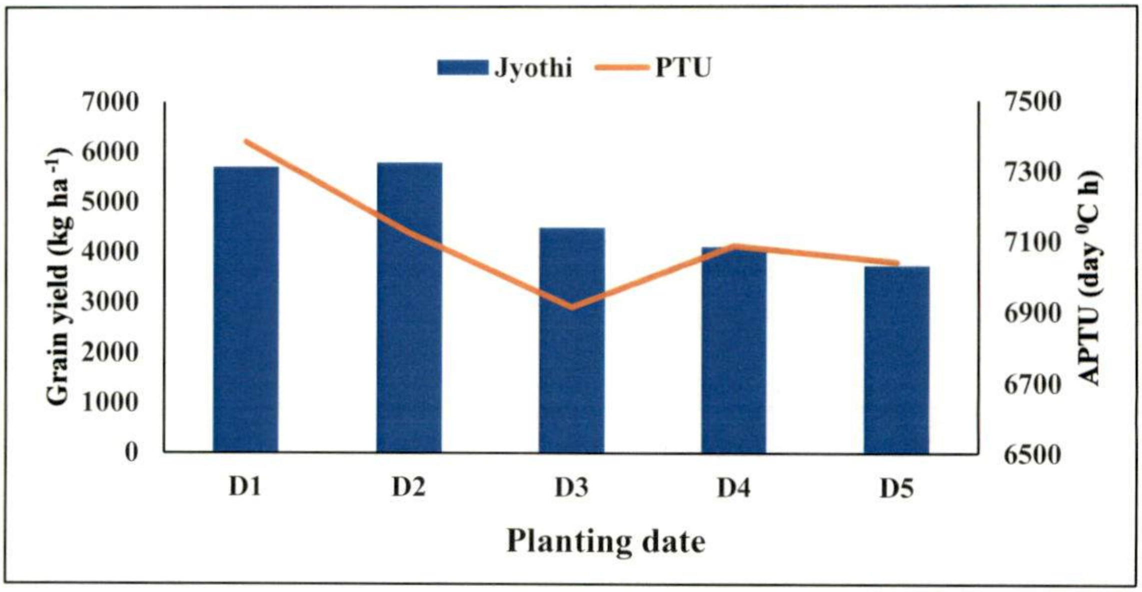

Fig 5.13. Effect of APTU on grain yield (kg ha^{-1}) of Jyothi during physiological maturity

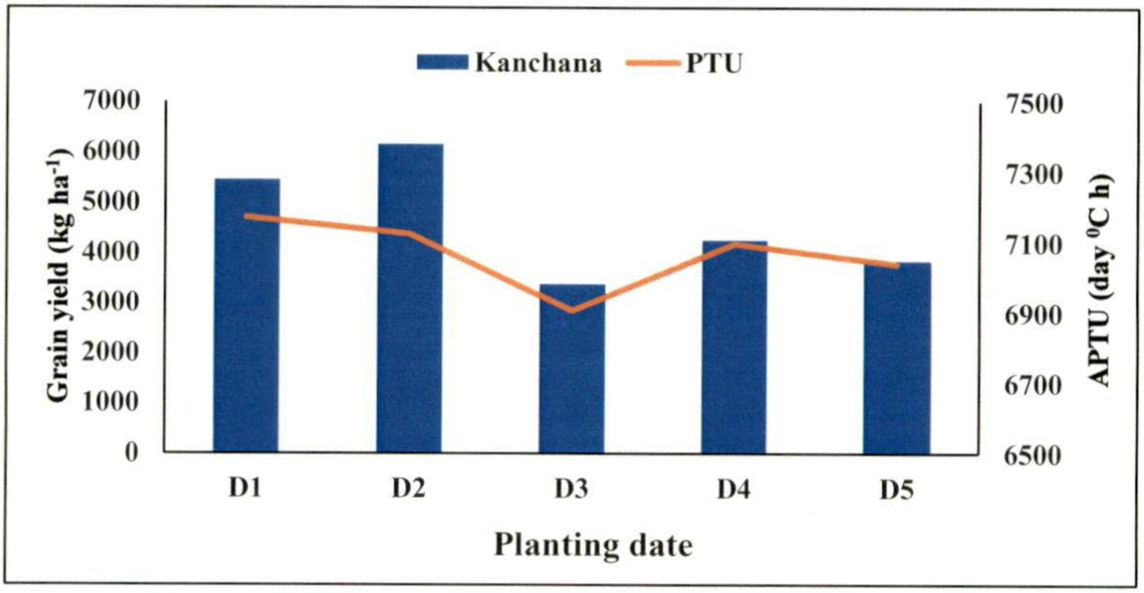

Fig 5.14. Effect of APTU on grain yield (kg ha^{-1}) of Kanchana during physiological maturity

panicle initiation in both the varieties. Same result was reported by Rani and Maragatham (2013). The number of days taken for transplanting to maturity was decreased in delayed plantings due to increased HTU. The accumulated helio thermal unit showed significant negative correlation in transplanting to active tillering (P1), active tillering to panicle initiation (P2), panicle initiation to booting (P3) and heading to 50% flowering (P5). Early transplanted crops required maximum PTU to complete physiological maturity than delayed planting in Jyothi and Kanchana. This result was in conformity with Amrawat *et al.*, (2013). The highest accumulated heat unit such as GDD, HTU and PTU was observed at physiological maturity for both Jyothi and Kanchana. Same result was reported by Sikder (2009).

5.4. CERES-RICE SIMULATION MODEL

Models help farmers to make decisions in agricultural planning by prediction of rice yields at various stages of crop growth, based on weather variables. In recent years it is gaining more importance for forecasting the yields and responding to the various weather aberrations by implementation of different management practices.

The performance of the CERES-Rice was tested and evaluated using the calibrated genetic coefficient for both the varieties with their respective planting dates. The results of simulation studies in respect of the effect of planting dates on important parameters of crop growth, development and yield of rice were compared with the observed values from the field experiment. The model could predict the phenophases more accurately. The Predicted yield of both rice varieties Jyothi and Kanchana under different planting dates reasonably closed to the observed values.

Two statistics were used to evaluate the model performances. (i) Root Mean Square Error (RMSE) and (ii) D-stat index. Willmott (1982) stated that the D-stat index value should approach unity and the RMSE approach zero for good performance of the model.

Fine tuning of the genetic coefficients were made during the study with 6000 iterations using DSSAT v. 4.6 and the calibrated genetic coefficients are given in Table 4.34. The validation of grain yield and phenology of the two rice varieties were discussed.

5.4.1. Grain yield

In case of Jyothi, predicted grain yield was satisfactorily agreed with observed yield with an RMSE (root mean square error) of 1525.7 kg ha-1 and D-stat index of 0.4, indicating good performance of the model Fig. 5.15(a & b). Similar findings were also reported by Arjun *et al*., (2016) who observed that, predicted grain yield was well agreed with observed yield (RMSE = 1186 kg ha-1, D-stat index= 0.4). The root mean square error (RMSE) and D-stat index values for yield are given in Table 5.4.

Predicted yield in Kanchana also was in good agreement with observed yield with an RMSE of 1409.3 kg ha^{-1} and D–stat index of 0.5, indicating good performance of the model Fig.5.16(a & b). Similar results were also reported by Timsina *et al.,* (2006) who reported that, predicted grain yields agreed well with observed yields with RMSE=815 kg ha^{-1}; D-stat index=0.74.

Table. 5.4. RMSE, D-stat index of yield for Jyothi and Kanchana.

Variety	RMSE	D-stat index
Jyothi	1525.7	0.40
Kanchana	1409.3	0.50

The relatively higher variation in observed and simulated yield during delayed planting was attributed to solar radiation. The variable performance of the model was probably due to combination of deficiencies in model inputs, experimental observations, and inclusion of non modeled factors such as (disease, lodging and pests) in model validation and insufficient capture of model processes.

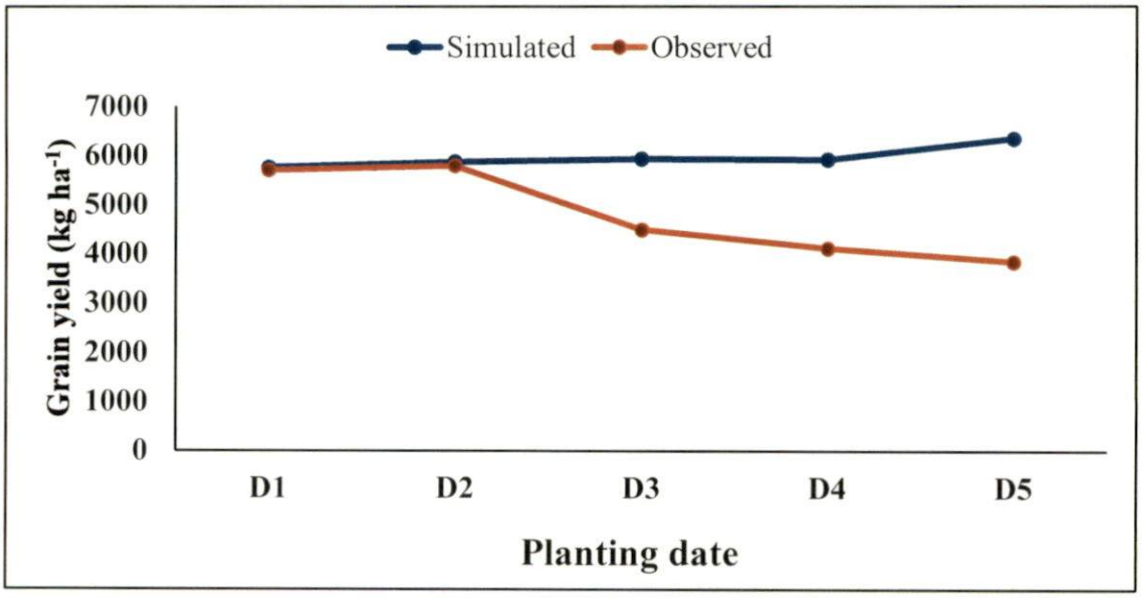

Fig.5.15(a). Comparison of observed and simulated yield in Jyothi

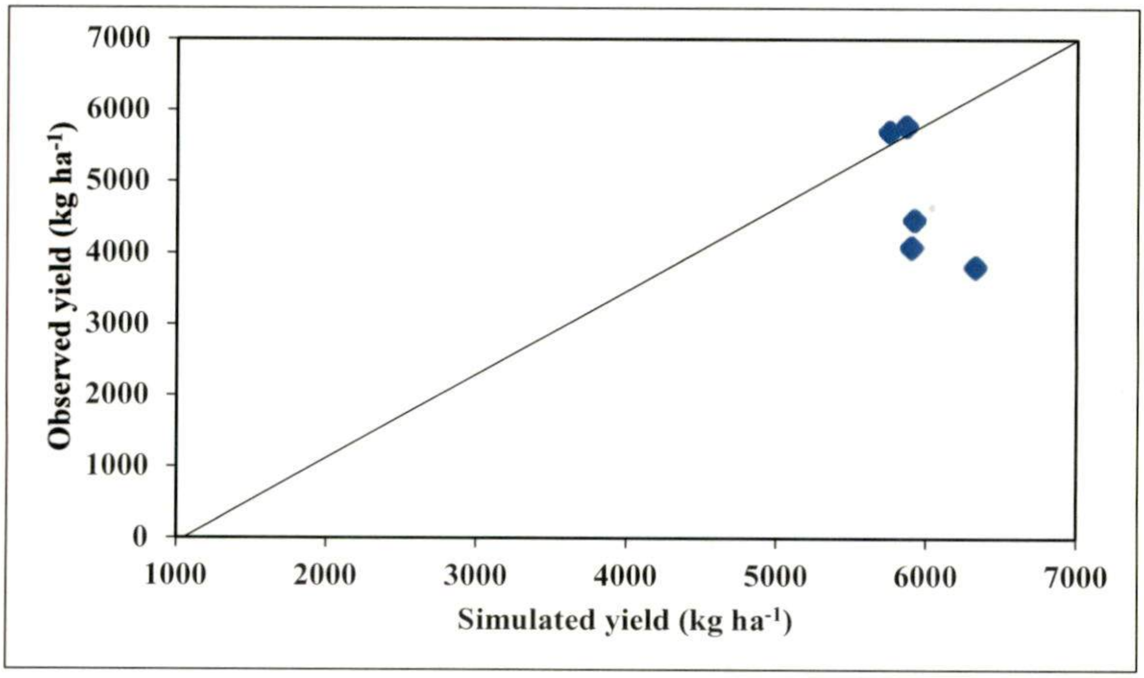

Fig.5.15(b). Scatter diagram of observed and simulated yield in Jyothi

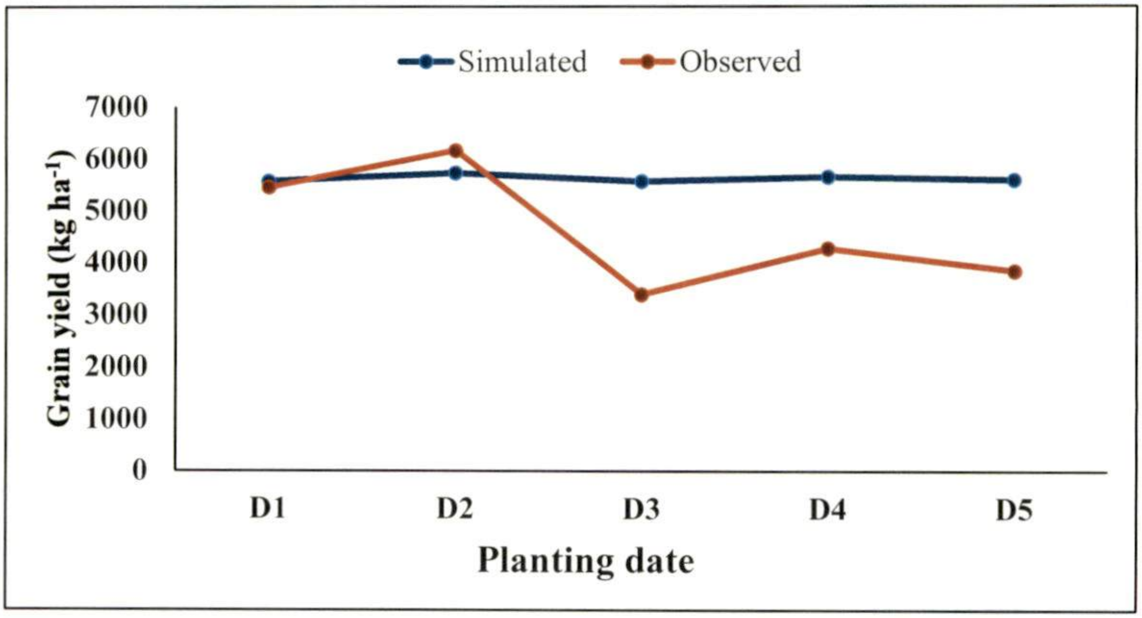

Fig.5.16(a). Comparison of observed and simulated yield in Kanchana

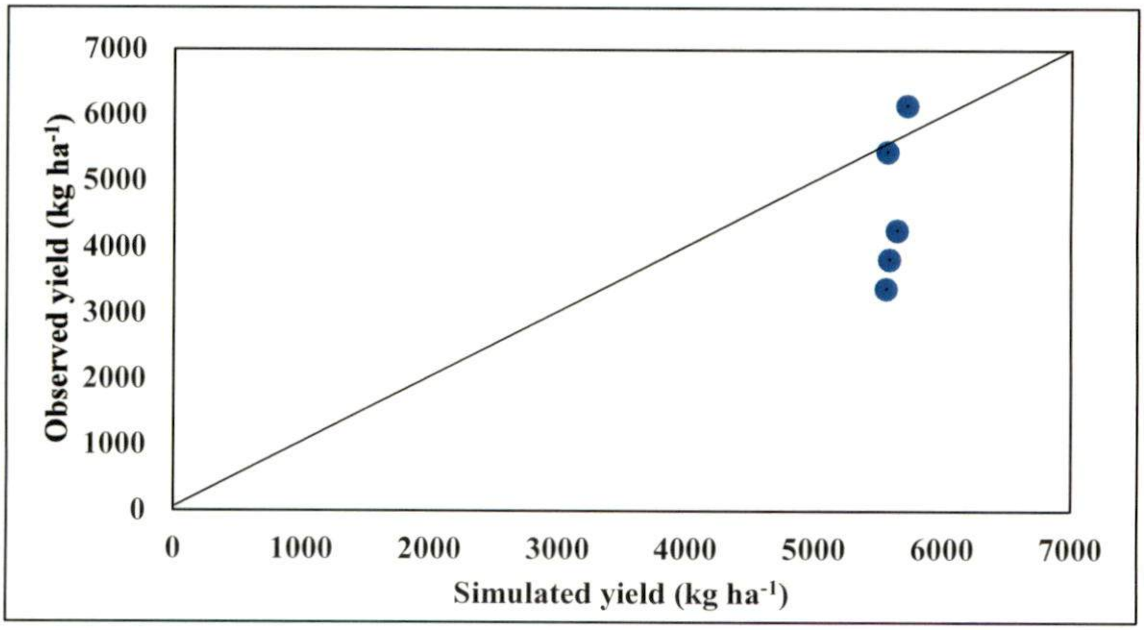

Fig.5.16(b). Scatter diagram of observed and simulated yield in Kanchana

5.4.2. Simulation of phenology

There was reasonably a good agreement between observed and simulated phenology for both Jyothi and Kanchana. The root mean square value (RMSE) and D-stat index for simulation of phenology are presented in Table 5.5.

Table 5.5. RMSE and D-stat index for Jyothi and Kanchana for the days to attain different phenophases

Variety	Panicle initiation day		Anthesis day		Maturity day	
	RMSE	D-stat index	RMSE	D-stat index	RMSE	D-stat index
Jyothi	2.3	0.13	1.6	0.71	2.0	0.57
Kanchana	2.1	0.60	2.9	0.68	2.2	0.77

5.4.2.1. Panicle initiation day

The results showed that, conformity between observed and simulated panicle initiation day for Jyothi was satisfactory with an RMSE of 2.3 and D-stat index of 0.13 Fig.5.17(a & b) and in Kanchana a reasonable agreement was followed between observed and simulated with an RMSE of 2.1 and D-stat index of 0.6 Fig.5.18(a & b). But the average error percentage was comparatively less in case of days taken for panicle initiation for Kanchana. The model correctly predict the panicle initiation day in Kanchana for D1 planting.

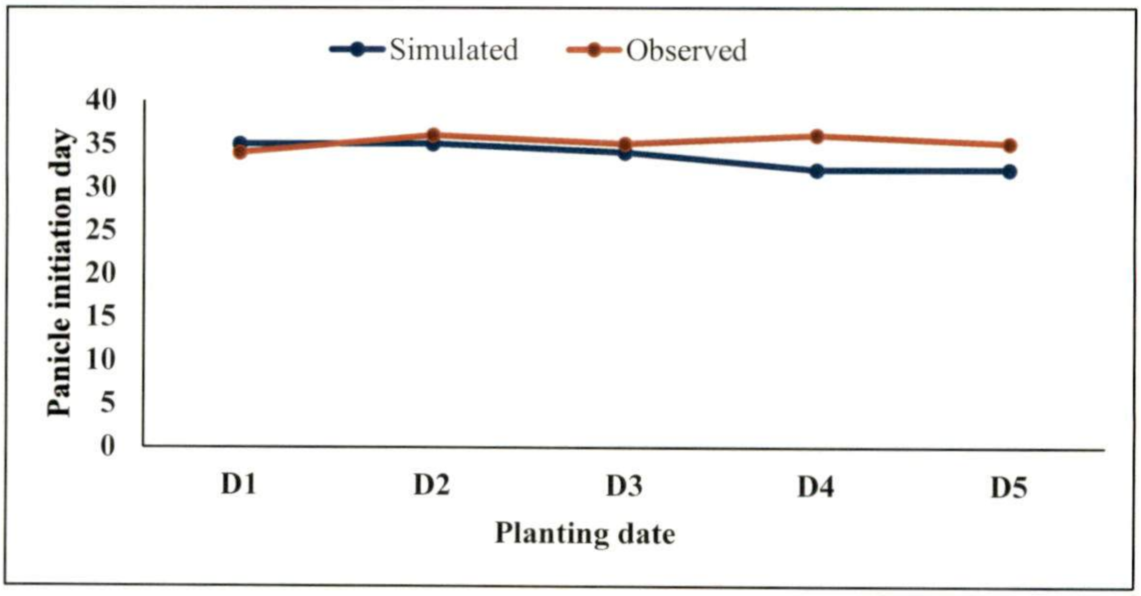

Fig.5.17(a). Observed and simulated panicle initiation day in Jyothi

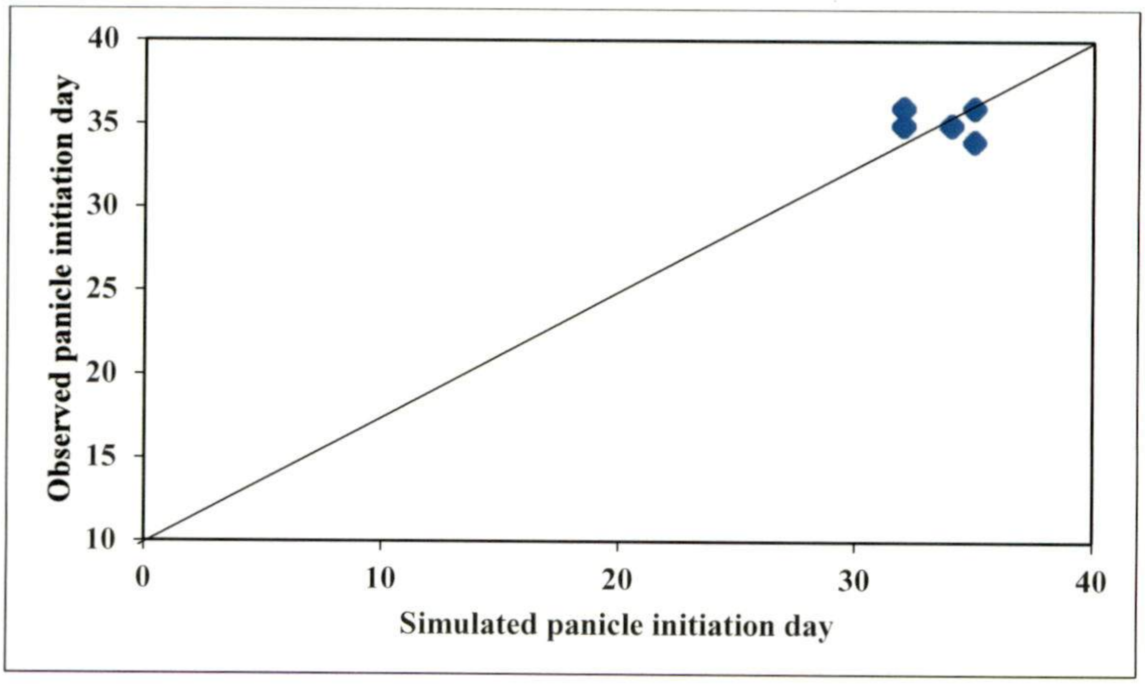

Fig.5.17(b). Scatter diagram of observed and simulated panicle initiation day in Jyothi

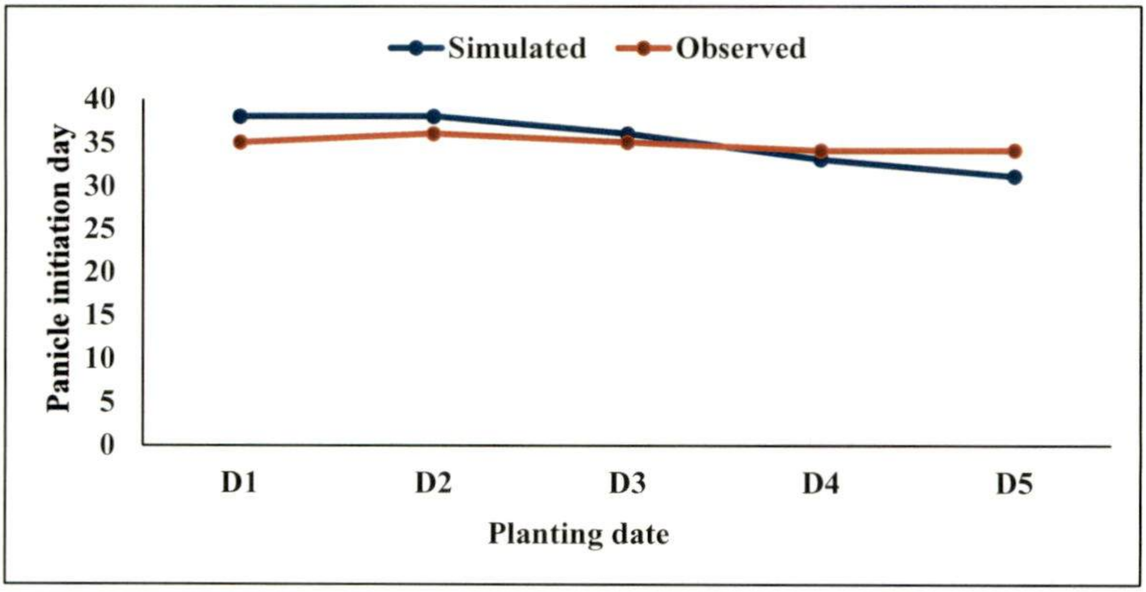

Fig.5.18(a). Observed and simulated panicle initiation day in Kanchana

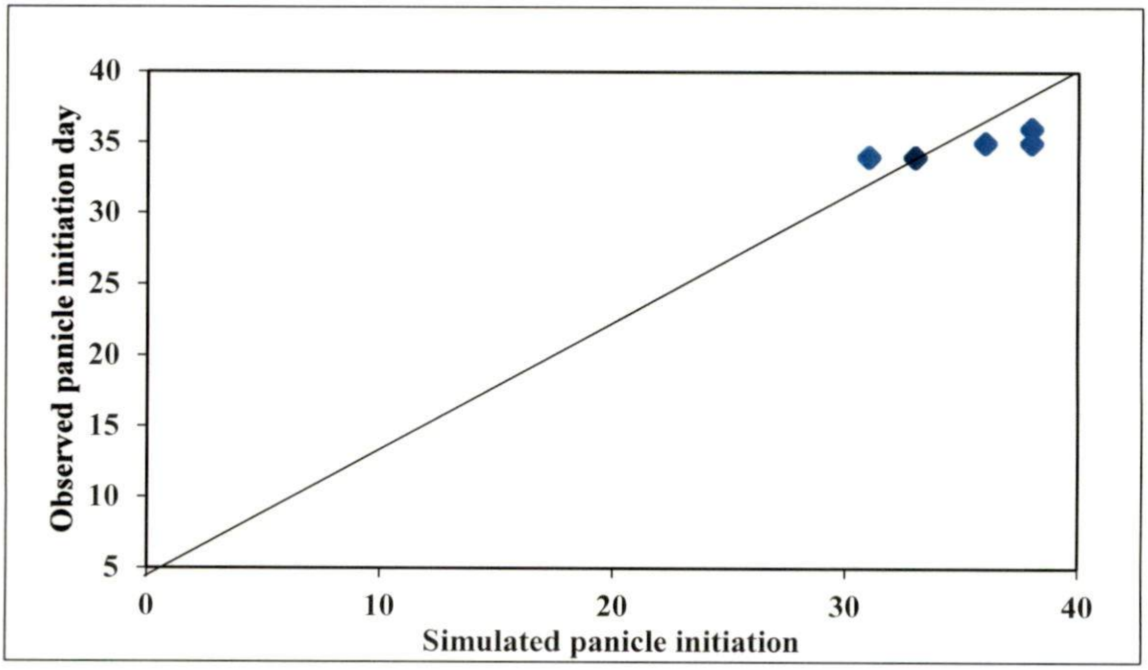

Fig.5.18(b). Scatter diagram of observed and simulated panicle initiation day in Kanchana

5.4.2.2. Anthesis day

Predicted anthesis day was reasonably agreed with simulated day in both the varieties. In Jyothi, the observed and simulated anthesis day showed a reasonable agreement with an RMSE of 1.6 and D-stat index of 0.71 Fig. 5.19(a & b), while in Kanchana it showed RMSE of 2.9 and D-stat index of 0.6 Fig. 5.20(a & b). The model satisfactorily predicted the anthesis day for both the varieties. This was in agreement with studies of Timisina *et al*., (1998) who also predicted the anthesis day for two varieties (Kanchan and Sowghat with an RMSE of 2.0 and D-stat index 0.90).

5.4.2.3 Physiological maturity day

There was reasonably a good agreement between actual and simulated physiological maturity day in Jyothi Fig.5.21(a & b), while a satisfactory agreement in Kanchana Fig.5.22(a & b). In Jyothi, an RMSE of 2.0 and D-stat index of 0.57 was obtained, while in Kanchana, it showed an RMSE of 2.2 and D-stat index of 0.77. Similar findings were studied by Alociljha and Ritchie (1991), reported good agreement between observed and predicted number of days to anthesis and maturity, with normalized RMSE of 4% and 3%, and D-stat index of 0.65 and 0.87, respectively for three upland rice cultivars in the Philippines.

5.5. CLIMATE CHANGE IMPACT ON RICE PRODUCTION

5.5.1. Projected changes in yields of Jyothi and Kanchana under RCP 4.5 scenario

5.5.1.1. First date of planting (DOP1)

During first date of planting projected grain yield for Jyothi and Kanchana shows a declining trend towards the future scenario RCP 4.5 from the baseline (2016). The grain yield of Jyothi will be reduced by 10.1 percent and 13.0 percent during 2050s and 2080s, respectively. Whereas in Kanchana, the grain yield will be reduced by 28.4 percent and

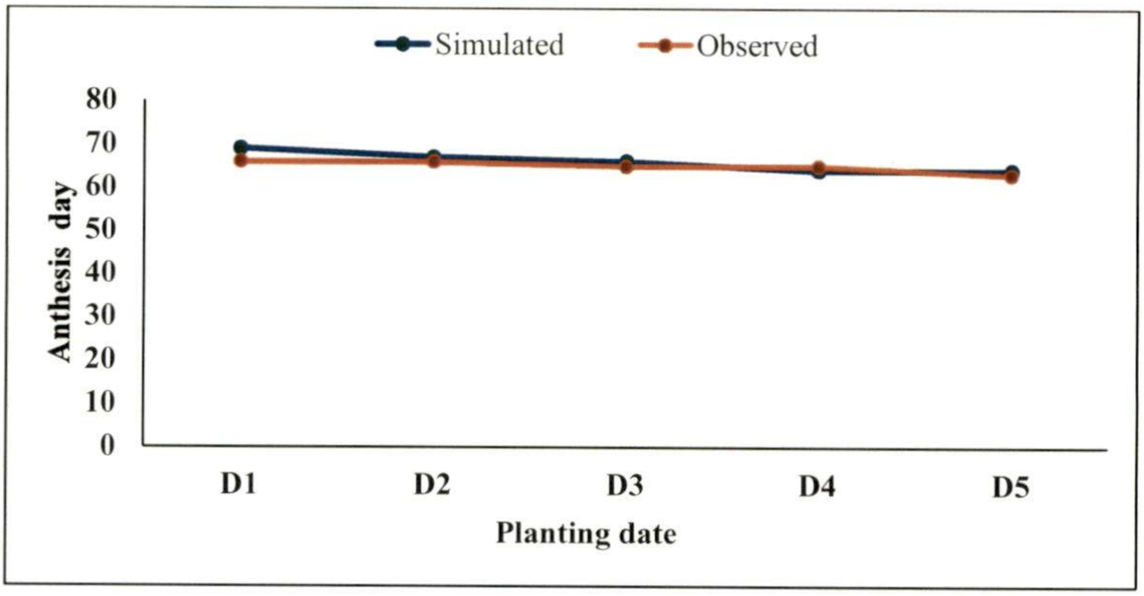

Fig.5.19(a). Observed and simulated anthesis day in Jyothi

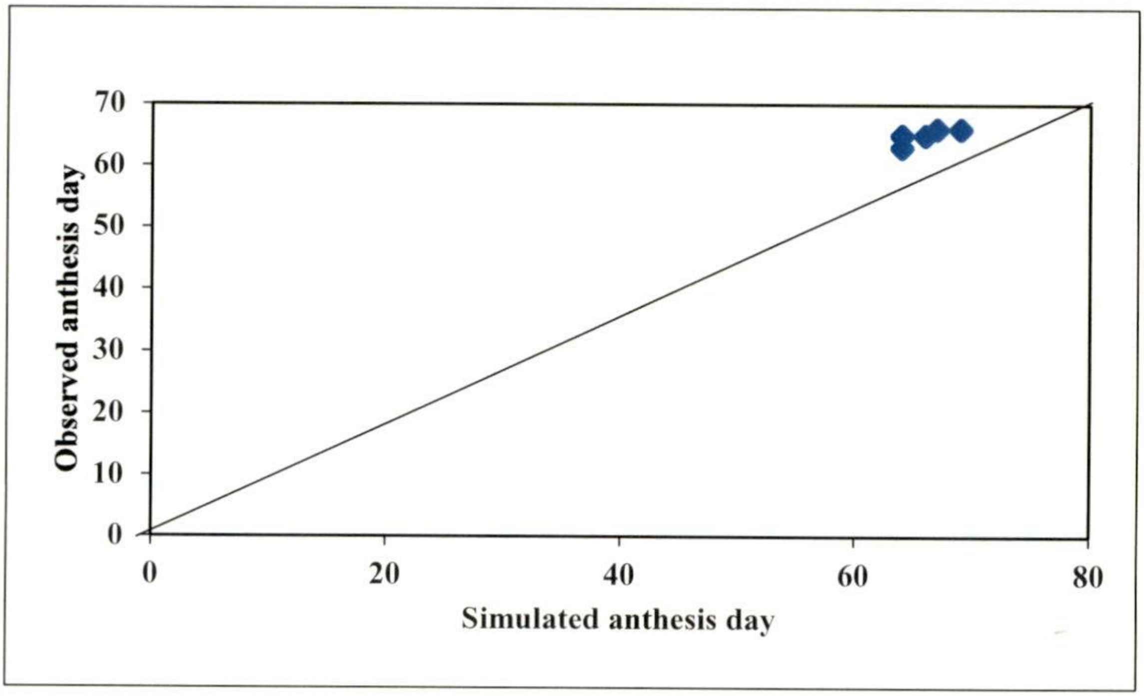

Fig.5.19(b). Scatter diagram of observed and simulated anthesis day in Jyothi

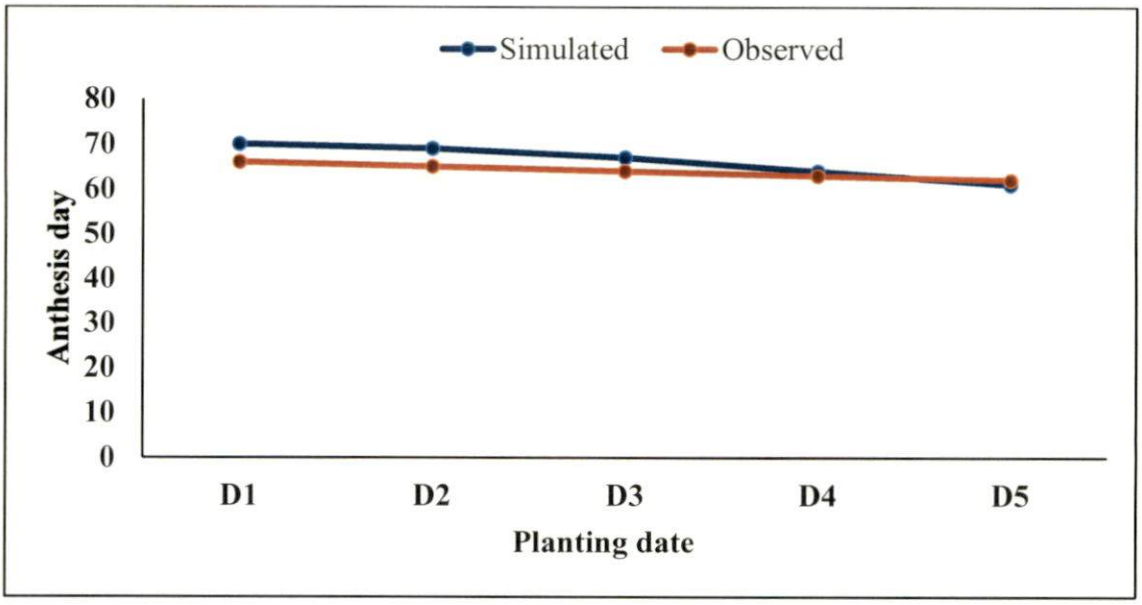

Fig.5.20(a). Observed and simulated anthesis day in Kanchana

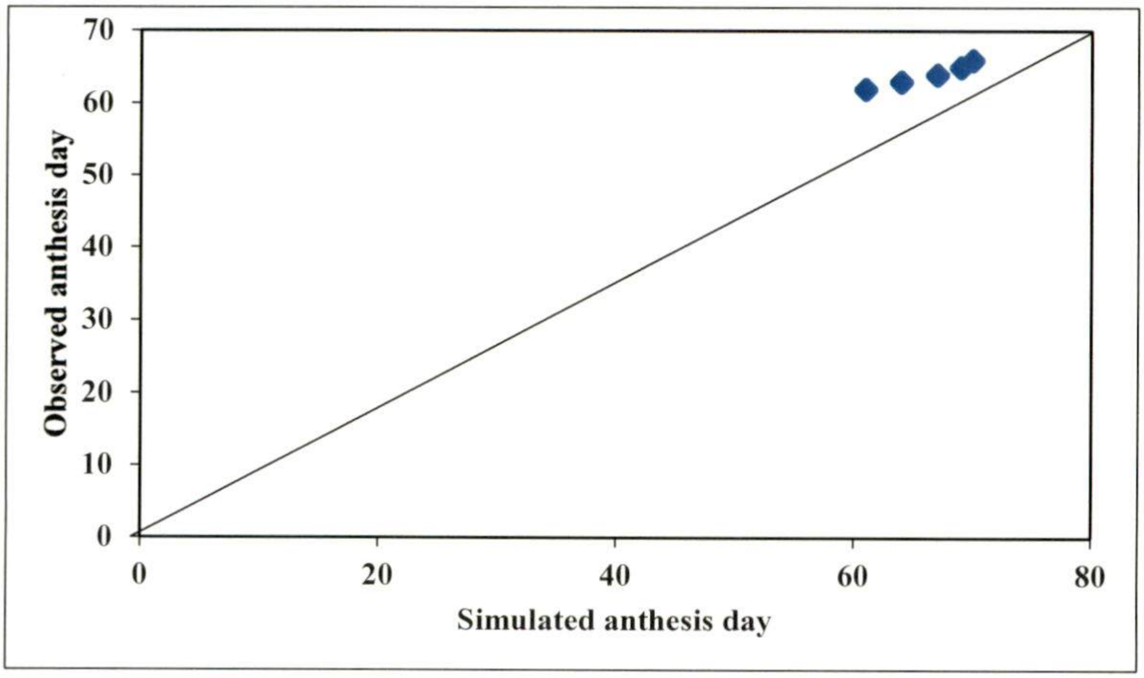

Fig.5.20(b). Scatter diagram of observed and simulated anthesis day in Kanchana

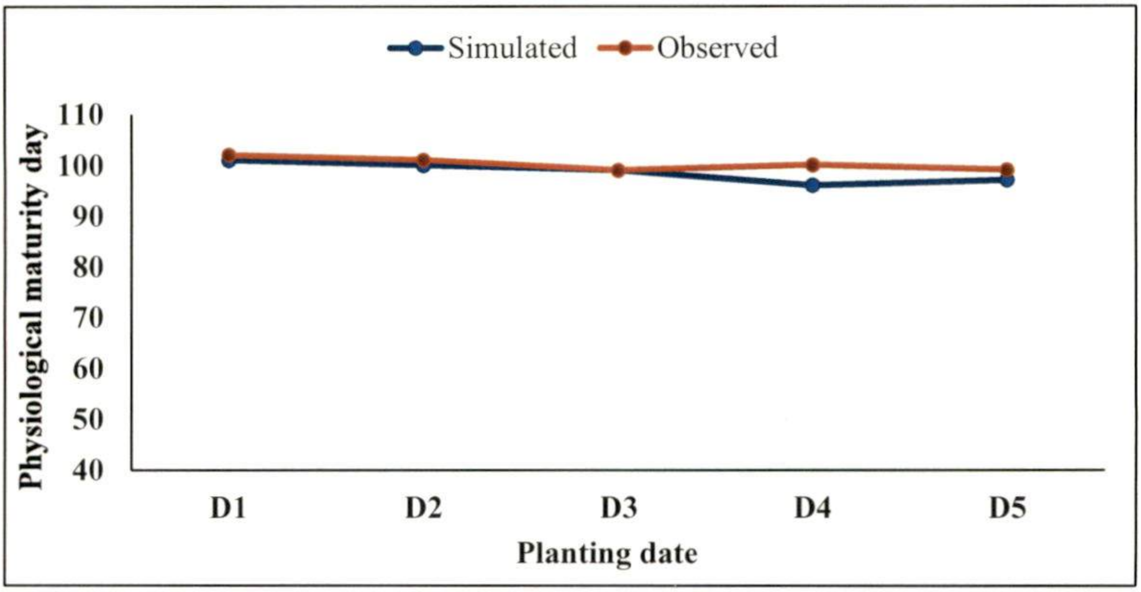

Fig.5.21(a). Observed and simulated physiological maturity day in Jyothi

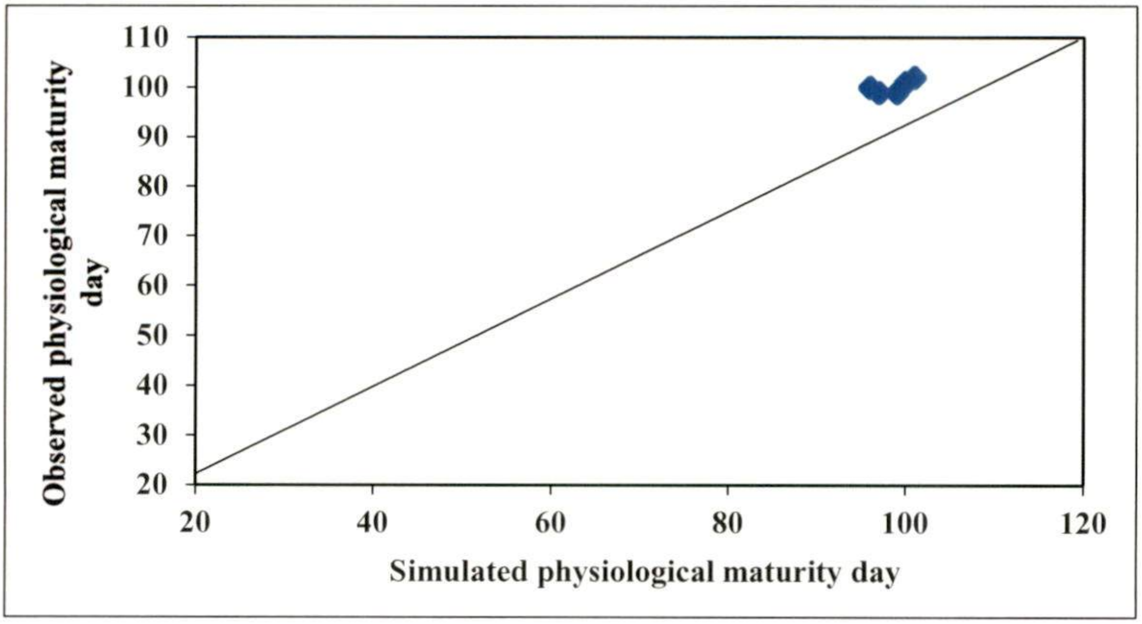

Fig.5.21(b). Scatter diagram of observed and simulated physiological maturity day in Jyothi

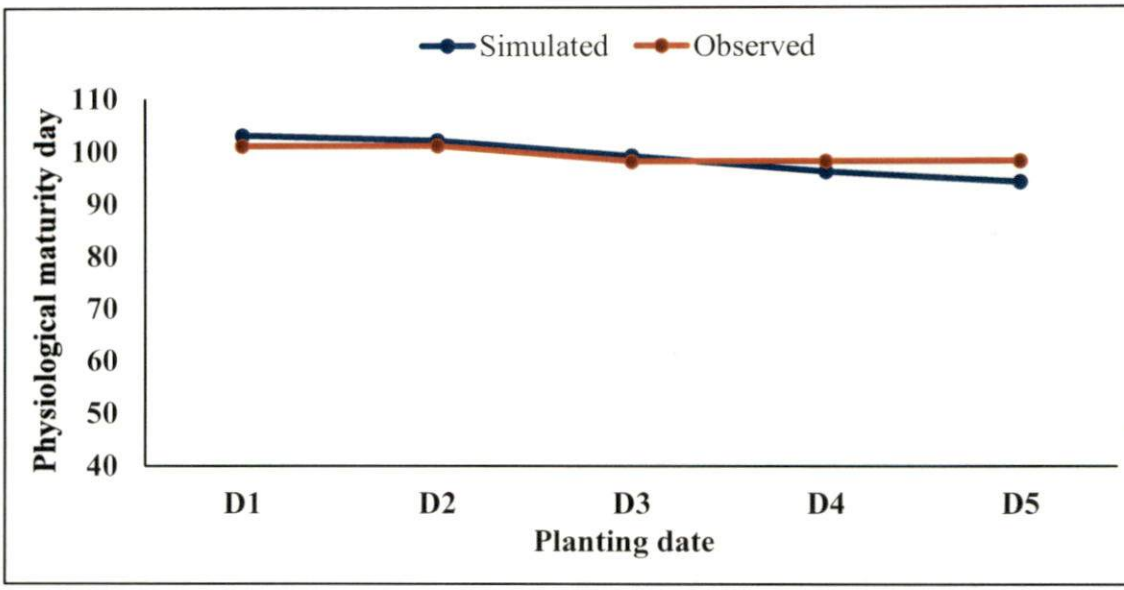

Fig.5.22(a). Observed and simulated physiological maturity day in Kanchana

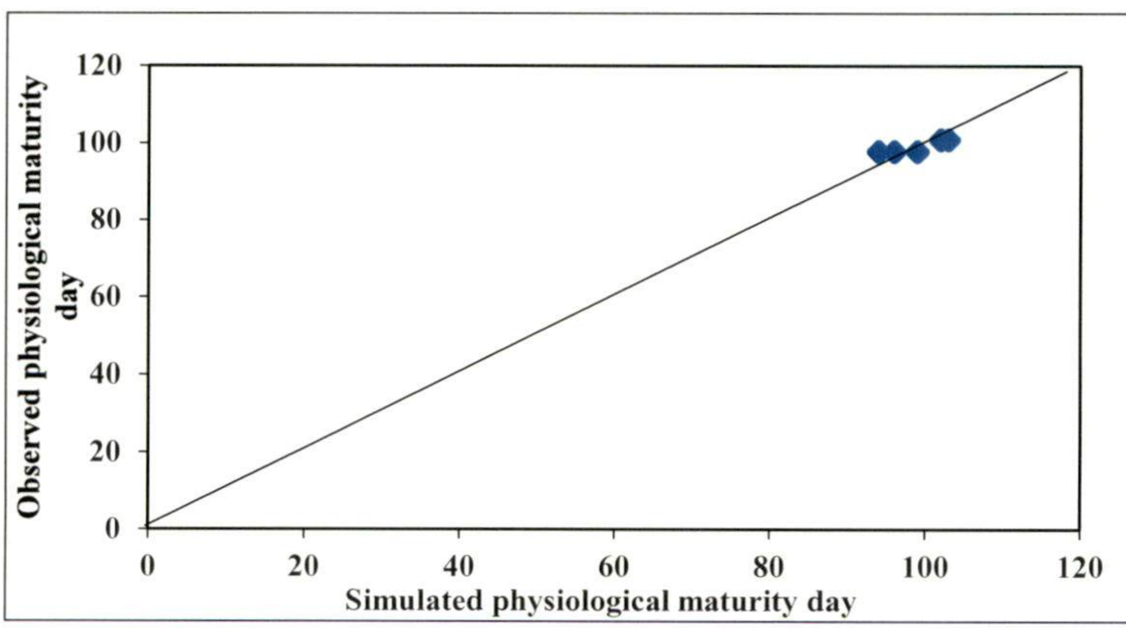

Fig.5.22(b). Scatter diagram of observed and simulated physiological maturity day in Kanchana

25.6 percent during 2050s and 2080s under RCP 4.5 scenario (Fig.5.23). This is mainly due to the projected increase in maximum temperature Fig.5.24(a & b), minimum temperature Fig.5.25(a & b) and decline in solar radiation Fig.5.26(a & b) during crop period. Under RCP 4.5 scenario, minimum temperature is increasing by 3.5 ^{0}C and 4.2 ^{0}C by 2050s and 2080s during the flowering stage which will increase the respiration losses and leads to reduction in the yield (Peng *et al.,* 2004) and increasing maximum temperature by 0.3 ^{0}C by 2080s shorten the length of the grain filling phase and reduce the seed setting rate in rice (Fu *et al.,* 2008). Solar radiation during reproductive or maturity phase is decreasing by 4.7 and 4.5 MJ/m^2/day by 2050s and 2080s respectively and this will have negative effect on the capacity of assimilation supply (photosynthesis), diminishing the number of filled spikelets in rice plants (Restrepo-Diaz and Garces-Varon, 2013).

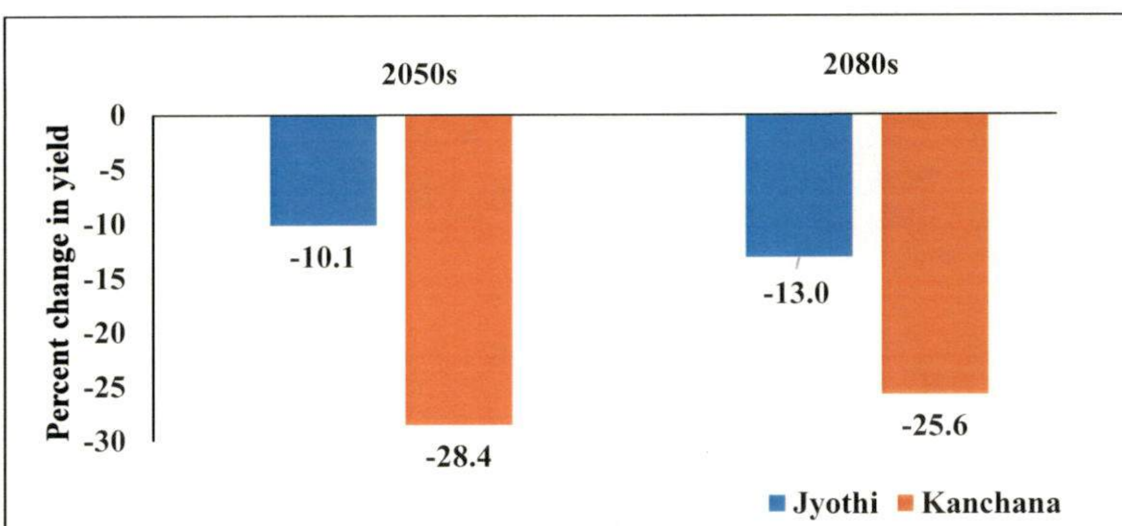

Fig.5.23. Percent change in yields of Jyothi and Kanchana under RCP 4.5 for the first date of planting

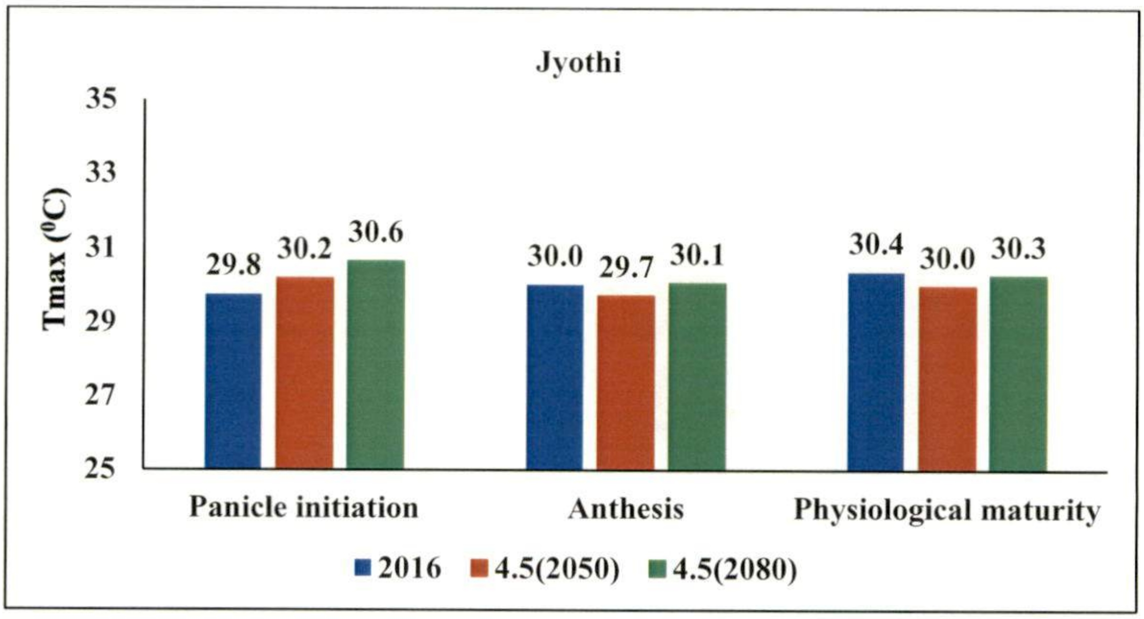

Fig.5.24(a). Effect of maximum temperature (^{0}C) on different phenophases of Jyothi under RCP 4.5 for the first date of planting

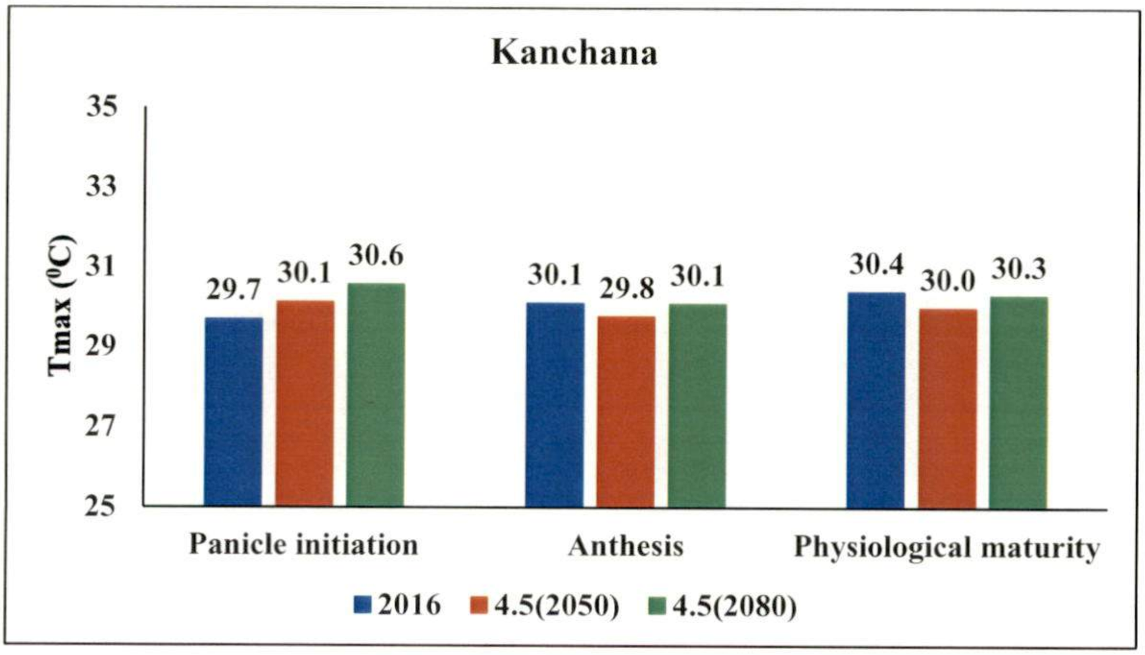

Fig.5.24(b). Effect of maximum temperature (^{0}C) on different phenophases of Kanchana under RCP 4.5 for the first date of planting

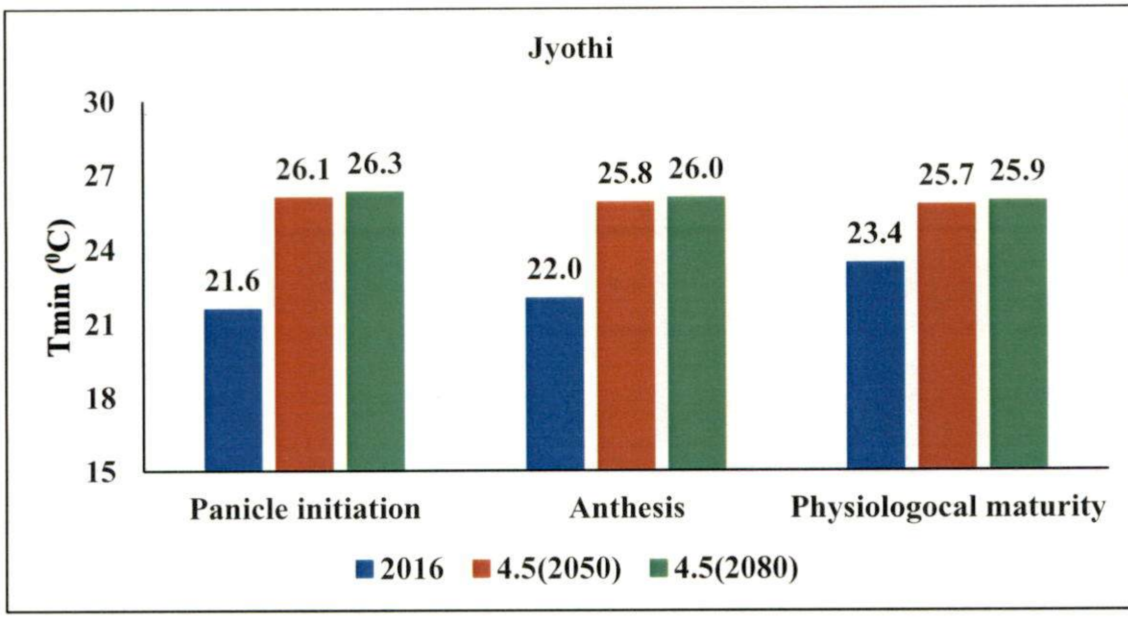

Fig.5.25(a). Effect of minimum temperature (^{0}C) on different phenophases of Jyothi under RCP 4.5 for the first date of planting

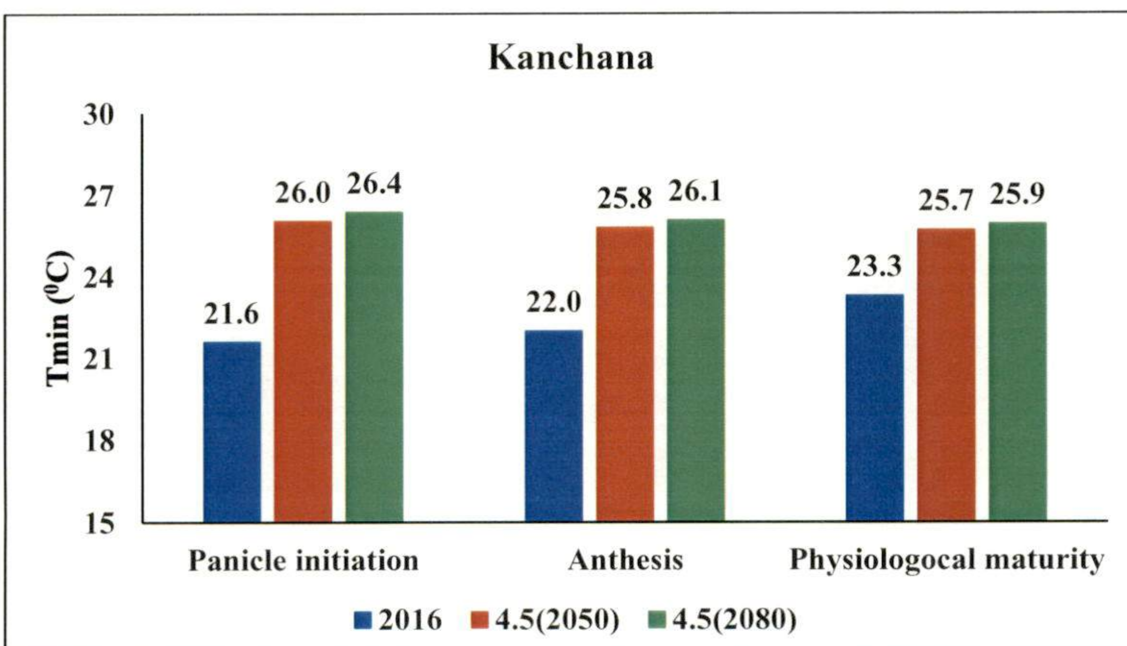

Fig.5.25(b). Effect of minimum temperature (^{0}C) on different phenophases of Kanchana under RCP 4.5 for the first date of planting

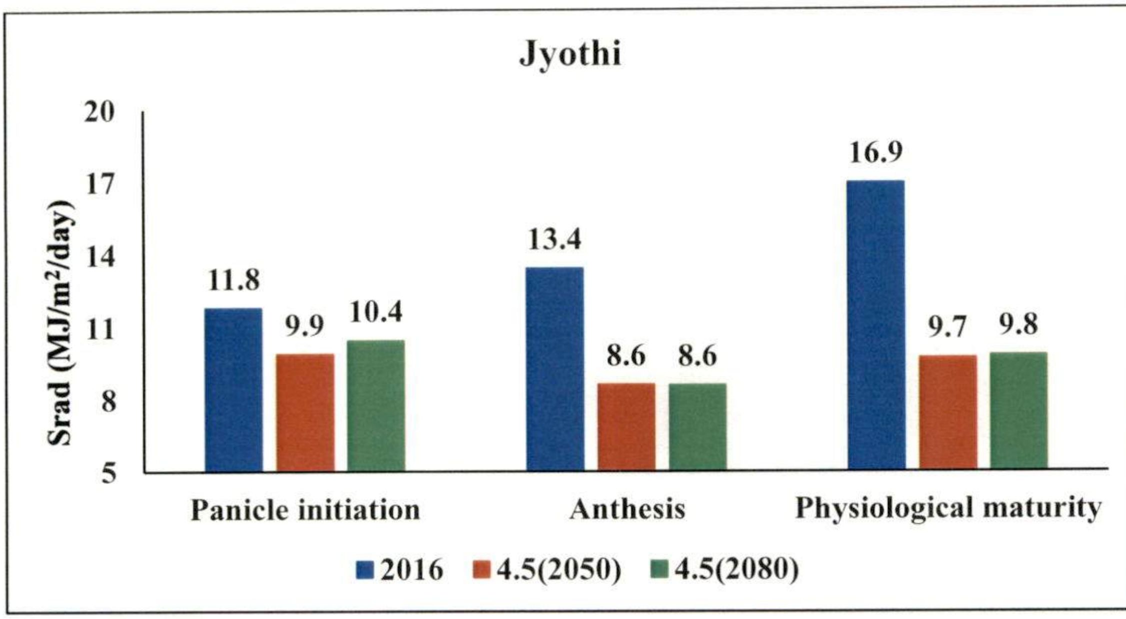

Fig.5.26(a). Effect of solar radiation (MJ/m^2/day) on different phenophases of Jyothi under RCP 4.5 for the first date of planting

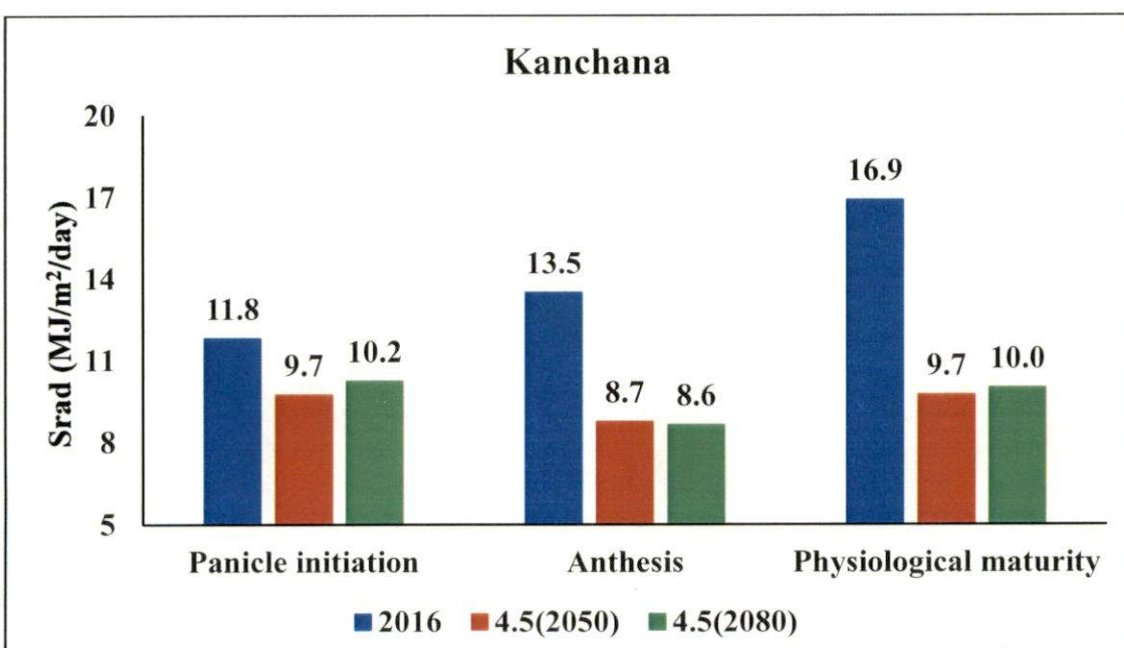

Fig.5.26(b). Effect of solar radiation (MJ/m^2/day) on different phenophases of Kanchana under RCP 4.5 for the first date of planting

5.5.1.2. Second date of planting (DOP2)

During second date of planting projected grain yield of Jyothi and Kanchana shows a declining trend towards the future scenario RCP 4.5 from the baseline (2016). The grain yield of Jyothi will be reduced by 13.4 percent and 14.1 percent during 2050s and 2080s, respectively. Whereas in Kanchana, the grain yield will be reduced by 36.7 and 35.3 percent during 2050s and 2080s under RCP 4.5 scenario (Fig 5.27). This is mainly due projected increase in maximum temperature Fig.5.28 (a & b), minimum temperatures Fig.5.29 (a & b) and decline in solar radiation Fig.5.30 (a & b) during crop period. Under RCP 4.5 scenario, minimum temperature is increasing by 3.2 ^{0}C and 4.5 ^{0}C by 2050s and 2080s during the flowering stage which will increase the respiration losses and leads to yield reduction (Peng *et al.,* 2004) and increasing maximum temperatures at 0.3 ^{0}C and 0.9^{0}C by 2050 and 2080s shorten the length of the grain filling phase and reduce the seed setting rate in rice (Fu *et al.,* 2008). Solar radiation during reproductive or maturity phase is decreasing by 4.7 and 4.5 MJ/m^2/day by 2050s and 2080s respectively and this will have negative effect on the capacity of assimilation supply (photosynthesis), diminishing the number of filled spikelets in rice plants. This is in agreement with the studies conducted by Restrepo-Diaz and Garces-Varon (2013).

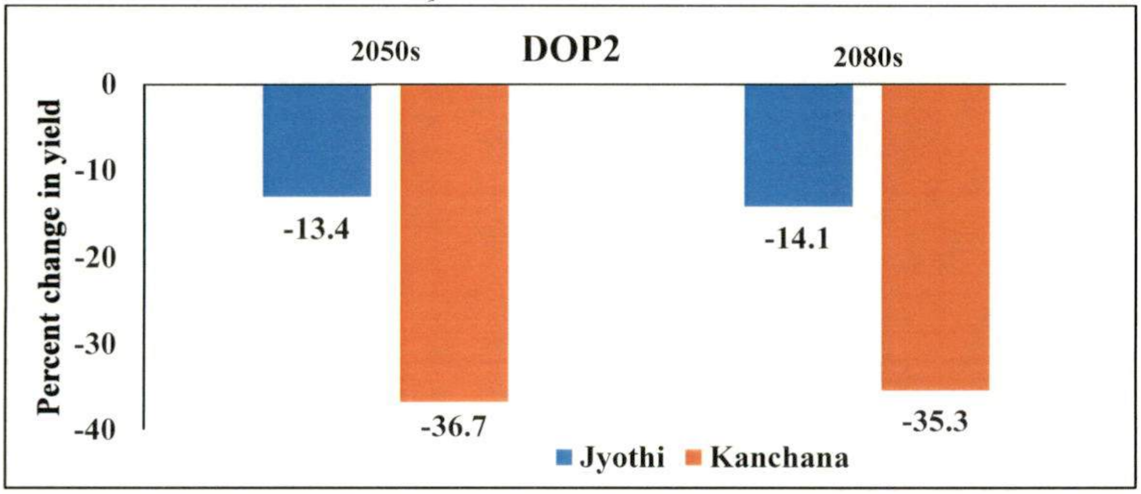

Fig.5.27. Percent change in yields of Jyothi and Kanchana under RCP 4.5 for the second date of planting

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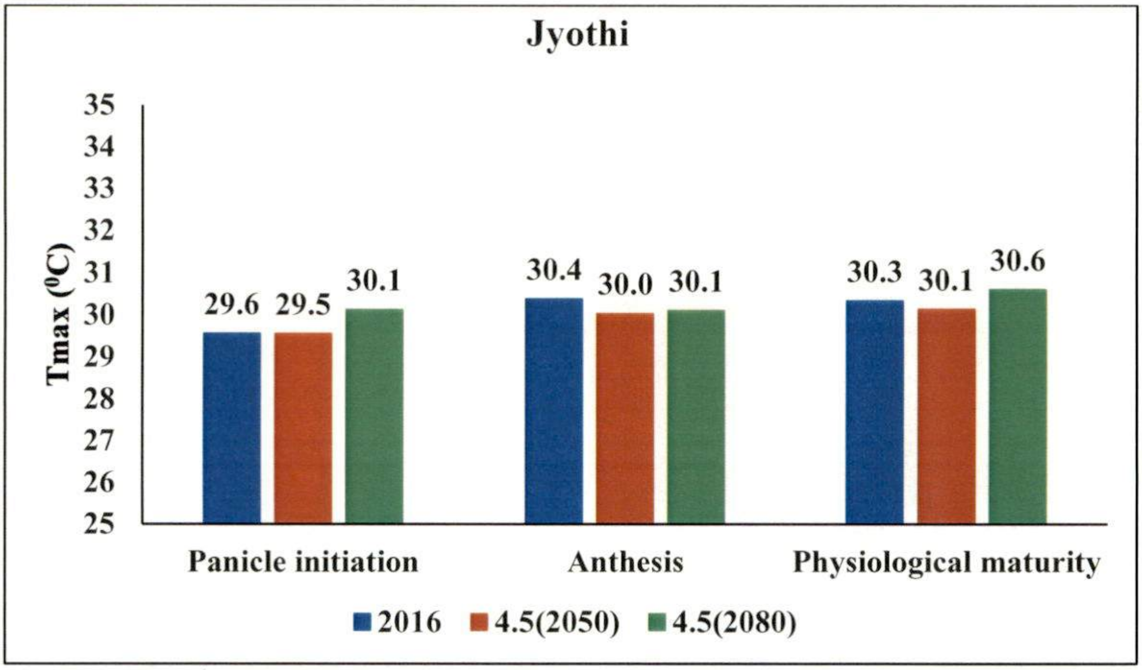

Fig.5.28(a). Effect of maximum temperature (^{0}C) on different phenophases of Jyothi under RCP 4.5 for the second date of planting

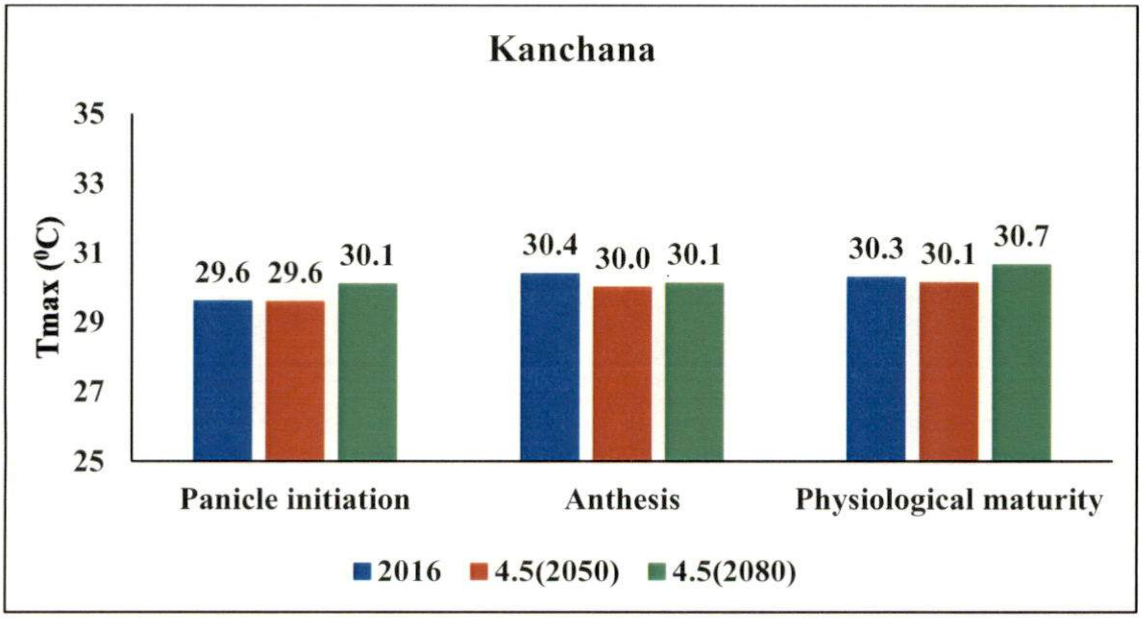

Fig.5.28(b). Effect of maximum temperature (^{0}C) on different phenophases of Kanchana under RCP 4.5 for the second date of planting

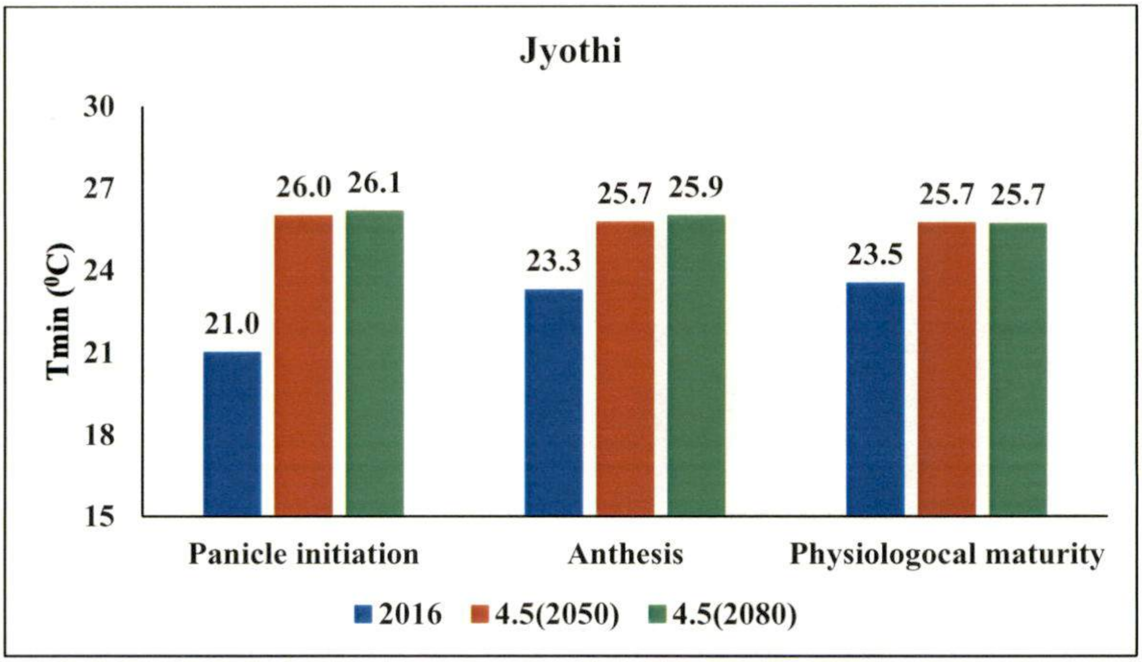

Fig.5.29(a). Effect of minimum temperature (^{0}C) on different phenophases of Jyothi under RCP 4.5 for the second date of planting

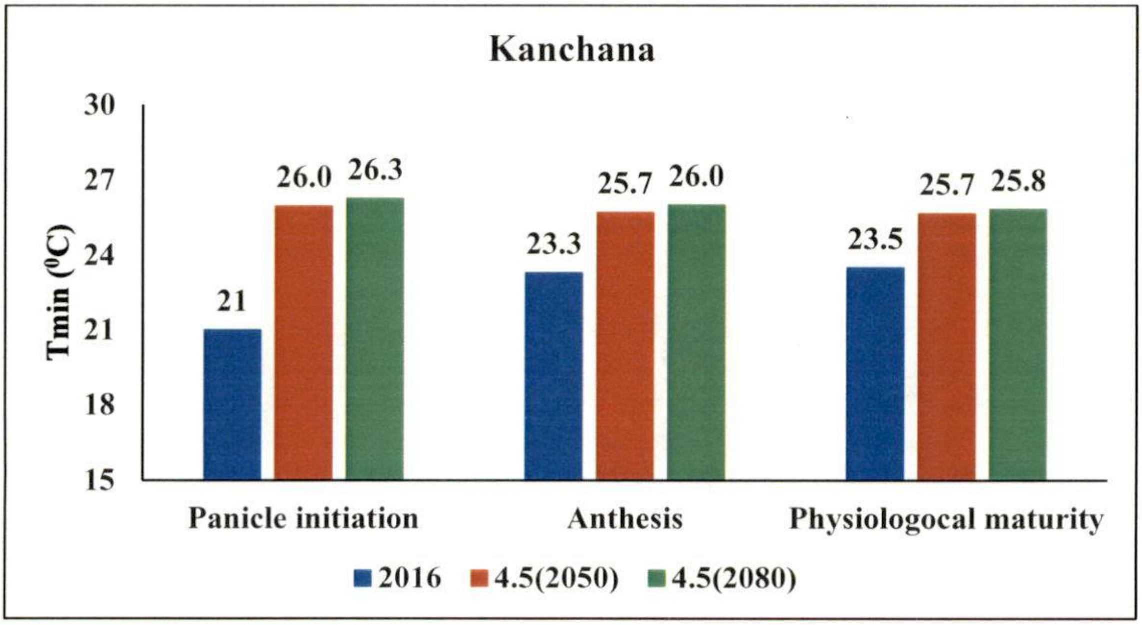

Fig.5.29(b). Effect of minimum temperature (^{0}C) on different phenophases of Kanchana under RCP 4.5 for the second date of planting

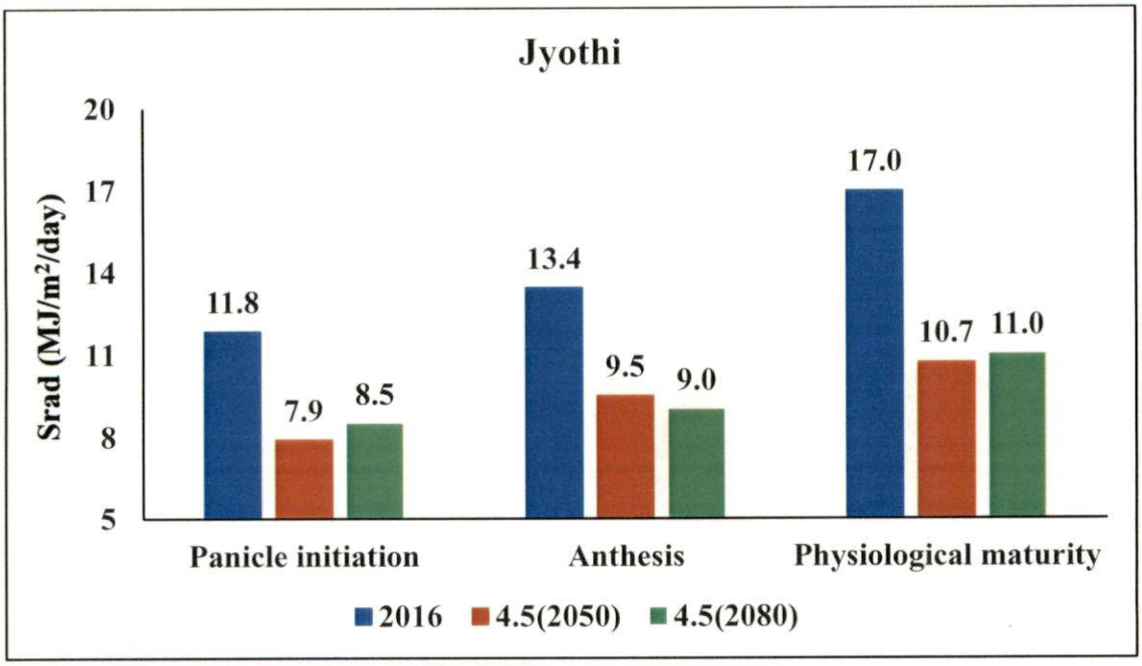

Fig.5.30(a). Effect of solar radiation (MJ/m^2/day) on different phenophases of Jyothi under RCP 4.5 for the second date of planting

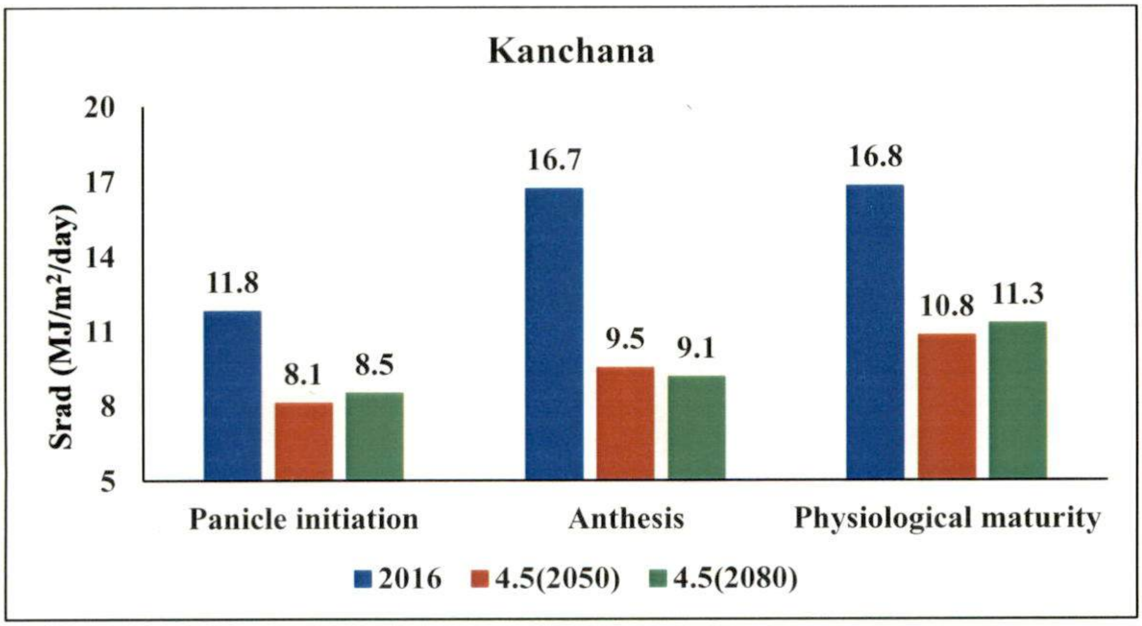

Fig.5.30(b). Effect of solar radiation (MJ/m^2/day) on different phenophases of Kanchana under RCP 4.5 for the second date of planting

5.5.1.3. Third date of planting (DOP3)

During third date of planting projected grain yield of Jyothi and Kanchana shows an increasing trend towards the future scenario RCP 4.5 from the baseline. The grain yield of Jyothi will be increasing by 17.1 and 20.0 percent during 2050s and 2080s, respectively. But in Kanchana, the grain yield will be increasing by 20.5 and 21.6 percent during 2050s and 2080s under RCP 4.5 scenario (Fig 5.31). This may be due to increase in rainfall Fig 5.32 (a & b) during panicle initiation and anthesis period and fertilization effect of CO_2. Under RCP 4.5, during 2050s and 2080s CO_2 concentration is projected to be 492 and 532 ppm than the baseline 380ppm. These results are in confirmation with Krishnan *et al.,* (2007) that every 1^0C increase in temperature decreases the rice yield by 7.2% at current CO_2 concentration (380ppm) but increase in CO_2 enrichment up to 700ppm will leads to an average increase of 31% rice yields in India.

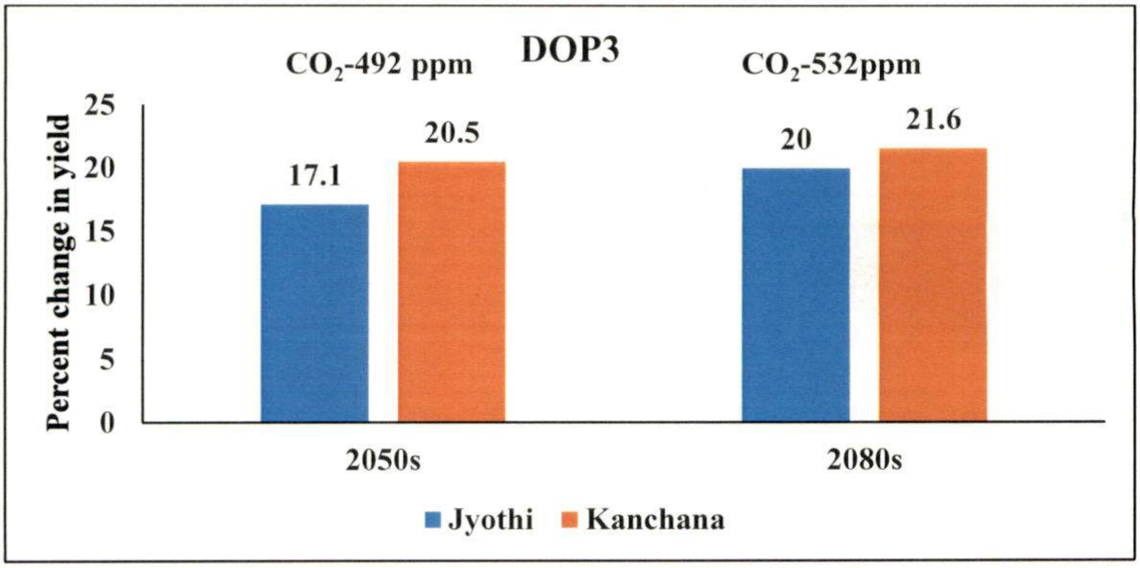

Fig.5.31. Percent change in yields of Jyothi and Kanchana under RCP 4.5 for the third date of planting

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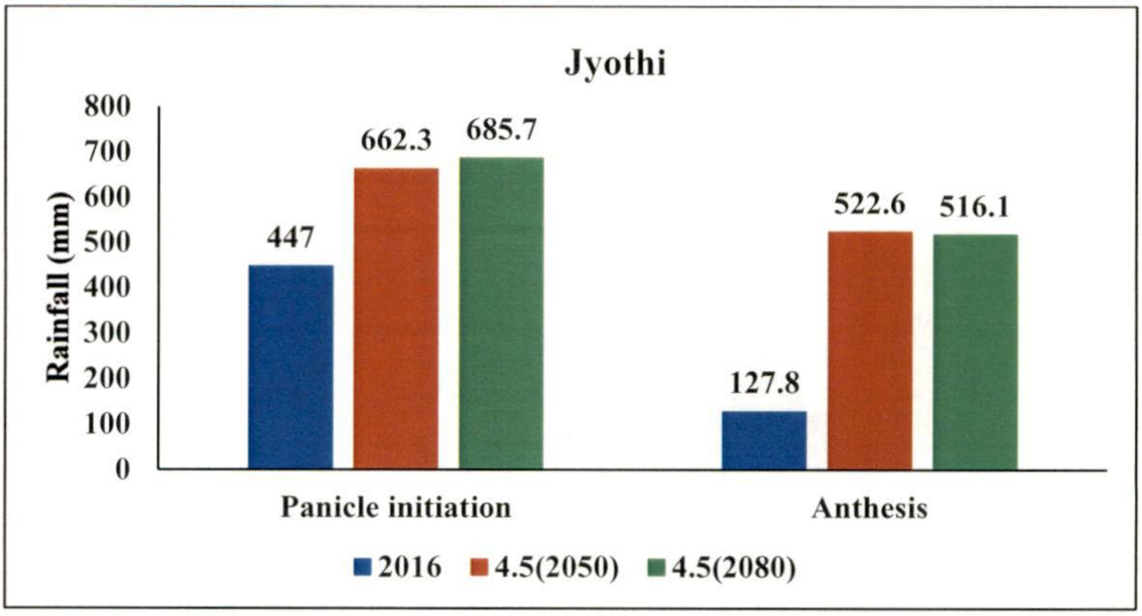

Fig.5.32(a). Effect of rainfall (mm) on different phenophases of Jyothi under RCP 4.5 for the third date of planting

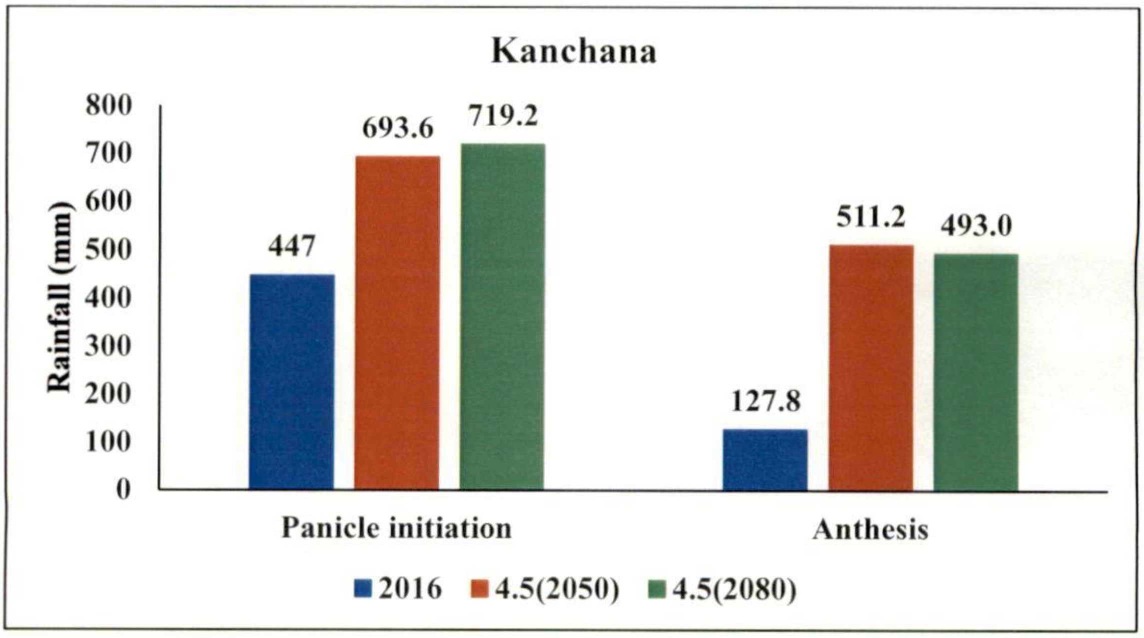

Fig.5.32(b). Effect of rainfall (mm) on different phenophases of Kanchana under RCP 4.5 for the third date of planting

5.5.1.4. Fourth date of planting (DOP4)

During fourth date of planting projected grain yield of Jyothi and Kanchana shows an increasing trend towards the future scenario RCP 4.5 from the baseline. The grain yield of Jyothi will be increasing by 37.3 and 40.3 percent during 2050s and 2080s, respectively. Whereas in Kanchana, the grain yield will be increasing by 0.3 and 3.2 percent during 2050s and 2080s under RCP 4.5 scenario (Fig 5.33). This is mainly due to increase in solar radiation Fig 5.34 (a & b) and fertilization effect of CO_2 enrichment. Increase in solar radiation during anthesis and physiological maturity period shows a positive effect on capacity of assimilation supply (photosynthesis), increasing the number of filled spikelets in rice plants and increase grain yield (Restrepo-Diaz and Garces-Varon, 2013). Under RCP 4.5, during 2050s and 2080s the projected CO_2 concentration to be increasing by 492 and 532 ppm than the baseline 380ppm. These results are in confirmation with Krishnan *et al.,* (2007) that every 1^0C increase in temperature decreases the rice yield by 7.2% at current CO_2 concentration (380ppm). But, increase in CO_2 enrichment up to 700ppm will leads to an average increase of 31% rice yields in India.

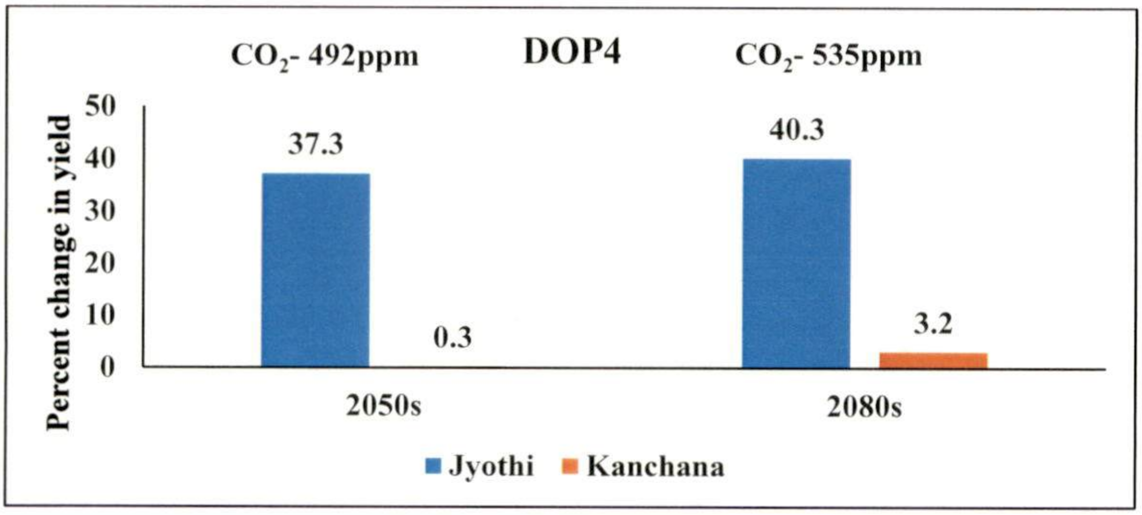

Fig.5.33. Percent change in yield of Jyothi and Kanchana under RCP 4.5 for the fourth date of planting

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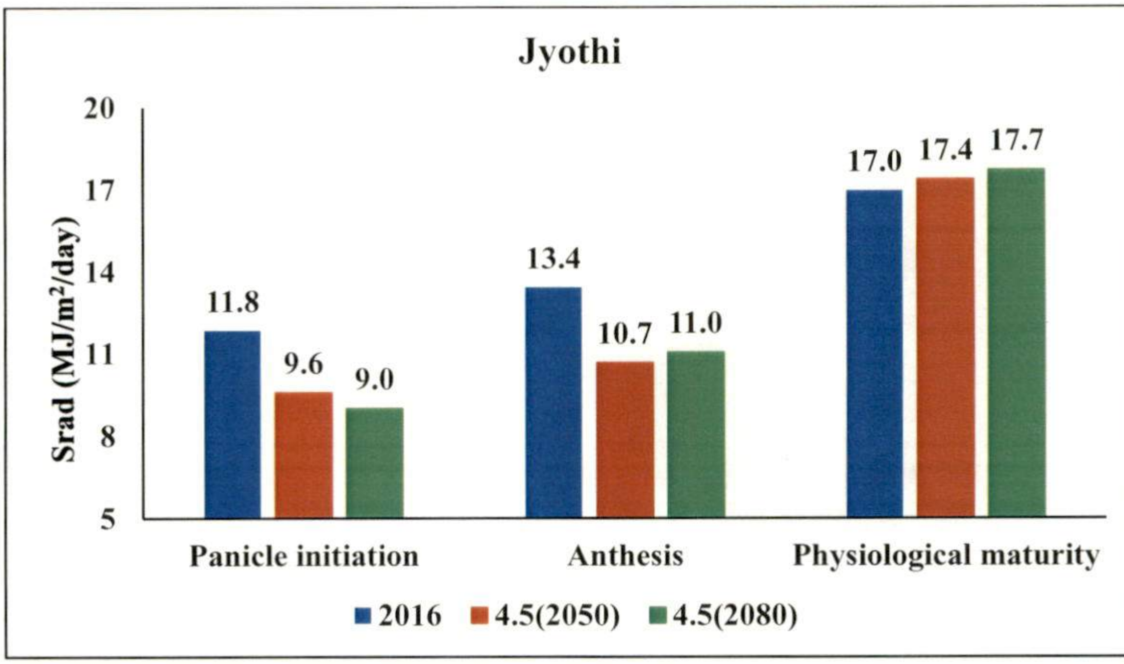

Fig.5.34(a). Effect of solar radiation (MJ/m^2/day) on different phenophases of Jyothi under RCP 4.5 for the fourth date of planting

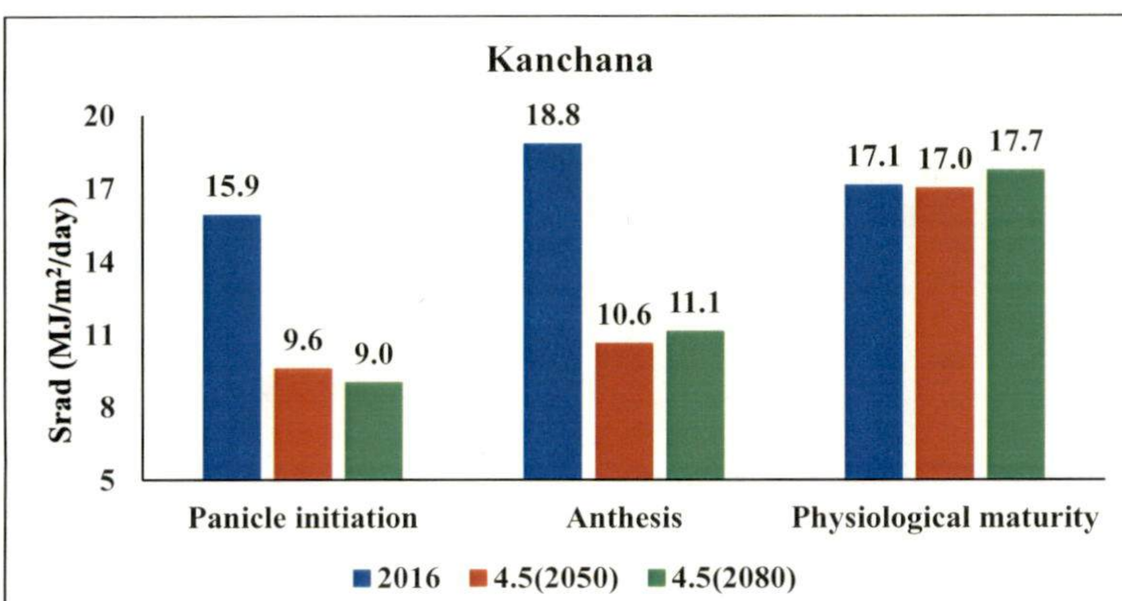

Fig.5.34(b). Effect of solar radiation (MJ/m^2/day) on different phenophases of Kanchana under RCP 4.5 for the fourth date of planting

5.5.1.5. Fifth date of planting (DOP5)

During fifth date of planting projected grain yield of Jyothi and Kanchana shows an increasing trend towards the future scenario RCP 4.5 from the baseline. The grain yield of Jyothi will be increasing by 66.9 and 72.8 percent during 2050s and 2080s, respectively. Whereas in Kanchana, the grain yield will be increasing by 20.4 and 28.7 percent during 2050s and 2080s under RCP 4.5 scenario (Fig 5.35). This is mainly due to increase in solar radiation Fig 5.36(a & b) and fertilization effect of CO_2 enrichment. Increase in solar radiation during anthesis and physiological maturity period shows a positive effect on capacity of assimilation supply (photosynthesis), increasing the number of filled spikelets in rice plants and increases grain yield (Restrepo-Diaz and Garces-Varon, 2013). Under RCP 4.5, during 2050s and 2080s the projected CO_2 concentration to be increasing by 492 and 532 ppm than the baseline 380ppm. These results are in confirmation with Krishnan *et al.,* (2007) that every 1^0C increase in temperature decreases the rice yield by 7.2% at current CO_2 concentration (380ppm). But, increase in CO_2 enrichment up to 700ppm will leads to an average increase of 31% rice yields in India.

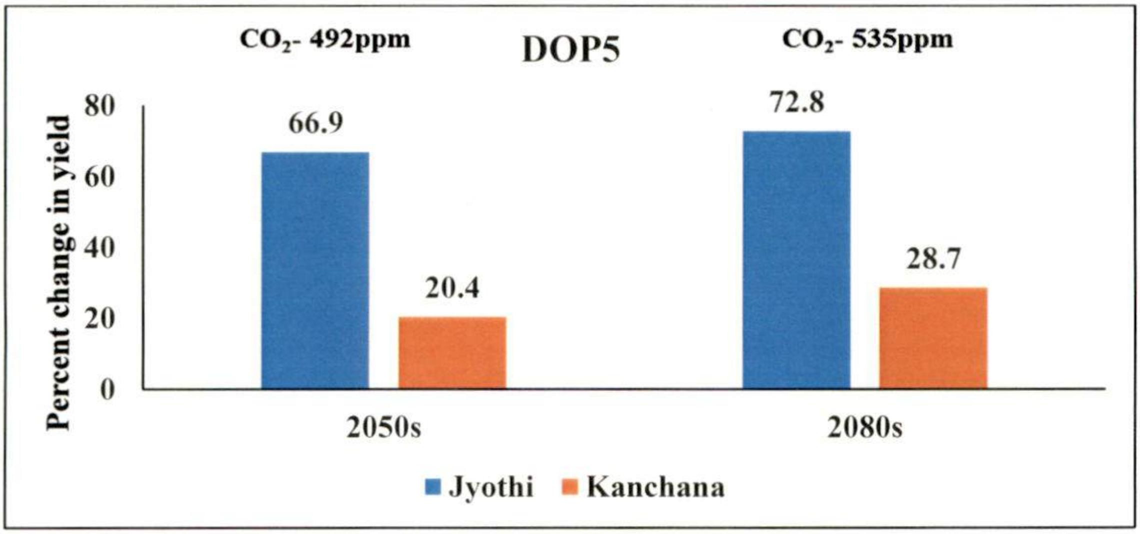

Fig.5.35. Percent change in yields of Jyothi and Kanchana under RCP 4.5 for the fifth date of planting

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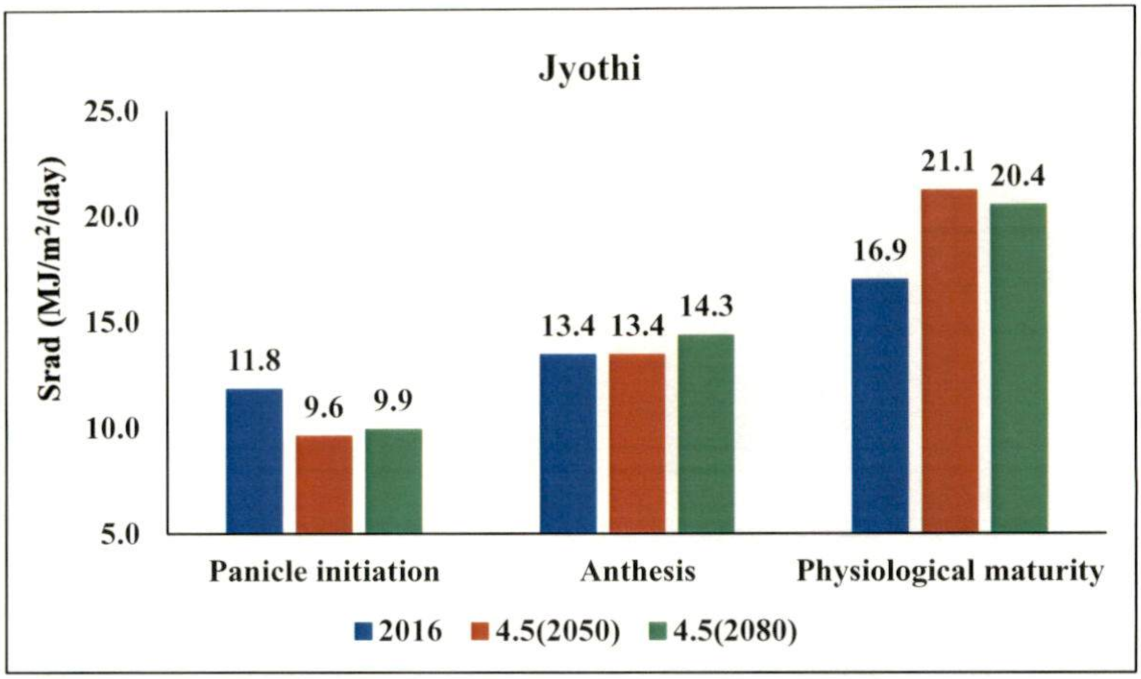

Fig.5.36(a). Effect of solar radiation (MJ/m²/day) on different phenophases of Jyothi under RCP 4.5 for the fifth date of planting

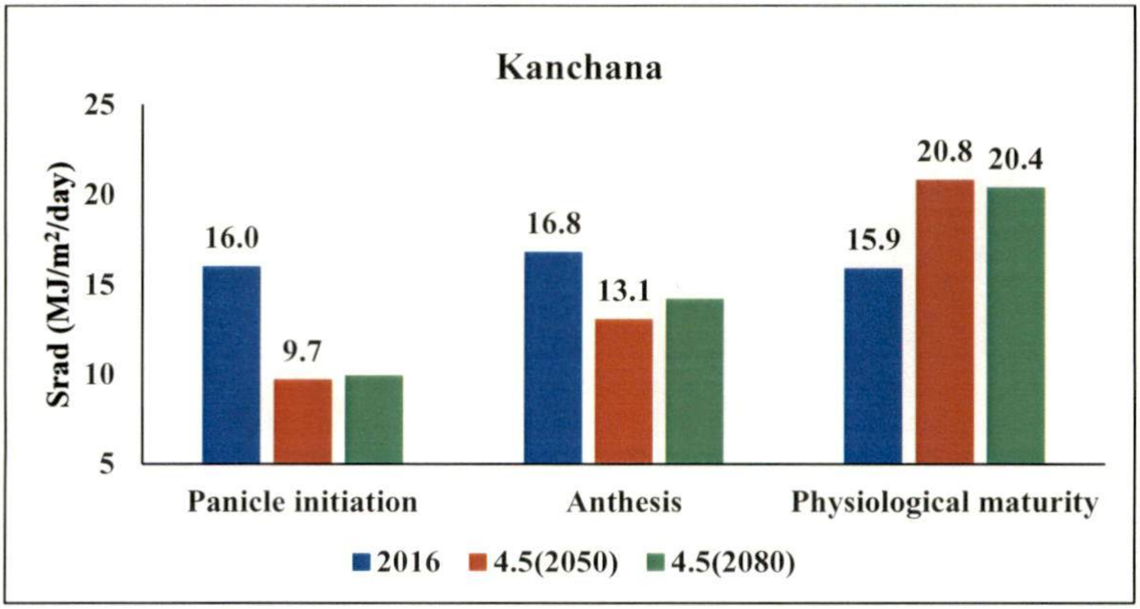

Fig.5.36(b). Effect of solar radiation (MJ/m²/day) on different phenophases of Kanchana under RCP 4.5 for the fifth date of planting

5.5.2. Projected changes in yields of Jyothi and Kanchana under RCP 8.5 scenario

5.5.2.1. First date of Planting (DOP1)

During first date of planting projected grain yield of Jyothi and Kanchana shows a declining trend towards the future scenario RCP 8.5 from the baseline. The grain yield of Jyothi will be reduced by 9.7 and 15.3 percent during 2050s and 2080s, respectively. Whereas in Kanchana, the grain yield will be reduced by 22.3 and 17.7 percent during 2050s and 2080s under RCP 8.5 scenario (Fig 5.37). This is mainly due to projected increase in maximum temperature Fig 5.38 (a & b) and minimum temperatures Fig 5.39 (a & b) and decline in solar radiation Fig 5.40 (a & b) during crop period. Under RCP 8.5 scenario, minimum temperature is increasing by 4.2 ^{0}C and 5.2 ^{0}C by 2050s and 2080s during the flowering stage which will increase the respiration losses and leads to yield reduction (Peng *et al.*, 2004) and increasing maximum temperatures at 0.9 ^{0}C and 1.8 ^{0}C by 2050s and 2080s shorten the length of the grain filling phase and reduce the seed setting rate in rice (Fu *et al.*, 2008). Solar radiation during reproductive or maturity phase is decreasing by 4.7 and 4.5 MJ/m^2/day by 2050s and 2080s respectively and this will have negative effect on the capacity of assimilation supply (photosynthesis), diminishing the number of filled spikelets in rice plants (Restrepo-Diaz and Garces-Varon, 2013).

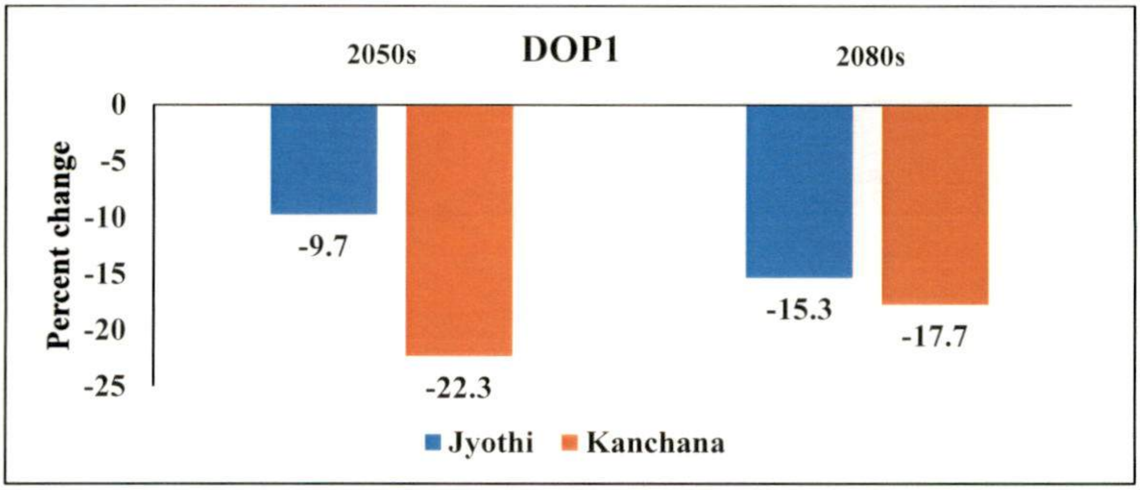

Fig.5.37. Percent change in yields of Jyothi and Kanchana under RCP 8.5 for the first date of planting

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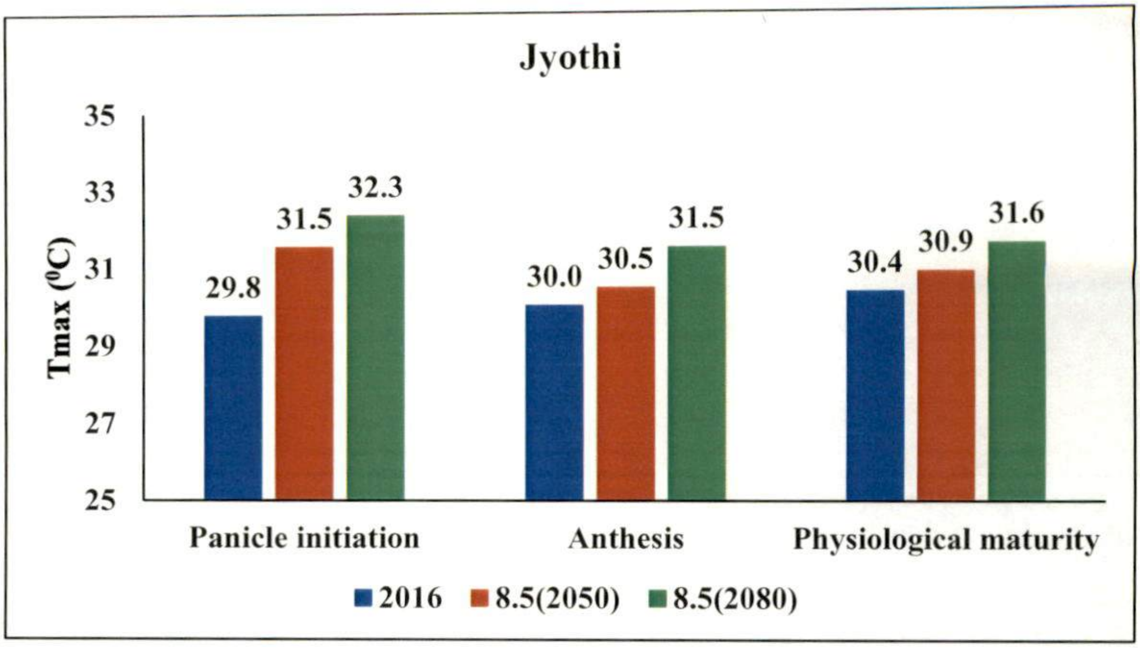

Fig.5.38(a). Effect of maximum temperature (^{0}C) on different phenophases of Jyothi under RCP 8.5 for the first date of planting

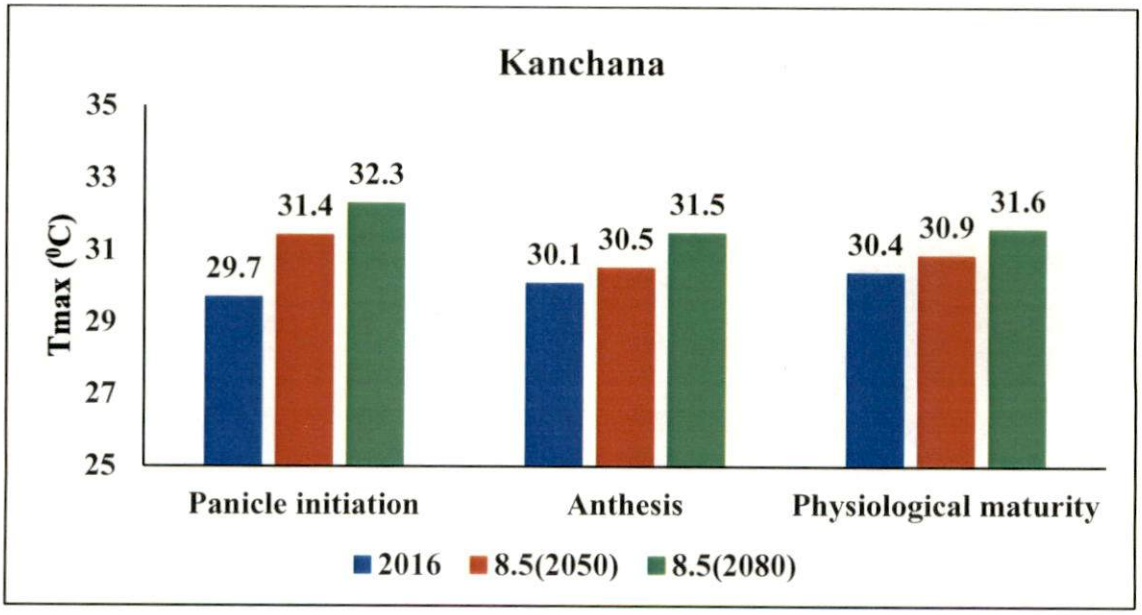

Fig.5.38(b). Effect of maximum temperature (^{0}C) on different phenophases of Kanchana under RCP 8.5 for the first date of planting

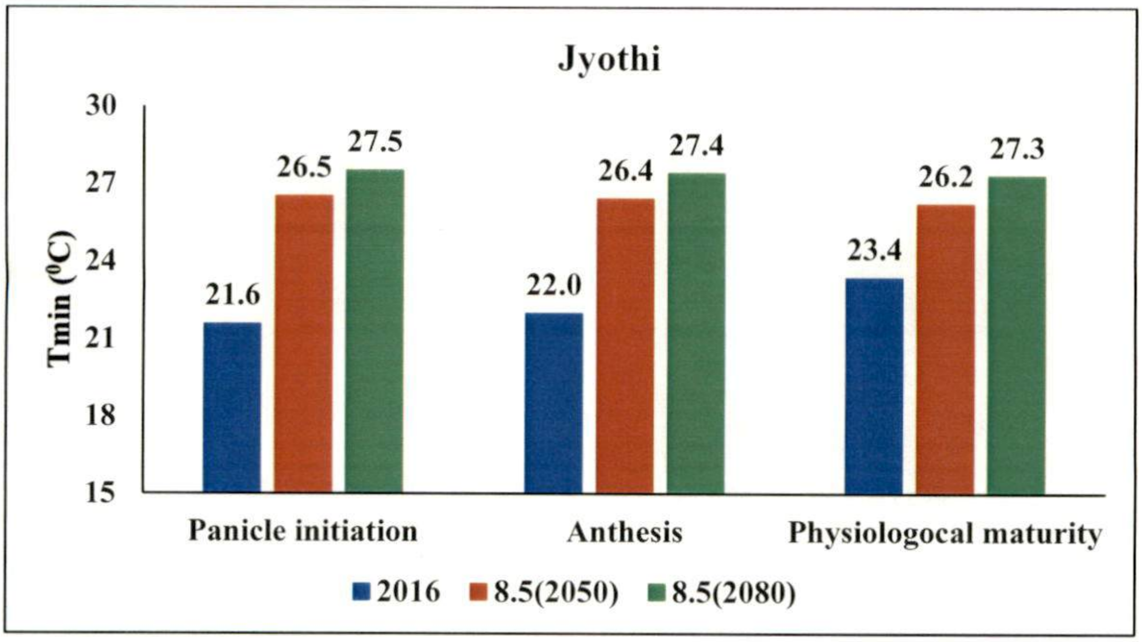

Fig.5.39(a). Effect of minimum temperature (^{0}C) on different phenophases of Jyothi under RCP 8.5 for the first date of planting

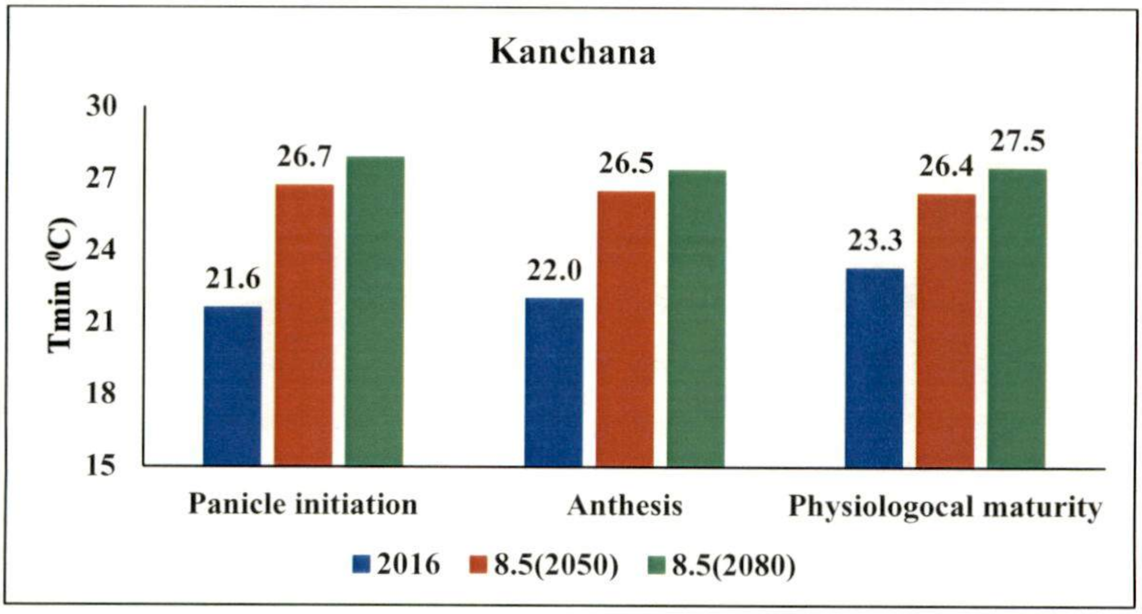

Fig.5.39(b). Effect of minimum temperature (^{0}C) on different phenophases of Kanchana under RCP 8.5 for the first date of planting

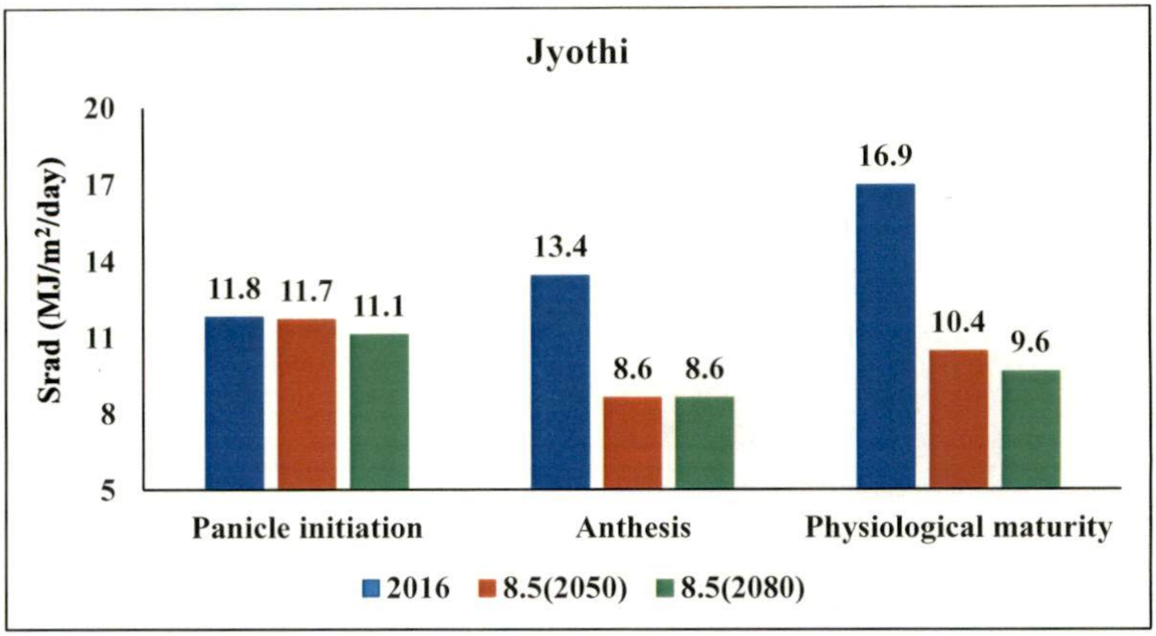

Fig.5.40(a). Effect of solar radiation (MJ/m^2/day) on different phenophases of Jyothi under RCP 8.5 for the first date of planting

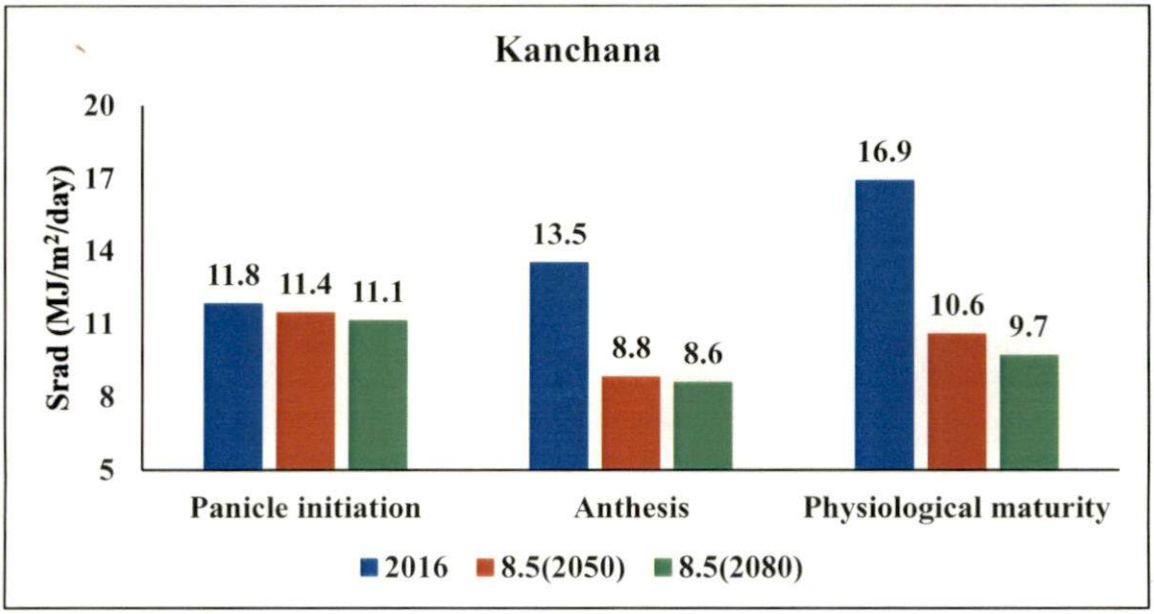

Fig.5.40(b). Effect of solar radiation (MJ/m^2/day) on different phenophases of Kanchana under RCP 8.5 for the first date of planting

5.5.2.2. Second date of planting (DOP2)

During second date of planting projected grain yield of Jyothi and Kanchana shows a declining trend towards the future scenario RCP 8.5 from the baseline. The grain yield of Jyothi will be reduced by 9.7 percent and 15.9 percent during 2050s and 2080s, respectively. Whereas in Kanchana, the grain yield will be reduced by 31.9 and 28.8 percent during 2050s and 2080s under RCP 8.5 scenario (Fig 5.41). This is mainly due to projected increase in maximum temperature Fig 5.42 (a & b) and minimum temperatures Fig 5.43 (a & b) and decline in solar radiation Fig 5.44 (a & b) during crop period. Under RCP 8.5 scenario, minimum temperature is increasing by 3.9 ^{0}C and 4.9 ^{0}C by 2050s and 2080s during the flowering stage which will increase the respiration losses and leads to yield reduction (Peng *et al.,* 2004) and increasing maximum temperatures at 0.8 ^{0}C and 1.6 by 2050 and 2080s shorten the length of the grain filling phase and reduce the seed setting rate in rice (Fu *et al.,* 2008). Solar radiation during reproductive or maturity phase is decreasing by 4.7 and 4.5 MJ/m^2/day by 2050s and 2080s respectively and this will have negative effect on the capacity of assimilation supply (photosynthesis), diminishing the number of filled spikelets in rice plants (Restrepo-Diaz and Garces-Varon, 2013).

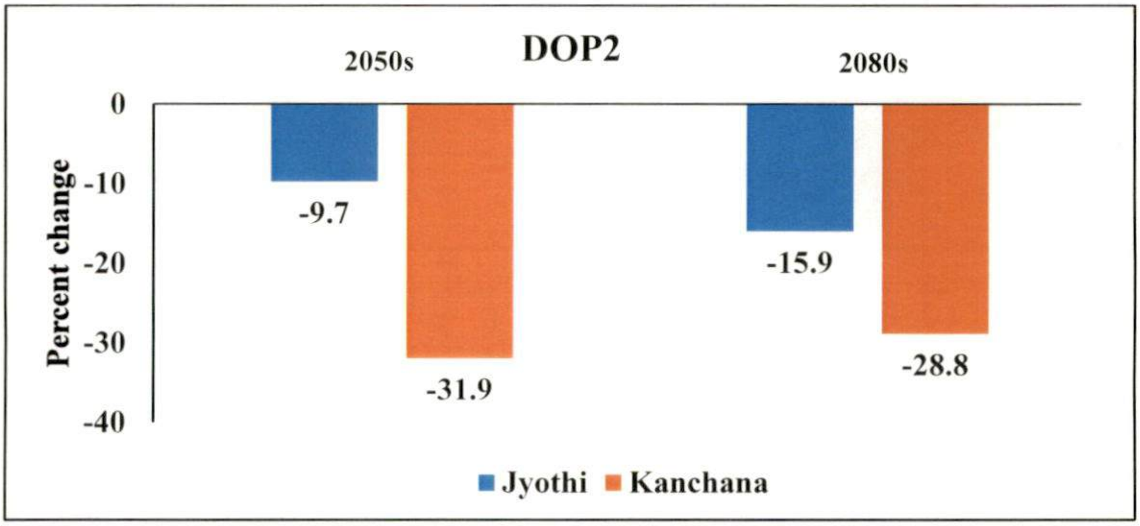

Fig.5.41. Percent change in yields of Jyothi and Kanchana under RCP 8.5 for the second date of planting

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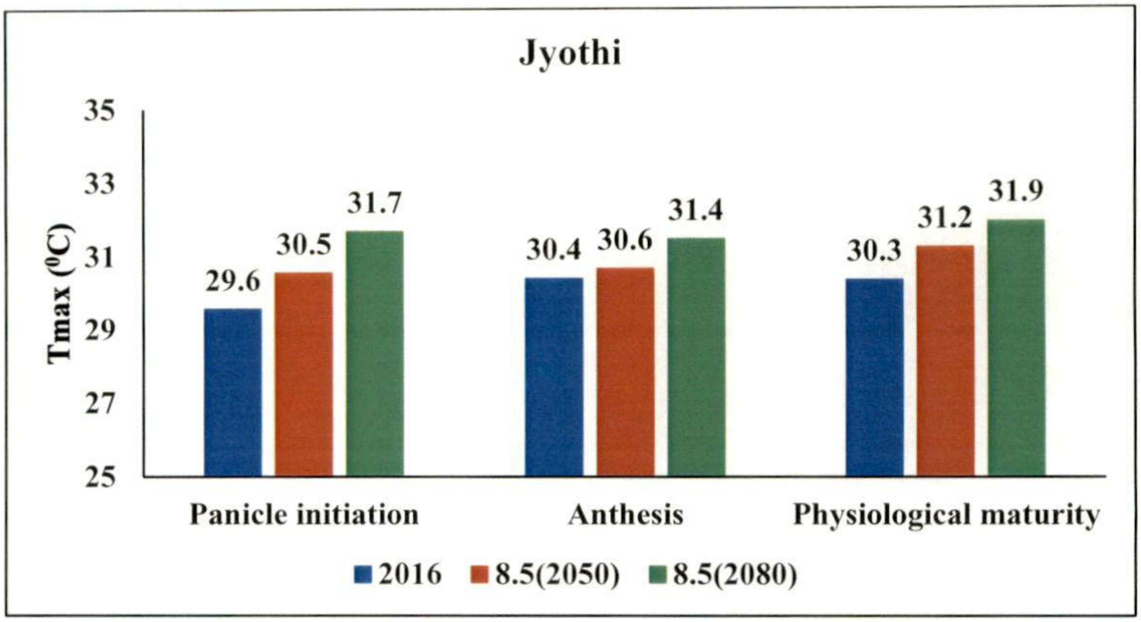

Fig.5.42(a). Effect of maximum temperature (^{0}C) on different phenophases of Jyothi under RCP 8.5 for the second date of planting

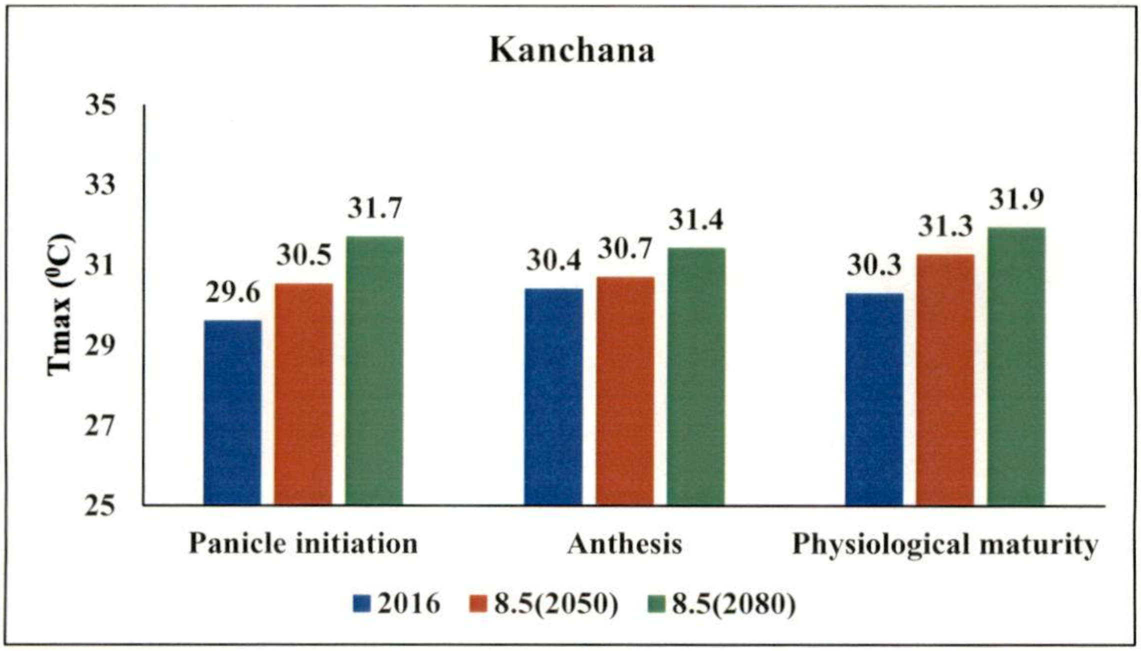

Fig.5.42(b). Effect of maximum temperature (^{0}C) on different phenophases of Kanchana under RCP 8.5 for the second date of planting

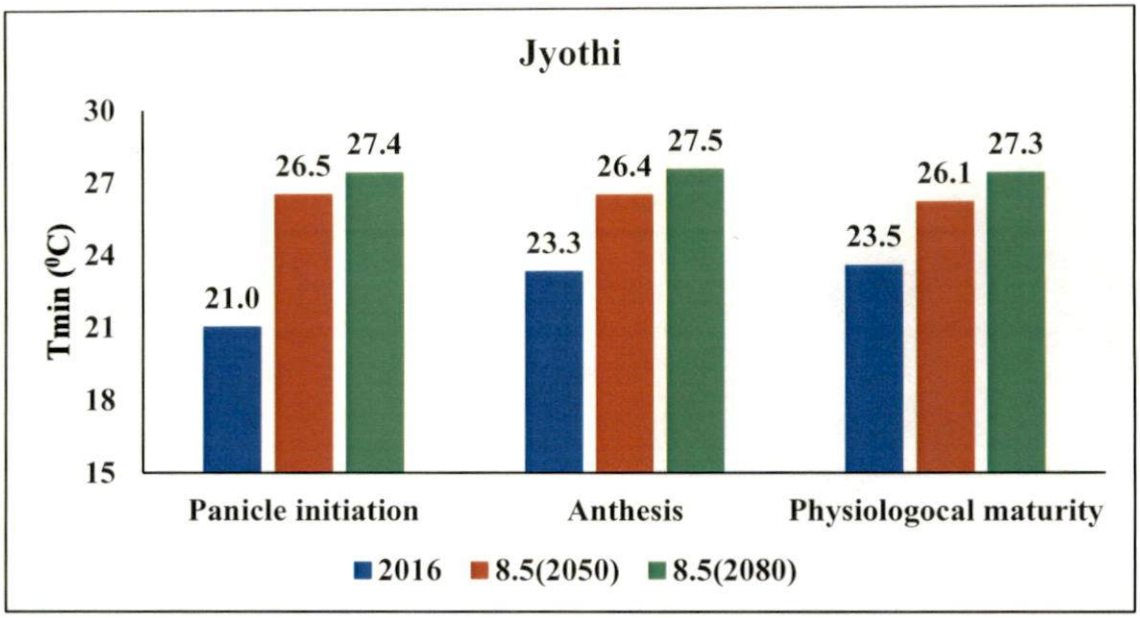

Fig.5.43(a). Effect of minimum temperature (^{0}C) on different phenophases of Jyothi under RCP 8.5 for the second date of planting

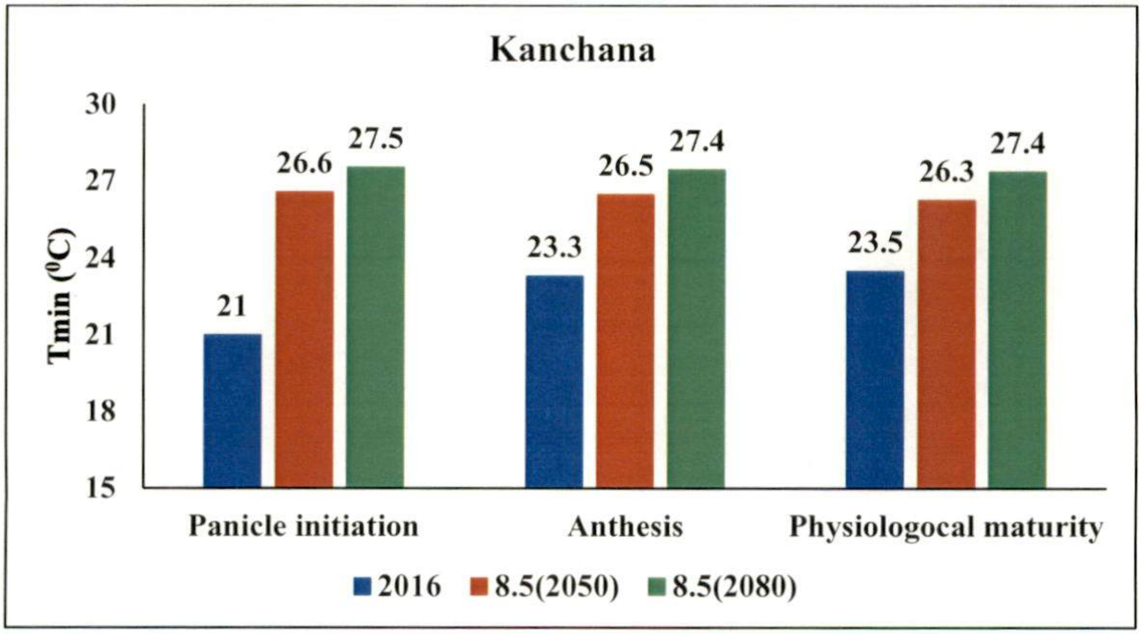

Fig.5.43(b). Effect of minimum temperature (^{0}C) on different phenophases of Kanchana under RCP 8.5 for the second date of planting

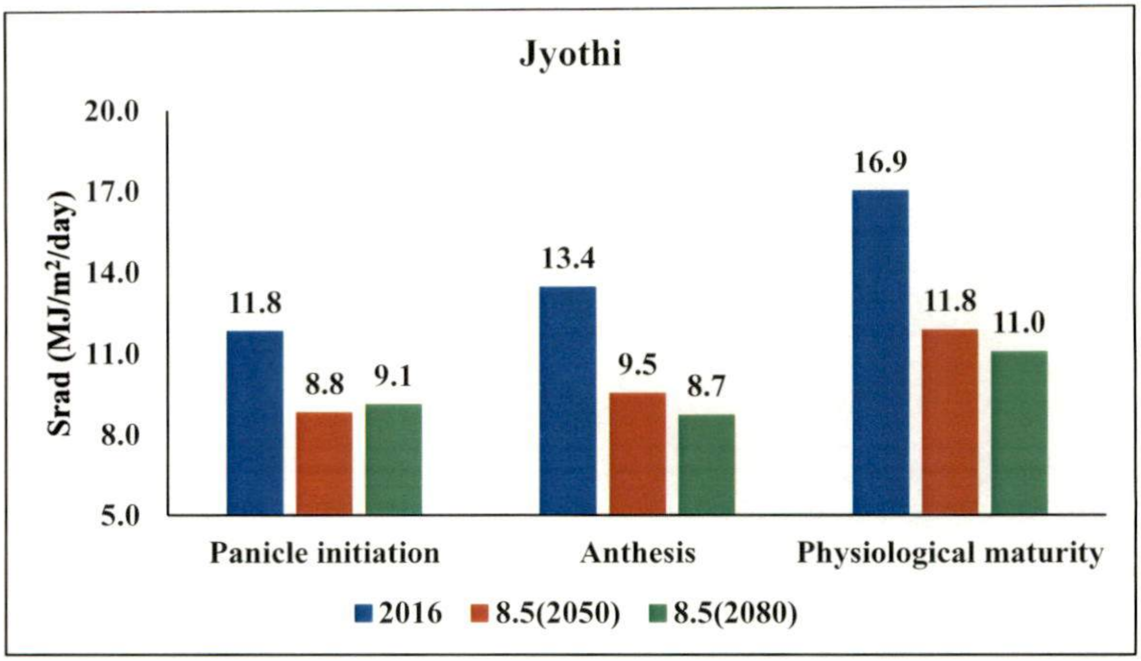

Fig.5.44(a). Effect of solar radiation (MJ/m²/day) on different phenophases of Jyothi under RCP 8.5 for the second date of planting

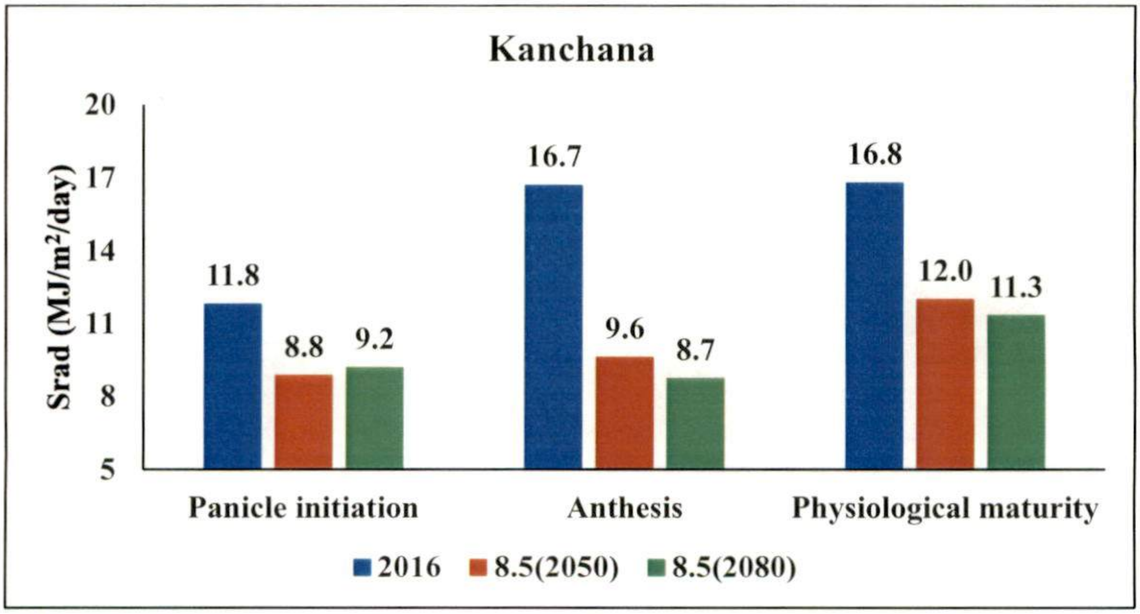

Fig.5.44(b). Effect of solar radiation (MJ/m²/day) on different phenophases of Kanchana under RCP 8.5 for the second date of planting

5.5.2.3. Third date of planting (DOP3)

During third date of planting projected grain yield of Jyothi and Kanchana shows an increasing trend towards the future scenario RCP 8.5 from the baseline. The grain yield of Jyothi will be increasing by 23.5 and 12.6 percent during 2050s and 2080s, respectively. But in Kanchana, the grain yield will be increasing by 23.7 and 31.6 percent during 2050s and 2080s under RCP 8.5 scenario (Fig 5.45). This is may be due to increase in rainfall Fig 5.46 (a & b) during panicle initiation and anthesis period and fertilization effect of CO_2. Under RCP 8.5, during 2050s and 2080s CO_2 concentration is projected to be 571 and 801 ppm than the baseline 380ppm. These results are in confirmation with Krishnan *et al.,* (2007) that every 1^0C increase in temperature decreases the rice yield by 7.2% at current CO_2 concentration (380ppm) but increase in CO_2 enrichment up to 700ppm will leads to an average increase of 31% rice yields in India.

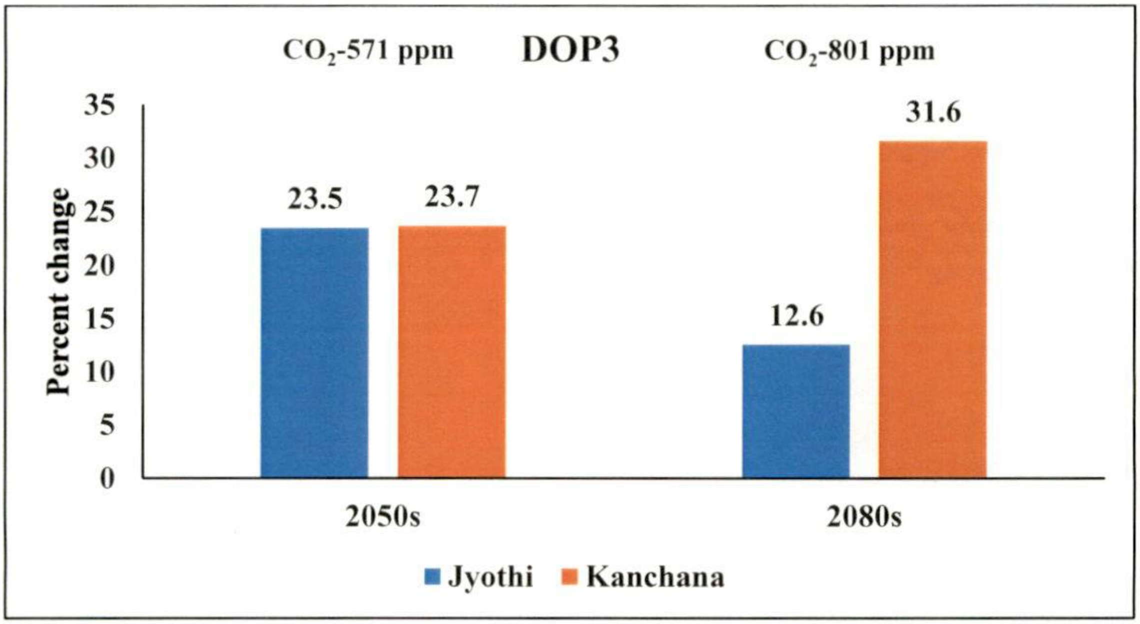

Fig.5.45. Percent change in yields of Jyothi and Kanchana under RCP 8.5 for the third date of planting

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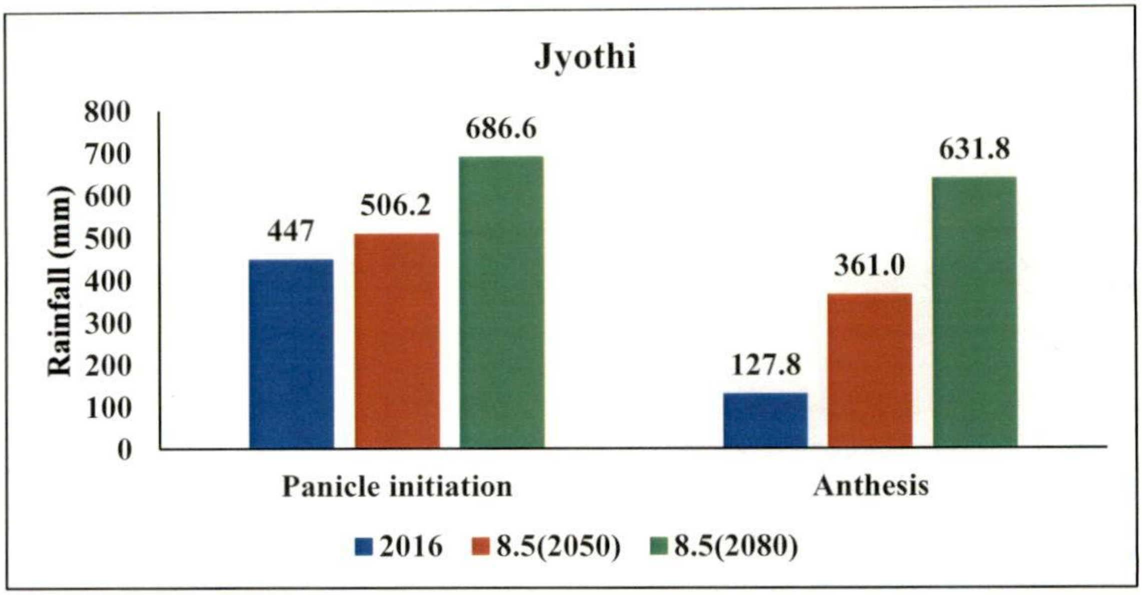

Fig.5.46(a). Effect of rainfall (mm) on different phenophases of Jyothi under RCP 8.5 for the third date of planting

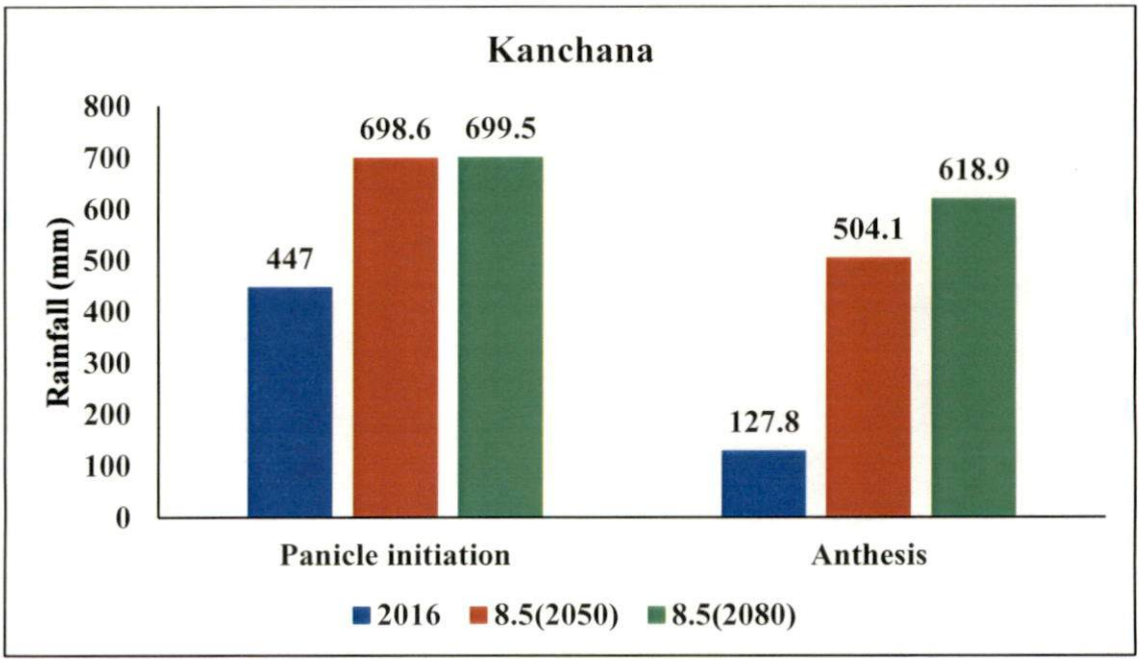

Fig.5.46(b). Effect of rainfall (mm) on different phenophases of Kanchana under RCP 8.5 for the third date of planting

5.5.2.4. Fourth date of planting (DOP4)

During fourth date of planting projected grain yield of Jyothi and Kanchana shows an increasing trend towards the future scenario RCP 8.5 from the baseline. The grain yield of Jyothi will be increasing by 46.5 and 33.7 percent during 2050s and 2080s, respectively. Whereas in Kanchana, the grain yield will be increasing by 2.6 and 10.5 percent during 2050s and 2080s under RCP 8.5 scenario (Fig 5.47). This is mainly due to increase in solar radiation and fertilization effect of CO_2 enrichment. Increase in solar radiation Fig 5.48 (a & b) during anthesis and physiological maturity period shows a positive effect on capacity of assimilation supply (photosynthesis), increasing the number of filled spikelets in rice plants and increases grain yield (Restrepo-Diaz and Garces-Varon, 2013). Under RCP 8.5, during 2050s and 2080s the projected CO_2 concentration to be increasing by 571 and 801 ppm than the baseline 380ppm. These results are in confirmation with Krishnan *et al.,* (2007) that every 1^0C increase in temperature decreases the rice yield by 7.2% at current CO_2 concentration (380ppm). But, increase in CO_2 enrichment up to 700ppm will leads to an average increase of 31% rice yields in India.

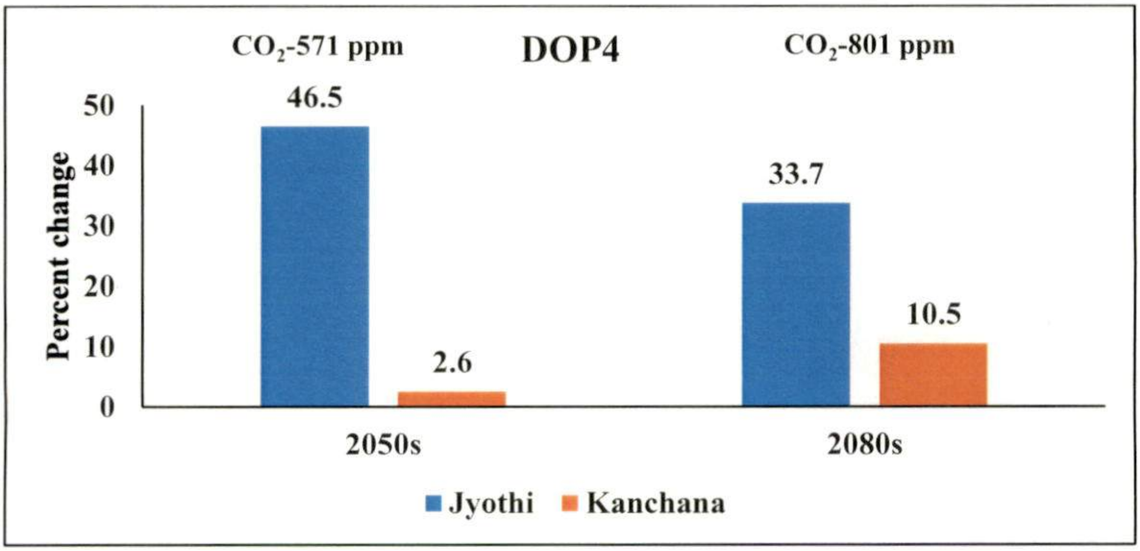

Fig.5.47. Percent change in yields of Jyothi and Kanchana under RCP 8.5 for the fourth date of planting

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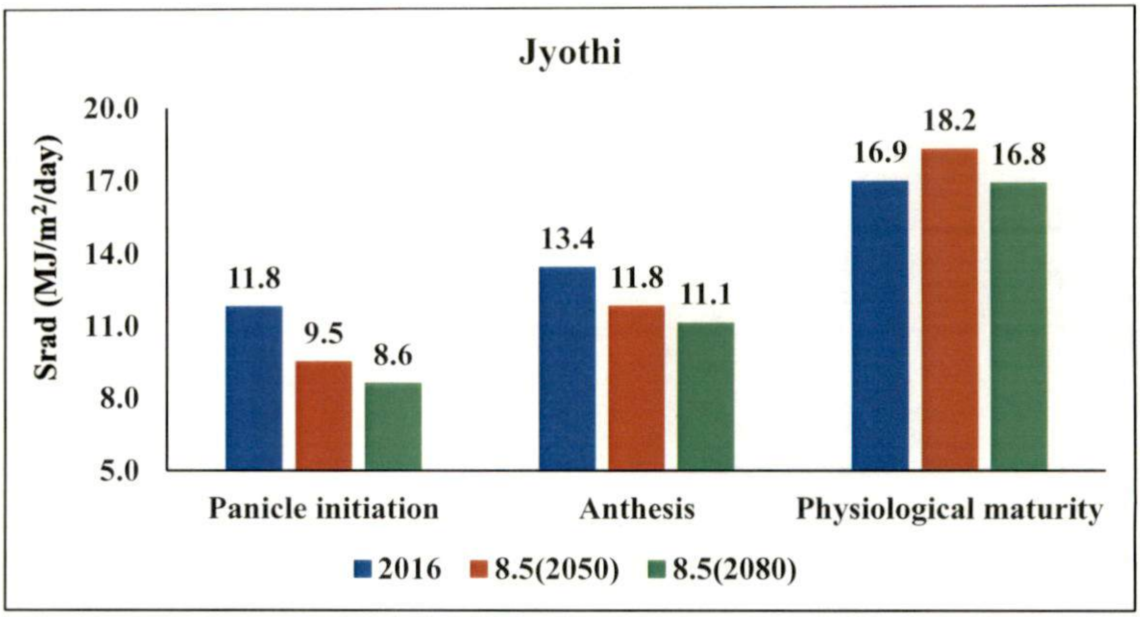

Fig.5.48(a). Effect of solar radiation (MJ/m²/day) on different phenophases of Jyothi under RCP 8.5 for the fourth date of planting

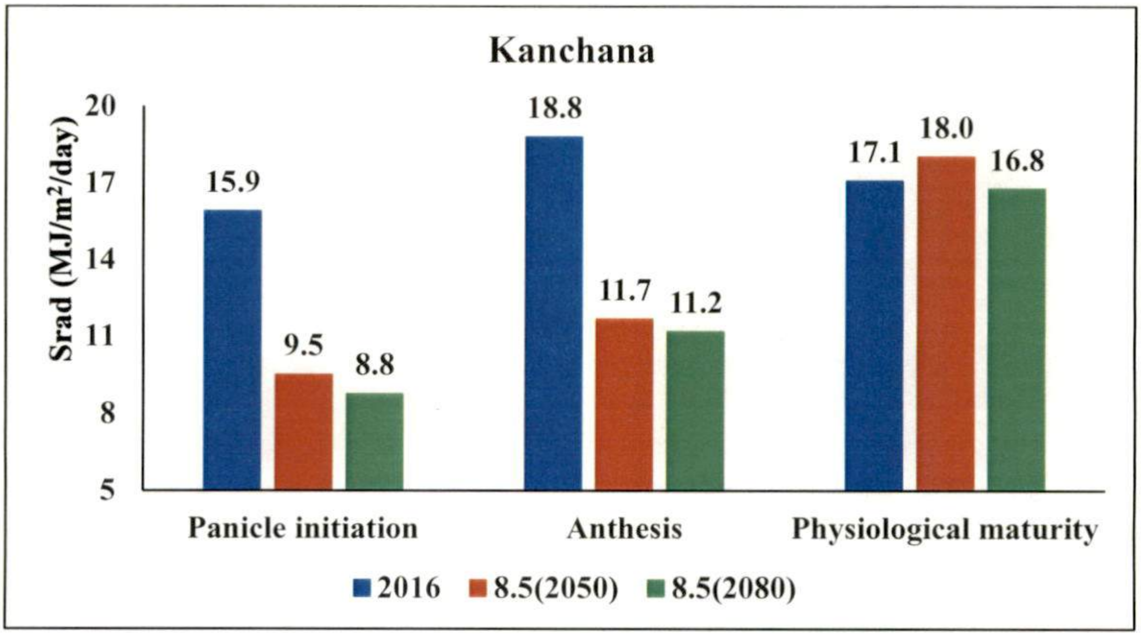

Fig.5.48(b). Effect of solar radiation (MJ/m²/day) on different phenophases of Kanchana under RCP 8.5 for the fourth date of planting

5.5.2.5. Fifth date of planting (DOP5)

During fifth date of planting projected grain yield of Jyothi and Kanchana shows an increasing trend towards the future scenario RCP 8.5 from the baseline. The grain yield of Jyothi will be increasing by 68.4 and 65.2 percent during 2050s and 2080s, respectively. Whereas in Kanchana, the grain yield will be increasing by 32.3 and 34.3 percent during 2050s and 2080s under RCP 8.5 scenario (Fig 5.49). This is mainly due to increase in solar radiation and fertilization effect of CO_2 enrichment. Increase in solar radiation Fig 5.50 (a & b) during anthesis and physiological maturity period shows a positive effect on capacity of assimilation supply (photosynthesis), increasing the number of filled spikelets in rice plants and increase grain yield (Restrepo-Diaz and Garces-Varon, 2013). Under RCP 8.5, during 2050s and 2080s the projected CO_2 concentration to be increasing by 571 and 801 ppm than the baseline 380ppm. These results are in confirmation with Krishnan *et al.,* (2007) that every 1^0C increase in temperature decreases the rice yield by 7.2% at current CO_2 concentration (380ppm). But, increase in CO_2 enrichment up to 700ppm will leads to an average increase of 31% rice yields in India.

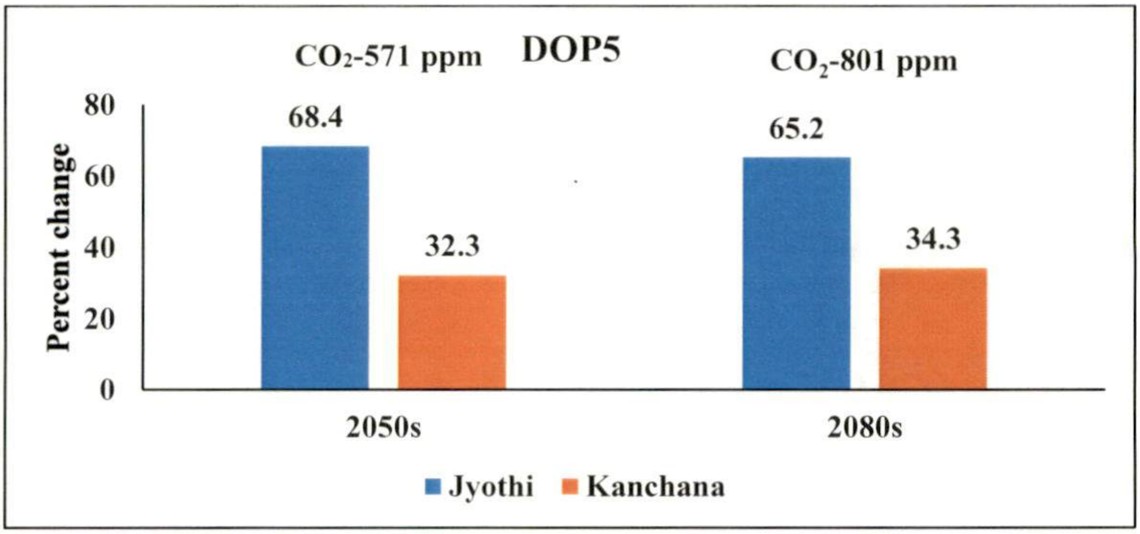

Fig.5.49. Percent change in yields of Jyothi and Kanchana under RCP 8.5 for the fifth date of planting

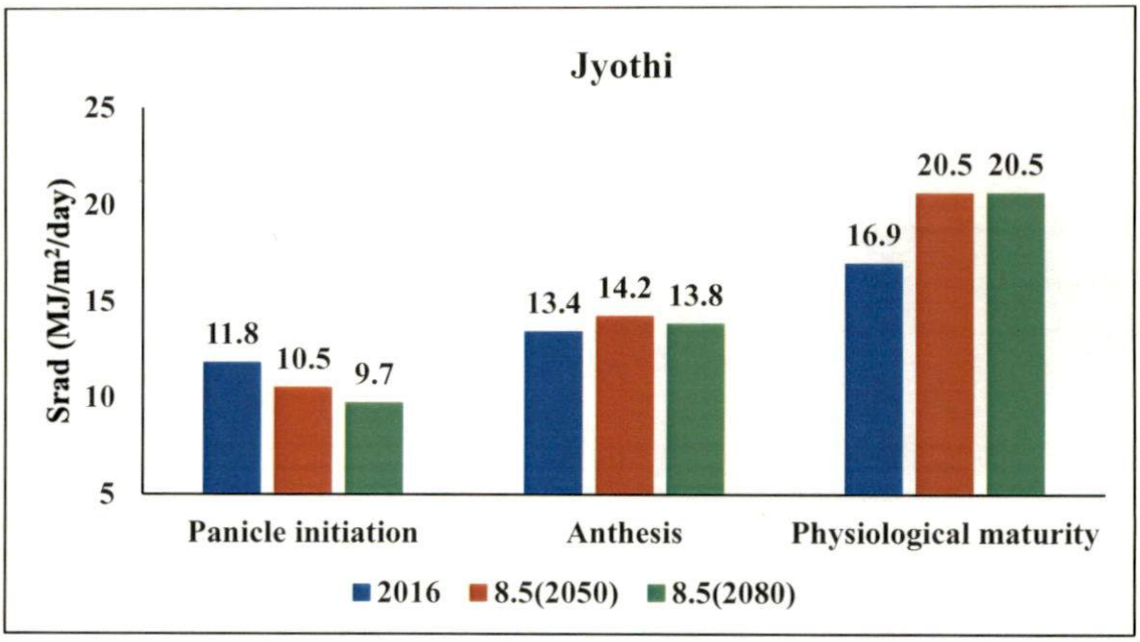

Fig.5.50(a). Effect of solar radiation (MJ/m²/day) on different phenophases of Jyothi under RCP 8.5 for the fifth date of planting

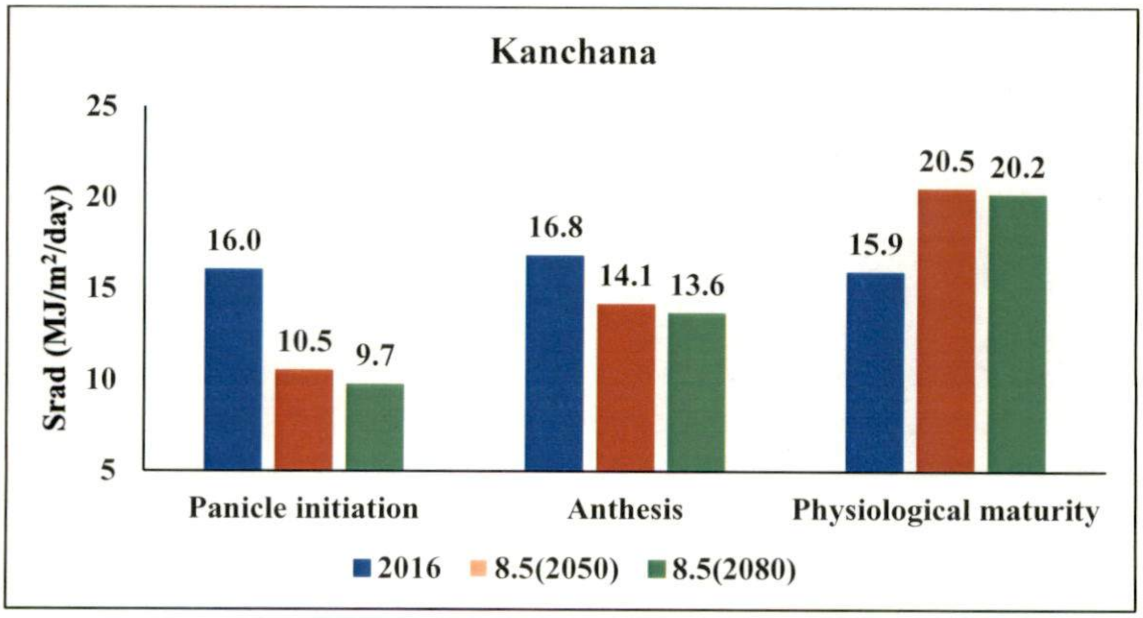

Fig.5.50(b). Effect of solar radiation (MJ/m²/day) on different phenophases of Kanchana under RCP 8.5 for the fifth date of planting

From the above results the projected solar radiation shows an increasing trend towards the delayed date of planting when compared to the baseline (2016) solar radiation. This increase in trend shows an increase in yields in third, fourth and fifth date of planting, compared to first and second date of planting. If this may be the case in future in central zone of Kerala, there is a need to shift in the date of planting to last week of July and first week of august.

Summary

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6. Summary

The study "Assessment of rice (*Oryza sativa* L.) production under climate change scenarios" was conducted at Department of Agricultural Meteorology, College of Horticulture, Vellanikkara, Thrissur during 2016–17. The study was carried out to assess the rice production for the varieties Jyothi and Kanchana under different climate change scenarios and to validate CERES-Rice for the varieties and to draw the crop weather relationship.

Observations such as weather, biometric, phenological and soil data were recorded on time. Crop weather relationship was studied. The growth indices were worked out based on the biometric observations taken during the study. The CERES-Rice model was validated by adjusting the genetic coefficients for Jyothi and Kanchana varieties. The results obtained from the study are summarized as follows.

Dry matter accumulation (DMA) in plants was reduced with delay in plantings for both the varieties and may be due to increased maximum temperature. But relative humidity and rainfall might have favoured the dry matter accumulation during early plantings. DMA was found to be maximum at 60 days after planting. June 5^{th} planting recorded highest value (15,693.2 kg ha^{-1}) and July 5^{th} planting recorded the lower (14,821.5 kg ha^{1}) in Jyothi, whereas, in Kanchana, June 5^{th} planting recorded highest value (15,675.0 kg ha^{-1}) and July 20^{th} planting recorded the lowest value (13461.0 kg ha^{1}).

Number of spikelets per panicle was found to be high for the early dates of planting in both varieties. June 5^{th} planting which is on par with June 20^{th} and July 20^{th} recorded higher number of spikelets per panicle.

Straw yield was recorded more for early planted crops compared to late planted ones. The mean straw yield of Jyothi (6137.9 kg ha^{-1}) was more than Kanchana (5685 kg ha^{-1}) during the entire crop period.

Grain yield was observed to decrease with delay in plantings. In Jyothi, June 20th planted crop (5782 kg ha^{-1}) recorded higher grain yield compared whereas and August 5th planted crop (3717 kg ha^{-1}) recorded lowest grain yield. In case of Kanchana, June 20th planted crop (6155 kg ha^{-1}) showed higher value of grain yield than other plantings. Reduction in grain yield during July 20th and August 5th crops of Jyothi may be due to high maximum and minimum temperatures during panicle initiation to booting. Reduction in grain yield for July 5th crop of Kanchana may be due to high minimum temperature during flowering to physiological maturity.

Duration taken for each phenophase was found to be different for both Jyothi and Kanchana. Environmental conditions like low temperature and high relative humidity was most favourable for early planted crops to attain full maturity. The variety Jyothi took more days to complete each phenophase compared to Kanchana.

Highest leaf area was recorded at 60 days after planting in both the varieties. High relative humidity, low sunshine hours and diurnal temperature range during beginning of grain filling stage favored the leaf area.

CERES-Rice model was tested and evaluated by adjusting the genetic coefficients for both the varieties with their respective planting dates. Calibrated genetic coefficients for both the rice varieties are given below

Variety	P1	P2R	P5	P2O	G1	G2	G3	G4	PHINT
Jyothi	537	18.5	445	10.2	48.5	0.025	1.10	1.10	81.0
Kanchana	470.7	150	445.5	12.3	50.5	0.021	1.30	1.10	76.0

Predicted grain yield showed satisfactory agreement with observed yield in case of Jyothi with an RMSE (root mean square error) of 1525.7 kg ha^{-1} and D-stat index of 0.4 and in case of Kanchana, predicted yield was in good agreement with an RMSE of 1409.3 kg ha^{-1} and D-index of 0.5, indicating good performance of the model.

The predicted and observed panicle initiation day for Jyothi was satisfactory with an RMSE of 2.3 and D-index of 0.13. In case of Kanchana, predicted panicle initiation day was good agreement with RMSE of 2.1 and D-index of 0.6 respectively.

Anthesis day predicted was satisfactory with an RMSE of 1.6 and D-index of 0.7 in case of Jyothi and RMSE of 2.9 and D-index of 0.6 in case of Kanchana.

Good agreement was observed between actual and simulated physiological maturity in both Jyothi and Kanchana with an RMSE of 2.0 and 2.2 respectively and D-index for Jyothi and Kanchana was 0.5 and 0.7, respectively.

The simulation analysis as per the projected climate change scenarios for the periods 2050s and 2080s indicate that among the two varieties, variety Jyothi will perform better in all the dates of planting.

The simulation results showed that with increase of 0.3-1.3 ^{0}C in maximum and 3-4 ^{0}C in minimum temperatures, there was a decrease in days to panicle initiation, days to anthesis and days to physiological maturity in both the rice varieties under RCP 4.5 and RCP 8.5 scenario.

The results also showed that the effect of increasing maximum temperature (0.3-1.3 ^{0}C), minimum temperature (3-4 ^{0}C) and decreasing solar radiation during first and second date of planting would drastically reduce the yield under RCP 4.5 and RCP 8.5 scenarios.

The effect of increased atmospheric CO_2 concentration along with increased solar radiation during anthesis and physiological maturity shows a positive impact on the yield during third, fourth and fifth date of planting.

Under RCP 4.5, which is the most likely scenario for India, the yield reduction will be 10.1 percent (2050s) and 13 percent (2080s) for the first date of planting, whereas, it will be 13.0 (2050s) and 14.1 (2080s) percent for the second date of planting in Jyothi. In case of Kanchana, yield reduction will be 28.4 (2050s), 25.6 (2080s) and 36.7 (2050s), 35.3 (2080s) percent during first and second dates of planting, respectively.

Under RCP 8.5, the yield reduction will be 9.7 (2050s) and 15.3 (2080s) percent for the first date of planting, whereas, it will be 9.7 (2050s) and 15.9 (2080s) percent for the second date of planting in Jyothi. In case of Kanchana, yield reduction will be 22.3 (2050s), 17.7 (2080s) and 31.9 (2050s), 28.8 (2080s) percent during first and second dates of planting, respectively.

From the above results the projected solar radiation shows an increasing trend towards the delayed date of planting when compared to the baseline (2016) solar radiation. This increase in trend shows an increase in yields in third, fourth and fifth date of planting, compared to first and second date of planting. If this may be the case in future in central zone of Kerala, there is a need to shift in the date of planting to last week of July and first week of august.

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Appendices

Appendix I

Abbreviations and units used

Weather parameters

Tmax : Maximum temperature

Tmin : Minimum temperature

DTR : Diurnal temperature range

RH I : Forenoon relative humidity

RH II : Afternoon relative humidity

VPD I : Forenoon vapour pressure deficit

VPD II: Afternoon vapour pressure deficit

RF : Rainfall

RD : Rainy days

WS : Wind speed

Ep : Pan evaporation

BSS : Bright sunshine hours

Srad : Solar radiation

Phenophases

TP – AT : Transplanting – active tillering

AT – PI : Active tillering – panicle initiation

PI – B : Panicle initiation – booting

B – H : Booting - heading

H – F : Heading - flowering

F – PM: Flowering - maturity

Heat units

GDD : Growing degree days

HTU : Helio thermal unit

PTU : Photo thermal unit

Units

g : gram

kg : kilogram

km hr^{-1}: kilometre per hour

^{0}C : degree Celsius

$MJ/m^2/day$: Mega Joule per metre square per day

kg ha^{-1} : kilogram per hectare

% : per cent

mm : millimetre

Others

DAT - Days after planting

LAI –Leaf area index

(ii)

Appendix II

Bias correction coefficients for rainfall

	a	b
January	0.000	5.523
February	0.052	1.519
March	0.005	2.373
April	3.709	0.968
May	2.019	0.949
June	4.989	0.741
July	4.884	0.715
August	3.228	0.896
September	2.337	0.976
October	5.084	0.757
November	1.530	0.896
December	0.004	1.946

Appendix II

Anova of different plant growth characters

Plant height at different weeks after planting

Sources of variation	DF	Mean sum of Squares					
		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Date of planting	4	8.6^{NS}	35.4*	40.9^{NS}	36.7*	72.4*	195.1*
Error (a)	12	6.1	9.6	17.2	7.4	18.1	8.8
Variety	1	47.3**	18.5^{NS}	147.4**	864.9**	697.2**	604.5**
DOP * Variety	4	4.3^{NS}	50.4*	112.6*	52.4*	64.3*	32.3^{NS}
Error (b)	15	4.0	5.7	6.0	3.9	4.7	13.2

Plant height at different weeks after planting

Sources of variation	DF	Mean sum of Squares					
		Week 7	Week 8	Week 9	Week 10	Week 11	Week 12
Date of planting	4	159.9*	65.0*	10.9^{NS}	17.8^{NS}	64.6*	15.2^{NS}
Error (a)	12	11.4	7.2	17.2	6.8	9.1	12.0
Variety	1	305.2*	27.8^{NS}	161.2*	460.4*	20.7^{NS}	56.2**
DOP * Variety	4	31.6*	55.1*	26.3^{NS}	7.0^{NS}	21.6^{NS}	26.8*
Error (b)	15	6.6	7.0	13.8	13.7	9.6	4.8

(iv)

(contd.)

Dry matter accumaulation at fortnight intervals

Sources of variation	DF	Mean sum of Squares					
		15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT
Date of planting	4	16647.4**	130666.2**	1025819.7**	1670704.0**	2951061.2**	1447681.3**
Error (a)	12	495.3	12849.3	15633.9	10112.1	8950.3	9071.3
Variety	1	435.6^{NS}	41152.2^{NS}	1455422.5**	476.1^{NS}	5215006.2**	3663275.6**
DOP * Variety	4	11591.2**	151576.2**	1779362.4**	3830239.2**	739843.1**	563812.2**
Error (b)	15	529.3	31161.0	16375.1	5827.0	7215.9	4889.0

Leaf area at fortnight intervals

Sources of variation	DF	Mean sum of Squares					
		15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT
Date of planting	4	114.7^{NS}	12817.6**	13259.1^{NS}	53929.5**	28205.4**	23740.9**
Error (a)	12	103.9	1568.2	23426.0	9063.7	10151.5	1218.0
Variety	1	3.9^{NS}	13691.7*	408.0^{NS}	137702.0**	31914.6**	15159.9**
DOP * Variety	4	406.7**	2603.2^{NS}	4903.4^{NS}	11605.0^{NS}	6111.7^{NS}	3930.6^{NS}
Error (b)	15	97.6	2941.4	4829.9	10642.2	3716.8	1613.7

(v)

(contd.)

Grain yield, panicles per unit area, spikelets per panicle, filled grains, 1000 grain weight and straw yield at the time of harvest

Sources of variation	DF	Mean sum of Squares					
		Grain yield	Panicles per unit area	Spikelets per panicle	Filled grains	1000 grain weight	Straw yield
Date of planting	4	8193608.7*	1969.6*	1082.3*	2383.6^{NS}	0.3^{NS}	6926979.6*
Error (a)	12	1817802.0	2009.9	142.0	747.9	0.7	1127818.0
Variety	1	186322.5^{NS}	39.4*	0.6^{NS}	30.6^{NS}	0.2^{NS}	2231617.6^{NS}
DOP * Variety	4	669303.7^{NS}	334.5*	4.9*	247.3^{NS}	0.4^{NS}	979950.9^{NS}
Error (b)	15	378720.8	738.6	1.4	458.7	0.6	533926.9

ASSESSMENT OF RICE (*Oryza sativa* L.) PRODUCTION UNDER CLIMATE CHANGE SCENARIOS

By

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ABSTRACT OF THE THESIS

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Abstract

Agriculture is sensitive to short term changes in weather and to seasonal, annual and long term variations in climate. Climate change will have decisive impact on crop production and the prediction of this climate change emerged as a major research priority during the past decade. Numerous estimates for the impending decade projects that continuous rise of anthropogenic forcing leads to increase in greenhouse gas (GHG) atmospheric concentrations, is expected to alter regional temperature and precipitation patterns, also contributing to higher risk of extreme weather events and climate irregularity (IPCC, 2013), with obvious implications on crops (Porter and Semenov, 2005). Rice (*Oryza sativa* L.) is vulnerable to unfavourable weather events and climate conditions. Despite technological advances such as improved crop varieties and irrigation systems, weather and climate play significant roles in rice production.

The present investigation "Assessment of rice (*Oryza sativa* L.) production under climate change scenarios" was carried out in the Department of Agricultural Meteorology, College of Horticulture, Vellanikkara during 2016-17, to determine the crop weather relationship, to validate the CERES (Crop Environment Resource Synthesis) -Rice model for the varieties Jyothi and Kanchana and to project the changes of rice yield and growth under climate change scenarios. The field experiment was conducted at Agricultural Research Station, Mannuthy during the *kharif* season of 2016. Split plot design was adopted with five dates of planting *viz.*, 5th June, 20th June, 5th July, 20th July and 5th August as the main plot treatments and two varieties *viz.*, Jyothi and Kanchana as the sub plot treatments. The number of replications for the experiment was four.

Analysis of weather with crop duration and yield showed that maximum and minimum temperatures showed increasing trend towards late plantings, whereas the relative humidity, rainfall and rainy days were found to be low in late planting than during early plantings. To determine the critical weather elements affecting the crop duration, correlation analysis was performed. Number of days for panicle initiation to booting stage, decreased with increase in maximum and minimum temperature, whereas, the reverse was observed with afternoon relative humidity, afternoon vapour pressure deficit and rainfall in Jyothi. In case of Kanchana, days for transplanting to active tillering decreased with increase in maximum, minimum temperatures and bright sunshine hours, whereas relative humidity, afternoon vapour pressure deficit, rainfall and

number of rainy days showed a positive influence. The mean yield of Jyothi and Kanchana on June 5th planting found to be on par with June 20th planting. The correlation analysis showed that with increase in maximum and minimum temperature during transplanting to Active tillering will reduce the yield for both Jyothi and Kanchana

The crop genetic coefficients that influence the occurrence of developmental stages in the CERES-Rice models were validated, to achieve the best possible agreement between the simulated and observed values. Predicted yield and phenology of both rice varieties, Jyothi and Kanchana under different planting dates were reasonably close to the observed values.

Analysis of yield and growth phases of rice under different climate change scenarios (Representative Concentration Pathways (RCP) 4.5 and 8.5) for the time periods 2050s and 2080s showed that, days taken to panicle initiation, anthesis and physiological maturity decreases for all the five different dates of planting. This may be due to increase in maximum and minimum temperatures during the future scenarios.

The predicted values of rice yield for the climate change scenarios during first and second plantings for the time periods 2050s and 2080s showed a low yield whereas increase in yield was observed in third, fourth and fifth plantings compared with 2016. This increase in yield is may be due to combined effect of increase in CO_2 (538 and 936ppm) and solar radiation during the panicle initiation, anthesis and physiological maturity for the delayed plantings. These findings suggests that, planting date need to be shifted to late July and early August in case of *kharif* crop in the central zone of Kerala in future.