ANALYSIS OF POTENTIAL YIELD AND YIELD GAP OF RICE (*Oryza sativa* L.) USING CERES RICE MODEL

by

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(2018-11-067)

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DECLARATION

I hereby declare that this thesis entitled **"ANALYSIS OF POTENTIAL YIELD AND YIELD GAP OF RICE (*Oryza sativa* L.) USING CERES RICE MODEL"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Vellanikkara
Date : 10-07-2020

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CERTIFICATE

Certified that this thesis entitled **"ANALYSIS OF POTENTIAL YIELD AND YIELD GAP OF RICE (*Oryza sativa* L.) USING CERES RICE MODEL"** is a bonafide record of research work done independently by **Ms. Harithalekshmi V. (2018-11-067)** 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 her.

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Date : 10.07.2020

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Harithalekshmi V.

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Introduction

INTRODUCTION

Agriculture plays an imperative role in the overall economic and social well-being of India. Agriculture with its allied sector is the largest source of livelihood in India and contributes 18% of India's gross domestic product (GDP). As per the 2011 census, 54.6 % of the total workforce is engaged in agriculture and allied sector activities. India is one of the leading countries in terms of agriculture production with a wide range of cultivated crops.

Rice is the staple food in India. It is the superior crop cultivated in India by contributing 41% of the nation's total food grain production. Rice is grown under climate and topography conditions. In India, it is cultivated from 8 to 35^o N latitude and from below sea level to an altitude of 3000 meters. India ranks first in the total rice harvesting area, covering 44 million hectares and second in rice production by contributing 22% of global rice production. Even though it is considered as a *kharif* crop in rain-fed areas, it can be cultivated throughout the year with assured irrigation.

Most of the field crops are dependent on the weather to provide life-sustaining water and energy. Being the most uncertain component in crop production, it plays a crucial role in determining the success of crop production. Adverse weather conditions may cause considerable production losses, especially if experienced during critical stages of crops. Optimum weather conditions are required to achieve optimum plant growth, development and yield. Weather influences the incidence of pests and diseases, crop duration and product quality. Considering the vital importance of weather in agriculture, we have a strong weather service network in our country to convey weather-related information to farmers. In addition, scientific research should be carried out to invent new strategies and to evaluate existing facilities in the field of weather service.

Yield is the primary concern of farmers. Most of the improved crop cultivars are meant for improve the yield. Potential yield is the highest achievable yield under optimum crop management and growing conditions. It is limited only by climatic conditions and crop genetic characteristics. It can be estimated using crop growth simulation models. Attainable yield is the yield obtained from an experimental station under best crop management strategies. Actual yield is the yield obtained in the farmers' field. The difference between this potential yield and actual yield is defined as the yield gap. Most of the existing rice varieties have potential yield higher than their actual yield. In India, irrigated rice varieties have a potential yield of 6.8 tonnes ha^{-1} and an actual yield of 4 tonnes ha^{-1}, hence there exists a yield gap of 2.8 tonnes ha^{-1} (Food and Agricultural Organization, 2004).

India ranks second in the global population. The hiking population demands more food production. Being the staple food, rice production has to be increased to satisfy the need for an expanding population. Narrowing the yield gap is the most promising way to increase crop production. The scientific analysis of yield gap is important because it reveals the causes behind the yield reduction and helps to identify the most suitable crop management strategies, which aim at improved resource utilization, reduced production costs, increased yield and thereby increases farm productivity. Increasing yield or agricultural productivity is vital to economic growth and development.

Crop growth simulation models are simplified mathematical representations of the complex physical, chemical and physiological mechanisms underlying plant growth and its response to the environment. Crop growth simulation model predicts crop growth and yield as a function of weather, soil conditions, and crop management practices. Crop Environment Resource Synthesis- Rice (CERES-Rice) model is widely used in the crop management studies in rice. This model has been included in the Decision Support System for Agrotechnology Transfer (DSSAT). A most relevant feature of crop models is that it reduces the need for expensive field experiments and saves time spent during experimentation. Potential yield and yield obtained under different management conditions can be simulated using CERES- rice model. This can be used as an efficient tool in yield gap studies and the impact of various crop management practices can be assessed and best crop management strategies can be formulated.

Various research works were conducted by Department of Agrl. Meteorology, College of Horticulture, Vellanikkara, in the field of crop weather relationships in rice. In the context of the above-mentioned facts, the current study titled "Analysis of potential yield and yield gap of rice (*Oryza sativa* L.) using CERES rice model" is aimed:

- To analyze potential yield and yield gap in two rice varieties
- To suggest better crop management practices to reduce the yield gap

Review of literature

2. REVIEW OF LITERATURE

Rice has shaped the culture, diet and wealth of millions of people. For more than half of population around the globe "Rice is life". It is the staple food for more than half of the global population. To satisfy the hunger of the global population in future, rice production has to be increased. One of the key strategies to increase food production is to bridge the yield gap. This research focuses on the estimation of yield gap and formulating management strategies to bridge the gap. This review of literature covers:

1. Significance of rice cultivation
2. Effect of weather parameters on growth and yield of rice
3. Effect of dates of planting on growth and yield of rice
4. Weather influences on the incidences of pests and diseases
5. Crop growth simulation models
6. Yield gap analysis
7. Bridging the yield gap

2.1 Relevance of rice cultivation

Rice is unique among all other food crops due to its adaptability to a wider range of climatic, edaphic, geographic and cultural conditions. Ninety per cent of global rice production is concentrated in Asia. In India rice is grown at an extent of 8 to 35^0 N latitude, under a wide range altitude ranging from foothills of Himalaya to below sea level in Kuttanad. It is best suited for humid regions having prolonged sunshine and assured water supply. Average temperature requirement of rice is 21-37^0C.

Worldwide production of rice was 495.9 million metric tons during 2019. China ranks first in rice production with 148.5 million metric tons followed by India with a production of 116.4 million metric tons. India's rice production should be increased by 3 % to achieve food self-sufficiency and to satisfy future food demand. (Thiyagarajan and Selvaraju, 2001).

Rice is a source of instant energy due to the higher concentration of carbohydrate present in it. It contains only 8 per cent of nitrogenous substances and less than one per cent of fat and lipids. Rice straw when mixed with some other substances can be used in the manufacture of porcelain, glass and pottery.

In India, paddy is grown in a wide range across the country except in some arid eastern regions of Rajasthan state (Aggarwal *et al.* 2008). It is grown in extremely diverse hydrological environments such as irrigated, rain-fed uplands, lowlands, as well as under deep-water conditions. Out of the 44 million hectares of harvested rice area, almost 54 per cent is irrigated.

Rice is the most important food crop grown in Kerala. It occupies 7.46 per cent of the total cropped area of the state. The area under rice cultivation has been falling at an alarming rate ever since the 1980s. In 1974-75 the area under paddy cultivation was 8.82 lakh hectare, but during 2015-2016 the paddy cultivating area has come down to 1.96 lakh hectare in 2015-16. The production has also concomitantly declined from 13.76 lakh MT in 1972-73 (peak of production) to 5.49 lakh MT in 2015-16.

The productivity of the crop is very low in Kerala (2790 kg ha^{-1}), though it is higher than the national average (2424 kg ha^{-1}). China, which is the major producer of rice in the world, reports productivity (6744 kg ha^{-1}) more than three times the productivity of rice in Kerala. The productivity of rice in Egypt is the highest in the world (9088 kg ha^{-1}), which is nearly four-fold of our productivity. Punjab is the state with the highest yield in the country (the average yield of paddy was 6167 kg ha^{-1} during 2018-19) (PAU, 2020).

2.2 Weather parameters affecting rice production

The potential production of rice depends on the prevailing weather and the effect of weather on crops can be observed through plant features like height, tillers, leaf number, leaf area and ultimately crop yield. The impact of weather parameters at various stages of crop growth may aid in understanding its effect on final yield and yield forecast. The influence of weather on crop yield depends both on its magnitude and frequency of occurrence.

According to Fadzillah *et al.* (1996), the minimum lethal temperature for the process of germination and shoot growth was found to be 4 °C. According to Yin and Kropff (1996), the principle environmental determinant of crop leaf appearance is temperature. Optimum temperature for development was found to be markedly higher than that needed for floral development.

Simulation study conducted by Saseendran *et al.* (2000) found out that in a future period of 2040-2049, 8 per cent of crop maturity period and 6 per cent of yield might decrease due to elevated temperature when they considered elevated temperature only.

Crop growth was found to be best under a range of weather factors. Deviation observed in these factors will cause severe stress on crops (Orcutt and Nelson, 2000). According to Chan and Cheong (2001), the average value of ET/Epan recorded during the crop growth period was 1.56 and during off-season, it was about 1.75. ET values differ between varieties and the difference was higher in off season.

Nakagawa *et al*. (2003) found out that increase in CO_2 concentration increased biomass production in rice by 25 per cent, while a higher temperature may cause rice yield reduction due to high temperature induced spikelet sterility, which is worsened by elevated CO_2. The dramatic increase in temperature is detrimental to crop growth, yield and quality of rice production by affecting its physiology, phenology and yield components (Sheehy *et al.* 2005).

Predictions suggest that the changes in spatial and temporal temperature pattern due to elevating concentrations of atmospheric greenhouse gases will be having serious consequences for crop production (Lobell and Field, 2007). Weather elements required for optimum growth and development of rice have reached its critical limits in most parts of the world and any further increment of temperature, as predicted by the IPCC (2013) will lead to a dramatic decline in rice grain (Wassmann *et al.* 2009).

To increase protein content and reduce chalky grains under high temperature the grain filling rate was increased and grain filling period is reduced. Also, a decline in amylase, grain weight and pollen germination was observed (Kim *et al.* 2011). Agricultural production was affected greatly when annual rainfall deviates from its mean value and yield of most of the crop diminishes (Aberra, 2011). Yield was decreased by 23 per cent and 13.3 per cent from current conditions when there was a rise of 4^{o}C and 2^{o}C in temperature (Rani and Maragatham, 2013).

Bhattacharya and Pandey, (2013) analyzed annual variability of maximum, minimum and mean temperatures and rainfall during crop growing season. The results showed that with an increase in 1^{o}C temperature, yield decreased by 156.2 kg ha^{-1} and with an increase in 1mm rainfall yield increases by 0.35 kg ha^{-1} in subtropical region.

The impact of inter seasonal variability in weather parameters on the yield and morphological attributes in rice genotypes were investigated by Shahid *et al.* (2013). The study revealed that compared to temperature and solar radiation, photo thermal quotient showed much closer relationship with yield and sunset. The minimum temperature required for sprouting is 10 ^{0}C. A minimum temperature range of 22-23^{0}C is required for flowering. Temperature requirement for blooming is in the range of 26.5 to 29.5^{o} C. Minimum temperature for grain formation ranges from 20-21^{0} C. A temperature range of 20-25 ^{o}C is required during the time of ripening (DRD, 2014).

Pattnayak and Kumar (2014) estimated weather sensitivity of rice yield in India between 1969 to 2007. Both day time and nighttime temperature affect crop yield adversely. The effect of higher day time temperature is more than that of higher night time temperature. A cumulative yield loss of 172 million tons over 38 years of study period were observed in the study.

Solar radiation and temperature were the most influencing weather parameters on crop growth when water supply is unlimited. The effect of relative humidity and wind velocity was not considered to be significant. Reproductive and ripening stages were more sensitive to weather (Sridevi and Chellamuthu, 2015).

A study has been undertaken by Pandey *et al.* (2015) in Uttar Pradesh to examine the effect of weather parameters on rice. According to the study, both minimum temperature and relative humidity showed a negative correlation with yield. Wind velocity, sunshine and rainfall will be having an individual significant effect on crop yield and a significant interaction effect of wind velocity and rainfall also found out.

Elevated temperature can adversely affect rice yields due to spikelet sterility and reduced accumulation of assimilates. Impact of increased temperature can be minimized by early sowing or the use of early maturing rice varieties to avoid high temperatures at grain filling (Korres *et al.*, 2017).

Rice yield in Punjab was favourable under the temperature range of 20-40 ^{o}C. Based on the annual variability in maximum and minimum temperature observed, increased temperature will hasten the leaf senescence which leads to less leaf area index and biomass (Dhaliwal, 2020).

2.3 Effect of date of planting

According to Lee *et al. (*1994) a delay in transplanting date caused a decrease in number of days taken from transplanting to maximum tillering under southern alpine conditions.

An experiment was conducted by Ghosh *et al.* (2004) to examine the effect of two dates of planting and four fertilizer levels on aromatic rice cultivars. It was observed that there was a reduction in grain yield by 0.88 t ha^{-1}, amylose content by 0.5 per cent and duration by 10 days due to delay in planting.

Baloch *et al.* (2006) conducted an experiment to analyze the effect of transplanting time and number of seedlings $hill^{-1}$ on the productivity of rice in Dera Ismail Khan District, Pakistan. They used four transplanting dates *viz.* 20th and 27th of June and 4th and 11th of July as main plots. Four subplot treatments were 1, 2, 3 and 4 seedlings $hill^{-1}$. Results revealed that for timely sowing 1 seedling $hill^{-1}$ was suitable. The yield loss due to late transplanting can be compensated by 4 seedlings hill^{-1}.

Chopra *et al.* (2006) revealed that delay in transplanting may significantly affect duration of 50 and 100 per cent flowering. Number of days for flowering was maximum during June 30 transplanting and a difference of 7-10 days was observed between June 30, July 28 and August 4 planting. Mahajan *et al.* (2009) reported that in Punjab and north west India early transplanting of rice during the period of peak evaporative demand resulted in exploitation of groundwater. He concluded that a substantial increase in yield and productive use of water can be achieved by planting short duration cultivar during the period of peak evaporation demand or by late transplanting of a photoperiod sensitive cultivar.

Nahar *et al.* (2009) reported that major injury due to low temperature is spikelet sterility. Filled grain production was found to be decreased with delayed planting because the anthesis and spikelet primordial initiation coincided with the period of occurrence of minimum temperature. Delayed planting *i.e* sowing after optimum sowing date resulted in a decline in yield because crops were more prone to disease, pest, lodging, cold and heat stress (Reza *et al.* 2011). Mannan *et al.* (2012) reported that plant height, no of tillers and dry matter increased with early planting and yield attributes and growth duration decreased with delay in planting.

Wani *et al.* (2016) analyzed the impact of date of planting on rice phenology. The results showed that duration of flowering and crop maturity was significantly different for different date of plantings. Crop sown during 15th SMW took maximum duration but it was on par with 16th SMW crop, while crop sown in 18th SMW took minimum number of days.

According to Jagatap *et al*. (2018) under changing climatic condition optimum sowing date for short duration rice varieties were found to be 23rd meteorological week. According to Biswas *et al.* (2018) 5-10 per cent yield reduction was observed in rice when transplanted in normal date *i. e* 4th week of May and for getting higher yield in *kharif* rice for the study area the rice should be sown before 15th July.

According to Patel *et al.* (2019) optimum sowing date ensures the occurrence of vegetative growth coincide with a period of optimum temperature and sunshine hours, cold sensitive stage occurs when the minimum night temperature is warmest.

A field experiment was conducted by Pazhanisamy *et al.* (2020) during Navarai season to investigate the performance of seed priming practices in aerobic rice at different date of sowings like February 6th, February 13th and February 20th. Among the date of plantings, February 6th showed the highest yield.

2.4 Weather parameters influencing pest and disease incidence

According to Yashoda *et al.* (2000) during the time of 50% flowering, false smut disease is significantly influenced by weather. Disease incidence was favoured by low temperature less than 31°C, low rainfall less than 5mm, high minimum temperature of 19°C and relative humidity greater than 90%.

A study conducted by Mousanejad *et al.* (2009) revealed that in the forecasting of rice blast disease, the weather factors such as pressure, maximum temperature, mean relative humidity and sunshine hours plays a significant role.

Results of the scientific study conducted by Magunmder *et al.* (2013) revealed that compared to later-transplanted rice early planted rice was less affected by pests and natural enemy's population, plant and leaf sucking pests.

As per the findings of Rana *et al.* (2017) yellow stem borer population have build up an interaction with weather parameters, which can be used in the decision making process. The regression analysis showed that disease incidence is associated with rainfall.

Kumari *et al.* (2018) conducted a field experiment to monitor the incidence of gall midge and to find out its relation with weather. Silver shoot symptom due to gall midge showed a significant positive correlation with temperature and a significant negative correlation with sunshine hours.

A scientific study conducted by Yadav *et al.* (2018) evaluated the impact of date of planting in the incidence of green leaf hopper. The pest population was found to be lowest during early date of planting and highest during the late planting. The incidence started to observe 40 days after planting and a gradual hike is observed as crop growth advances.

Sharma *et al.* (2019) conducted an experiment to evaluate the effect of environmental variables on the incidence of ear head bugs. The peak time of incidence of rice bug was observed during 44^{th} standard meteorological week. The incidence of rice ear head bug population showed a significant negative correlation with rainfall. As per the findings of a scientific study conducted by Shyamrao and Raghuraman (2019), incidence of leaf folder shows a significant positive correlation with maximum temperature and a significant negative correlation with rainfall.

Impact of abiotic factors on the incidence of yellow stem borer and leaf folder in rice during *khariff* season was analyzed by Jasrotia *et al.,* 2019. The infestation of both the pest was observed at its peak during 38 to 39 standard meteorological week. The infestation of stem borer showed a significant negative correlation between morning relative humidity, evening relative humidity and rainfall. Leaf folder incidence showed a significant positive correlation with maximum and minimum temperature.

As per the correlation study conducted by Chaudhari *et al.*, (2019) incidence of false smut disease in rice was influenced by cloudy weather, sunshine hours, maximum and average temperature, maximum and average humidity.

One of the emerging disease in rice is grain discolouration. The high incidence of this disease nowadays might due to climate change. Temperature in the range of 25 to 37 ^{o}C, moderate rainfall, high relative humidity of 70-76% and high wind speed plays a crucial role in the incidence of this disease (Baite *et al.*, 2020).

2.5 Crop growth simulation models

A new era in the field of agriculture started during 1960s with the work of de Wit on crop growth models. The first model described the photosynthetic rates of crop canopies to calculate crop yield (De Wit, 1965). Monteith (1996) defined crop model as a quantitative scheme to predict the growth, development and yield of a crop under a given set of genetic features and environmental variables.

The United States Department of Agriculture sponsored project *i.e* International Benchmark Sites Network for Agro-technology Transfer (IBSNAT) began the development of a modelling project for tropical and sub tropical environments in 1982. The primary objective of this project was to describe how the system and its components function (Jones *et al.* 2003). The DSSAT was created to enter, store and manipulate various kind of data related to weather, soil and crop to run the crop simulation model and analyze crop model outputs (Hoogenboom *et al*. 1999; Jones *et al*. 2003)

A scientific study was conducted by Ramaraj *et al.* (2013) to evaluate the impact of climate change on rice and groundnut in Tamil Nadu using DSSAT model and no trend of impact of predicted temperature was observed on both rice and groundnut yield but CO_2 enrichment had improved the yield of both crops.

Naziya (2014) calibrated the genetic coefficient of rice varieties Jyothi and Kanchana for CERES rice model at the Department of Agricultural Meteorology, College of Horticulture, Kerala Agricultural University.

Bhuvaneswari *et al.* (2014) evaluated the impact of climate change on rice using calibrated and validated CERES-Rice model and formulated adaptation strategies to sustain rice production in western zone of Tamil Nadu. The study revealed that 1 to 5°C increase in temperature will cause a yield reduction of 4 to 56 per cent from the present climate under various dates of planting from 1st June to 15th July.

Vysakh *et al.* (2015) simulated growth, yield and phenology of selected short duration rice varieties and genetic coefficients were calibrated and the CERES-Rice model was validated using field experiment. Future rice yield in Srilanka predicted by Dias *et al.* (2015) using DSSAT model showed a decreasing trend due to increasing temperature and solar radiation and decreasing rainfall.

According to Ravindran *et al.* (2018) crop weather model using 5 fortnightly weather variables which coincide with flowering stage has given a good forecast compared to the other models for both Jyothi and Kanchana.

An experiment was conducted by Kant *et al.* (2018) with three popular rice varieties in Umiam region of Meghalaya under four levels of nitrogen management and calibrated CERES rice model. The model under estimated phenological stages of two varieties, but it could predict yield accurately.

Ray *et al.* (2018) estimated rice yield in Keonjhar district of Odisha under changing climatic conditions by DSSAT crop simulation model and as per the simulation results the yield as influenced by changing minimum and maximum temperatures.

A scientific study conducted by Amgain *et al.* (2019) using CERES rice model suggested that there is an urgent need of developing climate ready crops to feed the emerging population and CSM CERES model can be used as a valid approach to assist decision support system with regards to formulate climate change adaptation strategies in Nepal. Chaudhari *et al.* (2019) assessed the impact of temperature and CO_2 on yield and growth of rice using DSSAT model at south Gujarat region. Simulation result showed that an increase in temperature by 1 to 2 ^{0}C will cause a yield reduction of 3.25 to -9.47% and decrease in maximum temperature by 1 to 2 ^{0}C will cause a yield increase of 5.93%.

A novel approach of agro-ecological zones (AEZs) based climate change impact analysis on rice production of India was done by Gupta and Mishra (2019). CERES-Rice model was used for analysis and it is fed with climate projections from eight Global Climate Models (GCMs) and an increase in rice yield was observed in all AEZ. A field experiment conducted by Subramanyam *et al.* (2019) on two rice varieties Athira and Vaisakh in Kerala using CERES-Rice model and obtained a good agreement between observed and predicted yields.

Modelling approaches have a wide spectrum of applications like to evaluate optimum cultural practices, seed rate, time and amount of irrigation and fertilizer, yield gap analysis. It is a user friendly research tools to evaluate the impact of climate change and various agronomic practices (Kaur and Singh, 2020). Sun *et al.* (2020) incorporated new heat stress function in CERES Rice model. The improved crop model could better predict rice yield in response to extreme heat compared to old model. An ensemble of five climate model data sets and four Representative Concentration Pathways (RCPs) were used to analyze the projected future (2020-2099) rice yield and considerable yield reduction due to high temperature was observed.

2.6 Yield gap analysis

Global population which is predicted to exceed 9 billion by 2050 will demand an extra food production of 80%. There is a considerable yield gap between attainable and farm level yields across different spatial and temporal scale in many rice growing countries Quantifying yield gap of present cropped lands will denote the possible extend of yield increase from actual values. After an assessment of this yield gap, realistic solutions are to be framed to close this gap (Sadras *et al*. 2015).

Pinnschmidt *et al.* (1997) used CERES-Rice simulation model to estimate weather and nitrogen (N) limited attainable yield levels in northwest Luzon (Philippines), northeast Thailand, and the Mekeong River delta (South Vietnam) from 1992 to 1994. Simulated results indicated that the deviations of the observed yields from the weather-limited simulated yields averaged about 35% in the Philippines, 45% in Vietnam, and 55% in Thailand.

According to Timsina *et al.* (2004) crop simulation models can be used to estimate potential yield and actual yield by overcoming other methods of yield gap analysis. Attainable yield was obtained from maize high yielding research plots, where best currently available management practices were followed. Aggarwal *et al.* (2008) reported that in India there is a considerable yield gap across all the states and there is a large scope of improving yield gap. Calculated was found to be highest for rice (1670 kg ha^{-1}). One of the most popular applications of CERES rice model is to analyze yield gap and long term yield trend and to evaluate crop management practices as a mean of bridging yield gap (Timsina and Humphrey, 2010).

Grassini *et al.* (2011) estimated potential yield of maize using simulation models and yield gap was quantified as the difference between actual yield and simulated potential yield and average yield gap was found to be 11% of potential yield gap.

According to Wart *et al.* (2013) quantifying yield gap is essential to form policies and prioritize research to achieve food security without the degradation of natural resource.

Van Ittersun *et al.*, (2013) summarized desirable features for models to be used in the yield gap analysis. These include use of daily weather data, ability to capture management practices that influence yield (e.g. sowing date, plant density, cultivar maturity).

Dias *et al.*, (2015) identified the yield gaps and growth changes under changing climatic conditions using DSSAT-CERES model and they concluded that there will be a yield reduction of 25 to 35%. Simulation studies conducted by Shakoor *et al.* (2015) predicted that in future, a long term increase in rainfall and temperature will negatively affect crop production.

Fischer (2015) quantification of crop yield potential, the attainable yield and corresponding yield gap is crucial to meet the increasing food demand and he added that simulation models can be used as a powerful tool to quantify potential yield.

Matthew *et al.*, (2016) estimated yield potential and yield gap in United States rice production systems using crop simulation model. Simulated potential yield ranged from 11.5 to 14.5 Mg ha^{-1}, while actual yield *i.e* obtained from field varied from 7.4 to 9.6 Mg ha^{-1}, or 58–76% of yield potential. Yield gap is quantified by assuming farmers could exploit up to 85% of yield potential, and it ranged from 1.1 to 3.5 Mg ha^{-1}. Cost of achieving best management practices were not accounted by attainable yield (Liu *et al.*, 2016).

Rice crop get benefited by dry weather coupled with reduced number of rainy days during the ripening phase which facilitates proper grain development and drying. Due to higher rainfall lodging of crops occur along with decaying of grains in standing water resulting in reduced yield (Islam *et al.*, 2017).

Zhang *et al.* (2019) investigated yield gap, changes in potential yields, water and nitrogen stressed yield based on the field data collected from 11 agrometeorological experimental station in China during the period of 1981–2009 using CERES rice model. Results showed that a 16% yield reduction was observed from potential yield.

Halder *et al.*, (2020) summarized that temperature and CO_2 are two important weather parameters that influence crop yield directly. Reduction of crop yield in response to increase in temperature was due to pollen sterility and poor pollen growth during reproductive growth stage. Elevated CO_2 concentration of 420, 530 and 650 ppm showed gradual increase in the rice grain yield whereas the total biomass yield decreases.

2.7 Bridging the yield gap

Bridging the yield gap offers a very rewarding opportunity to improve rice production by using available technologies and by adopting suitable crop management conditions. Simulation analysis performed for a long term to evaluate the sensitivity of potential yields to changes in selected management practices by Grassini *et al.* (2011) reported that potential yield can be increased by adopting higher plant densities and hybrids with longer duration.

Scientific study conducted by Singh *et al.* (2013) revealed that late sowing or transplanting, higher prices of seed, non-availability of fertilizer at sowing time, lack of funds with farmers and infestation of pest and disease were the major constraints responsible for yield gap and suggested that quality inputs can be provided to farmers at right time to reduce the gap.

According to Singh *et al.* (2013) yield gap analysis carried out by CERES model revealed that a lower yield was observed during both late sowing and early sowing compared to the optimum planting date of July 15 in south and north west plane of Bihar.

Debnath *et al.* (2018) analyzed crop management conditions which are primarily contributing to yield gap, by using field experimental and DSSAT simulated rice yield. The results showed that rice transplantation after 30th July was responsible for an average attainable yield gap of 0.33 t ha^{-1} in rain fed condition, where as an attainable yield gap of 0.86 t ha^{-1} in irrigated condition was due to the use of supplementary irrigations. Average yield is reduced by 0.29 t ha^{-1} due to poor agronomic practices by farmers. The study also suggested that emphasis should be given more on quantity of N fertilizer applied, timing of fertilizer applications, supplementary irrigation and date of transplanting.

Jain *et al.* (2019) assessed yield and yield attributes gap under irrigated and rain fed condition in rice crop for different agro climatic zones of Chhattisgarh using DSSAT Simulation model. According to him, the yield gap between no fertilizer stress and with fertilizer was highest in all three agro climatic zones both under irrigated and rain fed conditions and the variety Karma Mahsuri showed the highest yield gap *i. e* 7.5, 9.7 and 9.4 t ha^{-1} at Raipur, Ambikapur and Jagdalpur respectively under irrigated condition. Yield gap was 4.5, 4.7 and 4.6 t ha^{-1} in Karma Mahsuri under rain fed condition in Raipur, Ambikapur and Jagdalpur respectively.

A scientific study conducted by Zhang *et al.* (2019) found out that rice yield could improve significantly by 29.2 to 68.9% with cultivar with longer growth durations and greater spikelet number together with early transplanting.

Scientific study conducted by Jha *et al.* (2020) suggest that CERES rice model can be used in decision support system to improve rice yield in Bihar. The study revealed that there will be a yield reduction of 24, 43, and 33%, due to water stress during vegetative, reproductive and maturity phase and residue incorporation of

2.5 tons ha^{-1} would improve the yield by 21.94%. A row spacing of 15–25 cm and a 2–4 cm of planting depth would found to produce optimum rice yield.

Materials and methods

3. MATERIALS AND METHODS

The study on “Analysis of potential yield and yield gap of rice (*Oryza sativa*) using CERES-Rice model” was accomplished during 2019-2020 at the Department of Agricultural Meteorology, College of Horticulture, Vellanikkara.

3.1 DETAILS OF THE EXPERIMENT

3.1.1. Location of experiment

The field experiment was carried out during May 2019 to November 2019 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 22 m above mean sea level.

3.1.2. Soil Characters

Sandy loam type soil was found in the experimental field. Mechanical composition of soil is described in Table 3.1.

Table 3.1. Mechanical composition of soil of the experimental field

Sl. No.	**Particulars**	**Value**
1	Coarse sand (%)	27.6
2	Fine sand (%)	24.2
3	Silt (%)	22.2
4	Clay (%)	26

3.1.3Climate

Area where the experiment conducted can be categorized as a warm humid tropical region. Rainfall is available during both southwest and northeast monsoons. The experimental location experienced a mean maximum temperature of 31.4 ^{0}C and a mean minimum temperature of 22.4 ^{0}C during the experimental period. The total rainfall during the experimental period was 2865.6 mm, whereas August month received a maximum rainfall of 977.5 mm during the experimental period. Average sunshine hours received during experiment was 3.7 hrs day^{-1}. The mean forenoon relative humidity was 93.8 % and the mean afternoon relative humidity was 73.4%. The average wind speed was 1.6 km h^{-1}. Weather experienced during the experimental period is described in Table 3.2

3.1.4 **Season of the experiment**

The field experiment was conducted from May 2019 to November 2019 during *kharif* season.

3.2 EXPERIMENTAL MATERIALS AND METHODS

3.2.1 **Variety**

The experiment was conducted using two rice varieties Jaya and Jyothi. Jaya is a medium duration variety having a duration of 120-125 days. Jaya is recommended for general cultivation all over the country either in *kharif* or *rabi* season. It is the first variety developed after the commencement of AICRP on rice, which is evolved from a cross between Taichung (Native) 1 and the tall local photosensitive variety T-141 of Orissa.

Jyothi is cultivated in all the three seasons and in a wide range of field conditions because of its wide adaptability. It was evolved by the cross between PTB-10, the short duration (110-115) improved local strain and IR 8, a famous high yielding genotype.

Table 3.2. Weekly weather parameters during the period of experiment 2019

SMW	Tmax (°C)	Tmin (°C)	TR (°C)	RH I (%)	RH II (%)	VPD I (mm Hg)	VPD II (mm Hg)	WS (km hr^{-1})	BSS (hrs)	RF (mm)	RD (days)	Epan (mm)
23	34.2	24.3	9.9	90.9	65.3	25.1	25.1	1.8	6.9	32.3	2.0	3.6
24	35.0	25.3	9.7	88.0	58.4	25.2	23.4	1.8	7.0	0.7	0.0	3.9
25	34.4	24.1	10.3	88.3	60.9	24.1	23.3	2.1	5.7	10.7	1.0	3.7
26	33.9	23.5	10.4	89.1	74.6	23.7	23.9	2.4	5.8	103.9	2.0	3.4
27	30.8	23.1	7.7	96.3	76.4	25.1	24.4	1.4	2.7	101.2	5.0	2.2
28	31.0	22.7	8.2	95.3	78.6	23.2	24.5	1.0	1.8	114.0	7.0	2.3
29	32.2	24.7	7.5	94.4	70.1	24.9	23.9	2.1	4.5	8.5	2.0	2.9
30	31.0	23.2	7.8	95.7	78.9	23.4	24.4	2.1	2.6	154.6	6.0	3.1
31	31.0	22.5	8.5	92.6	70.3	22.2	22.9	1.4	2.9	115.2	4.0	2.4
32	28.7	21.9	6.8	97.0	84.4	21.9	22.7	2.1	1.7	339.7	6.0	1.7
33	30.2	22.6	7.6	96.0	72.4	22.8	23.0	1.2	2.8	41.2	4.0	2.1
34	30.8	23.5	7.3	94.9	79.4	23.5	23.8	2.1	3.0	72.3	3.0	2.5
35	27.6	21.0	6.7	97.9	87.3	22.2	22.2	1.7	0.4	508.1	7.0	1.0
36	30.1	22.4	7.8	96.6	74.7	22.7	23.5	1.1	1.5	144.5	3.0	1.8
37	29.6	21.1	8.5	95.9	83.9	21.6	22.3	1.3	1.4	165.8	7.0	2.4
38	29.4	21.7	7.6	95.0	86.6	22.5	25.5	1.1	0.8	152.7	7.0	1.6
39	30.5	21.6	8.9	97.3	78.4	23.2	23.8	1.9	2.1	224.2	6.0	2.4
40	31.5	22.5	9.0	96.4	72.3	23.6	23.4	1.4	3.4	37.7	3.0	2.7
41	31.7	21.8	10.0	95.7	72.1	22.8	23.5	1.2	4.2	69.4	5.0	2.8
42	32.2	21.7	10.5	91.7	68.4	22.2	23.2	1.4	4.5	24.0	2.0	2.6
43	33.4	22.3	11.0	89.9	65.3	22.8	23.7	1.0	7.7	14.3	1.0	3.3
44	33.4	21.7	11.6	92.4	70.1	22.7	23.1	1.5	6.9	125.8	3.0	2.6
45	31.9	21.3	10.6	92.1	68.7	22.3	22.1	1.6	5.1	171.9	5.0	2.5
46	31.5	20.5	11.0	92.3	65.1	21.0	21.4	1.4	4.1	72.0	5.0	2.4
47	31.8	19.7	12.1	91.3	64.9	20.7	21.7	3.1	5.7	93.2	4.0	2.7

SMW - Standard meteorological week
Tmin - Minimum temperature
Tmax - Maximum temperature
TR - Temperature range
BSS - Bright sunshine hours
RF - Rainfall
RH I - Forenoon relative humidity
RH II - Afternoon relative humidity
VPD I - Forenoon vapour pressure deficit
VPD II - Afternoon vapour pressure deficit
RD - Rainy days
Epan - Pan evaporation

3.2.2. Design and Layout

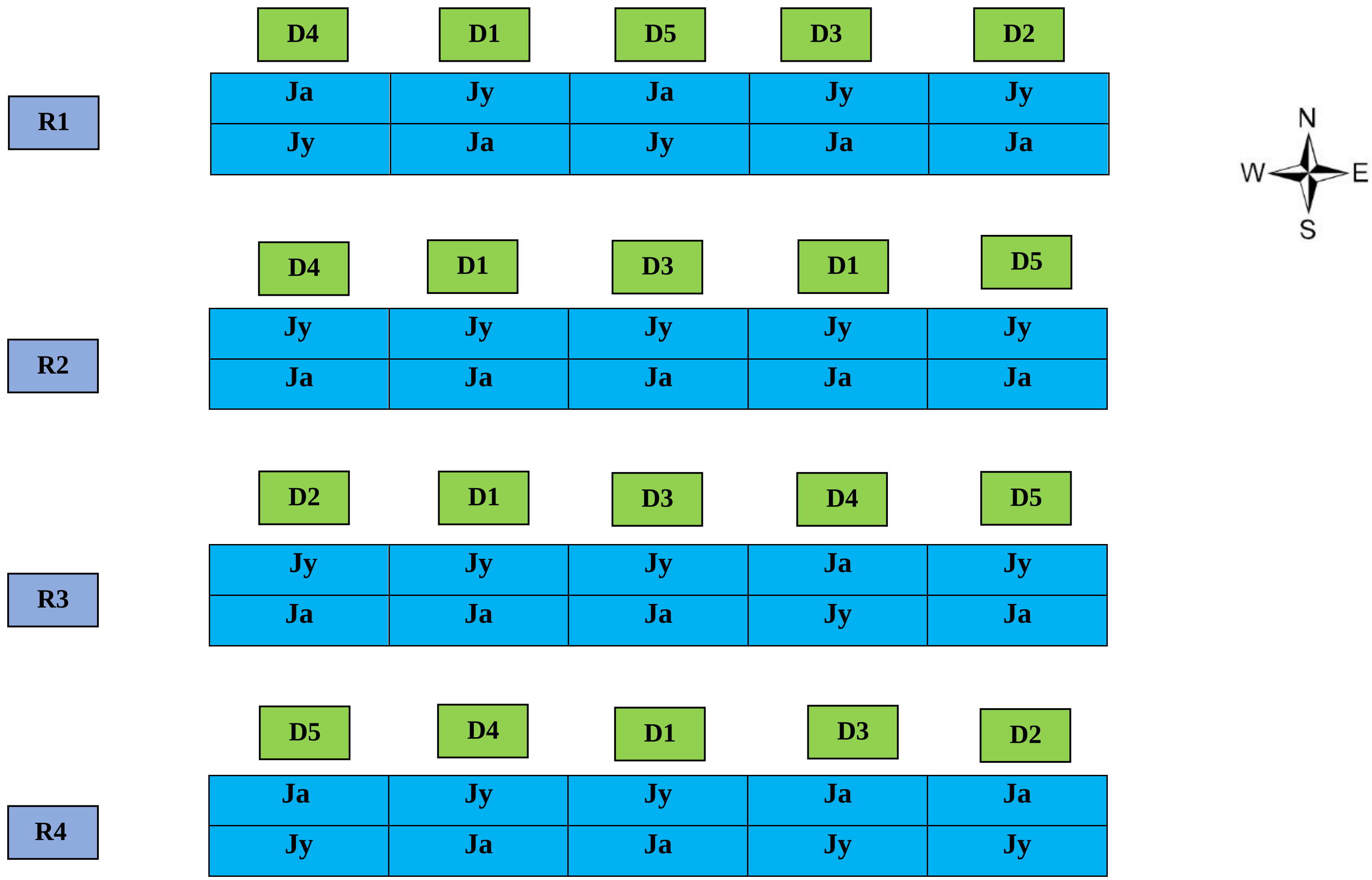
Experimental design used for the study was split plot with five dates of planting (from 5th June to 5th August with 15 days interval) as the main plot treatments and two varieties, Jyothi and Jaya as sub plot treatments. It was replicated four times. Fig. 3.1 shows the field layout. The field was divided into 40 plots each with 4 x 4 m^2 size. A spacing of 15 x 10 cm was provided for Jyothi and 20 x 15 cm was provided for Jaya.

3.2.3. Treatments

The treatments included were five dates of planting starting from 5th June to 5th August at 15 days interval and two rice varieties Jyothi and Jaya. These are given in the following Table 3.3.

Table 3.3. Treatments used in the experiment

MAIN PLOT	**SUB PLOT**
Dates of planting	**Variety**
5th June	Jyothi
	Jaya
20th June	Jyothi
	Jaya
5th July	Jyothi
	Jaya
20th July	Jyothi
	Jaya
5th August	Jyothi
	Jaya



D1 – June 5th, D2 – June 20th, D3 – July 5th , D4 – July 20th and D5 – August 5th planting

Fig. 3.1. Lay out of the experimental plot in split plot design

3.3 CROP MANAGEMENT

3.3.1. Nursery Management

Nurseries were prepared eighteen days before transplanting for Jyothi and twenty one days before for Jaya. For adequate irrigation and drainage all the necessary provisions were taken. In addition, plant protection measures were also taken in the nursery as per package of practices recommended (KAU, 2016).

3.3.2. Land Preparation and planting

Experimental field was ploughed well using tractor to incorporate weeds and stubble and then puddled. After that plots were prepared as per the layout. Two to three seedlings were planted in a hill. Recommended spacing were adopted for Jaya and Jyothi according to package of practices recommended (KAU, 2016)

3.3.3. Application of Manures and Fertilizers

Farm yard manure was applied in the field at the rate of 5000 kg ha^{-1} during land preparation. To supply the required nutrients (70 N: 35 P_2O_5: 35 K_2O kg ha^{-1} for short duration and 90 N: 45 P_2O_5 : 45 K_2O kg ha^{-1} for medium duration) fertilizers like urea, rajphos and potash were used. 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

Weed control is done by the application of a pre-emergence herbicide Londax (Bensulfuron methyl 0.6% + Pretilachlor 6% GR) at the rate of 1 kg ha^{-1}. Hand weeding was done twice, first at 30 days after transplanting and second at 45 days after transplanting. Recommended plant protection measures were applied to control pests and diseases at proper stages.

3.4. OBSERVATIONS

Five random plant samples were taken from each replications of each treatment avoiding the border plants to take the observations of height and yield and different phenological stages and were recorded for the two varieties.

3.4.1. **Biometric characters**

3.4.1.1. Plant height

The plant height of each variety were recorded at weekly intervals after transplanting and measured in cm. It was measured using a meter scale from the bottom of the culm to tip of the largest leaf or the ear head tip.

3.4.1.2. Leaf area

The observation of the leaf area of each variety was recorded in cm^2 at an interval of 15 days. Two plant samples were collected from each plot for the same. The leaf area of fresh samples was recorded using the leaf area meter.

3.4.1.3. Dry matter production

The observation on dry matter accumulation for each variety were taken at 15 days interval after transplanting. Two sample hills were randomly uprooted from the experimental field. First, the samples were dried in sun and then oven dried at a temperature of 80^0C to a constant weight. Then the biomasses were recorded in gram per plant.

3.4.1.4. Number of tillers per unit area

Number of tillers per unit area were counted at the harvesting time.

3.4.1.5. Number of panicles per unit area

Number of panicles per unit area were counted at the time of harvest.

Plate I. General view of experimental field

Plate II. Nursery preparation

Plate III. Transplanting

Plate IV. Harvesting

Plate V. Threshing

3.4.1.6. Number of spikelets per panicle

Number of spikelets per panicle were counted randomly from five plants at the time of harvest.

3.4.1.7. Number of filled grains per panicle

Number of filled grains per panicle were counted at the time of harvest from five selected plants randomly from each experimental plot.

3.4.1.8. Thousand grain weight

Thousand grains were counted from the cleaned dry grains from each plot and the weight was recorded in grams.

3.4.1.9. Grain yield

From each plot the produce was threshed, properly winnowed and dried to 14 per cent moisture, weighed and expressed as kg ha^{-1}.

3.4.1.10. Straw yield

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

3.4.2. Phenological observations

3.4.2.1. Number of days for active tillering

Number of days taken for active tillering by both the varieties were counted and recorded in days.

3.4.2.2. Number of days for panicle initiation

Number of days taken from transplanting to panicle initiation by both the varieties were noted and recorded in days.

3.4.2.3. Number of days for booting

Number of days taken from transplanting to booting by both the varieties was noted and recorded in days for each date of planting.

3.4.2.4. Number of days for heading

Number of days taken from transplanting to heading by both the varieties were counted and recorded in days for each date of planting.

3.4.2.5. Number of days for 50% flowering

Number of days taken from transplanting to 50% flowering by Jyothi and Jaya were determined and recorded in days for each planting.

3.4.2.6. Number of days for physiological maturity

Number of days taken from transplanting to physiological maturity by both the varieties were counted and expressed in days.

3.4.3 Physiological observations

3.4.3.1. Leaf Area Index (LAI)

$$Leaf\ Area\ Index = \frac{Total\ leaf\ area\ of\ plant}{Leaf\ area\ occupied\ by\ plant}$$

Leaf area index was measured at 15 days interval from transplanting to harvest using leaf area meter from randomly selected plants. It was suggested by Williams in 1946.

3.4.3.2. Leaf Area Duration (LAD)

The concept of Leaf Area Duration (LAD) was suggested by Power *et al.* (1967). It is the leaf area index over a period of time. The duration and extent of photosynthetic tissue of the crop canopy is considered under this concept.

$$LAD = \frac{(L_2 + L_1)}{2} \times (t_2 - t_1)$$

L_1 = LAI at time t_1

L_2 = LAI at time t_2

$(t_2 - t_1)$ = Time interval in days

3.4.3.3. Crop Growth Rate (CGR)

The dry matter accumulated per unit time per unit land area is determined by Crop Growth Rate (CGR) (g m $^{-2}$ day $^{-1}$). Watson put forward this method in 1956.

$$CGR = \frac{(W_2 - W_1)}{\rho(t_2 - t_1)}$$

Where W_1 and W_2 are the dry weight of the whole plant at times t_2 and t_1 and ρ is the ground area on which W_1 and W_2 are noted.

3.4.3.4. Net Assimilation Rate (NAR)

$$NAR = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{log_e L_2 - log_e L_1}{L_2 - L_1}$$

Where, W_1 and W_2 are dry weights of the whole plant at times t_1 and t_2 respectively. L_1 and L_2 are leaf area (m^{-2}) at t_1 and t_2 respectively; $t_1 - t_2$ is the time interval.

NAR is the net increase in dry matter per unit leaf area per unit time. It is a measure of average photosynthetic efficiency of leaves in a crop community and expressed in g m^{-2} day $^{-1}$.

3.4.4. Soil analysis

Soil samples were collected from the experimental field from 15 cm and 30 cm depths before planting. These samples were dried and powdered separately and were analyzed for pH, available nitrogen, available phosphorous, available potassium and organic carbon content. Table 3.4 shows the results of chemical analysis.

3.4.5. Weather data

Different weather parameters on daily basis (maximum temperature, minimum temperature, relative humidity, rainfall, number of rainy days, bright sunshine hours, wind speed, and evaporation) were collected from Agromet observatory of College of Horticulture, Vellanikkara and weekly converted data was used for the study. The different weather parameters used in the study are presented in the Table 3.5.

Table 3.4. Chemical properties of the soil

Sl. No.	Parameter	Sampling depth in cm	
		0 - 15	15 - 30
1	Organic carbon (%)	0.69	0.7
2	Soil pH	4.4	4.43
3	Available nitrogen (%)	0.06	0.06
4	Available phosphorous (kg ha^{-1})	40.63	40.21
5	Available potassium (kg ha^{-1})	192.42	182

Table 3.5. Weather parameters used in the experiment

Sl. No.	Weather parameter	Unit
1	Maximum temperature (Tmax)	^{0}C
2	Minimum temperature (Tmin)	^{0}C
3	Rainfall (RF)	mm
4	Rainy days (RD)	Days
5	Forenoon relative humidity (RH I) Afternoon relative humidity (RH II)	%
6	Forenoon vapour pressure deficit (VPD I) Afternoon vapour pressure deficit (VPD II)	mm Hg
7	Bright sunshine hours (BSS)	hrs
8	Wind speed (WS)	km hr^{-1}
9	Evaporation (Epan)	mm

3.5 STATISTICAL ANALYSIS

Standard procedure for split plot design given by Fisher (1947) was used for statistical analysis of the experimental data. The significant difference between main plot treatments (dates of planting) and sub plot treatments (varieties) and their interaction were analyzed by performing analysis of variance (ANOVA). When significant difference was found between the treatments and interaction, critical difference values were calculated and pair wise comparisons were carried out.

Critical difference was calculated for comparing two main plot treatments (dates of planting) by using the formula,

$CD_1 = t_1 \times SE_1$

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

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

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

r = number of replications

b = number of sub plot treatments

Critical difference was calculated for comparing two sub plot treatments (varieties) by using the formula,

$CD_2 = t_2 \times SE_2$

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

SE_2 = Standard error of difference between two sub plot treatments

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

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

r = Number of replications

a = Number of main plot treatments

Critical difference value for the comparison of main plot treatment means at the same or different levels of sub plot treatment was found as

CD_3 = t x SE_3

Where,

$$t = \frac{(b-1)E_2t_2 + E_1t_1}{(b-1)E_2 + E_1}$$

t_1 = table value of t corresponding to the degrees of freedom for main plot error
t_2 = table value of t corresponding to the degrees of freedom for sub 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

The impact of weather parameters on biometric and phenological characters of the crop was analyzed using correlation. Weather variables during critical growth stages were calculated and correlated with yield, yield attributes and important growth characteristics obtained from field experiment. Various statistical analyses were done using different software packages like Microsoft – Excel, SPSS and R software Version 1.2.5.

3.6. CROP GROWTH SIMULATION MODEL

Crop growth simulation models have become a widely accepted tools for agricultural research. It simulates the crop growth and development as a function of crop management, weather and soil conditions. These crop simulation models have wider applicability in agricultural fields for assessing the yield and analyzing impact of climate change in agriculture, and also helpful in modifying the management practices so as to get an optimum yield. Decision support system for agro technology transfer (DSSAT) and crop simulation models embedded in it can be used for this purpose. The inputs required for these crop simulation models include the daily weather data, soil surface and profile information and detailed crop management information.

The principle advantage of DSSAT is, it has the potential to reduce substantially the time and cost of experimentation necessary for the proper evaluation of new cultivars and new management systems.

DSSAT contains crop specific file including the genetic information of the crop. User can also provide experimental data to the model. DSSAT also evaluates the simulated outputs with that of experimental data. By accurate calibration and validation DSSAT can be used as an efficient tool in modern agriculture.

3.6.1. CERES-Rice model

Crop Estimation through Resource and Environment Synthesis (CERES) model has been applied to a range of areas, including crop management and shifting weather patterns. The ultimate aim of this model is to help farmers by identifying major yield limiting factors and developing research areas to improve cropping systems. This model simulate crop growth, development and yield as a function of weather, soil, water, cultivar, planting density and nitrogen. CERES-Rice model also requires a common input and output data format. Hunt and Boote (1994) proposed the minimum data set for the calibration and operation of the CERES- Rice models. In the present study, CERES-Rice model was run using the weather, soil, crop management practices and experimental data for the year 2019 for two varieties Jyothi and Jaya. The input and output files of CERES-Rice include the following given in Table 3.6 and Table 3.7.

3.6.1.1. Input files and experiment data files

The CERES-Rice model uses input files and experiment data files to run which is given in Table 3.6.

Table 3.6. Input files of CERES-Rice model

Internal file name		External description	Name
Experiment	FILE X	Experiment details file for a specific experiment (e.g., rice at AGVK): Contains data on treatments, field conditions, crop management and simulation controls	AGVK1701.RIX
Weather and soil	FILE W	Weather data, daily, for a specific (e.g., ATRA) station and time period (e.g., for one year)	ATRA1701.WTH
	FILE S	Soil profile data for a group of experimental sites in general (e.g., SOIL.SOL) or for a specific institute (e.g., AGSANDLOAM. SOL)	SOIL.SOL
Crop and cultivar	FILE C	Cultivar/variety coefficients for a particular crop species and model; e.g., rice for the 'CERES' model, version 046	RICER046.CUL[1]
	FILE E	Ecotype specific coefficients for a particular crop species and model; e.g., rice for the 'CERES' model, version 046	RICER046.ECO[1]
	FILE G	Crop (species) specific coefficients for a particular model; e.g., rice for the 'CERES' model, version 046	RICERO46.SPE[1]
Experiment data files	FILE A	Average values of performance data for a rice experiment. (Used for comparison with summary model results.)	AGVK1701.RIA
	FILE T	Time course data (averages) for a rice experiment. (Used for graphical comparison of measured and simulated time course results.)	AGVK1701.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.

3.6.1.2. Output files

The output files helps the users to select the information required for a specific application which is listed in Table 3.7.

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

3.6.2. Running the Crop Model

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

3.6.3. Model calibration and evaluation

The adjustment of genetic coefficients for comparing simulated and observed values is known as model calibration. Genetic coefficient calibration of CERES-Rice model was done with minimum data set such as planting date, plant density, spacing, fertilizer amount, irrigation levels, date of panicle initiation, physiological maturity, harvesting, harvesting method, yield and leaf area. To evaluate the goodness of fit and performance of the model, the statistical parameters like Normalized Root Mean Square Error (RMSE) and d-stat index were used as common tools.

3. 7. ANALYSIS OF POTENTIAL YIELD AND YIELD GAP

Yield gap analysis was carried out for rice varieties during *kharif* season (2019) by estimating different production levels as suggested by Rabbinge *et al. (*1993).

3.7.1 Potential yield

The maximum yield of a variety restricted only by the season specific climatic conditions without limitation of water and nutrients and with optimum cultural management is defined as potential yield. Thus, potential yield of crop depends on the temporal variation in maximum and minimum temperatures, solar radiation, soil water, CO_2 level in the atmosphere during the crop season and genotypic characteristics of variety (Patel *et al.* 2004). Observations obtained from field experiments conducted at Agricultural Research Station, Mannuthy during *kharif* season (2019) with five dates of plantings were used to run CERES rice model. Genetic coefficients of CERES model was validated and fine-tuned using the field experiment conducted during the same period. No stress condition was simulated using model by providing simulation option as “No” for both nitrogen and water in the file X. Yield simulated under this condition was considered as potential yield and was simulated for all the five dates of planting.

3.7.2 Attainable yield

The maximum yield obtained from the experimental plot under best management practices was taken as attainable yield. Attainable yield will be less than potential yield (Hall *et al.*, 2013). Survey was conducted among rice farmers to collect yield data and planting time. Based on the survey most of the farmers started cultivation during second or third week of June. Hence yield obtained from the experimental plots at Agricultural Research Station, Mannuthy during June 20th planting was considered as attainable yield.

3.7.3 Actual yield

Actual yield for Ollukkara block was obtained from Department of Economics and Statistics report and farmers survey. It is the yield obtained from the farmers field. The reducing elements like water, nutrients, pest or diseases and their interaction effect decides the extent of yield loss.

3.7.4 Yield gap

Yield gap is the difference between any two production levels. Total yield gap was calculated as the difference between potential yield and actual yield. Total yield gap is further divided in to gap I and gap II. Gap I is defined as the difference between potential yield and attainable yield. Gap II is defined as the difference between attainable yield and actual farmers yield (FAO, 2004). Each yield gap is expressed as a percentage of potential yield. Different production levels and yield gaps are represented in Fig. 3.2.

Gap I = Potential yield – Attainable yield

Gap II = Attainable yield – Actual yield

Total yield gap = Potential yield – Actual yield

Yield gap expressed as the percentage of potential yield was calculated by,

$$\% \text{ Yg} = \frac{Yield\ gap}{Potential\ yield} \times 100$$

3.7.5 Evaluating fertilizer management practices to reduce yield gap using CERES model

Narrowing yield gap is one of the key component in achieving sustainable food production. It increases food productivity, resource utilization efficiency and sustainability. Yield was simulated under different fertilizer management practices using CERES rice model. General nitrogen recommendation for Jaya was 90 kg ha^{-1}. Yield was simulated when this amount of nitrogen was applied in two split dose (45:45) and three split dose (45:23:23). General nitrogen recommendation for Jyothi was 70 kg ha^{-1}. Yield was simulated when this amount of nitrogen was applied in two split dose (47:23) and three split dose (35:18:18). Yield response with additional nitrogen input was also simulated and plotted in graph. Normally Nitrogen is applied through broad casting in rice. Simulated yield obtained under broad casting method was compared with the yield simulated when nitrogen is applied through irrigation water and urea super granule method. Corresponding yield gaps were also estimated.

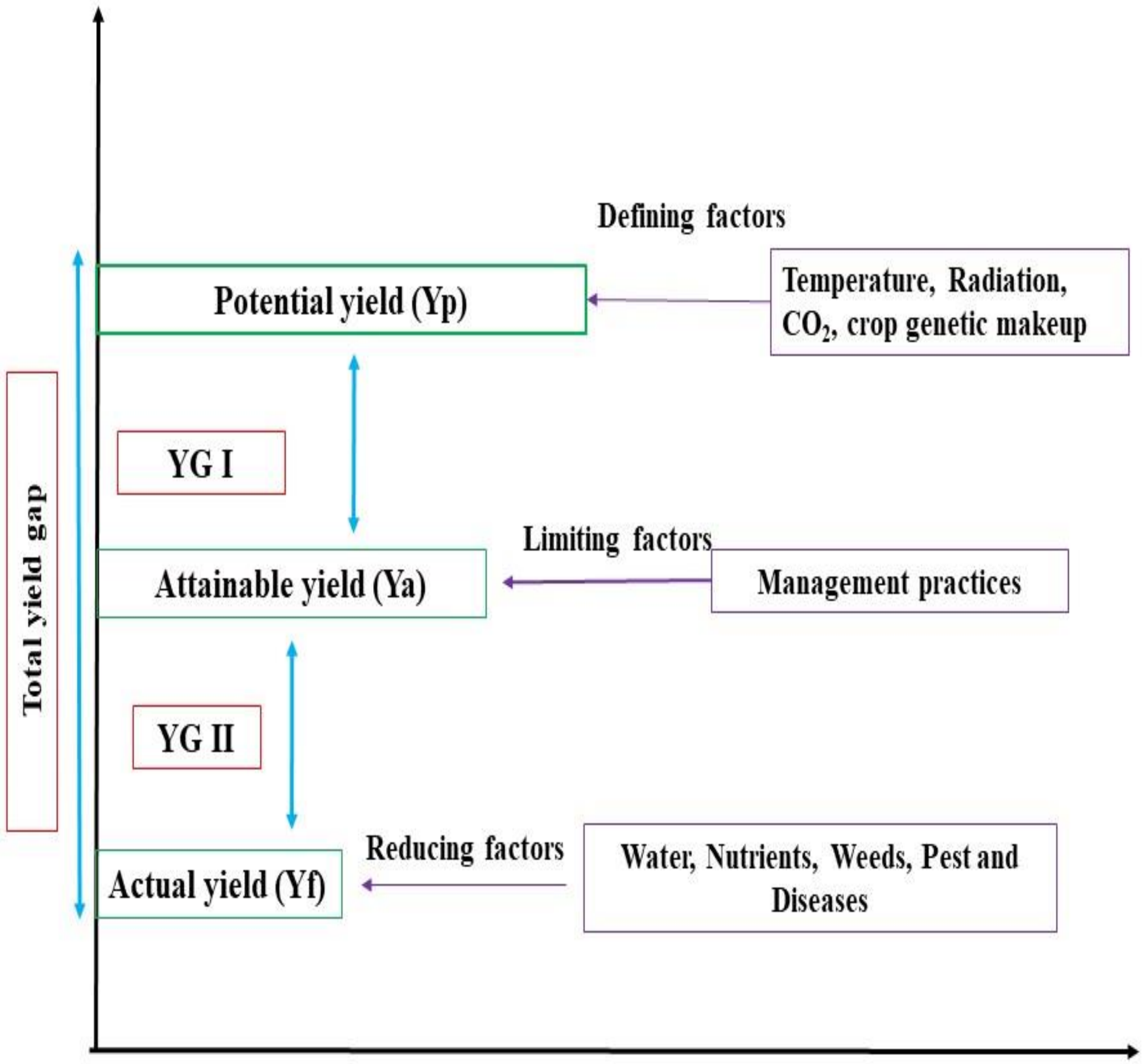


Fig. 3.2. Different production levels and various yield gaps

Results

4. RESULTS

The results congregated from the research "Analysis of potential yield and yield gap of rice (*Oryza sativa*) using CERES rice model" were explained here.

4.1. PHENOPHASES

The study of the timing of plant life cycle events in relation to plant environment and climatic conditions is termed as phenology. The accurate knowledge on phenology will aid in adopting feasible crop management practices and stabilize crop yield and improve product quality. The life cycle of rice was subdivided into six different growth and development phases. Which were recognized as phenophases (Satish *et al.*, 2017)

a. Transplanting to active tillering (P1)
b. Active tillering to panicle initiation (P2)
c. Panicle initiation to booting (P3)
d. Booting to heading (P4)
e. Heading to 50% flowering (P5)
f. 50% flowering to physiological maturity (P6)

Among the six phenophases, vegetative period consist of transplanting to panicle initiation, panicle initiation to 50% flowering included in reproductive period and ripening period was between 50% flowering to physiological maturity.

Duration of each phenophases *i.e* from P1 to P6 for both Jaya and Jyothi for different dates of planting (June 5th – August 20th) during *kharif* season 2019 were exhibited by phenological calender. Fig 4.1(a and b).

In the calendar each phenophase corresponds to the standard meteorological week when it occurred. Duration of phenophases for both varieties and five different dates of planting showed variations. Duration was more observed in case of Jaya compared to Jyothi.

4.2. WEATHER PREVAILED DURING CROP GROWTH PERIOD

The weather parameters *viz.* maximum temperature, minimum temperature, relative humidity, vapour pressure deficit, rainfall, number of rainy days, bright sunshine hours, wind speed and pan evaporation were recorded on daily basis during the field experiment for the year 2019. These meteorological parameters averaged over standard meteorological weeks were represented graphically from Fig 4.2 to 4.7.

4.2.1. Air temperature

The weekly average of maximum temperature, minimum temperature, mean temperature and temperature range experienced during the crop growth period is plotted graphically against standard meteorological weeks (Fig. 4.2.). Both maximum and minimum temperature varied non linearly throughout the crop growth period. Maximum temperature varied between 27.6-35.0 ^{o}C and a maximum value of 35 ^{o}C was observed on 24th week and minimum value of 27.6 ^{o}C was observed on 35th week. Among all the five plantings temperature experienced at the time of planting was more for second planting.

Minimum temperature varied between 19.7-25.3 ^{o}C, which showed a maximum value on 24th week and minimum value on 47th week. Mean temperature was calculated with maximum and minimum temperature. Mean temperature varied between 24.3 - 30.1 ^{o}C. Maximum value of mean temperature was on 24th week and minimum value was on 35th week.

Maximum, minimum and mean temperature showed a similar trend, the temperature decrease towards the commencement of fifth planting and then showed an increase. Temperature range was experience in the range of 6.7-12.1 ^{o}C. Temperature range calculated during 47th week showed a maximum value and 35th week showed a minimum value. Temperature range decreased after second planting and it gradually increased during maturing stages.

4.2.2. Relative humidity (RH)

Average value of forenoon, afternoon and mean relative humidity calculated for each standard meteorological week for entire crop period is depicted in the Fig. 4.3. Forenoon relative humidity varied between 88-97.9%, afternoon relative humidity

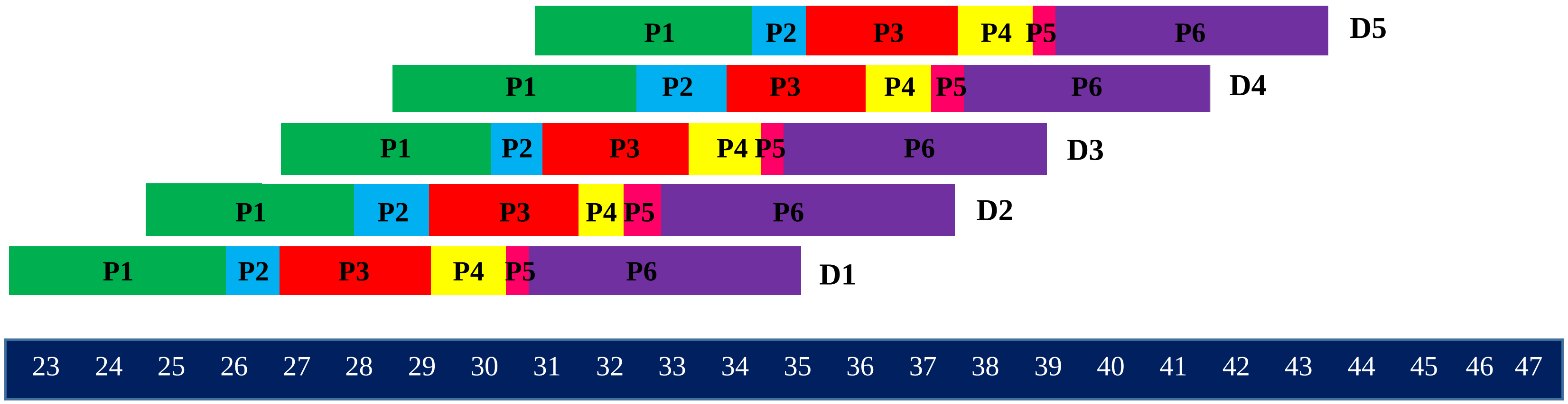


Fig. 4.1(a) Phenological calendar of Jaya **Standard meteorological weeks (2019)**

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

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

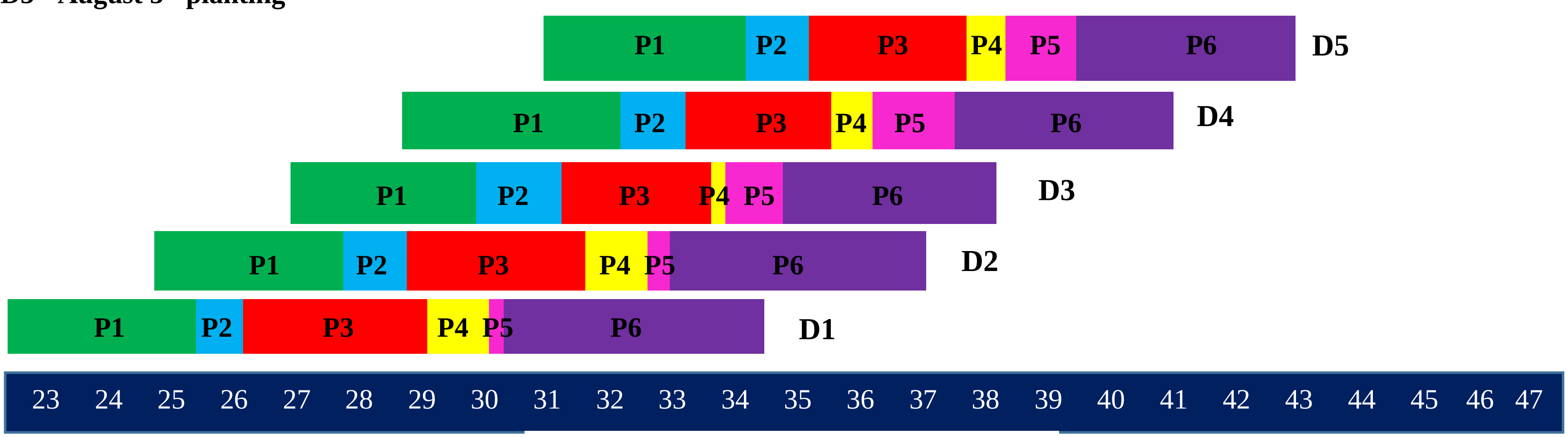


Fig. 4.1(b) Phenological calendar of Jyothi **Standard meteorological weeks (2019)**

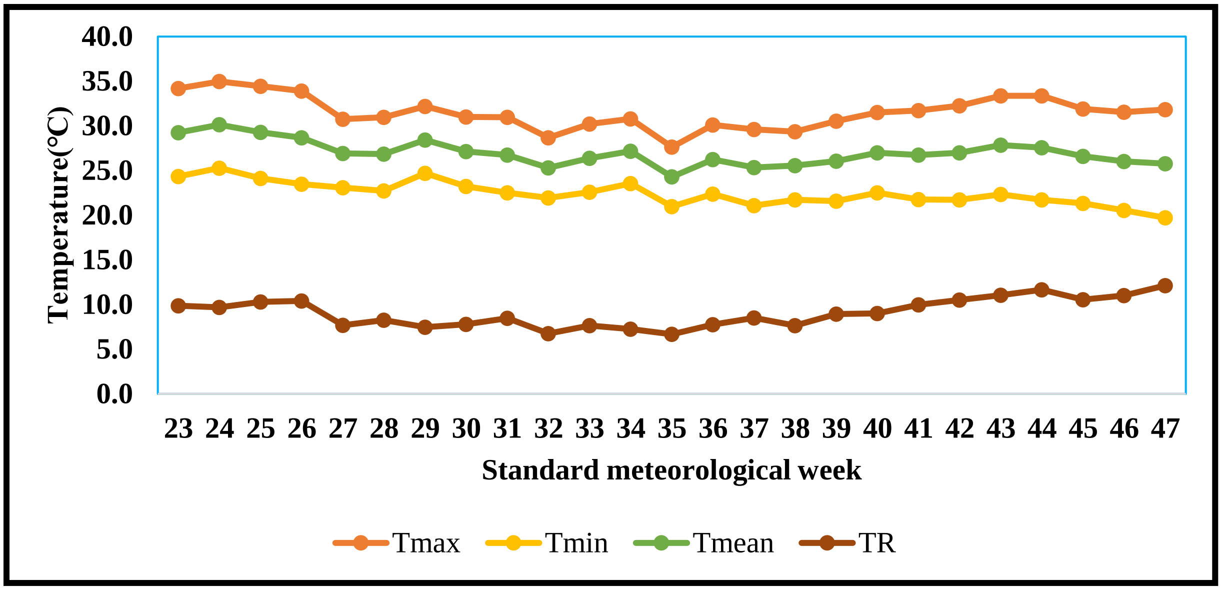


Fig. 4.2. Temperature experienced during experimental period

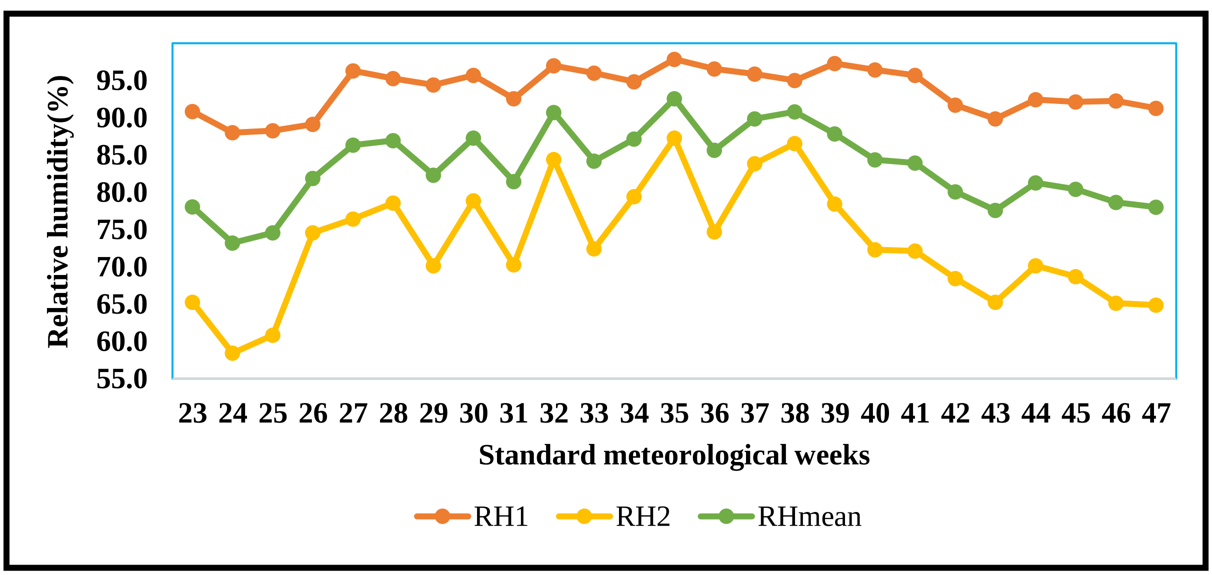


Fig. 4.3. Relative humidity experienced during experimental period

varied between 58.4-87.3% and mean relative humidity varied between 73.2-92.6% and all the three relative humidity showed a same trend. Maximum value in each case was recorded during 35th week and minimum value was recorded during 24th week. Relative humidity was somewhat more stable in the later stages of August 5th planting.

4.2.3. Vapour pressure deficit (VPD)

Forenoon and afternoon vapour pressure deficit was calculated using dry bulb and wet bulb temperature recorded during the crop growth period. Weekly average value was then calculated and plotted against standard week (Fig. 4.4). Forenoon vapour pressure deficit was recorded in the range of 20.7- 25.2 mm Hg and afternoon vapour pressure was in the range of 21.4- 25.5mm Hg. In case of forenoon vapour pressure deficit maximum and minimum values were recorded during 24th week and 47th week respectively. In case of afternoon vapour pressure deficit maximum and minimum values were recorded on 38th and 46th week respectively. Both forenoon and afternoon vapour pressure deficit showed a decreasing trend during the crop season.

4.2.4. Pan evaporation (Epan)

Fig. 4.5 represents the weekly pan evaporation value recorded during crop growing season. Maximum value of recorded pan evaporation was 3.9 mm, which is recorded during 24th week and minimum value of pan evaporation was 1 mm which was recorded during 35th week.

4 .5. Bright sunshine hours (BSS)

Weekly average value of bright sunshine hours received during the experimental period was exhibited in the Fig. 4.5. Bright sunshine hour recorded was in the range of 0.4 – 7.7 hrs day^{-1}. Bright sunshine hours decreased initially and then showed an increasing value towards the later stage of last two dates of planting. Maximum and minimum bright sunshine hours was recorded on 43rd week and 35th week respectively.

4.2.6. Rainfall and rainy days (RF and RD)

Weekly total rainfall and rainy days recorded during the crop growth period was represented graphically in Fig. 4.6. Rainfall recorded in the range of 0.7-508.1mm per week. A minimum of 0.7mm was recorded during 24^{th} week *i.e* during initial days of first planting. A maximum value of 508.1mm per week is obtained during 35^{th} week. Among all the dates of planting, rainfall recorded during last planting was higher. Number of rainy days ranged from 0.0-7 days. There was no rainy day during second week.

4.2.7. Wind speed (WS)

Fig. 4.7 illustrated the weekly wind speed plotted against standard meteorological week. Minimum value of wind speed was 1km hr^{-1} which was recorded during 28^{th} week. Maximum value of wind speed was 3.1 km hr^{-1} recorded during 47^{th} week. Wind speed showed a stable trend during crop season except for a sudden increasing in the last week of experiment.

4.3. Phenological observations of crop growth and development

Duration of each phenophase for five dates of plantings were recorded for both Jaya and Jyothi. Phenophases considered to record observations were active tillering, panicle initiation, booting, heading, 50% flowering and physiological maturity. Number of days taken to reach each phenophases was different for different dates of planting. The observations are exhibited in Table 4.1. Maximum crop duration was recorded during June 20^{th} planting in both Jaya and Jyothi. Minimum duration was taken during July 20^{th} and August 5^{th} planting for Jaya and July 20^{th} planting for Jyothi.

4.3.1. Number of days for active tillering

Among all the five dates of planting 3^{rd} and 4^{th} planting of Jaya took more days *i.e* 30 days from transplanting to reach active tillering stage. Fifth June and 20^{th} June planting of Jyothi took less number of days *i.e* 25 days from transplanting to active tillering. In

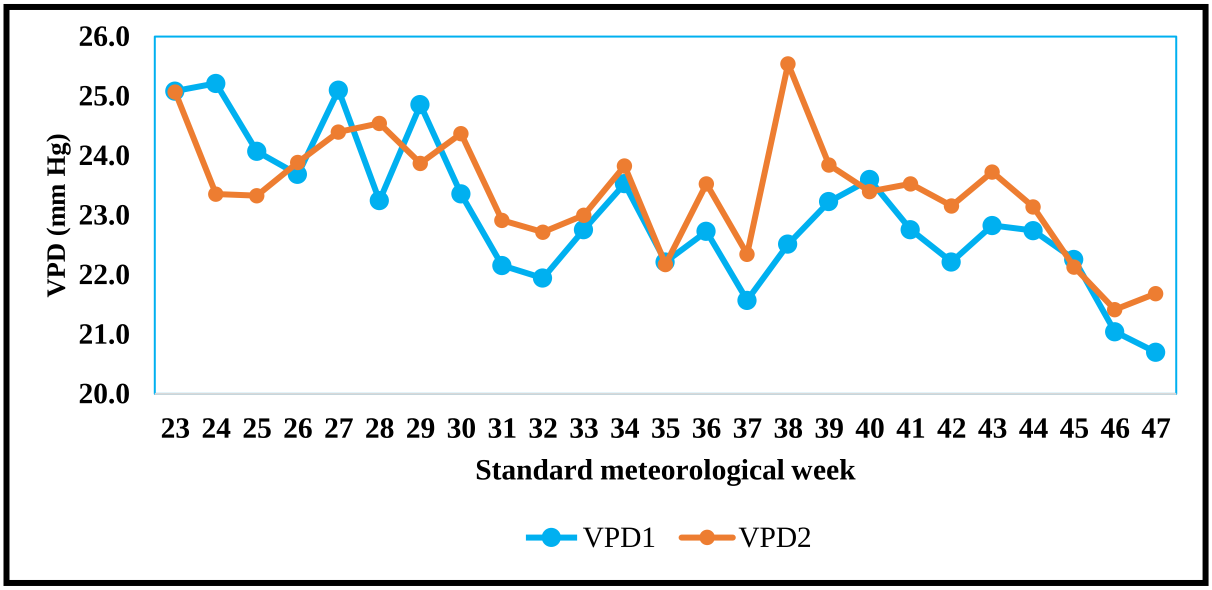


Fig. 4.4. Vapour pressure deficit (VPD) experienced during experimental period

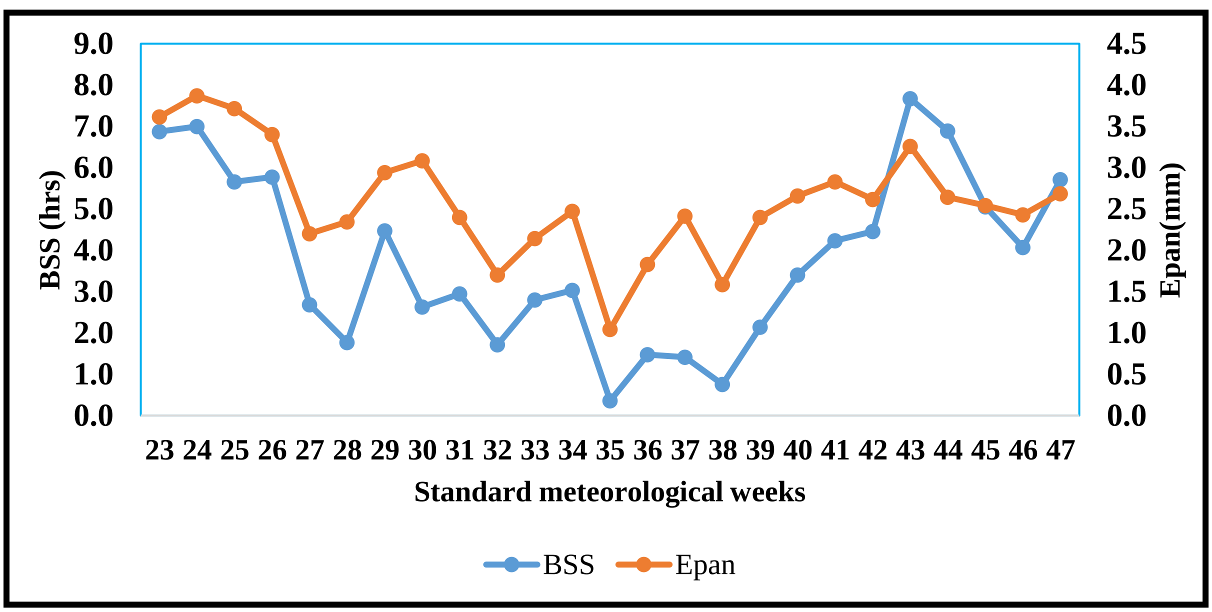


Fig. 4.5. Pan evaporation and bright sunshine hours experienced during experimental period

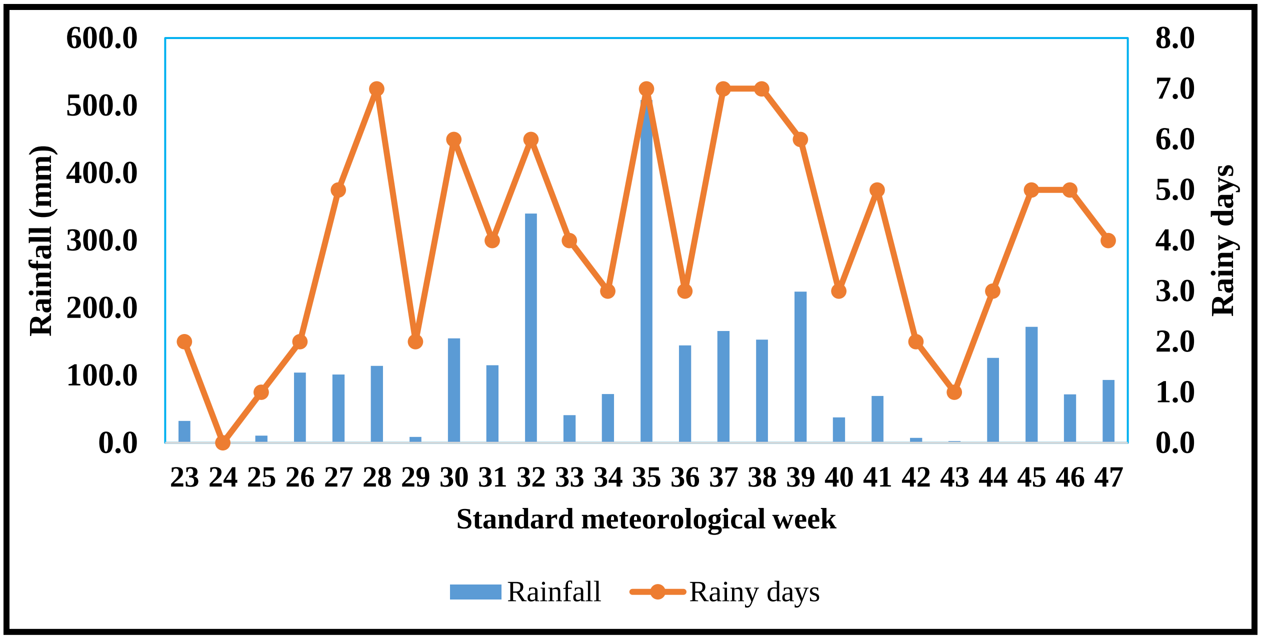


Fig. 4.6. Rainfall and rainy days experienced during experimental period

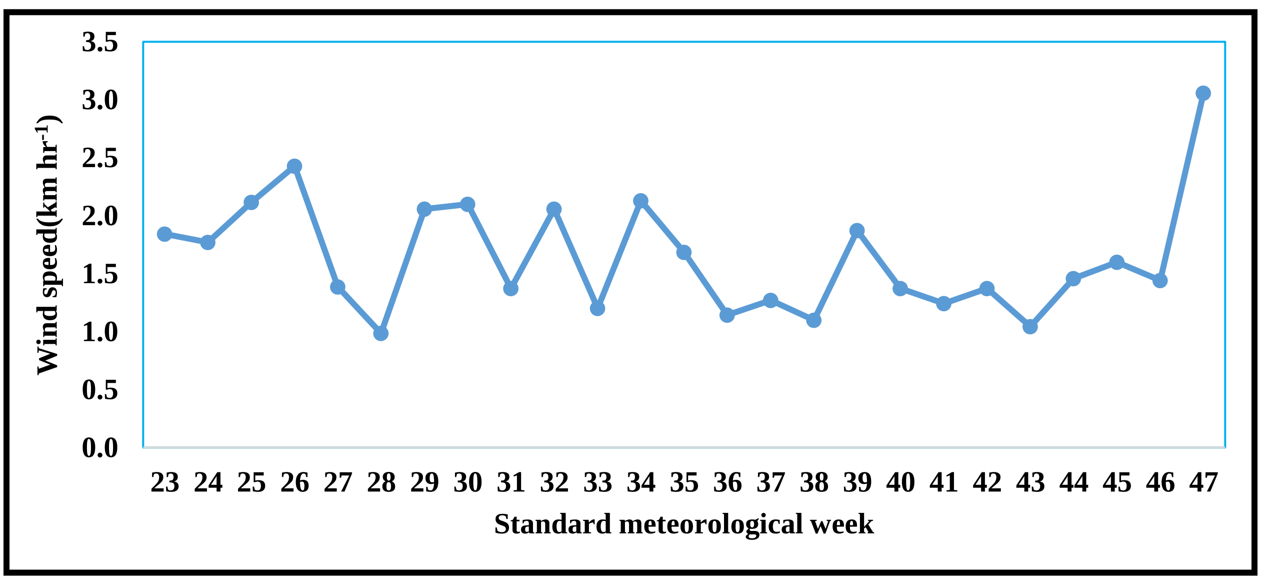


Fig. 4.7. Wind speed experienced during experimental period

case of Jaya, June 20th planting took least number of days to reach active tillering. In case of Jyothi number of days to reach active tillering was more during July 20th planting. Among the two varieties Jaya took more days to reach active tillering stage.

4.3.2.Number of days for panicle initiation

Maximum number of days taken to attain panicle initiation stage was more in Jaya (42 days) which is planted on 5th August. Jaya took minimum days to attain panicle initiation during June 5th planting (36 days). In case of Jyothi it took 38 days to reach panicle initiation in July 5th transplanting.

Minimum number of days taken to attain panicle initiation was noticed in Jyothi (31 days) during June 5th planting. Jaya took more days to attain panicle initiation than Jyothi. During July 5th planting both the varieties showed a less difference *i.e* Jaya took 40 days and Jyothi took 38 days to attain panicle initiation.

4.3.3.Number of days for booting

Number of days taken to reach booting varied between variety and dates of planting. Number of days taken to reach booting for Jaya and Jyothi was 56 and 55 days during first date of planting (June 5th), 58 and 56 days for second date of planting (June 20th), 60 and 59 days in third date(July 5th) of plantings respectively.

Variation in duration was more in last two dates of planting *i.e* Jaya took 58 and 60 days during July 20th and August 5th planting respectively while Jyothi took 53 and 54 days during July 20th and August 5th planting respectively. For Jaya maximum duration was observed during July 5th planting and August 5th planting and least duration was observed during June 5th planting.

Table 4.1. Phenological observations of Jyothi and Jaya under different dates of planting

Crop Stages	Dates of planting									
	June 5th		June 20th		July 5th		July 20th		August 5th	
	Ja	Jy	Ja	Jy	Ja	Jy	Ja	Jy	Ja	Jy
Active tillering	29	25	28	25	30	26	30	27	29	26
Panicle initiation	36	31	38	33	40	38	41	35	42	34
Booting	56	55	58	56	60	59	58	53	60	54
Heading	66	63	64	64	64	61	66	58	65	59
50% flowering	69	65	69	67	70	69	70	68	67	68
Physiological maturity	105	99	108	102	106	99	100	95	100	96

Jy – Jyothi   Ja – Jaya

For Jyothi maximum duration was seen during July 5th planting and minimum duration was seen during July 20th planting.

4.3.4. Number of days for heading

Number of days to reach heading ranged from 64-66 days in case of Jaya and 58 - 64 in case of Jyothi. Maximum number of days taken for heading (66 days) was noted in Jaya during June 5th and July 20th date of planting. Minimum number of days taken to reach heading was noted in Jyothi (58 days) during July 20th planting. During June 20th planting both the varieties attained heading stage simultaneously (64 days each).

4.3.5. Number of days for 50% flowering

From heading less than 10 days were taken to reach 50% flowering in both the varieties during all five dates of planting. Among the two varieties Jaya took maximum number of days (70 days) to reach 50% flowering during July 5th and July 20th date of planting and Jyothi took minimum days (65 days) during June 5th planting. In case of Jaya a minimum duration to 50% flowering was observed on August 5th planting *i.e* 67 days. In case of Jyothi, July 5th planting took maximum days to attain 50% flowering. In case of Jaya, June 5th and June 20th plantings and July 5th and July 20th planting took same days to reach 50% flowering *i.e* 69 and 70 days respectively. In case of Jyothi July 20th and August 5th planting took equal days (68 days) to attain 50% flowering.

4.3.6. Number of days for physiological maturity

Among the two varieties Jyothi attained physiological maturity earlier than Jaya. In both the varieties maximum duration was observed during June 20th transplanting (Jaya-108 days and Jyothi- 102 days) and minimum duration was observed during July 20th transplanting (Jaya 100 days and Jyothi- 95days). Number of days taken to reach physiological maturity was equal during July 20th and August 5th for Jaya (100 days). Number of days to attain physiological maturity did not showed a linear trend. In June 5th planting Jaya took 105 and Jyothi took 99 days it increased to 108 and 102 for Jaya and Jyothi respectively during June 20th planting. It was then decreased during July 5th planting (Jaya-106 days and Jyothi-99 days).

4. 4. Weather conditions prevailed during different growth stages

Weather conditions prevailed during different stages of crop growth were given from Table 4.2 to 4.7.

4.4.1. Weather conditions prevailed during the crop period from transplanting to active tillering stage in different dates of planting (Table 4.2)

4.4.1.1. Temperature (Maximum temperature, Minimum temperature, and Temperature range)

Highest value of maximum temperature, 31.9 ^{o}C and 31.9 ^{o}C in June 5th planting and lowest value of 29.2^{o}C in August 5th planting were observed for Jyothi and Jaya. Higher minimum temperature, 23.6 ^{o}C for Jaya was observed during June 5th planting and for Jyothi this value is 23.4 ^{o}C which was observed during June 20th planting, whereas the lowest minimum temperature was noticed during August 5th planting with a value 21.7 ^{o}C for Jaya and 21.6 for Jyothi. The highest temperature range value was observed during June 5th planting *i.e* 8.4 ^{o}C and 8.6 ^{o}C for Jaya and Jyothi respectively. Lowest value of 7.1 ^{o}C and 7.13 ^{o}C was observed for Jaya and Jyothi respectively during July 20th planting.

4.4.1.2. Relative Humidity (RH I, RH II and RH mean) and Vapour Pressure Deficit (VPD I and VPD II)

Range of forenoon relative humidity varied from 96.7 to 93.7% in case of Jaya and 96.7 to 93.6% in case of Jyothi. Highest humidity was recorded during July 20th planting and the lowest humidity was noted during June 5th planting for both the varieties. Afternoon relative humidity varied between 74.9-84.0% in case of Jaya and 74.88- 83.12 % in case of Jyothi. Mean relative humidity range for Jaya was 84.3-90.3% in case of Jaya and 84.5- 89.9% in case of Jyothi. In case of both Jaya and Jyothi

Table 4.2. Weather conditions experienced by the crop from transplanting to active tillering

	Variety	Tmax °C	Tmin °C	RH I %	RH II %	RH mean %	WS km hr^{-1}	BSS hrs	RF mm	Rainy days	Epan mm day^{-1}	Trange °C	VPD I mm Hg	VPD II mm Hg
D1	Ja	31.9	23.6	93.7	74.9	84.3	1.8	3.6	328.6	16.0	2.7	8.4	24.3	24.2
	Jy	31.9	23.3	93.6	75.4	84.5	1.7	3.6	323.7	15.0	2.7	8.6	24.1	24.2
D2	Ja	31.2	23.3	94.4	74.9	84.7	1.7	3.1	384.8	19.0	2.7	7.9	23.4	23.9
	Jy	31.3	23.4	94.3	74.9	84.6	1.7	2.9	454.1	17.0	2.7	7.9	23.5	23.9
D3	Ja	30.3	22.6	95.2	75.4	85.3	1.6	2.7	613.3	20.0	2.3	7.8	22.6	23.2
	Jy	30.2	22.4	95.4	76.0	85.7	1.6	2.5	610.7	19.0	2.2	7.7	22.5	23.1
D4	Ja	29.3	22.2	96.6	80.2	88.5	1.6	1.7	1015.0	21.0	1.8	7.1	22.6	23.0
	Jy	29.3	22.2	96.7	80.6	88.6	1.7	1.8	1010.3	20.0	1.8	7.1	22.6	23.0
D5	Ja	29.2	21.7	96.5	84.0	90.3	1.4	1.0	1040.2	26.0	1.7	7.5	22.4	23.5
	Jy	29.2	21.6	96.6	83.1	89.9	1.4	1.0	971.5	22.0	1.8	7.5	22.3	23.4

Ja – Jaya , Jy – Jyothi , D1 – June 5th, D2- June 20th , D3 – July 5th , D4- July 20th , D5- August 5th

maximum and minimum value of mean and afternoon relative humidity was noted during August 5th and June 5th plantings respectively. Forenoon vapour pressure deficit varied between 22.4 - 24.3 mm Hg in case of Jaya and 22.3 - 24.1 mm Hg in case of Jyothi. During June 5th planting maximum values of both forenoon and afternoon vapour pressure deficit were noticed while a minimum value of forenoon vapour pressure deficit was observed during August 5th planting in case of both Jaya and Jyothi. For afternoon vapour pressure deficit this minimum value was seen during July 20th planting. Both forenoon and afternoon relative humidity decreased towards last dates of planting, even though a slight increase was observed during July 20th transplanting in case of forenoon relative humidity and a slight increase was observed during August 5th planting in case of afternoon relative humidity.

4.4.1.3. Wind speed (WS)

Wind speed experienced during this period was nearly stable throughout all dates of planting. For Jaya the range of wind speed was 1.4 – 1.8 km hr^{-1} and for Jyothi the range was 1.4- 1.7 km hr^{-1}. Minimum wind speed was observed during August 5th planting and maximum wind speed was observed during June 5th planting.

4.4.1.4. Bright sunshine hours (BSS)

A broad variation was recorded in bright sunshine hours received during different dates of planting. A maximum value of 3.64 hrs was observed during June 5th planting in both varieties. A minimum value of 0.96 hrs for Jaya and 1.02 hrs for Jyothi was recorded during August 5th planting.

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

Rainfall received during different dates of planting showed a wide range of variation. Jaya received a maximum rainfall of 1040 mm during August 5th planting and a minimum rainfall of 328.6 mm during June 5th planting. A maximum rainfall of 1010 mm was received during August 5th and a minimum rainfall of 323.7 mm was received during June 5th planting in case of Jyothi. In Jaya there was a maximum of 26 rainy days during August 5th and a minimum of 16 days during June 5th. A maximum of 22 rainy days and a minimum of 15 days were observed during August 5th and June 5th planting respectively in Jyothi.

4.4.1.6. Pan Evaporation (Epan)

Range of pan evaporation was almost same for both Jaya and Jyothi. In case of Jaya, a maximum value of 2.72 mm per day was recorded during June 5th planting and June 20th planting. A minimum value of 1.7 mm per day was noted during August 5th planting. For Jyothi a maximum value of 2.7 mm per day was recorded during June 5th planting and June 20th planting and a minimum value was observed during 20th July planting and August 5th planting.

4.4.2. Weather conditions prevailed during the crop period from transplanting to panicle initiation stage in different dates of planting (Table 4.3)

4.4.2.1. Temperature (Maximum temperature, Minimum temperature, and Temperature range)

Maximum temperature prevailed during transplanting to panicle initiation was varied between 29.4 - 31.8 ºC. Maximum value of maximum temperature was noted during June 5th planting and minimum value was observed during July 20th planting. The temperature range was near equal in both varieties.

Minimum temperature range was almost same for both the varieties *i e.* a maximum value of 23.4℃ during June 5th planting, and a minimum value of 21.7℃ during August 5th planting. A temperature range of 7.4 to 8.3℃ was noted in both Jaya and Jyothi. Minimum value was observed during July 20th planting for Jyothi and July 5th and July 20th planting for Jaya. A maximum value was observed during June 5th planting. Maximum temperature, and temperature range showed a decreasing trend towards July 20th planting.

Table 4.3. Weather conditions experienced by the crop from transplanting to panicle initiation

	Variety	Tmax ºC	Tmin ºC	RH I %	RH II %	RH mean %	WS km hr^{-1}	BSS hrs	RF mm	Rainy days	Epan mm day^{-1}	Trange ºC	VPD I mm Hg	VPD II mm Hg
D1	Ja	31.8	23.4	94.2	75.7	84.9	1.8	3.5	482.2	22.0	2.8	8.3	24.0	24.2
	Jy	31.7	23.4	93.9	75.9	84.9	1.8	3.4	527.6	23.0	2.8	8.3	24.0	24.3
D2	Ja	30.7	23.0	95.0	76.5	85.9	1.7	2.7	741.9	26.0	2.5	7.8	23.1	23.6
	Jy	30.6	22.4	95.6	78.6	85.8	1.6	2.6	747.4	27.0	2.4	7.8	23.0	23.6
D3	Ja	29.8	22.4	95.6	78.6	87.1	1.7	2.2	1162.5	28.0	2.1	7.4	22.6	23.1
	Jy	29.8	22.4	95.7	78.6	87.2	1.7	2.2	1190.5	29.0	2.1	7.5	22.6	23.1
D4	Ja	29.4	22.0	96.4	80.5	88.5	1.5	1.6	1181.0	28.0	1.9	7.4	22.5	22.9
	Jy	29.4	22.0	96.4	80.7	88.5	1.5	1.6	1218.8	30.0	1.9	7.4	22.5	23.2
D5	Ja	29.5	21.7	96.5	82.6	89.6	1.5	1.2	1278.3	33.0	1.9	7.8	22.6	23.6
	Jy	29.7	21.7	96.7	82.0	89.4	1.4	1.5	1293.1	34.0	1.9	7.9	22.7	23.6

Ja – Jaya , Jy – Jyothi , D1 – June 5th, D2- June 20th , D3 – July 5th , D4- July 20th , D5- August 5th

It increases during August 5th planting. Minimum temperature showed a decreasing trend towards August 5th planting.

4.4.2.2. Relative Humidity (RH I, RH II and RH mean) and Vapour Pressure Deficit (VPDI and VPD II)

Forenoon relative humidity was higher during August 5th planting and a lower value during June 5th planting. Similar trend was observed for afternoon relative humidity and mean relative humidity. Jaya experienced a maximum forenoon relative humidity of 96.5% and Jyothi experienced a maximum forenoon relative humidity of 96.7%. Minimum value of forenoon relative humidity was 94.2% in case of Jaya and 93.9% in case of Jyothi. Range of afternoon relative humidity was 75.7- 82.6% for Jaya and 75.9- 82.0% for Jyothi. Mean relative humidity ranged between 84.9- 89.6% for Jaya and 84.9-89.4% for Jyothi.

Both forenoon vapour pressure deficit and afternoon vapour pressure deficit showed a decreasing trend towards July 20th planting and then showed an increase towards August 5th planting. In both Jaya and Jyothi maximum value of both forenoon and afternoon vapour pressure deficit was observed during June 5th planting. Maximum value of forenoon vapour pressure deficit which was 24.0 mm Hg in case of both Jaya and Jyothi. Maximum value of afternoon vapour pressure deficit was 24.2 mm Hg for Jaya and 24.3 mm Hg for Jyothi. Minimum value of both forenoon and afternoon vapour pressure deficit was observed during July 20th planting. For Jaya minimum value for forenoon vapour pressure deficit was 22.5 mm Hg and for afternoon relative humidity the value is 22.9 mm Hg. For Jyothi minimum value of forenoon vapour pressure deficit was 22.5 mm Hg and for afternoon relative humidity the value is 23.2 mm Hg.

4.4.2.3. Wind speed (WS)

Wind speed was almost stable among all five dates of planting. Maximum value of wind speed experienced was 1.8 km hr^{-1} in both varieties and minimum value of 1.5 km hr^{-1} was noted for Jaya and 1.4 km hr^{-1} was noted for Jyothi.

4.4.2.4. Bright sunshine hours (BSS)

Maximum bright sunshine value of 3.5 hrs for Jaya and 3.4 hrs for Jyothi was observed during June 5th planting, a minimum value of 1.2 hrs for Jaya and 1.5 hrs for Jyothi was observed during August 5th planting.

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

Rainfall showed a wide range of variation during transplanting to panicle initiation. For Jaya the rainfall varied from 482.2 to 1278.3 mm and for Jyothi it varied 1293.1 mm to 527.6 mm. Maximum value of rainfall was recorded during August 5th planting and a minimum rainfall was noted during June 5th for both the varieties. Rainy days also showed the same trend. The rainy days varied between 22 to 33 days for Jaya and 23 to 34 days for Jyothi.

4.4.2.6. Pan Evaporation (Epan)

Pan evaporation noted during this stage ranged between 1.9 to 2.8 mm in both Jaya and Jyothi. Maximum value was observed during June 5th planting and minimum value was observed during July 20th and August 5th planting. Pan evaporation gradually decrease towards last date of planting.

4.4.3. Weather conditions prevailed during the crop period from transplanting to booting stage in different dates of planting (Table 4.4)

4.4.3.1. Temperature (Maximum temperature, Minimum temperature, and Temperature range)

Maximum temperature experienced during transplanting to booting stage was same for both Jaya and Jyothi during June 5th, July 5th and July 20th planting. The highest value of maximum temperature during this stage was 31.0^{o}C and was noted at 5th June planting lowest value of maximum temperature was 29.8^{o}C and was observed at July 5th and July 20th planting. Minimum temperature varied within 21.9 to 23.0 ^{o}C in Jaya and Jyothi.

Table 4.4. Weather conditions experienced by the crop from transplanting to booting

	Variety	Tmax °C	Tmin °C	RH I %	RH II %	RH mean %	WS km hr^{-1}	BSS hrs	RF mm	Rainy days	Epan mm day^{-1}	Trange °C	VPD I mm Hg	VPD II mm Hg
D1	Ja	31.1	23.0	94.5	75.5	85.0	1.7	3.1	978.3	36.0	2.5	8.1	23.4	23.7
	Jy	31.1	23.0	94.6	75.7	85.1	1.7	3.1	978.3	36.0	2.5	8.1	23.4	23.7
D2	Ja	30.4	22.9	95.4	77.3	86.4	1.7	2.7	1337.0	40.0	2.3	7.6	23.2	23.5
	Jy	30.6	22.9	95.3	77.3	86.3	1.7	2.7	1213.4	38.0	2.3	7.7	23.2	23.6
D3	Ja	29.8	22.1	95.7	79.7	87.7	1.5	1.9	1653.5	46.0	2.0	7.6	22.5	23.3
	Jy	29.8	22.1	95.8	79.4	87.6	1.5	1.9	1632.9	45.0	2.0	7.6	22.5	23.3
D4	Ja	29.8	22.0	96.4	80.3	88.3	1.5	1.8	1595.2	44.0	2.0	7.8	22.7	23.4
	Jy	29.8	22.0	96.4	80.3	88.3	1.5	1.8	1595.2	44.0	2.0	7.8	22.7	23.4
D5	Ja	30.4	21.9	95.8	78.5	87.2	1.5	2.4	1379.8	43.0	2.2	8.4	22.7	23.5
	Jy	30.1	21.9	96.1	79.6	87.8	1.5	2.1	1377.9	42.0	2.1	8.2	22.7	23.5

Ja – Jaya , Jy – Jyothi , D1 – June 5th, D2- June 20th , D3 – July 5th , D4- July 20th , D5- August 5th

The maximum value of minimum temperature was seen during 5th June planting and minimum value was noted during August 5th planting for both Jaya and Jyothi. For Jaya a temperature range of 8.4^{o}C noted on August 5th planting was found to be maximum and 7.6^{o}C recorded during June 20th and July 5th planting was found to be minimum among other dates of planting. For Jyothi temperature range recorded during August 5th planting (8.2^{o}C) was found to be maximum and that recorded during 5th July (7.6^{o}C) was found to be minimum.

4.4.3.2. Relative Humidity (RH I, RH II and RH mean) and Vapour Pressure Deficit (VPDI and VPD II)

For both varieties forenoon relative humidity showed almost same range. 94.5 to 96.4% for Jaya and 94.6 to 96.4 % for Jyothi. A range of 75.5 to 80.3% afternoon relative humidity was noted for Jaya and a range of 75.7 to 80.3% afternoon relative humidity was noted for Jyothi. Maximum value of both afternoon relative humidity and forenoon relative humidity was noted during 20th July and minimum value was noted during June 5th planting. The same trend was observed in mean relative humidity with a range of 85.0 to 88.3 % for Jaya and 85.1 to 88.3 % for Jyothi. Forenoon vapour pressure deficit varied between 22.5mm Hg of July 5th planting to 23.4 mm Hg of June 5th planting. Afternoon vapour pressure deficit showed the same trend. It varied between 23.3 to 23.7 mm Hg for both Jaya and Jyothi.

4.4.3.3. Wind speed (WS)

Wind speed of 1.7 km hr^{-1} was recorded during June 5th and June 20th planting. Wind speed of 1.5 km hr^{-1} was recorded during July 5th, July 20th and August 5th planting.

4.4.3.4. Bright sunshine hours (BSS)

Maximum bright sunshine hours of 3.1 hrs per day was recorded during 5th June and minimum value of 1.8 hrs was recorded during 20th July in case of both Jaya and Jyothi.

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

In case of Jaya a maximum rainfall of 1653.5 mm was obtained during July 5th planting and a minimum rainfall of 978.3 mm was obtained during June 5th planting. The same trend in rainfall was seen in case of Jyothi with a maximum value of 1632.9 mm and a minimum value of 978.3 mm. Number of rainy days showed same trend as that of rainfall. For Jaya rainy days varied between 36 to 46 days and for Jyothi it varied between 36 to 45 days. Minimum number of rainy days were there during June 5th planting while maximum number of rainy days were there during July 5th planting.

4.4.3.6. Pan Evaporation (Epan)

Pan evaporation was recorded maximum during June 5th panting (2.5 mm) and it was minimum during July 5th planting and July 20th planting (2 mm).

4.4.4. Weather conditions prevailed during the crop period from transplanting to heading stage in different dates of planting (Table 4.5)

4.4.4.1. Temperature (Maximum temperature, Minimum temperature, and Temperature range)

Maximum temperature was found to be decreasing up to July 20th planting and then showed an increase. The maximum temperature varied from 29.8^{0}C to 30.9^{0}C. Higher value of 30.9^{0}C was noted in Jaya during June 5th planting whereas minimum value of 29.8^{0}C was observed during July 5th and July 20th planting. For Jyothi a maximum value of 31.0^{0}C was recorded during June 5th planting and a minimum value of 29.7 was recorded during July 20th planting. Minimum temperature varied from 21.9^{0}C to 22.9^{0}C in case of Jaya and from 21.9^{0}C to 23.0^{0}C for Jyothi. Minimum temperature was higher in June 5th planting for both varieties, while it was found to be lower during August 5th planting.

Table 4.5. Weather conditions experienced by the crop from transplanting to heading

	Variety	Tmax °C	Tmin °C	RH I %	RH II %	RH mean %	WS km hr^{-1}	BSS hrs	RF mm	Rainy days	Epan mm day^{-1}	Trange °C	VPD I mm Hg	VPD II mm Hg
D1	Ja	30.9	22.9	94.8	77.2	86.0	1.8	2.9	1407.1	43.0	2.4	7.9	23.3	23.6
	Jy	31.0	23.0	94.7	76.7	85.7	1.8	3.0	1183.6	41.0	2.5	8.0	23.4	23.7
D2	Ja	30.4	22.8	95.6	77.1	86.4	1.6	2.5	1509.3	44.0	2.2	7.6	23.1	23.5
	Jy	30.4	22.8	95.6	77.2	86.4	1.7	2.5	1504.3	43.0	2.3	7.6	23.1	23.5
D3	Ja	29.8	22.1	95.9	79.5	87.7	1.6	1.8	1814.0	50.0	2.0	7.7	22.6	23.4
	Jy	29.8	22.1	95.8	79.6	87.7	1.5	1.8	1709.9	47.0	2.0	7.6	22.5	23.3
D4	Ja	29.8	22.0	96.4	80.0	88.2	1.5	1.9	1600.8	45.0	2.0	7.8	22.7	23.4
	Jy	29.7	22.0	96.4	80.7	88.5	1.5	1.7	1584.5	43.0	2.0	7.7	22.6	23.4
D5	Ja	30.6	21.9	95.4	77.3	86.4	1.4	2.8	1384.7	44.0	2.3	8.7	22.8	23.5
	Jy	30.3	21.9	95.8	78.6	87.2	1.5	2.3	1377.9	42.0	2.2	8.4	22.7	23.5

Ja – Jaya , Jy – Jyothi , D1 – June 5th, D2- June 20th , D3 – July 5th , D4- July 20th , D5- August 5th

Temperature range was maximum during August 5th planting (8.7^{0}C for Jyothi and 8.4^{0}C for Jaya) while it was minimum during June 20th planting for Jaya and June 20th and July 5th for Jyothi.

4.4.4.2. Relative Humidity (RH I, RH II and RH mean) and Vapour Pressure Deficit (VPDI and VPD II)

Forenoon relative humidity was higher in both Jyothi and Jaya during July 20th planting (96.4%) and lower value was noted on June 5th planting (94.8% for Jaya and 94.7% for Jyothi).

Afternoon relative humidity showed a maximum value during July 20th planting (80.0% for Jaya and 80.7% for Jyothi) and a minimum value was observed during June 20th planting for Jaya *i.e* 77.1% and for Jyothi a minimum value of 76.7% was observed during June 5th planting.

Mean relative humidity showed same trend as that of forenoon relative humidity. For Jaya mean RH varied from 86.0 to 88.0 % and for Jyothi range was observed during 85.7% to 88.5%.

Forenoon and afternoon vapour pressure deficit only showed a slight variation among the different dates of planting. Vapour pressure deficit was more during June 5th planting and it was less during July 5th planting.

4.4.4.3. Wind speed (WS)

Wind speed also showed a slight variation among different dates of planting. Maximum wind speed was noted during June 5th planting (1.8 km hr^{-1}) for both varieties and minimum wind speed was noted during August 5th planting for Jaya (1.4 km hr^{-1}) and Jyothi (1.5 km hr^{-1}).

4.4.4.4. Bright sunshine hours (BSS)

Bright sunshine hours was recorded a highest value during June 5th planting (2.9 hrs for Jaya and 3.0 hrs for Jyothi) and a minimum value of 1.8 hrs and 1.7 hrs for Jaya and Jyothi during July 5th and July 20th respectively.

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

Rainfall received during July 5th was highest among all the dates of planting. Highest value of rainfall recorded for Jaya was 1814mm and for Jyothi was 1709.9 mm. Less amount of rainfall received for Jaya was 1384.6 mm (August 5th) and for Jyothi it was 1183.6 mm (June 5th). Rainy days showed same trend as that of rainfall. It varied between 41 to 50 days.

4.4.4.6. Pan evaporation (Epan)

Pan evaporation was found to be decreasing towards July 20th planting and afterwards it showed an increase. Evaporation showed a slight variation among various dates of planting. The range of pan evaporation was 2.0 - 2.4 mm for Jaya and 2.0 - 2.5 mm for Jyothi.

4.4.5. Weather conditions prevailed during the crop period from transplanting to 50% flowering stage in different dates of planting (Table 4.6).

4.4.5.1. Temperature (Maximum temperature, Minimum temperature, and Temperature range)

A decreasing trend of maximum temperature was observed towards July 5th planting, thereafter it showed an increasing trend towards the last planting (August 5th). The maximum temperature noticed as highest during August 5th planting for Jaya and during June 5th planting for Jyothi.

Table 4.6. Weather conditions experienced by the crop from transplanting to 50% flowering

	Variety	Tmax °C	Tmin °C	RH I %	RH II %	RH mean %	WS km hr^{-1}	BSS hrs	RF mm	Rainy days	Epan mm day^{-1}	Trange °C	VPD I mm Hg	VPD II mm Hg
D1	Ja	30.6	22.8	95.0	77.5	86.3	1.7	2.7	1649.5	47.0	2.3	7.8	23.2	23.6
	Jy	30.7	22.9	94.9	77.4	86.2	1.7	2.8	1530.7	45.0	2.4	7.8	23.3	23.6
D2	Ja	30.4	22.8	95.6	77.0	86.3	1.6	2.5	1526.8	44.0	2.2	7.6	23.1	23.5
	Jy	30.4	22.8	95.6	77.1	86.3	1.6	2.5	1506.9	43.0	2.3	7.6	23.1	23.5
D3	Ja	29.9	22.1	95.9	79.7	87.8	1.6	1.9	1840.4	51.0	2.0	7.8	22.6	23.4
	Jy	29.9	22.0	95.9	79.8	87.9	1.6	1.9	1864.6	53.0	2.1	7.8	22.6	23.4
D4	Ja	30.0	22.0	96.3	79.2	87.7	1.4	2.1	1573.6	48.0	2.1	8.0	22.7	23.4
	Jy	29.9	22.0	96.3	79.5	87.9	1.5	1.9	1549.4	47.0	2.1	7.9	22.7	23.4
D5	Ja	30.7	21.9	95.1	77.1	86.1	1.4	2.9	1381.9	43.0	2.3	8.8	22.7	23.5
	Jy	30.5	21.9	95.5	77.9	86.7	1.5	2.6	1380.6	42.0	2.2	8.6	22.7	23.5

Ja – Jaya , Jy – Jyothi , D1 – June 5th, D2- June 20th , D3 – July 5th , D4- July 20th , D5- August 5th

For both of the varieties a maximum value of 30.7°C was recorded. Minimum temperature showed a range from 21.9 to 22.8^{0}C for Jaya and 21.9°C-22.9°C for Jyothi. The higher values obtained during June 5th planting and the lower values were obtained during July 5th planting. From the 1st planting to the last, the temperature range showed an increasing trend towards last dates of planting with a maximum value of 8.8^{0}C and 8.6 ^{0}C for Jaya and Jyothi respectively.

4.4.5.2. Relative Humidity (RH I, RH II and RH mean) and Vapour Pressure Deficit (VPDI and VPD II)

Forenoon relative humidity was higher in both Jyothi and Jaya during July 20th planting (96.3%) and lower value was noted on June 5th planting (95.0% for Jaya and 94.9% for Jyothi). Afternoon relative humidity showed a maximum value during July 5th planting (79.7% for Jaya and 79.8% for Jyothi) and a minimum value was observed during June 20th planting (77.0% for Jaya and 77.1% for Jyothi). Mean relative humidity showed same trend as that of forenoon relative humidity. For Jaya RH varied from 86.1% to 87.8 % and for Jyothi range was 86.7 to 87.9 %. Forenoon and afternoon vapour pressure deficit only showed a slight variation among the different dates of planting. Forenoon vapour pressure deficit was more during June 5th planting (23.2 mm Hg for Jaya and 23.3mm Hg for Jyothi) and it was less during July 5th (22.6 mm Hg) planting for both Jaya and Jyothi. Afternoon vapour pressure deficit was more during June 5th planting (23.6 mmHg for Jaya and Jyothi) and it was less during July 5th and July 20th planting (23.4 mmHg for Jaya and Jyothi).

4.4.5.3. Wind speed (WS)

Wind speed also showed a slight variation among different dates of planting. Maximum wind speed was noted during June 5th planting (1.7 km hr^{-1} for Jaya and Jyothi) and less wind speed was noted during July 20th and August 5th planting (1.4 km hr^{-1} for Jaya and 1.5 km hr^{-1}for Jyothi).

4.4.5.4. Bright sunshine hours (BSS)

Maximum bright sunshine hours of 2.9 hrs per day was recorded during August 5th planting and minimum value of 1.9 hrs was recorded during July 5th for Jaya. In case of Jyothi maximum bright sunshine hours of 2.8 hrs per day was recorded during 5th June planting and minimum value of 1.9 hrs was recorded during July 5th planting.

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

Rainfall received during 5th July was highest among all the dates of planting and was lowest during 5th August planting. Highest value of rainfall recorded for Jaya was 1840.4 mm and for Jyothi was 1864.6 mm. Least amount of rainfall received for Jaya was 1381.8 mm (August 5th) and for Jyothi it was 1380.6 mm (August 5th). Rainy days showed same trend as that of rainfall. It varied between 42 to 53 days.

4.4.5.6. Pan Evaporation (Epan)

Pan evaporation did not showed any specific trend. Evaporation showed a slight variation among various dates of planting. The range of pan evaporation was 2.0-2.3 mm for Jaya and 2.1-2.4 mm for Jyothi.

4.4.6. Weather conditions prevailed during the crop period from transplanting to physiological maturity stage in different dates of planting (Table 4.7)

4.4.6.1. Temperature (Maximum temperature, Minimum temperature, and Temperature range)

Maximum temperature showed an increasing trend towards the last planting (August 5th). The maximum temperature noticed as higher during August 5th planting for both Jaya and for Jyothi (31.2^{0}C). Minimum value of maximum temperature was observed during June 5th and June 20th planting (20.6^{0}C) for both Jaya and Jyothi.

Table 4.7. Weather conditions experienced by the crop from transplanting to physiological maturity

	Variety	Tmax °C	Tmin °C	RH I %	RH II %	RH mean %	WS km hr^{-1}	BSS hrs	RF mm	Rainy days	Epan mm day^{-1}	Trange °C	VPD I mm Hg	VPD II mm Hg
D1	Ja	30.6	22.5	95.3	77.7	86.5	1.6	2.6	2328.0	76	2.3	8.1	23.1	23.6
	Jy	30.6	22.5	95.4	77.9	86.6	1.6	2.5	2315.4	74	2.3	8.0	23.1	23.6
D2	Ja	30.6	22.4	95.4	76.7	86.0	1.5	2.8	2168.0	74	2.3	8.3	23.0	23.6
	Jy	30.6	22.4	95.4	76.9	86.2	1.5	2.6	2166.6	74	2.3	8.2	22.9	23.6
D3	Ja	30.8	22.0	94.8	75.6	85.2	1.5	3.2	2299.4	72	2.3	8.8	22.6	23.3
	Jy	30.8	22.0	94.8	75.7	85.2	1.5	3.2	2229.8	69	2.3	8.8	22.7	23.3
D4	Ja	30.9	21.8	94.6	75.3	84.9	1.6	3.3	2076.9	67	2.3	9.1	22.5	23.1
	Jy	30.9	21.8	94.7	75.2	85.0	1.4	3.3	2044.7	65	2.3	9.0	22.5	23.2
D5	Ja	31.2	21.6	94.2	73.9	84.0	1.5	3.8	1984.4	63	2.4	9.6	22.5	23.2
	Jy	31.2	21.6	94.3	74.1	84.2	1.6	3.7	1847.6	61	2.4	9.5	22.4	23.1

Ja – Jaya , Jy – Jyothi , D1 – June 5th, D2- June 20th , D3 – July 5th , D4- July 20th , D5- August 5th

Minimum temperature showed a range from 21.6 to 22.5^{0}C. The higher values obtained during June 5th planting and the lower values were obtained during August 5th planting for both Jaya and Jyothi. From the 1st planting to the last, the temperature range showed an increasing trend towards last dates of planting with a maximum value of 9.6 and 9.5 ^{0}C for Jaya and Jyothi respectively.

4.4.6.2. Relative Humidity (RH I, RH II and RH mean) and Vapour Pressure Deficit (VPDI and VPD II)

A maximum value of forenoon relative humidity was 94.4% which was recorded during June 20th planting for Jaya and during June 5th and June 20th planting for Jyothi. Lower value of forenoon relative humidity was noted on August 5th planting (94.2% for Jaya and 94.3% for Jyothi). Afternoon relative humidity showed a maximum value during June 5th planting (77.7% for Jaya and 77.9% for Jyothi) and a minimum value was observed during August 5th planting (73.9% for Jaya and 74.1% for Jyothi). Mean relative humidity showed same trend as that of afternoon relative Humidity. For Jaya RH varied from 84.0% to 86.5% and for Jyothi range was observed between 84.2 to 86.6%.

Forenoon and afternoon vapour pressure deficit only showed a slight variation among the different dates of planting. Forenoon vapour pressure deficit was more during June 5th planting (23.1 mm Hg for Jaya and Jyothi) and it was less during July 20th and August 5th planting for Jaya (22.5 mm Hg) and August 5th planting for Jyothi. Afternoon vapour pressure deficit was more during June 5th planting (23.6 mm Hg for Jaya and Jyothi) and it was less during July 20th for Jaya (23.1 mm Hg) and for Jyothi this minimum value was noted during 5th August (23.1 mm Hg).

4.4.6.3. Wind speed (WS)

Wind speed ranged between 1.4 to 1.6 km hr^{-1} in case of Jaya and 1.5 to 1.6 km hr^{-1} in case of Jyothi. Maximum wind speed was noted during June 5th planting

(1.6 km hr^{-1} for Jaya and Jyothi) and less wind speed was noted during 5th July (1.5 km hr^{-1} for Jaya and Jyothi).

4.4.6.4. Bright sunshine hours (BSS)

Maximum bright sunshine hours of 3.8 hrs per day was recorded during August 5th planting and minimum value of 2.6 hrs was recorded during 5th June for Jaya. In case of Jyothi maximum bright sunshine hours of 3.7 hrs per day was recorded during 5th August planting and minimum value of 2.5 hrs per day was recorded during 5th June.

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

Total rainfall received during June 5th planting was highest among all the dates of planting and was lowest during August 5th planting. Highest value of rainfall recorded for Jaya was 2328.0 mm and for Jyothi was 2315.4 mm. Least amount of rainfall received during August 5th planting for Jaya was 1984.4 mm and for Jyothi it was 1847.6 mm. Rainy days showed same trend as that of rainfall. It varied between 63 to 76 days for Jaya and 61 to 74 days for Jyothi.

4.4.6.6. Pan evaporation (Epan)

Pan evaporation showed same value for all dates of planting (2.3 mm) except for August 5th planting (2.4 mm).

4.5. Crop weather relationship

Correlation analysis was carried out between weather variables and duration of each phenophase, yield and yield attributes for both Jyothi and Jaya individually using data collected from the experiment conducted at ARS, Mannuthy, during 2019. Results obtained from the analysis are described below.

4.5.1. Influence of weather parameters on crop duration of Jaya

Results of correlation analysis done between crop duration of Jaya and weather parameters are represented in the Table 4.8.

4.5.1.1. Transplanting to active tillering (P1)

Forenoon relative humidity showed a significant positive correlation with number of days taken from transplanting to active tillering. Maximum temperature, minimum temperature, pan evaporation, forenoon vapour pressure deficit and afternoon vapour pressure deficit showed a significant negative correlation with number of days taken from transplanting to active tillering.

5.1.2. Active tillering to panicle initiation (P2)

Minimum temperature, wind speed and pan evaporation showed a significant negative correlation with number of days taken from active tillering to panicle initiation.

4.5.1.3. Panicle initiation to booting (P3)

Rainfall and afternoon vapour pressure deficit showed a significant positive correlation. Maximum temperature, bright sunshine hours and pan evaporation showed a significant negative correlation with number of days taken from panicle initiation to booting.

Table 4.8. Correlation between duration of phenophase and weather variables in Jaya

Crop stages	Tmax	Tmin	RHI	RHII	VPDI	VPDII	RF	RD	BSS	WS	Epan
P1	-0.557*	-0.507*	0.456*	0.303	-0.616**	-0.570**	-0.157	0.312	-0.353	-0.157	-0.616**
P2	-0.181	-0.833**	0.155	0.073	0.284	-0.394	0.110	0.344	-0.429	-0.679**	-0.537*
P3	-0.672**	0.000	0.234	0.313	0.143	0.760**	0.497*	0.043	-0.510*	0.154	-0.616**
P4	0.357	0.730**	-0.097	-0.340	-0.005	0.544*	0.299	0.583**	0.815**	-0.168	0.441
P5	0.250	0.368	-0.451*	0.390	0.465*	0.055	-0.075	0.481*	-0.447*	0.615**	0.107
P6	-0.578**	0.915**	0.652**	0.657**	-0.010	-0.244	0.549*	0.712**	-0.596**	-0.321	-0.386

*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

4.5.1.4. Booting to heading (P4)

Minimum temperature, bright sunshine hours, rainy days and afternoon vapour pressure deficit showed a significant positive correlation with number of days taken from booting to heading.

4.5.1.5. Heading to 50% flowering (P5)

Wind speed, rainy days and forenoon vapour pressure deficit showed a significant positive correlation with no of days taken from heading to 50% flowering while forenoon relative humidity and bright sunshine hours showed a significant negative correlation.

4.5.1.6. 50% flowering to physiological maturity (P6)

Minimum temperature, forenoon relative humidity, afternoon relative humidity, rainfall and rainy days showed a significant positive correlation and maximum temperature and bright sunshine hours showed a significant negative correlation with number of days taken from 50% flowering to physiological maturity.

4.5.2. Influence of weather parameters on crop duration of Jyothi

The results obtained from the correlation analysis done between weather parameters and duration of each phenophases are represented in Table 4.9.

4.5.2.1. Transplanting to active tillering (P1)

Forenoon relative humidity, afternoon relative humidity, rainfall and rainy days showed a significant positive correlation with number of days taken from transplanting to active tillering. Maximum temperature, minimum temperature, wind speed, bright sunshine hours, pan evaporation, forenoon vapour pressure deficit and afternoon vapour pressure deficit showed a significant negative correlation.

Table 4.9. Correlation between duration of phenophase and weather variables in Jyothi

Crop stages	Tmax	Tmin	RHI	RHII	VPDI	VPDII	RF	RD	BSS	WS	Epan
P1	-0.901**	-0.571**	0.523**	0.704**	-0.770**	-0.931**	0.569**	0.778**	-0.787**	-0.568**	-0.631**
P2	-0.862**	-.507*	0.456*	0.997**	-0.221	-0.188	0.567**	0.312	-0.827**	-0.157	-.616**
P3	-0.622**	0.702**	-0.653**	-0.123	-0.468*	-0.949*	0.565**	-0.153	-0.134	0.463*	-0.476*
P4	0.393	0.744**	0.131	-0.603**	0.175	-0.122	-0.049	0.312	0.463*	0.660**	0.579**
P5	-0.420	-0.650**	0.658**	0.484*	0.132	0.088	-0.634**	-0.667**	-0.496*	-0.665**	-0.110
P6	-0.847**	-0.118	0.918**	0.901**	0.464*	0.771**	0.653**	0.767**	-0.584**	-0.557*	-0.581**

*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

4.5.2.2. Active tillering to panicle initiation (P2)

Forenoon relative humidity, afternoon relative humidity and rainfall showed a significant positive correlation with number of days taken from active tillering to panicle initiation while maximum temperature, minimum temperature, bright sunshine hours and pan evaporation showed a significant negative correlation.

4.5.2.3. Panicle initiation to booting (P3)

Minimum temperature, wind speed and rainfall showed a significant positive correlation while maximum temperature, forenoon relative humidity, pan evaporation, forenoon vapour pressure deficit and afternoon vapour pressure deficit showed a significant negative correlation with number of days taken from panicle initiation to booting.

4.5.2.4. Booting to heading (P4)

Minimum temperature, wind speed, bright sunshine hours and pan evaporation showed a significant positive correlation but afternoon relative humidity showed a significant negative correlation with number of days taken from booting to reach heading.

4.5.2.5. Heading to 50% flowering (P5)

Number of days taken from heading to 50% flowering was positively correlated with forenoon relative humidity and afternoon relative humidity while it showed a significant negative correlation with wind speed, minimum temperature, bright sunshine hours, rainfall and rainy days.

4.5.2.6. 50% flowering to physiological maturity (P6)

Forenoon relative humidity, afternoon relative humidity, rainfall, rainy days, forenoon vapour pressure deficit and afternoon vapour pressure deficit showed a significant positive correlation while maximum temperature, wind speed, bright sunshine hours and pan evaporation showed a significant negative correlation with number of days taken from 50% flowering to physiological maturity.

4.5.3. Influence of weather parameters on grain yield of Jaya

Findings of correlation analysis done between grain yield and weather variables are described in Table 4.10.

4.5.3.1. Transplanting to active tillering (P1)

Grain yield of Jaya showed a significant positive correlation with maximum temperature, minimum temperature, bright sunshine hours, forenoon vapour pressure deficit and afternoon vapour pressure deficit, while forenoon relative humidity, afternoon relative humidity and rainfall showed a significant negative correlation.

4.5.3.2. Active tillering to panicle initiation (P2)

Minimum temperature, forenoon relative humidity and wind speed showed a significant positive correlation

4.5.3.3. Panicle initiation to booting (P3)

A significant positive correlation was observed between grain yield and weather variables like minimum temperature and wind speed while forenoon vapour pressure deficit and afternoon vapour pressure deficit showed a significant negative correlation.

4.5.3.4. Booting to heading (P4)

Afternoon relative humidity, rainfall, rainy days and afternoon vapour pressure deficit showed a significant positive correlation with grain yield while pan evaporation and maximum temperature showed a significant negative correlation.

Table 4. 10. Correlation between yield and weather variables in Jaya

Crop stages	Tmax	Tmin	RHI	RHII	VPDI	VPDII	RF	RD	BSS	WS	Epan
P1	0.845**.	0.736**	-0.887**	-0.580**	0.747**	0.909**	-0.802**	-0.508	0.711**	0.495	0.855.
P2	0-.255	0.463*	0.464*	0.370	0.165	0.172	0.156	0.057	0.182	0.593**	0.073
P3	-0.333	0.761**	0.310	0.322	-0.572**	-0.928**	0.108	-0.041	-0.303	0.648**	-0.262
P4	-0.562**	0.271	0.325	0.639**	-0.177	0.731**	0.656**	0.646**	0.019	0.231	-0.725**
P5	-0.596**	-0.209	0.456*	0.782**	-0.466*	-0.621**	0.497*	0.045	-0.570**	-0.326	-0.793**
P6	-0.840**	0.397	0.595**	0.617**	0.534*	0.672**	0.817**	0.802**	-0.784**	-0.505*	-0.780**

*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

4.5.3.4. Booting to heading (P4)

Afternoon relative humidity, rainfall, rainy days and afternoon vapour pressure deficit showed a significant positive correlation with grain yield while pan evaporation and maximum temperature showed a significant negative correlation.

4.5.3.5. Heading to 50% flowering (P5)

Forenoon relative humidity, afternoon relative humidity and rainfall showed a significant positive correlation with grain yield while a significant negative correlation was seen between maximum temperature, bright sunshine hours, pan evaporation, forenoon vapour pressure deficit and afternoon vapour pressure deficit.

4.5.3.6. 50% flowering to physiological maturity (P6)

A significant positive correlation between grain yield and weather parameters like forenoon relative humidity, afternoon relative humidity, rainfall, rainy days, forenoon vapour pressure deficit and afternoon vapour pressure deficit experienced between flowering to physiological maturity while wind speed, bright sunshine hours, pan evaporation and maximum temperature showed a significant negative correlation.

4.5.4. Influence of weather variables and yield of Jyothi

Table 4.11 represent the result of correlation analysis done between grain yield of Jyothi and weather variables recorded during each phenophases.

4.5.4.1. Transplanting to active tillering (P1)

Maximum temperature, minimum temperature, bright sunshine hours, pan evaporation, forenoon vapour pressure deficit and afternoon vapour pressure deficit experienced during P1 stage showed a significant positive correlation with grain yield while a significant negative correlation was seen between forenoon relative humidity, afternoon relative humidity and rainfall experienced during P1 stage.

Table 4.11. Correlation between yield and weather variables in Jyothi

Crop stages	**Tmax**	**Tmin**	**RHI**	**RHII**	**VPDI**	**VPDII**	**RF**	**RD**	**BSS**	**WS**	**Epan**
P1	0.679**	0.669**	-0.670**	-0.584**	0.716**	0.830**	-0.721**	-0.269	0.564**	0.272	0.749**
P2	-0.412	0.549*	0.416	-0.175	0.467*	0.095	0.115	-0.234	0.814**	0.912**	0.512*
P3	-0.445*	0.675**	-0.164	0.085	-0.402	-0.931**	0.594**	-0.264	-0.065	0.629**	-0.420
P4	0.135	0.256	0.217	-0.295	-0.329	0.665**	-0.333	-0.034	0.181	0.340	-0.450*
P5	-0.640**	0.169	0.488*	0.672**	-0.171	-0.095	0.520*	-0.071	-0.626**	0.533*	-0.686**
P6	-0.793**	0.081	0.637**	0.602**	0.292	0.559*	0.635**	0.861**	-0.820**	-0.161	-0.694**

*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

4.5.4.2.Active tillering to panicle initiation (P2)

A significant positive correlation between grain yield and weather variables like minimum temperature, pan evaporation, bright sunshine hours, wind speed and forenoon vapour pressure deficit.

4.5.4.3.Panicle initiation to booting (P3)

Minimum temperature, wind speed and rainfall experienced during P3 stage showed a significant positive correlation and maximum temperature and after noon vapour pressure deficit showed a significant negative correlation with grain yield.

4.5.4.4.Booting to heading (P4)

Grain yield showed a significant positive correlation with after noon vapour pressure deficit and significant negative correlation between grain yield and pan evaporation.

4.5.4.5. Heading to 50% flowering (P5)

Forenoon relative humidity, afternoon relative humidity, wind speed and rainfall experienced during P5 stage showed a significant positive correlation with grain yield whereas maximum temperature, bright sunshine hours and pan evaporation showed a significant negative correlation.

4.5.4.6. 50% flowering to physiological maturity (P6)

Grain yield showed a significant positive correlation between forenoon relative humidity, afternoon relative humidity, rainfall, rainy days and afternoon vapour pressure deficit experienced during P6 stage while maximum temperature, bright sunshine hours and pan evaporation showed a significant negative correlation.

4.5.5. Influence of weather variables and yield attributes of Jaya

Correlation analysis were carried out between the yield attributes *viz*. thousand grain weight, number of panicles per m^2, number of spikelets per panicle, number of filled grains per panicle, number of tillers and straw yield with weather variables for the variety Jaya in the year 2019 and the results obtained are given below from the Table 4.12 to 4.23.

4.5.5.1. Correlation between weather variables and thousand grain weight in Jaya

Table 4.12 shows results of correlation analysis carried out between weather variables and thousand grain weight. Maximum temperature, minimum temperature, wind speed, bright sunshine hours, pan evaporation experienced during transplanting to active tillering showed a significant positive correlation with 1000 grain weight while forenoon relative humidity, afternoon relative humidity and rainfall experienced during the same period showed a significant negative correlation.

Wind speed experienced during active tillering to panicle initiation showed a significant positive correlation, maximum temperature and forenoon vapour pressure deficit showed a significant negative correlation. Forenoon relative humidity, afternoon relative humidity, wind speed and rainfall experienced during panicle initiation to booting showed a significant positive correlation while bright sunshine hours, pan evaporation and maximum temperature showed a significant negative correlation. Forenoon relative humidity, rainfall and rainy days prevailed during booting to heading showed a significant positive correlation while maximum temperature, pan evaporation and bright sunshine hours showed a significant negative correlation.

During heading to 50% flowering stage afternoon relative humidity and rainy days showed a significant positive correlation and maximum temperature, minimum temperature and bright sunshine hours showed a significant negative correlation. Minimum temperature, forenoon relative humidity, afternoon relative humidity and rainy days prevailed during 50% flowering to physiological maturity showed a significant positive correlation while wind speed and forenoon vapour pressure deficit and afternoon vapour pressure deficit showed a significant negative correlation.

Table 4.12. Correlation between weather variables and thousand grain weight in Jaya

Crop stages	Tmax	Tmin	RHI	RHII	VPDI	VPDII	RF	RD	BSS	WS	Epan
P1	0.564**	0.622**	-0.559*	-0.760**	0.263	-0.034	-0.633**	-0.415	0.611**	0.591**	0.660**
P2	-0.605**	0.198	0.319	0.426	-0.557*	-0.285	0.226	-0.321	0-.266	0.585**	-0.292
P3	-0.878**	-0.320	0.749**	0.779**	-0.198	-0.362	0.549*	-0.088	-0.797**	0.533*	-0.872**
P4	-0.542*	-0.053	0.787**	0.267	0.151	0.171	0.769**	0.832**	-0.581**	0.099	-0.478*
P5	-0.539*	-0.732**	0.348	0.759**	0.022	-0.252	0.159	0.478*	-0.707**	0.127	-0.266
P6	-0.335	0.778**	0.467*	0.490*	0.820*	0.838*	0.262	0.494*	-0.398	-0.663**	-0.091

*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

4.5.5.2. Correlation between weather variables and thousand grain weight in Jyothi

The results of correlation between weather variables and thousand grain weight in Jyothi is described in Table 4.13. Forenoon relative humidity, afternoon relative humidity, wind speed and rainfall experienced during active tillering to panicle initiation showed a significant positive correlation and maximum temperature and pan evaporation showed a significant negative correlation. Wind speed, rainy days and afternoon vapour pressure deficit prevailed during booting to heading showed a significant negative correlation. Forenoon relative humidity and afternoon relative humidity experienced during heading to 50% flowering showed a significant positive correlation while maximum temperature, minimum temperature, wind speed, bright sunshine hours and pan evaporation showed a significant negative correlation. Minimum temperature prevailed during 50% flowering to physiological maturity showed a significant positive correlation while wind speed showed a significant negative correlation.

4.5.5.3. Correlation between weather variables and number of filled grains per panicle in Jaya

The results of correlation between weather variables and number of filled grains per panicle in Jaya is described in Table 4.14. Number of filled grains per panicle showed a significant positive correlation with maximum temperature, minimum temperature, wind speed, bright sunshine hours and pan evaporation, and significant negative correlation with forenoon relative humidity, afternoon relative humidity and rainfall experienced during transplanting to active tillering. Forenoon relative humidity, afternoon relative humidity, wind speed and rainfall experienced during active tillering to panicle initiation showed a significant positive correlation while maximum temperature showed a significant negative correlation. Bright sunshine hours, pan evaporation, maximum temperature and forenoon vapour pressure deficit experienced during panicle initiation to booting showed a significant negative correlation. Forenoon relative humidity, wind speed, rainfall, rainy days and afternoon vapour pressure deficit experienced during booting to heading showed a significant positive correlation.

Table 4.13. Correlation between weather variables and thousand grain weight in Jyothi

Crop stages	Tmax	Tmin	RHI	RHII	VPDI	VPDII	RF	RD	BSS	WS	Epan
P1	0.165	0.117	-0.219	-0.434	0.216	0.328	-0.343	0.144	0.197	0.060	0.354
P2	-0.822**	-0.260	0.908**	0.684**	-0.040	-0.464	0.856**	0.239	-0.439	0.466*	-0.752**
P3	-0.294	-0.169	0.414	0.422	-0.588*	-0.363	0.359	0.059	-0.332	0.004	-0.306
P4	-0.264	-0.313	0.163	0.326	-0.357	-0.708*	-0.318	-0.489*	-0.307	-0.563**	-0.417
P5	-0.613**	-0.487*	0.486*	0.640**	-0.396	-0.259	-0.148	-0.406	-0.591**	-0.454*	-0.743**
P6	0.100	0.568**	0.032	-0.035	0.424	0.416	-0.116	0.024	0.069	-0.551*	0.121

*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

Table. 4.14. Correlation between weather variables and number of filled grains per panicle in Jaya

Crop stages	Tmax	Tmin	RHI	RHII	VPDI	VPDII	RF	RD	BSS	WS	Epan
P1	0.601**	0.550*	-0.693**	-0.762**	0.295	0.338	-0.718**	-0.425	0.652**	0.576**	0.704**
P2	-0.534*	0.410	0.697**	0.760**	-0.030	-0.371	0.680**	0.282	-0.232	0.867**	-0.156
P3	-0.616**	-0.152	0.260	0.383	-0.694*	-0.364	0.407	0.070	-0.542*	0.102	-0.574**
P4	-0.099	-0.195	0.497*	-0.095	0.098	0.730*	0.761**	0.748**	-0.196	0.490*	0.041
P5	-0.454*	-0.464*	0.296	0.652**	0.234	-0.130	0.262	0.119	-0.572**	0.355	-0.355
P6	-0.355	0.635**	0.517*	0.469*	0.658*	0.599*	0.356	0.505*	-0.393	-0.357	-0.188

*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

During heading to 50% flowering afternoon relative humidity showed a significant positive correlation while maximum temperature, minimum temperature and bright sunshine hours showed a significant negative correlation. Minimum temperature, forenoon relative humidity, afternoon relative humidity, rainy days, forenoon vapour pressure deficit and afternoon vapour pressure deficit experienced during 50% flowering to physiological maturity showed a significant positive correlation.

4.5.5.4. Correlation between weather variables and number of filled grains per panicle in Jyothi

The results of correlation between weather variables and number of filled grains per panicle in Jyothi is described in Table 4.15. Maximum temperature, minimum temperature, bright sunshine hours and pan evaporation during transplanting to active tillering showed a significant positive correlation and forenoon relative humidity, afternoon relative humidity and rainfall showed a significant negative correlation. During active tillering to panicle initiation forenoon relative humidity, after noon relative humidity, wind speed and rainfall showed a significant positive correlation while maximum temperature and afternoon vapour pressure deficit showed showed a significant negative correlation. During panicle initiation to booting maximum temperature, pan evaporation, bright sunshine hours and afternoon vapour pressure deficit showed a significant negative correlation with number of filled grains per panicle. Forenoon relative humidity and afternoon vapour pressure deficit prevailed during booting to heading showed a significant positive correlation while maximum temperature, bright sunshine hours and pan evaporation showed a negative correlation. Pan evaporation and temperature range prevailed during heading to flowering showed a significant negative correlation. Rainfall and rainy days during 50% flowering to physiological maturity showed a significant positive correlation while bright sunshine hours and pan evaporation showed a significant negative correlation.

Table 4.15. Correlation between weather variables and number of filled grains per panicle in Jyothi

Crop stages	Tmax	Tmin	RHI	RHII	VPDI	VPDII	RF	RD	BSS	WS	Epan
P1	0.539*	0.552*	-0.568**	-0.833**	0.138	0.142	-0.650**	-0.293	0.633**	0.375	0.654**
P2	-0.584**	0.209	0.732**	0.463*	0.03	-0.324	0.649**	-0.387	0.017	0.712**	0.303
P3	-0.616**	-0.152	0.260	0.383	-0.399	-0.462*	0.407	0.070	-0.542*	0.102	-0.574**
P4	-0.587**	0.079	0.683**	0.373	-0.260	0.602*	-0.010	-0.184	-0.521*	-0.217	-0.491*
P5	-0.379	-0.064	0.103	0.338	-0.446	-0.295	0.312	0.065	-0.314	-0.029	-0.666**
P6	-0.421	0.333	0.401	0.429	0.601*	0.503*	0.471*	0.571**	-0.447*	-0.298	-0.463*

*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

4.5.5.5. Correlation between weather variables and number of spikelets per panicle in Jaya.

The results of correlation between weather variables and number of spikelets per panicle in Jaya was described in Table 4.16. Afternoon vapour pressure prevailed during transplanting to active tillering showed a significant negative correlation. Afternoon relative humidity and rainfall prevailed during active tillering to panicle initiation showed a significant positive correlation. Wind speed during panicle initiation to booting and minimum temperature during booting to heading showed a significant negative correlation while wind speed, forenoon vapour pressure deficit and afternoon vapour pressure deficit during heading to flowering showed a significant positive correlation.

4.5.5.6. Correlation between weather variables and number of spikelets per panicle in Jyothi.

The results of correlation between weather variables and number of spikelets per panicle in Jyothi was described in Table 4.17. Forenoon relative humidity, afternoon relative humidity, rainfall and rainy days during planting to active tillering showed a significant positive correlation while maximum temperature, minimum temperature, wind speed, bright sunshine hours, pan evaporation, forenoon vapour pressure deficit and afternoon vapour pressure deficit showed a significant negative correlation. Afternoon relative humidity and rainy days showed a significant positive correlation while minimum temperature, wind speed, bright sunshine hours and evaporation showed a significant negative correlation. Maximum temperature, forenoon relative humidity, pan evaporation, forenoon vapour pressure deficit and afternoon vapour pressure deficit experienced during panicle initiation to booting showed a significant positive correlation while minimum temperature, wind speed and rainfall showed a significant negative correlation. Minimum temperature, and wind speed experienced during booting to heading showed a significant negative correlation.

Table 4.16. Correlation between weather variables and number of spikelets per panicle in Jaya.

Crop stages	Tmax	Tmin	RHI	RHII	VPDI	VPDII	RF	RD	BSS	WS	Epan
P1	-0.190	-0.230	0.053	-0.085	-0.326	-0.574*	0.075	0.235	-0.065	-0.041	-0.108
P2	-0.428	-0.204	0.424	0.546*	0.454	-0.328	0.653**	0.371	-0.551*	0.244	-0.409
P3	0.012	-0.420	-0.080	0.076	-0.203	0.346	0.097	0.393	-0.209	-0.529*	0.024
P4	0.034	-0.629**	0.073	-0.028	-0.310	0.321	0.031	0.049	-0.101	0.099	0.098
P5	0.243	0.311	0.084	-0.169	0.505*	0.518*	-0.173	-0.145	0.142	0.572**	0.192
P6	0.358	0.058	-0.225	-0.293	-0.424	-0.534*	-0.315	-0.267	0.327	0.011	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

Table 4.17. Correlation between weather variables and number of spikelets per panicle in Jyothi.

Crop stages	Tmax	Tmin	RHI	RHII	VPDI	VPDII	RF	RD	BSS	WS	Epan
P1	-0.774**	-0.801**	0.741**	0.603**	-0.840*	-0.713*	0.695**	0.798**	-0.730**	-0.775**	-0.698**
P2	-0.433	-0.753**	0.033	0.534*	-0.464	-0.005	0.356	0.744**	-0.799**	-0.448*	-0.625**
P3	0.604**	-0.590**	0.594**	-0.001	0.456*	0.495*	-0.560*	-0.075	0.218	-0.489*	0.492*
P4	-0.025	-0.786**	-0.432	0.389	-0.310	-0.005	0.029	0.061	-0.170	-0.666**	-0.325
P5	-0.476*	-0.689**	0.674**	0.553*	-0.082	-0.109	-0.623**	-0.700**	-0.541*	-0.689**	-0.230
P6	0.837**	-0.025	-0.795**	-0.834**	-0.340	-0.646*	-0.792**	-0.765**	0.833**	0.136	0.805**

*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

Maximum temperature, bright sunshine hours and evaporation experienced during 50% flowering to physiological maturity showed a significant positive correlation while forenoon relative humidity, afternoon relative humidity, rainfall, rainy days and afternoon vapour pressure deficit showed a significant negative correlation.

4.5.5.7. Correlation between weather variables and number of panicle per m^2 in Jaya.

The results of correlation between weather variables and number of panicle per m^2 in Jaya was described in Table 4.18. Forenoon and afternoon vapour pressure deficit during transplanting to active tillering, minimum temperature during active tillering to panicle initiation showed a positive correlation. Forenoon and afternoon vapour pressure deficit experienced during heading to 50% flowering showed a significant negative correlation. Maximum temperature, bright sunshine hours and pan evaporation experienced during 50% flowering to physiological maturity showed a significant negative correlation while forenoon relative humidity showed a significant positive correlation.

4.5.5.8. Correlation between weather variables and number of panicle per m^2 in Jyothi.

The results of correlation between weather variables and number of panicle per m^2 in Jyothi was described in Table 4.19. Maximum temperature and pan evaporation experienced during transplanting to active tillering showed a significant negative correlation while forenoon relative humidity and rainfall showed a significant positive correlation. Minimum temperature, wind speed, bright sunshine hours and forenoon vapour pressure deficit experienced during active tillering to panicle initiation showed a significant negative correlation. Afternoon vapour pressure deficit experienced during panicle initiation to booting showed a significant positive correlation. Afternoon vapour pressure deficit experienced during booting to heading showed a significant positive correlation. Wind speed experienced during heading to 50% flowering showed a significant negative correlation.

Table 4.18. Correlation between weather variables and number of panicle per m^2 in Jaya

Crop stages	Tmax	Tmin	RHI	RHII	VPDI	VPDII	RF	RD	BSS	WS	Epan
P1	0.417	0.387	-0.4	-0.174	0.259	0.31	-0.303	-0.302	0.353	0.511*	0.544*
P2	0.353	0.535*	-0.451	-0.352	0.134	0.418	-0.349	-0.438	0.432	0.069	0.389
P3	0.353	0.535	-0.451	-0.352	0.134	0.418	-0.349	-0.438	0.432	0.069	-0.350
P4	-0.139	0.407	0.028	0.157	0.195	0.037	0.394	0.347	-0.190	-0.071	0.121
P5	-0.414	-0.305	0.224	0.403	-0.273	-0.382	0.464	0.153	-0.541	-0.534*	-0.501*
P6	-0.540*	0.113	0.383	0.448*	-0.141	-0.499*	0.557	0.427	-0.570*	0.169	0.292

*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

Table 4.19. Correlation between weather variables and number of panicle per m^2 in Jyothi

Crop stages	Tmax	Tmin	RHI	RHII	VPDI	VPDII	RF	RD	BSS	WS	Epan
P1	-0.482*	-0.37	.516*	0.429	-0.368	-0.436	.465*	0.313	-0.435	-0.102	-.486*
P2	-0.393	-0.453*	-0.029	0.060	-0.448*	0.241	-0.056	0.165	-0.522*	-0.582*	-0.410
P3	0.166	-0.348	0.242	0.226	0.328	0.547*	-0.247	-0.108	0.006	-0.136	0.185
P4	0.265	-0.055	-0.034	-0.325	0.242	0.471*	-0.164	-0.185	0.201	-0.225	0.261
P5	0.290	-0.297	-0.280	-0.358	-0.156	0.138	-0.148	0.159	0.278	-0.465*	0.332
P6	-0.435*	-0.219	-0.453*	-0.365	-0.254	0.297	-0.218	-0.174	0.425*	-0.110	0.342

*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

Maximum temperature and forenoon relative humidity experienced during 50% flowering to physiological maturity showed a significant negative correlation and bright sunshine hours showed a significant positive correlation.

4.5.5.9. Correlation between weather variables and straw yield in Jaya

The results of correlation between weather variables and straw yield in Jaya was described in table 4. 20. Afternoon relative humidity, rainfall and rainy days prevailed during transplanting to active tillering stage showed a significant positive correlation and minimum temperature, wind speed and bright sunshine hours showed a significant negative correlation. Forenoon and afternoon relative humidity, rainfall and rainy days experienced during active tillering to panicle initiation showed a significant positive correlation while Maximum temperature, minimum temperature, bright sunshine hours and pan evaporation showed a significant negative correlation. Forenoon and afternoon vapour pressure deficit recorded during panicle initiation to booting showed a significant positive correlation and minimum temperature showed a significant negative correlation. Afternoon relative humidity and rainfall experienced during booting to heading showed a significant negative correlation. Weather parameters experienced during heading to 50% flowering like maximum temperature, minimum temperature, bright sunshine hours, evaporation, forenoon and afternoon vapour pressure deficit showed a significant positive correlation.

4.5.5.10. Correlation between weather variables and straw yield in Jyothi

As per the correlation analysis carried out between straw yield of Jyothi and weather variables, none of the weather variables was found to be correlated with straw yield (Table 4. 21).

4.5.5.11. *Correlation between weather variables and number of tillers in Jaya.*

Results of correlation between weather variables and number of tillers in Jaya was described in table 4. 22.

Table 4.20. Correlation between weather variables and straw yield in Jaya

Crop stages	Tmax	Tmin	RHI	RHII	VPDI	VPDII	RF	RD	BSS	WS	Epan
P1	-0.365	-0.464*	0.318	0.455*	-0.338	0.158	0.460*	0.839*	-0.549*	-0.761*	-0.344
P2	-0.583*	-0.795*	0.732*	0.768**	-0.409	0.199	0.758*	0.877**	-0.801*	-0.339	-0.432*
P3	0.179	-.507*	0.147	0.250	.501*	.694**	-0.173	-0.050	-0.078	-0.213	0.196
P4	0.293	-0.310	-0.033	-0.436*	0.023	0.391	-0.527*	-0.219	0.063	-0.328	0.356
P5	0.604*	0.535*	-0.329	-0.599	0.613*	0.717*	-0.342	0.118	0.513*	0.104	0.756**
P6	0.211	0.031	-0.064	-0.164	0.079	0.060	-0.276	-0.249	0.196	-0.013	0.245

*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

Table 4.21. Correlation between weather variables and straw yield in Jyothi

Crop stages	**Tmax**	**Tmin**	**RHI**	**RHII**	**VPDI**	**VPDII**	**RF**	**RD**	**BSS**	**WS**	**Epan**
P1	-0.009	-0.128	0.085	-0.102	-0.119	0.111	-0.234	-0.381	-0.004	-0.136	0.032
P2	0.082	0.008	-0.115	0.152	0.071	0.039	0.031	0.050	0.092	0.086	0.007
P3	-0.063	-0.156	0.213	0.057	0.077	0.012	0.103	0.010	-0.091	-0.163	-0.046
P4	-0.263	-0.349	0.194	0.359	-0.179	0.277	0.403	0.364	-0.281	-0.042	-0.285
P5	0.029	-0.152	0.084	-0.042	0.038	0.043	0.267	0.277	-0.005	0.002	-0.017
P6	0.087	0.187	0.012	-0.084	0.221	0.054	-0.205	-0.190	0.048	-0.040	0.143

*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

Table 4.22. Correlation between weather variables and number of tillers in Jaya.

Crop stages	Tmax	Tmin	RHI	RHII	VPDI	VPDII	RF	RD	BSS	WS	Epan
P1	-0.303	-0.332	0.269	0.189	-0.355	-0.312	0.220	0.427	-0.209	0.359	0.486
P2	-0.336	-0.373	0.334	0.320	-0.075	-0.379	0.308	0.262	-0.424	0.277	0.412
P3	0.062	-0.385	-0.045	0.055	-0.118	0.008	-0.311	-0.179	0.076	-0.092	-0.502
P4	0.205	-0.433	-0.150	-0.288	-0.310	0.125	-0.181	-0.131	0.172	-0.225	0.188
P5	0.405	0.264	-0.376	-0.170	-0.039	0.316	-0.473*	-0.367	0.453*	-0.521*	-0.415
P6	0.400	-0.220	-0.364	-0.371	0.272	0.406	-0.401	-0.352	0.423	-0.047	0.080

*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

Pan evaporation recorded during heading to 50% flowering showed a significant positive correlation while rainfall and forenoon vapour pressure deficit showed a significant negative correlation

4.5.5.12. *Correlation between weather variables and number of tillers in Jyothi*

Results of correlation between weather variables and number of tillers in Jaya was described in table 4. 23. Forenoon vapour pressure deficit experienced during transplanting to active tillering showed a significant negative correlation. Forenoon and afternoon vapour pressure deficit experienced during panicle initiation to booting showed a significant positive correlation while it experienced during 20% flowering to physiological maturity showed a significant negative correlation.

4.6. PLANT CHARACTERS

4.6.1 Weekly plant height

The outcomes of Analysis of variance carried out for weekly plant height up to harvesting stage are represented in Appendix II. Table 4.24 (a&b) describes the effect of dates of planting, variety and their interaction with plant height. A significant influence of dates of planting on weekly plant height irrespective of the variety was seen in all weeks. Plant height recorded on 5th August dates of planting was found to be higher over other dates of planting during 1st (24.5cm), 2nd (36.3cm), 3rd (53 cm), 4th (65.8 cm), 5th (83.0 cm), 6th (98.2 cm) and 7th (104.7cm) week. Height recorded during July 5th planting was found to be highest during 11th (120.4 cm), 12th (122.2 cm) and 13th (123.8 cm) week. At 13 weeks after planting plant height recorded during July 5th planting was higher, plant height recorded during June 20th and August 5th planting were on par and that recorded during June 5th planting was found to be lesser over other dates of planting. Effect of varieties on plant height was also found to be significant except for 2nd, 3rd and 11th week. The weekly recorded height of Jyothi was found to be higher over Jaya during every week where the significant effect was observed. The difference in height of both varieties decreases towards maturity.

Table 4.23. Correlation between weather variables and number of tillers in Jyothi

Crop stages	**Tmax**	**Tmin**	**RHI**	**RHII**	**VPDI**	**VPDII**	**RF**	**RD**	**BSS**	**WS**	**Epan**
P1	-0.129	-0.213	0.078	0.056	-0.532*	-0.432	0.117	0.002	0.001	-0.346	-0.168
P2	0.035	0.115	-0.240	0.257	-0.433	0.011	0.154	-0.042	-0.221	0.199	0.005
P3	0.062	-0.385	-0.045	0.055	0.615**	0.492*	-0.311	-0.179	0.008	-0.118	0.076
P4	-0.029	-0.050	-0.136	0.006	-0.076	-0.316	-0.178	-0.085	0.009	0.043	-0.004
P5	0.208	0.136	-0.128	-0.150	-0.009	-0.122	0.286	0.176	0.175	0.152	0.213
P6	0.166	0.226	-0.113	-0.178	-0.502*	-0.591**	-0.170	-0.229	0.150	-0.037	0.108

*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

Table 4.24. (a) Effect of dates of planting on plant height at weekly intervals

Dates of planting	Plant height (cm)														
	Week 1			Week 2			Week 3			Week 4			Week 5		
	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean
5^{th} June	16.5^{d}	19.3^{bc}	17.6^{c}	23.4	24.5	23.9^{c}	35.2^{bc}	30.2^{d}	32.3^{c}	42.8^{c}	41.0^{d}	41.9^{d}	57.1^{c}	57.9^{d}	57.1^{c}
20^{th} June	21.4^{b}	19.1^{c}	19.9^{b}	25.7	25.6	25.6^{bc}	37.6^{b}	41.7^{bc}	38.4^{b}	53.6^{b}	54.2^{b}	53.9^{b}	67.7^{b}	62.6^{c}	67.7^{b}
5^{th} July	21.6^{bc}	20.8^{b}	20.1^{b}	26.0	27.4	26.6^{b}	34.0^{c}	42.7^{b}	37.5^{b}	50.1^{b}	57.5^{b}	53.8^{b}	67.0^{b}	68.1^{b}	67.0^{b}
20^{th} July	19.0^{c}	19.4^{bc}	18.9^{b}	26.8	26.9	26.8^{b}	38.0^{bc}	38.4^{c}	36.2^{b}	46.3^{c}	47.2^{c}	46.7^{c}	66.7^{b}	66.9^{b}	66.7^{b}
5^{th} August	23.7^{a}	26.6^{a}	24.5^{a}	37.5	35.1	36.3^{a}	54^{a}	52.9^{a}	53.0^{a}	64.0^{a}	67.6^{a}	65.8^{a}	83.3^{a}	77.7^{a}	83.0^{a}
CD	1.72		1.28	NS		2.24	3.99		3.7	3.8		2.57	2.76		2.16

Dates of planting	Plant height (cm)											
	Week 6			Week 7			Week 8			Week 9		
	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean
5^{th} June	68.2^{d}	73.4^{d}	70.0^{d}	75.2^{c}	87.3^{b}	80.6^{e}	86.6^{d}	96.7^{c}	91.4^{c}	97.1^{c}	105.7^{c}	101.2^{b}
20^{th} June	79.4^{b}	78.4^{cd}	77.9^{b}	89.3^{b}	83.7^{b}	86.6^{d}	93.5^{c}	91.0^{d}	92.6^{c}	101.2^{b}	100.2^{b}	100.8^{b}
5^{th} July	77.3^{c}	76.6^{c}	75.8^{c}	93.0^{ab}	98.0^{a}	95.5^{c}	102.7^{b}	105.6^{b}	104.0^{b}	110.2^{a}	111.8^{a}	111.1^{a}
20^{th} July	79.2^{b}	79.6^{b}	79.1^{b}	97.9^{ab}	98.6^{a}	97.7^{b}	108.2^{a}	108.0^{ab}	108.2^{a}	112.2^{a}	113.2^{a}	112.4^{a}
5^{th} August	97.6^{a}	99.6^{a}	98.2^{a}	103.3^{a}	106.1^{a}	104.7^{a}	108.1^{a}	108.8^{a}	108.3^{a}	111.3^{a}	111.4^{a}	111.5^{a}
CD	1.95		1.37	1.72		2.03	2.53		1.9	2.43		2.04

Dates of planting	Plant height (cm)											
	Week 10			Week 11			Week 12			Week 13		
	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean
5th June	103.05^{b}	110.0^{c}	106.43^{c}	107.8^{c}	111.3^{c}	109.4^{c}	112.4	114.1	111.8^{e}	112.8^{d}	123.9^{d}	113.2^{d}
20th June	105.25^{b}	106.6^{d}	105.51^{c}	110.9^{c}	109.9^{c}	110.3^{c}	113.6	116.9	113.1^{d}	114.0^{d}	117.0^{c}	115.2^{c}
5th July	115.40^{a}	117.8^{a}	116.10^{a}	120.7^{a}	120.2^{a}	120.4^{a}	123.5	124.3	122.2^{a}	124.2^{a}	124.0^{a}	123.8^{a}
20th July	114.35^{a}	115.8^{a}	114.84^{a}	115.9^{b}	116.2^{b}	116.0^{b}	118.3	118.6	117.3^{b}	118.5^{b}	118.7^{b}	118.4^{b}
5th August	113.25^{a}	113.1^{b}	113.08^{b}	114.3^{b}	114.7^{b}	114.6^{b}	115.9	116.0	115.6^{c}	116.2^{c}	116.9^{c}	116.4^{c}
CD	2.11		1.71	2.09		1.70	NS		1.14	1.39		1.17

Table 4.24. (b) Comparison between varieties with respect to plant height at weekly intervals

Variety	Plant height (cm)												
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
Jaya	19.7^{b}	27.9	39.1	51.3^{b}	69.7^{a}	79.6^{b}	91.6^{b}	99.7^{b}	106.2^{b}	110.2^{b}	113.9	115.6^{b}	116.7^{b}
Jyothi	20.7^{a}	28.3	39.9	53.5^{a}	66.9^{b}	80.8^{a}	94.5^{a}	102.1^{a}	108.5^{a}	112.1^{a}	114.5	116.5^{a}	118.1^{a}
CD	1.61	NS	NS	1.76	1.08	0.87	1.32	1.07	0.844	0.782	NS	0.56	0.47

Interaction effect of dates of planting and variety was also found to be significant during every week except for 2nd week and 12th week. In case of Jaya weekly recorded plant height during 5th August planting was higher up to first six weeks, afterwards August 5th planting was on par with July 20th planting up to 9th week. From 11th week onwards weekly plant height recorded was higher during July 5th planting and maximum plant height recorded at maturity was during July 5th planting (124.2 cm). The same trend was observed in case of Jyothi. Plant height observed during first dates of planting was lesser over all other dates of planting during 1st week, 6th week, 7th week, 8th week and 9th week in case of Jaya and it was during 3rd week, 4th week, 5th week, 6th week, 9th week and 13th week in case of Jyothi. Plant height of Jyothi recorded during 8th week and 10th week was less during June 20th planting compared to other dates of planting.

4.6.2 Dry matter accumulation at fortnightly intervals

Analysis of variance was performed for dry matter accumulation at fortnightly intervals for different dates of planting and are given in the Appendix II. Table 4.25 (a&b) describes the effect of dates of planting, variety and their interaction with dry matter accumulation.

All dates of planting irrespective of variety showed a significant difference in dry matter accumulation except during 45th days after planting. Dry matter accumulation at 15 days (448.28kg ha^{-1}) and 30 days (2247.6 kg $ha^{-1)}$ after planting was lesser during June 5th planting. During 15 days after planting dry matter accumulation recorded for July 5th and July 20th were on par and June 20th and August 5th were on par. Dry matter accumulated during 20th June, 5th July, 20th July were on par at 30 days after planting. Sixty days after planting dry matter accumulation during 5th August was found to be higher over other dates of planting at 60 days after planting (16110.0 kg ha^{-1}), 75 days after planting (19649.7 kg ha^{-1}) and 90 days after planting (12585.5 kg ha^{-1}) while it is minimum during July 5th planting(9360.7 kg ha^{-1}) during 60 and 75 days after planting.

Table 4.25. (a). Effect of dates of planting on dry matter accumulation at fortnightly intervals

Dates of planting	**Dry matter accumulation (kg ha^{-1})**								
	15 DAP			**30 DAP**			**45 DAP**		
	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean
5th June	244.4^{d}	414.9^{b}	448.28^{c}	1361.3^{c}	3129.6^{c}	2247.6^{c}	3765.8	7870	5818.4
20th June	362.5^{c}	506.6^{a}	509.94^{b}	1916.7^{a}	4152.9^{a}	3034.8^{a}	3610.5	8384.2	5997
5th July	460.0^{b}	539^{a}	541.61^{a}	1784.2^{ab}	4119.5^{a}	2936.9^{a}	3808.3	8149.2	5978
20th July	509.7^{ab}	566.6^{a}	551.61^{a}	1620.2^{abc}	3936.2^{ab}	2778.2^{ab}	3885.3	8759.1	6322
5th August	583.5^{a}	241.6^{c}	577.46^{b}	1553.2^{bc}	3736.2^{b}	2644.7^{b}	3564.8	8370.8	5937
CD	75.85		61.32	317.1		256.94	NS		NS

Dates of planting	**Dry matter accumulation (kg ha^{-1})**								
	60 DAP			**75 DAP**			**90 DAP**		
	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean
5th June	4264.3^{c}	11955.4^{b}	11803.8^{c}	8685.5^{c}	16719.9^{c}	16490.0^{c}	7745.9^{b}	14956.8^{b}	11351.3^{b}
20th June	5911.0^{b}	10992.2^{c}	10958.9^{bc}	8793.7^{c}	16984.97^{c}	17086.6^{c}	7802.5^{b}	14926.8^{b}	11364.6^{b}
5th July	4506.5^{c}	9402.3^{d}	9360.7^{d}	7432.5^{d}	13863.6^{d}	13940.2^{d}	6652.2^{c}	12670.4^{d}	9661.3^{c}
20th July	6191.0^{b}	11815.4^{bc}	11760.4^{b}	9434.7^{b}	17664.9^{b}	17334.9^{b}	7172.2^{bc}	13756.9^{c}	10464.6^{c}
5th August	8520.0^{a}	16288.3^{a}	16110.0^{a}	10192^{a}	19649.7^{a}	19474.7^{a}	8724.5^{a}	16446.6^{a}	12585.5^{a}
CD	761.9		632.3	631.6		544.11	860.62		804.8

Table 4.25. (b) Comparison between varieties with respect to dry matter accumulation

Variety	**15 DAP**	**30 DAP**	**45 DAP**	**60 DAP**	**75 DAP**	**90 DAP**
Jaya	244.4^{b}	1641.7^{b}	3714.9^{b}	5913.2^{b}	8907.8^{b}	7990.9^{b}
Jyothi	414.9^{a}	3814.9^{a}	8306.8^{a}	12170.7^{a}	16976.6^{a}	14551.5^{a}
CD	63.28	117.8	213.3	270.0	204.9	860.6

DAP – Days After Planting

At 90 days after planting dry matter accumulation during 5th June was on par with 20th June, 5th July was on par with 20th July. Interaction of dates of planting and variety was found to be significant. In case of Jaya dry matter accumulation during 5th August was found to be higher over other dates of planting when recorded at 60 (8520 kg ha^{-1}), 75 (10192 kg ha^{-1}) and 90 (8724.5 kg ha^{1}) days after planting while dry matter accumulation during 5th June was minimum compared to other dates of planting at 15 days after planting (244.4 kg ha^{-1}) and 60 (8520 kg ha^{-1}) days after planting. In case of Jyothi dry matter accumulation during 5th August planting was found to be maximum among other dates of planting at 60 (16288.3 kg ha^{-1}), 75 (19649.7kg ha^{-1}) and 90 (16446.6 kg ha^{-1}) days after planting. In Jyothi dry matter accumulation was found to be minimum during 5th August at 15 days after planting (241.6 kg ha^{-1}), 5th June at 30 days after planting (3129.6kg ha^{-1}), 5th July at 60 (9402.3 kg ha^{1}),75 (13863.6kg ha^{-1}), 90 (12670.4kg ha^{-1}) days after planting.

Effect of varieties on dry matter accumulation was also found to be significant throughout all fortnightly interval. Among the two varieties dry matter accumulation in Jyothi was higher over Jaya during all fortnightly intervals. Maximum dry matter accumulation was recorded during 75 DAP in both the varieties. Dry matter accumulation in Jyothi (16976.6 kg ha^{-1}) was found to be higher over Jaya (8907.8 kg ha^{-1}).

4.6.3. Yield and yield attributes

Analysis of variance (ANOVA) was completed on yield and yield attributes and is presented in Appendix II.

Mean values for yield and yield attributes for both Jaya and Jyothi with respect to different dates of planting and also for various dates of planting irrespective of the variety is depicted in the Table 4.26 (a) Effect of varieties on yield and yield attributes are depicted in Table 4.26 (b). When ANOVA showed significant difference for dates of planting, variety and interaction between dates of planting and variety, critical difference (CD) values were calculated and comparisons were made.

Table 4.26. (a) Effect of dates of planting on yield and yield attributes

Dates of planting	Number of tillers per m^2			Number of panicles per m^2			Number of spikelets per panicle			Number of filled grains per panicle		
	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean
5th June	338^{ab}	331^{a}	334.5^{a}	334.2	265	284.5	97^{b}	62.7^{b}	79.8^{c}	79	67	72.2^{b}
20th June	322^{ab}	263^{bc}	292.5^{b}	303	251	295	117.7^{b}	80.8^{b}	99^{b}	87	66	75.2^{b}
5th July	282^{b}	238^{c}	260^{b}	262	235	259	142.8^{a}	129.6^{a}	136^{a}	104	76	89.7^{a}
20th July	$306a^{b}$	315^{bc}	310.5^{b}	277	276	294	111.3^{b}	122.9^{b}	117^{b}	68	49	57.6^{b}
5th August	354^{a}	370^{bc}	362^{a}	291	311	286	147.1^{a}	144^{a}	145^{a}	80	57	69.9^{b}
CD	66.75		54.6	NS		NS	23.03		18.96	NS		14.54

Dates of planting	1000 grain weight (g)			Straw yield (kg ha^{-1})			Grain yield (kg ha^{-1})		
	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean
5th June	30.2^{a}	29^{a}	29.6^{a}	3581	3425	3503	4487^{a}	3655^{a}	4418.4^{a}
20th June	29.6^{a}	28.2^{ab}	28.9^{a}	3646	3581	3613	4111^{a}	3609^{a}	4029.4^{a}
5th July	27.8^{ab}	29.1^{a}	28.5^{a}	4587	4162	4374	2932^{b}	2775^{b}	2836.2^{b}
20th July	25.6^{bc}	22.1^{c}	23.9^{b}	3506	3400	3453	1058^{c}	1250^{d}	1249.2^{c}
5th August	23.3^{c}	25.15^{bc}	24.2^{b}	4062	3950	4006	2849^{b}	2269^{c}	2846.2^{b}
CD	3.44		2.45	NS		NS	413.9		300.67

Table 4.26. (b) Comparison between varieties and yield attributes

Variety	**Number of tillers per m^2**	**Number of panicles per m^2**	**Spikelets per panicle**	**Filled grains per panicle**	**1000 grain weight (g)**	**Straw yield ($kg\ ha^{-1}$)**	**Grain yield ($kg\ ha^{-1}$)**
Jaya	320.2	294 [a]	123 [a]	83.3 [a]	27.3 [a]	3876	3052[a]
Jyothi	303.4	266 [b]	102 [b]	62.7 [b]	26.7 [b]	3703	2712[b]
CD	NS	20.08	8.59	7.24	0.786	NS	179.2

4.6.3.1 Number of tillers per m^2

ANOVA showed significant difference between dates of planting. Interaction between dates of planting and varieties was also significant. Number of tillers recorded in August 5th planting was on par with June 5th planting irrespective of variety. In case of Jaya number of tillers recorded during August 5th planting was on par with all other dates planting except for July 5th planting and vice versa. In case of Jyothi, number of tillers recorded during June 5th planting was higher. There was no significant difference between varieties.

4.6.3.2 Number of panicles per m^2

ANOVA carried out for number of panicle per m^2 showed no significant difference between dates of planting and varieties. The effect of varieties on number of panicles was found to be significant. Number of panicles in Jaya was found to be higher over Jyothi.

4.6.3.3 Number of spikelets per panicle

ANOVA showed significant difference between dates of planting July 5th and August 5th planting were found to be on par. June 20th and July 20th planting were on par. Number of spikelet in June 5th planting (79.8) was found to be lesser over other dates of planting. Interaction between dates of planting and varieties was also significant. In case of both Jaya and Jyothi, number of spikelets recorded during June 5th planting was on par with June 20th and July 20th planting and July 5th and August 5th planting were also on par. Significant difference was found between two varieties. Among the two varieties number of spikelet in Jaya (123) was found to be higher over Jyothi (102).

4.6.3.4 Number of filled grains per panicle

Number of filled grains per panicle was influenced by different dates of planting irrespective of variety. Number of filled grains recorded during 5th July planting (89.7) was found to be higher over other dates of planting. Interaction between dates of planting and variety was found to be non-significant. Effect of variety on number of filled grains per panicle was also found to be significant. Number of filled grains per panicle in Jaya (83) was found to be higher over Jyothi (62.7).

4.6.3.5 1000 grain weight (g)

Effect of dates of planting on 1000 grain weight was found to be significant. Among five dates of planting, 5th June was on par with 20th June and 5th July, also 20th July was on par with 5th August planting irrespective of the variety. Interaction between dates of planting and variety was also found to be significant. In case of Jaya, 5thJune, 20th June and 5th July planting were on par. July 20th planting was on par with August 5th planting. In case of Jyothi June 5th, June 20th and July 5th planting were on par. June 20th and August 5th planting were on par and 20th July and 5th August plantings were on par. Effect of variety on 1000 grain weight was also significant. Among the two varieties 1000 grain weight recorded in Jaya (27.3 g) was found to be higher over Jyothi (26.7 g).

4.6.3.6 Straw yield (kg ha^{-1})

Effect of dates of planting on straw yield was found to non-significant. Effect of variety and Interaction between variety and dates of planting on straw yield was found to be non-significant.

4.6.3.7 Grain yield (kg ha^{-1})

Grain yield was influenced by dates of planting and variety. Grain yield recorded on 20th July was found to be lesser over all other planting irrespective of variety.

Among the five dates of planting grain yield recorded during June 5th planting (4418.4 kg ha^{-1}) was on par with June 20th planting (4029.4 kg ha^{-1}), July 5th planting (2836.2 kg ha^{-1}) was on par with 5th August planting (2846.2 kg ha^{-1}) . July 20th planting was found to be lesser over all other dates of planting with a yield of 1249.2 kg ha^{-1}. Interaction between dates of planting and variety was also found to be significant. In case of Jaya, the same trend as followed by dates of planting alone was observed. Grain yield obtained from Jaya during 20th July (1058 kg ha^{-1}) was lesser over other dates of planting. In case of Jyothi June 5th planting was on par with June 20th planting and July 5th, July 20th and August 5th planting were significantly different. Grain yield obtained from Jyothi during 5th August planting (1250 kg ha^{-1}) was lesser among all other dates of planting. Among the two varieties yield obtained from Jaya (3052 kg ha^{-1}) was higher over Jyothi (2712 kg ha^{-1}).

4.7. GROWTH INDICES

Growth indices like leaf area index, leaf area duration and crop growth rate were calculated using measurements such as leaf area and dry weight observed at fortnightly intervals. The analysis of variance was carried out for growth indices.

4.7.1. Leaf area index (LAI) at fortnightly intervals

As per the results of ANOVA performed for leaf area index significant difference was observed between five different dates of planting and between varieties (Table.4.27 (a & b)).

Except for LAI values calculated at 30 and 45 days after planting all other fortnightly intervals showed a significant influence of dates of planting on leaf area index. Interaction also found significant during the same period.

During 15 days after planting LAI recorded at August 5th was on par with June 20th. June 5th, June 20th and July 20th planting were also on par with each other. June 5th, July 5th and July 20th planting were also on par with each other.

Table 4. 27 (a) Effect of dates of planting on leaf area Index (LAI) at fortnightly intervals

Dates of planting	Leaf area index								
	15 DAP			**30 DAP**			**45 DAP**		
	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean	Ja	Jy	Mean
5^{th} June	0.17	0.34	0.26^{bc}	0.75	1.36	1.05	1.19	2.26	1.72
20^{th} June	0.23	0.4	0.31^{ab}	0.95	1.64	1.29	1.3	2.52	1.9
5^{th} July	0.2	0.30	0.24^{c}	0.82	1.5	1.15	1.24	2.29	1.76
20^{th} July	0.2	0.33	0.26^{bc}	0.81	1.42	111	1.36	2.56	1.96
5^{th} August	0.24	0.45	0.34^{a}	0.81	1.98	114	1.33	2.46	1.89
CD	NS		0.064	NS		NS	NS		NS

Dates of planting	Leaf area index								
	60 DAP			**75 DAP**			**90 DAP**		
	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean
5^{th} June	1.71^{b}	3.08^{b}	2.39^{b}	2.42^{b}	4.59^{b}	3.51^{b}	1.63^{b}	3.03^{c}	2.33^{b}
20^{th} June	1.52^{b}	3.35^{b}	2.44^{b}	2.4^{b}	4.61^{b}	3.56^{b}	1.62^{b}	3.2^{c}	2.41^{b}
5^{th} July	1.72^{b}	3.2^{b}	2.46^{b}	3.64^{a}	5.46^{a}	4.5^{a}	1.79^{b}	3.46^{b}	2.63^{b}
20^{th} July	2.1^{a}	4.07^{a}	3.08^{a}	3.08^{a}	6.03^{a}	4.56^{a}	2.33^{a}	4.46^{a}	3.39^{a}
5^{th} August	2.11^{a}	4.17^{a}	3.14^{a}	3.12^{a}	6.09^{a}	4.61^{a}	2.19^{a}	4.24^{a}	3.21^{a}
CD	0.318		0.240	0.236		0.041	0.131		0.365

Table 4. 27 (b) Comparison of leaf area index (LAI) of varieties at fortnightly intervals

Variety	15 DAP	30 DAP	45 DAP	60 DAP	75 DAP	90 DAP
Jaya	0.20[b]	0.82[b]	1.28[b]	1.83[b]	2.81[b]	1.91[b]
Jyothi	0.36[a]	1.48[a]	2.41[a]	3.57[a]	5.46[a]	3.68[a]
CD	0.026	0.043	0.071	0.131	0.10	0.131

LAI recorded at 60 and 90 days after planting were compared and found out that during both the intervals June 5th, June 20th and July 5th planting were on par while July 20th planting was on par with August 5th planting. At 75 days after planting LAI recorded during June 5th and June 20th planting were on par and July 5th planting was on par with July 20th and August 5th. Maximum leaf area index was recorded during 75 DAP.

Interaction between dates of planting and variety was also found to be significant during 60 DAP, 75 DAP and 90 DAP (Table.4.27 (a&b)). In both the varieties leaf area reached a maximum value at 75 DAP then decreased towards 90 DAP.

Among the two varieties the calculated leaf area index was higher in Jyothi compared to Jaya in all cases. Leaf area index recorded at 75 days after planting was 5.46 in Jyothi and 2.81 in Jaya.

4.7.2. Leaf area duration at fortnightly intervals

Analysis of variance was carried out for leaf area duration at fortnightly intervals and significant difference was observed for different dates of planting and between varieties (Table.4.28 (a & b)).

Minimum value of leaf area duration was recorded on June 5th planting at 15 to 30 days after planting and 30- 45 days after planting. During these intervals lead area duration calculated on June 20th planting was on par with July 5th, July 20th and August 5th planting. LAD recorded during 5th June and 20th June was on par and 5th July planting was on par with 20th July and 5th August during the interval of 45-60 DAP. In case of LAD calculated for the interval of 60-75 days after planting and 75 to 90 days after planting 20th July and 5th August planting were on par and 5th June and 20th June planting were on par. Interaction of dates of planting with varieties was found to be non-significant. LAD calculated for Jyothi was higher over Jaya throughout the crop growth period.

Table 4. 28 (a). Effect of dates of planting on leaf area duration (LAD) at fortnightly intervals

Dates of planting	**Leaf area duration (days)**								
	15 - 30 DAP			**30 - 45 DAP**			**45 – 60 DAP**		
	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean
5th June	6.92	12.8	9.8^{b}	14.55	27.1	20.84^{b}	21.8	40.08	30.93^{b}
20th June	8.75	15.32	12.1^{a}	16.45	31.17	24.06^{a}	21.22	44.65	32.64^{b}
5th July	7.62	13.45	10.54^{a}	15.47	28.95	21.96^{a}	22.25	41.25	31.75^{a}
20th July	7.57	13.12	10.35^{a}	16.27	24.8	23.06^{a}	26.02	49.77	37.90^{a}
5th August	7.4	14.45	11.18^{a}	16.07	29.5	22.83^{a}	25.82	49.77	37.8^{a}
CD	NS		1.658	NS		2.49	NS		2.295

Dates of planting	**Leaf area duration (days)**					
	60 – 75 DAP			**75 – 90 DAP**		
	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean
5th June	31.07	57.6	44.3^{c}	30.95	57.27	43.86^{c}
20th June	24.42	59.8	44.61^{c}	30.22	58.67	44.5^{c}
5th July	35.8	68.7	52.29^{b}	36.35	70.7	53.54^{b}
20th July	38.8	75.8	57.38^{a}	40.65	78.75	59.70^{a}
5th August	39.32	39.3	58.19^{a}	39.9	77.57	58.74^{a}
CD	NS		3.374	NS		4.415

Table 4. 28 (b). Comparison of leaf area duration (LAD) of varieties at fortnightly intervals

Varieties	**Leaf area duration (days)**				
	15 - 30 DAP	**30 - 45 DAP**	**45 - 60 DAP**	**60 - 75 DAP**	**75 - 90 DAP**
Jaya	7.78 [b]	15.86 [b]	23.42 [b]	34.91 [b]	35.51[b]
Jyothi	13.83 [a]	29.23 [a]	44.8 [a]	67.80 [a]	68 [a]
CD	0.363	0.675	1.127	1.496	1.137

4.7.3. Crop growth rate at fortnightly intervals

Analysis of variance was carried out for CGR calculated at fortnightly interval and effect of dates of planting and variety on crop growth rate was found to be significant (Table 4.29 (a & b))

Effect of dates of planting on crop growth is significant in all fortnightly intervals except during 30-45 DAP. CGR calculated during June 5th planting (14.6 g m^{-2} day^{-1}) was found to be lesser over other planting at 15-30 DAP interval. Among all the five planting CGR recorded at 5th August planting (50.7 g m^{-2} day^{-1}) was higher at 45-60 DAP interval. Interaction between dates of planting and varieties were also found to be significant. In case of Jaya during the interval of 15 to 30 days after planting a maximum CGR was recorded during June 20th planting (15.5 g m^{-2} day^{-1}) and during the interval of 45 to 60 days after planting a maximum value of CGR was recorded during August 5th planting (49.6 g m^{-2} day^{-1}). In case of Jyothi during the interval of 15-30 DAP crop growth rate was minimum during June 5th planting (18.1 g m^{-2} day^{-1}), and during the interval of 45 to 60 days after planting maximum CGR was recorded during August 5th (51.8 g m^{-2} day^{-1}) planting and minimum CGR was recorded during July 5th planting (8.9 g m^{-2} day^{-1}). Maximum CGR was recorded during 45 to 60 days after planting. Effect of varieties on CGR was found to be significant in all cases except for 45-60 DAP interval. CGR of Jyothi was higher than Jaya during 15-30 DAP and 60-75 DAP while during 30-45 DAP CGR was maximum in Jaya.

4.7.4. Net assimilation rate at fortnightly intervals

Analysis of variance was carried out for NAR calculated at fortnightly interval. Effect of dates of planting and variety was found to be significant (Table 4.30 (a & b)). Maximum NAR was recorded during 15-30 days after planting. NAR during July 5th planting was on par with June 20th, July 20th and August 5th planting. During 30-45 days after planting June 5th planting was on par with July 20th planting and August 5th planting.

Table. 4.29 (a). Effect of dates of planting on crop growth rate (CGR) at fortnightly intervals

Date of planting	**Crop growth rate (g m^{-2} day^{-1})**								
	15 - 30 DAP			**30 - 45 DAP**			**45 - 60 DAP**		
	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean
5th June	11.1^{bc}	18.1^{b}	14.6^{d}	24.9	33.4	27.8	29.8^{ab}	31.4^{ab}	30.6^{ab}
20th June	15.5^{a}	24.3^{a}	19.9^{a}	17	28.3	22.5	28.3^{ab}	38.4^{a}	33.3^{a}
5th July	12.9^{b}	23.8^{a}	18.4^{ab}	20	26.7	23.7	23.4^{bc}	29.1^{bc}	26.2^{bc}
20th July	11.1^{bc}	22.4^{a}	16.7^{bc}	22	33.9	27.4	31.9^{a}	37.8^{a}	34.9^{a}
5th August	9.6^{c}	23.3^{a}	16.4^{c}	19	31.2	25.2	17.1^{c}	23.3^{c}	20.2^{c}
CD	2.2		1.7	NS		NS	7		6.1

Date of planting	**Crop growth rate (g m^{-2} day^{-1})**					
	60 – 75 DAP			**75 - 90 DAP**		
	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean
5th June	19.3^{b}	27.5^{b}	23.4^{b}	-9.3^{a}	-11.7^{a}	-10.5^{ab}
20th June	23.4^{b}	18.9^{c}	21.1^{b}	-9.9^{a}	-13.7^{ab}	-11.8^{ab}
5th July	12.8^{c}	8.9^{d}	10.8^{c}	-7.8^{a}	-7.9^{a}	-7.8^{a}
20th July	23.5^{b}	21.5^{bc}	22.5^{b}	-22.6^{b}	-26^{c}	-24.3^{c}
5th August	49.6^{a}	51.8^{a}	50.7^{a}	-14.6^{ab}	-21.3^{bc}	$-18b^{c}$
CD	6.4		5.9	8.2		7.8

Table.4.29. (b). Comparison of crop growth rate (CGR) of varieties at fortnightly intervals

Varieties	**Crop growth rate (g m^{-2} day^{-1})**				
	15 - 30 DAP	**30 - 45 DAP**	**45 - 60 DAP**	**60 - 75 DAP**	**75 - 90 DAP**
Jaya	12^{b}	29.9^{a}	32.15	26.1^{b}	-12.8^{b}
Jyothi	22.4^{a}	20.7^{b}	32.2	32^{a}	-16.1^{a}
CD	0.8	1.56	NS	2.2	1.6

Table.4.30. (a). Effect of date of planting on net assimilation rate (NAR) at fortnightly intervals

Date of planting	**Net assimilation rate (g m^{-2} day^{-1})**								
	15 – 30 DAP			**30 - 45 DAP**			**45 – 60 DAP**		
	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean
5^{th} June	8.50	10.60 ^{c}	9.50 ^{b}	7.22	7.78	7.40 ^{a}	3.99 ^{b}	4.53 ^{b}	4.20 ^{b}
20^{th} June	9.02	12.20 ^{abc}	10.60 ^{ab}	4.41	6.03	5.20 ^{c}	5.20 ^{a}	2.84 ^{c}	4.02 ^{b}
5^{th} July	8.60	14.10 ^{a}	11.38 ^{a}	5.87	6.28	6.00 ^{bc}	2.52 ^{b}	1.43 ^{c}	1.97 ^{c}
20^{th} July	7.47	13.10 ^{ab}	10.39 ^{ab}	6.19	7.29	6.70 ^{ab}	4.01 ^{ab}	2.85 ^{c}	3.43 ^{b}
5^{th}	8.50	11.70 ^{bc}	10.10 ^{ab}	6.02	7.00	6.50 ^{ab}	5.42 ^{a}	6.93 ^{a}	6.19 ^{a}
CD	2.12		1.79	NS		1.20	1.62		1.40

Date of planting	**Net assimilation rate (g m^{-2} day^{-1})**					
	60 - 75 DAP			**75 – 90 DAP**		
	Jaya	Jyothi	Mean	Jaya	Jyothi	Mean
5^{th} June	4.21	3.62	3.90 ^{ab}	-1.37	-1.39	-1.37 ^{a}
20^{th} June	4.37	4.24	4.30 ^{a}	-1.44	-1.51	-1.49 ^{ab}
5^{th} July	2.91	2.81	2.80 ^{c}	-0.96	-0.76	-0.85 ^{a}
20^{th} July	3.63	3.33	3.40 ^{c}	-2.49	-2.21	-2.34 ^{b}
5^{th} August	1.92	1.99	1.90 ^{d}	-1.62	-1.81	-1.71 ^{ab}
CD	NS		0.714	NS		0.90

Table.4.30. (b). Comparison of net assimilation rate (NAR) of varieties at fortnightly intervals

Varieties	**Net assimilation rate (g m^{-2} day^{-1})**				
	15 - 30 DAP	**30 - 45 DAP**	**45 - 60 DAP**	**60 - 75 DAP**	**75 - 90 DAP**
Jaya	8.40 [b]	5.90 [b]	4.21	3.40	-1.57
Jyothi	12.40	6.87	3.72	3.20	-1.54
CD	0.73	0.52	NS	NS	NS

DAP – Days After Planting

NAR was found to be higher for August 5th planting (6.19 g m^{-2} day $^{-1}$) during 45-60 days after planting. During 60-75 days after planting NAR recorded for June 5th planting was on par with June 20th planting. During 75-90 days after planning NAR recorded for June 5th planting was on par with June 20th planting, July 5th planting and August 5th planting. Interaction between dates of planting and variety was also found to be significant during 15 to 30 days after planting and 45 to 60 days after planting. During 15 to 30 days after planting NAR recorded for June 20th planting was on par with July 5th planting and July 20th planting in Jyothi. During 45 to 60 days after planting NAR recorded for June 20th planting was on par with July 20th and August 5th planting in Jaya and NAR recorded during August 5th planting was higher in Jyothi. Effect of variety was also found to be significant during 15 to 30 days after planting and 30 to 45 days after planting. NAR recorded in Jyothi was higher compared to Jaya. NAR was found to be decreasing as crop growth proceeds and reaches a negative value during 75 to 90 days after planting.

4.8 CERES-RICE SIMULATION MODEL

The data collected from the experimental field during the year 2019 were used to run CERES – Rice model. The observed weather data, phenology, yield and yield attributes were used in model. Weather file, crop management file, soil file and experimental files were prepared and given as input for running the CERES-Rice model for Jaya and Jyothi during the experiment year 2019. Based on the previously calibrated genetic coefficients, fine tuning of genetic coefficients were done using 6000 iterations for both the varieties separately. Fine-tuned genetic coefficients used in the study were depicted in Table 4.31.

Table 4.31. Genetic coefficients of Jyothi and Jaya used in CERES-Rice model

Variety	P1	P2R	P5	P2O	G1	G2	G3	G4	PHINT
Jyothi	551.0	22.3	444.0	11.4	50.4	0.0256	1.10	1.10	82.0
Jaya	575.2	75.60	443.9	12.9	48.50	0.0280	1.00	1.0	82.0

The precision of the model was tested by comparing predicted output and observed output using two statistics RMSE (Root mean square error) and d- stat index (Index of agreement) value.

The average yield of Jaya and Jyothi simulated by CERES rice model was 428 kg ha^{-1} and 3451 kg ha^{-1} respectively. Average observed yield was 3036 kg ha^{-1} for Jaya and 2672 kg ha^{-1} for Jyothi. Model overestimated yield for both varieties. The d-stat index for yield was 0.57 for Jaya and 0.61 for Jyothi. (Table 4.32). The simulated yield showed a good agreement with observed yield.

Table 4.32. Observed and simulated yield from CERES model of two varieties

Variety name	Observed	Simulated	RMSE	d-stat
Jaya	3036	4281	1488.63	0.57
Jyothi	2672	3451	1043	0.61

Observed duration of each phenophases showed a good agreement with simulated values. Duration of anthesis, panicle initiation, and physiological maturity were simulated using model with a good Root Mean Square Error (RMSE) and d-stat index except for physiological maturity for Jyothi. The simulated and observed duration of phenophases with corresponding RMSE and d-stat index are depicted in the Table 4.33.

Table 4.33. Observed and simulated phenophase duration of varieties

Variety	Phenophases	Observed	Simulated	RMSE	d-stat
Jaya	Anthesis	69	69	1.844	0.49
	Panicle initiation	39	36	3.72	0.584
	Physiological maturity	104	102	3.55	0.584
Jyothi	Anthesis	67	69	1.673	0.686
	Panicle initiation	34	35	1.949	0.643
	Physiological maturity	98	102	4.98	0.328

4.9. ESTIMATION OF YIELD GAP

Yield gap was analyzed by estimating different production levels *viz.* potential yield (Y_p), attainable yield (Y_a), and actual yield (Y_f). Total yield gap was estimated by the difference between potential yield and actual yield. Total yield gap was further divided into two components, *i. e* yield gap I and yield gap II. Yield gap one was estimated as the difference between potential yield and attainable yield and yield gap II was estimated as the difference between attainable yield and farmers yield. Different production levels used for estimating and yield gap were described below.

4.9.1. Potential yield

Potential yield is the maximum yield obtained from a cultivar. It is limited only by the climatic conditions and genetic characteristics of crops. This production level is attained under no stress conditions of water and nutrients. Using CERES rice model no stress conditions for water and nitrogen were simulated and the resultant simulated yield was considered as potential yield. Potential yield was predicted for each date of planting for both Jyothi and Jaya using CERES rice model by simulating no stress condition of water and nutrients (Table 4.34). It was done by changing simulation options in DSSAT- CERES model for water and nitrogen as "No". Among all the five dates of planting simulated potential yield of Jaya was more in June 5th planting (6057 kg ha^{-1}). Simulated potential yield decreased with delay in planting. Potential yield of 5797 kg ha^{-1}, 5618 kg ha^{-1}, 5154 kg ha^{-1} and 5560 kg ha^{1} were simulated for June 20th, July 5th, July 20th and August 5th planting respectively. In case of Jyothi potential yield was more during June 20th planting (5687 kg ha^{-1}). Potential yield of 5651 kg ha^{-1}, 5488 kg ha^{-1}, 5424 kg ha^{-1} and 5577 kg ha^{-1} were simulated for June 5th, July 5th, July 20th and August 5th planting respectively.

Table 4.34. Potential yield simulated for Jaya and Jyothi under five dates of planting

Dates of planting	**Potential yield (kg ha^{-1})**	
	Jaya	**Jyothi**
June 5th	6057	5651
June 20th	5797	5687
July 5th	5618	5488
July 20th	5154	5424
August 5th	5560	5577

4.9.2. Actual yield

Actual farmers yield was collected from direct farmer survey and report of ECOSTAT Kerala for the year 2019. The average yield obtained during *kharif* season, 2019 from farmer's field were considered as actual yield. The actual yield of Jaya was 2430 kg ha^{-1} and for Jyothi was 2330 kg ha^{-1}.

4.9.3. Attainable yield

Based on the survey conducted among the 15 paddy farmers, the date of planting followed by majority of farmers was found to be on second week to third week of June. Yield obtained under best management practices were considered as attainable yield. In the experimental plots crop management practices as suggested by Kerala Agricultural University were followed. Yield obtained from the experimental plots during June 20th planting was considered as attainable yield. Attainable yield for Jaya was 4057 kg ha^{-1} and for Jyothi was 3609 kg ha^{-1}.

Similarly potential yield simulated for June 20th planting using CERES rice model was taken for further analysis in both Jaya and Jyothi, Different yield levels used to calculate yield gap were described in Table 4.35.

Table 4.35. Yield levels calculated for both Jaya and Jyothi

Yield levels	**Jaya (kg ha^{-1})**	**Jyothi (kg ha^{-1})**
Potential Yield (Yp)	5797	5687
Attainable Yield (Ya)	4057	3609
Actual yield (Yf)	2340	2330

4.9.4. Yield gap

Total yield gap that is the difference between potential yield and actual yield was split into two components, yield gap I and yield gap II. Yield gap I was calculated by the difference between potential yield and attainable yield. Yield gap II was estimated as the difference between attainable yield and actual yield. Total yield gap was calculated by the difference between potential yield and actual farmers yield. Percentage of yield gap with respect to potential yield was also calculated. All three yield gaps for both Jaya and Jyothi was presented in Table 4.36. In case of Jaya yield gap I calculated was 1740 kg ha^{-1}, which was 30% of potential yield and yield gap II was 1717 kg ha^{-1}, which was 29.6% of potential yield. In case of Jyothi 2078 kg ha^{-1} was obtained as yield gap I, which was 36.5% of potential yield and calculated value of yield gap II was 1279, which was 22.3% of potential yield. In both varieties yield gap I was more compared to yield gap II *i e.* difference between potential yield and attainable yield is more compared to the difference between attainable yield and actual yield. Total yield gap in case of Jaya was calculated as 60% of potential yield *i e*. 3457 kg ha^{-1} whereas in Jyothi total yield gap was 59% of potential yield *i. e* 3357 kg ha^{-1}. Total yield gap of Jaya was more than Jyothi.

Table 4.36. Yield gap calculated for Jaya and Jyothi

Yield gap	Jaya		Jyothi	
	kg ha^{-1}	**% of Yp**	**kg ha^{-1}**	**% of Yp**
YGI (Yp-Ya)	1740	30.0	2078	36.5
YGII (Ya-Yf)	1717	29.6	1279	22.3
Total yield gap (Yp-Yf)	3457	60.0	3357	59.0

4.10. DETAILS OF FERTILIZER MANAGEMENT STRATEGIES FOLLOWED BY FARMERS

Details of fertilizer management strategies adopted by farmers along with that adopted in experimental field are described in Table 4.37. Yield obtained from experiment during June 20th planting was 3608 kg ha^{-1} when nitrogen was applied at a rate of 70 kg ha^{-1} in two split doses. Among the five farmers, the maximum yield was achieved by 3rd farmer and minimum yield was achieved by farmer 2. Yield obtained by first framer is 2600 kg ha^{-1} when nitrogen is applied at a rate of 29.75 kg ha^{-1} in two split. 40.25 kg less nitrogen was applied by farmer one as compared to general recommendation. Farmer 2 applied 107.5 kg ha^{-1} nitrogen in two split doses and corresponding yield obtained was 500 kg ha^{-1}. Farmer 3 applied 91 kg ha^{-1} nitrogen in three split doses and corresponding yield obtained was 3250 kg ha^{-1}. Farmer 4 applied 133.75 kg ha^{-1} nitrogen in two split and yield obtained was 2800 kg ha^{-1}. Farmer 5 applied 58.5 kg ha^{-1} nitrogen and yield obtained was 2500 kg ha^{-1}. Maximum yield was obtained by farmer 3 who applied 91 kg ha^{-1} in three split doses. Minimum yield was obtained by farmer 2. None of the farmers followed proper management practices as recommended by KAU. Farmers either applied excess fertilizer or less fertilizer and application time was also differed as mention in the Table 4.37. Yield obtained by farmers was less than attainable yield due to improper fertilizer application.

Table 4.37. Details of fertilizer management strategies adopted by farmers

Farmer	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Yield (kg ha^{-1})	Fertilizer application time	Variation in fertilizer application time relative to KAU package of practices for rice
Experiment done as per recommendations of package of practices, KAU	70	35	35	3608	15 DAP – 47:35:17.5 27 DAP – 23:0:0 33 DAP – 0:0: 17.5	Nil
Farmer 1	29.75 (40.25kg less)	12.5 (22.5kg less)	37.5 (2.5kg more)	2600	20 DAP- 12.5:12.5:0 30 DAP- 17.25:0:37.5	K is not applied during initial times First application is delayed by 5 days Second application is delayed by one week
Farmer 2	107.5 (37.5kg more)	50 (15kg more)	37.5 (2.5kg more)	500	20 DAP – 50:50:0 45 DAP- 57.5:0:37.5	K is not applied during initial times First application is delayed by 5 days Second application is delayed by more than a week
Farmer 3	91 (21kg more)	45 (10kg more)	90 (55kg more)	3250	15 DAP – 45:45:0 30 DAP – 23:0: 45 50 DAP – 23:0:45	K is not applied during first application
Farmer 4	133.75 (63.75kg more)	47.5 (12.5kg more)	45 (10kg more)	2800	7DAP- 37.5:37.5:0 30DAP - 96.25:10:45	K is not applied during first application First application is delyed by a week P is done in two split dose
Farmer 5	58.5 (11.5kg less)	28 (7kg less)	98.5 (63.5kg more)	2500	Basal – 27:28:16 45 DAP – 34.5: 0: 82.5	Second application is delayed by two weeks

4.11. Simulating yield responses under different fertilizer management practices using CERES rice model.

Yield responses under different nitrogen management practices were simulated by CERES rice model by considering phosphorous and potassium were present in adequate amount.

4.11.1. Yield responses under increased nitrogen input simulated using CERES rice model

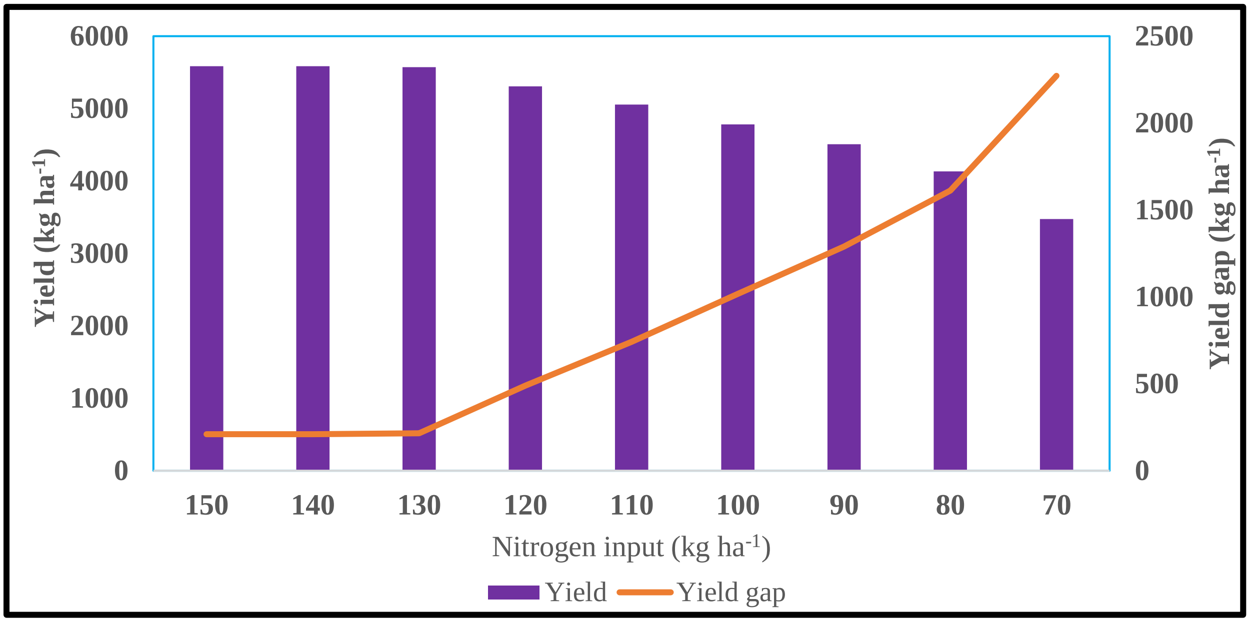
Basic doses of nitrogen as recommended by KAU is 90 kg ha^{-1} for Jaya and 70 kg ha^{-1} for Jyothi. The yield response of both the varieties under higher nitrogen application rate was simulated using model. The model output suggested that with an additional increase in nitrogen, yield was found to be increased and it reached a plateau after 140 kg ha^{-1} nitrogen in both Jaya and Jyothi. Yield obtained under 140 kg ha^{-1} nitrogen was 5587 kg ha^{-1} and 5425 kg ha^{-1} for Jaya and Jyothi and corresponding yield gap calculated was 210 kg ha^{-1} and 262 kg ha^{-1} for Jaya and . Jyothi respectively. Yield obtained under 130 kg ha^{-1} nitrogen was 5572 kg ha^{-1} for Jaya with a yield gap of 215 kg ha^{-1} and 5387 kg ha^{-1} for Jyothi with an yield gap of 300 kg ha^{-1}. The yield increment between 130 kg ha^{-1} and 140 kg ha^{-1} was negligible hence a nitrogen input of 130 kg ha^{-1} was considered as optimum amount. Yield was found to be increasing with increase in nitrogen input and corresponding yield gap was found to be decreasing. These results were described in Fig. 4.8. (a & b).

4.11.2. Yield responses under different split doses of nitrogen simulated using CERES rice model

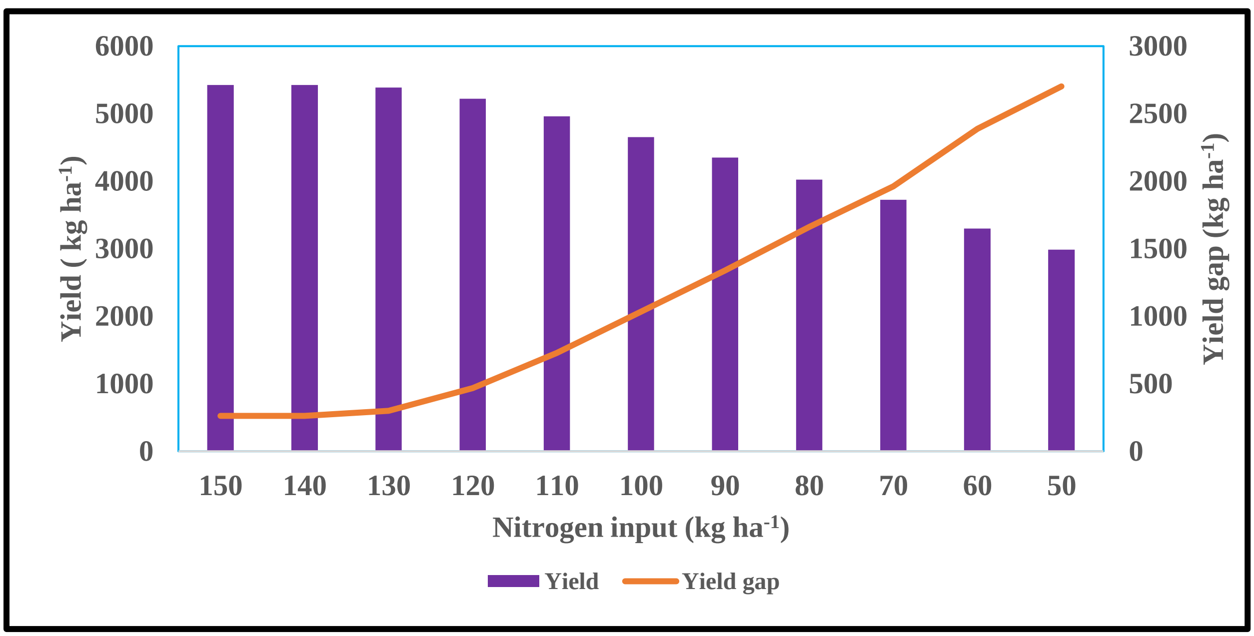
As per general recommendation of KAU Nitrogen is applied in two split doses. The yield responses under different split doses of nitrogen was simulated using the model. A comparison was made between 2 split nitrogen application and three split nitrogen application. For Jaya nitrogen recommendation was 90 kg ha^{-1} as per KAU. Yield of Jaya was simulated when 90 kg ha^{-1} was applied in two split doses (45 kg ha^{-1} during 15 days after planting and remaining 45 kg ha^{-1} after panicle initiation) and 3 split doses (45 kg ha^{-1} during 15 days after planting, 22.5 kg ha^{-1} during active tillering and 22.5 kg ha^{-1} after panicle initiation). For Jyothi nitrogen recommendation was 70 kg ha^{-1} as per KAU. Yield of Jyothi was simulated when 70 kg ha^{-1} was applied in two split doses (35 kg ha^{-1} during 15 days after planting and remaining 35 kg ha^{-1} after panicle initiation) and 3 split doses (35 kg ha^{-1} during 15 days after planting, 17.5 kg ha^{-1} during active tillering and 17.5 kg ha^{-1} after panicle initiation). The yield responses under two conditions as simulated by the model was presented in Table 4.38. Simulated yield was higher under three split doses of nitrogen application compared to two split doses in Jaya during all the five dates of planting. In case of Jyothi yield simulated was more under 3 split doses of nitrogen application during first three dates of planting and it was higher under 2 split doses during last two dates of planting. The yield increment under three split doses of nitrogen was more in Jaya compared to Jyothi.

4.11.3 Yield responses under different application methods

Yield responses under different nitrogen application methods and nitrogen levels were simulated using the model. Results obtained were represented by Table 4.39 (a & b). Simulated yield was found to be different under different application methods even though the amount of fertilizer applied was same. Normally followed fertilizer application method was broadcasting. Simulated yield for Jaya when the general recommended dose *i. e* 90 kg ha^{-1} nitrogen was applied in three split doses through broad casting was 4507 kg ha^{-1} and corresponding total yield gap (potential yield – actual yield) was 1290 kg ha^{-1}. Yield simulated for Jyothi when the general recommended dose *i.e* 70 kg ha^{-1} was applied in three split doses through broadcasting was 3726 kg ha^{-1} in case of Jyothi and corresponding yield gap was 1961 kg ha^{-1} respectively when the application method adopted was broadcasting. Yield was simulated under the higher doses of nitrogen application through broadcasting was found to be increasing and reached a plateau at 140 kg ha^{-1} in both the variety, even though 130 kg ha^{-1} was taken as the optimum input as mentioned earlier. Yield simulated under this condition was 5587 kg ha^{-1} for Jaya and corresponding yield gap



4.8. (a) Yield increase and yield gap reduction with increased N application in Jaya



4.8. (b) Yield increase and yield gap reduction with increased N application in Jyothi

Table 4.38. Yield responses under different split doses of nitrogen

Dates of planting	**Jaya**				**Jyothi**			
	2 split N input	**Yield kg ha^{-1}**	**3 split N input**	**Yield kg ha^{-1}**	**2 split N input**	**Yield kg ha^{-1}**	**3 split N input**	**Yield kg ha^{-1}**
June 5th	45: 45	3731	45:23:23	4578	47:23	3683	35:18:18	3731
June20th	45: 45	3726	45:23:23	4507	47:23	3655	35:18:18	3726
July 5th	45: 45	3688	45:23:23	4498	47:23	3603	35:18:18	3688
July 20th	45: 45	3040	45:23:23	3339	47:23	3669	35:18:18	3040
August 5th	45: 45	3068	45:23:23	4482	47:23	3700	35:18:18	3068

was 215 kg ha^{-1}. For Jyothi yield simulated under optimum nitrogen input was 5387 kg ha^{-1} and corresponding yield gap was 300 kg ha^{-1}.

When we followed general recommended dose of nitrogen (90 kg ha^{-1}) application along with irrigation water (fertigation) simulated yield was 4520 kg ha^{-1} and yield gap estimated was 1227 kg ha^{-1} in case of Jaya. In case of Jyothi simulated yield under general nitrogen recommendation (70 kg ha^{-1}) was 3729 kg ha^{-1} and yield gap calculated was 1958 kg ha^{-1}. Under this application method also yield was found to be increased at higher doses of nitrogen application and reaches a maximum value of 5391 kg ha^{-1} and corresponding yield gap was 296 kg ha^{-1}.

Third method used for comparison was application through urea super granules. Simulated yield under the general fertilizer recommendation was 4500 kg ha^{-1} and yield gap was 1247 kg ha^{-1} in case of Jaya and in case of Jyothi simulated yield was 3705 kg ha^{-1} and yield gap was 1982 kgha^{-1} when fertilizer application followed was through urea super granules. Maximum yield obtained under this method was 5574 kg ha^{-1} for Jaya and 5409 kg ha^{-1} for Jyothi and corresponding yield gap was 215 and 278 kg ha^{-1} respectively.

Comparison between these three application methods suggests that yield was higher when nitrogen was applied through irrigation under general nitrogen dose than other two method. Yield simulated under nitrogen application through urea super granules was less compared to other two methods. At optimum dose of nitrogen *i.e* 130 kg ha^{-1} yield simulated under all the three methods were same. Nitrogen use efficiency was found to be decreasing with an additional nitrogen input. The yield simulated was higher and yield gap was lower when the fertilizer application method followed was through fertigation in both Jaya and Jyothi.

Comparison of different fertilizer management practices suggested that there was a large scope in increasing yield by adopting better fertilizer management practices.

4.39. (a) Simulated attainable yield in response to given nitrogen dose and application method in Jaya

Total Nitrogen	**N application in split**			**Fertilizer application methods**								
				Broadcasting			**Through Irrigation**			**Urea supergranule**		
	1 st split	**2nd split**	**3rd split**	**Yield**	**NUE**	**Y_{gb}**	**Yield**	**NUE**	**Y_{gi}**	**Yield**	**NUE**	**Y_{gu}**
150	75	38	38	5587	37.2	210	5587	37.2	210	5588	37.3	210
140	70	35	35	5587	39.9	210	5587	39.9	210	5588	39.9	210
130	65	33	33	5572	42.9	215	5572	42.8	215	5574	42.9	215
120	60	30	30	5308	44.2	489	5308	44.2	489	5308	44.2	489
110	55	27.5	27.5	5055	46.0	742	5156	46.8	591	5198	47.3	549
100	50	25	25	4780	47.8	1017	4837	48.3	920	4775	47.8	972
90	45	23	23	4507	50.1	1290	4520	50.2	1227	4500	50.0	1297
80	40	20	20	4135	51.7	1612	4145	51.8	1602	4140	51.8	1607
70	35	18	18	3475	49.6	2272	3508	50.1	2239	3465	49.5	2332

Y_{gb} - Yield gap obtained when nitrogen is applied through broadcasting

Y_{gi} - Yield gap obtained when nitrogen is applied through irrigation

Y_{gu} - Yield gap obtained when nitrogen is applied through urea super granules

4.39. (b) Simulated attainable yield in response to given nitrogen dose and application method in Jyothi

Total Nitrigen	N application in split			Fertilizer application methods								
				Broadcasting			Through Irrigation			Urea super granule		
	1 st split	2nd split	3rd split	Yield	NUE	Y_{gb}	Yield	NUE	Y_{gi}	Yield	NUE	Y_{gu}
150	75	38	38	5425	36.2	262	5425	36.2	262	5425	36.2	262
140	70	35	35	5425	38.8	262	5425	38.8	262	5425	38.8	262
130	65	33	33	5387	41.4	300	5391	41.5	296	5409	41.6	278
120	60	30	30	5220	43.5	467	5264	43.9	423	5179	43.2	508
110	55	28	28	4960	45.1	727	4932	44.8	755	4966	45.1	721
100	50	25	25	4654	46.5	1033	4684	46.8	1003	4657	46.6	1030
90	45	23	23	4349	48.3	1338	4356	48.4	1331	4427	49.2	1260
80	40	20	20	4025	50.3	1662	4049	50.6	1638	4008	50.1	1679
70	35	18	18	3726	53.2	1961	3729	53.3	1958	3705	52.9	1982
60	30	15	15	3298	55.0	2389	3321	55.4	2366	3007	50.1	2680
50	25	13	13	2985	59.7	2702	2988	59.8	2699	2945	58.9	2742

Y_{gb} - Yield gap obtained when nitrogen is applied through broadcasting

Y_{gi} - Yield gap obtained when nitrogen is applied through irrigation

Y_{gu} - Yield gap obtained when nitrogen is applied through urea super granules

Discussion

5. DISCUSSION

The research work was accomplished with a perspective to analyze potential yield and yield gap in two rice varieties and to suggest better crop management tactics to diminish the yield gap. The outcomes of the study are discussed underneath.

5.1 Weather experienced during the experimental period

Weather conditions experienced during the crop period was recorded on daily basis. Average value of weather parameters like maximum temperature, minimum temperature, rainfall, afternoon relative humidity, forenoon relative humidity, wind speed, bright sunshine hours and rainy days were calculated for each phenophases and represented in Table 5.1 to 5.16.

Maximum temperature experienced was higher during 50% flowering to physiological maturity period of July 20th planting in both Jaya and Jyothi with the values of 32.4°C and 32.9°C respectively. A minimum value of maximum temperature was recorded during heading to 50% flowering period of June 5th planting in both the variety. The minimum value of maximum temperature was 26.9°C for Jaya and 29.1°C for Jyothi.

Maximum value of minimum temperature was observed during transplanting to active tillering stage of June 5th planting in Jaya with a value of 23.6°C whereas in case of Jyothi this maximum value (24.3°C) was observed during active tillering to panicle initiation stage. Lowest value of minimum temperature (20.9°C) was observed during heading to 50% flowering stage of June 5th planting and 50% flowering to physiological maturity stage of August 5th planting in Jaya. In Jyothi the lowest value of minimum temperature was 20.9°C and it was observed during 50% flowering to physiological maturity period of August 5th planting.

The highest amount of rainfall recorded for Jaya was 1040 mm during transplanting to active tillering and it was 1209.2 mm for Jyothi during 50% flowering to physiological maturity stage in both variety.

Table 5.1. Maximum temperature (°C) experienced by Jaya during crop period

Date of planting	P1	P2	P3	P4	P5	P6
June 5th	31.9	30.9	29.9	30.1	26.9	30.4
June 20th	31.2	28.8	29.5	29.9	30.6	31.2
July 5th	30.3	28.3	29.7	30.0	30.8	32.3
July 20th	29.3	29.7	30.5	31.9	31.4	32.4
August 5th	29.2	30.8	32.3	33.2	33.2	32.3

Table 5.2. Maximum temperature (°C) experienced by Jyothi during crop period

Date of planting	P1	P2	P3	P4	P5	P6
June 5th	31.9	31.3	30.1	31.5	29.1	29.5
June 20th	31.3	29.7	29.3	30.6	29.6	30.9
July 5th	30.2	30.4	29.2	29.7	30.8	32.6
July 20th	29.3	30.0	30.0	31.9	31.4	32.9
August 5th	29.2	29.8	31.3	33.4	33.7	32.2

Table 5.3. Minimum temperature (°C) experienced by Jaya during crop period

Date of planting	P1	P2	P3	P4	P5	P6
June 5th	23.6	22.6	22.4	22.8	20.9	21.9
June 20th	23.3	22.0	22.4	22.2	22.6	21.8
July 5th	22.6	21.7	21.7	21.5	21.9	21.9
July 20th	22.2	21.5	21.9	22.6	21.9	21.5
August 5th	21.7	22.0	21.9	22.4	21.9	20.9

Table 5.4. Minimum temperature (°C) experienced by Jyothi during crop period

Date of planting	P1	P2	P3	P4	P5	P6
June 5th	23.3	24.3	22.3	23.6	23.4	21.6
June 20th	23.4	22.2	22.2	22.7	21.3	21.8
July 5th	22.4	23.2	21.5	21.5	21.7	22.0
July 20th	22.1	22.0	21.5	22.9	21.9	21.8
August 5th	21.6	21.6	22.0	21.8	22.6	20.9

Table 5.5. Rainfall (mm) experienced by Jaya during crop period

Date of planting	P1	P2	P3	P4	P5	P6
June 5th	328.6	199.0	450.7	351.0	229.4	769.3
June 20th	384.8	362.9	593.6	172.3	20.1	639.9
July 5th	613.3	577.2	442.4	169.3	37.6	459.6
July 20th	1015.0	203.8	367.8	9.0	44.4	436.9
August 5th	1040.2	282.1	78.5	1.3	80.7	519.0

Table 5.6. Rainfall (mm) experienced by Jyothi during crop period

Date of planting	P1	P2	P3	P4	P5	P6
June 5th	323.7	115.9	536.9	5.0	69.1	1209.2
June 20th	454.1	356.2	810.5	5.2	88.7	566.2
July 5th	610.1	124.0	871.3	196.8	99.7	327.0
July 20th	1010.3	93.6	478.2	13.5	44.4	297.7
August 5th	971.5	279.5	174.0	4.1	2.7	462.9

Table 5.7. Rainy days experienced by Jaya during crop period

Date of planting	P1	P2	P3	P4	P5	P6
June 5th	16.0	7.0	13.0	6.0	4.0	30.0
June 20th	19.0	8.0	13.0	4.0	1.0	30.0
July 5th	20.0	9.0	16.0	4.0	2.0	21.0
July 20th	21.0	9.0	13.0	1.0	4.0	19.0
August 5th	26.0	10.0	7.0	1.0	2.0	17.0

Table 5.8. Rainy days experienced by Jyothi during crop period

Date of planting	P1	P2	P3	P4	P5	P6
June 5th	15.0	4.0	17.0	1.0	2.0	31.0
June 20th	17.0	7.0	17.0	1.0	4.0	26.0
July 5th	19.0	4.0	21.0	5.0	5.0	15.0
July 20th	20.0	5.0	18.0	1.0	4.0	11.0
August 5th	22.0	10.0	11.0	1.0	1.0	17.0

Table 5.9. Forenoon relative humidity (%) experienced by Jaya during crop period

Date of planting	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**
June 5th	93.7	94.7	95.7	95.8	97.8	96.1
June 20th	94.4	96.5	96.2	97.3	96.0	94.6
July 5th	95.2	97.2	96.0	96.8	96.3	93.2
July 20th	96.7	95.7	96.4	95.0	95.0	91.7
August 5th	96.5	96.6	93.3	89.0	92.0	90.3

Table 5.10. Forenoon relative humidity (%) experienced by Jyothi during crop period

Date of planting	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**
June 5th	93.6	95.9	95.0	94.2	98.5	96.6
June 20th	94.3	97.1	96.5	96.0	95.8	95.4
July 5th	95.3	95.0	96.4	97.0	97.0	92.6
July 20th	96.7	95.6	96.3	95.8	95.0	91.7
August 5th	96.6	96.0	95.5	91.0	90.8	92.0

Table 5.11. Afternoon relative humidity (%) experienced by Jaya during crop period

Date of planting	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**
June 5th	74.9	80.0	75.5	83.6	82.8	78.4
June 20th	74.9	81.6	79.9	75.5	75.0	75.5
July 5th	75.4	88.1	80.9	84.0	76.0	69.8
July 20th	80.2	81.9	80.2	65.5	72.6	68.4
August 5th	84.1	77.7	69.2	65.0	71.3	65.8

Table 5.12. Afternoon relative humidity (%) experienced by Jyothi during crop period

Date of planting	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**
June 5th	75.4	75.1	76.5	71.7	97.5	82.0
June 20th	74.9	80.5	79.6	75.0	80.0	76.9
July 5th	76.0	80.6	82.3	83.8	79.7	68.0
July 20th	80.6	77.1	83.6	67.8	72.6	68.2
August 5th	83.1	82.4	73.6	65.0	65.6	67.1

Table 5.13. Wind speed (km hr^{-1}) experienced by Jaya during crop period

Date of planting	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**
June 5th	1.8	1.9	1.6	2.2	1.3	1.3
June 20th	1.7	1.6	1.7	1.1	1.1	1.3
July 5th	1.6	2.0	1.2	1.6	1.9	1.3
July 20th	1.6	1.2	1.5	1.8	1.2	1.7
August 5th	1.4	1.5	1.3	1.0	0.9	2.1

Table 5.14. Wind speed (km hr^{-1}) experienced by Jyothi during crop period

Date of planting	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**
June 5th	1.7	2.3	1.5	2.1	2.4	1.4
June 20th	1.7	2.1	1.6	1.0	1.2	1.4
July 5th	1.6	2.0	1.3	1.5	1.6	1.3
July 20th	1.6	1.1	1.4	1.5	1.2	1.4
August 5th	1.4	1.4	1.4	1.3	1.0	1.8

Table 5.15. Bright sunshine hours (hrs) experienced by Jaya during crop period

Date of planting	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**
June 5th	3.6	2.4	2.6	2.3	0.2	2.1
June 20th	3.1	1.5	2.1	1.1	1.9	3.4
July 5th	2.7	0.5	1.3	0.4	3.0	5.2
July 20th	1.7	1.4	2.2	3.2	3.9	5.4
August 5th	1.0	2.5	5.1	6.8	5.7	5.9

Table 5.16. Bright sunshine hours (hrs) experienced by Jyothi during crop period

Date of planting	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**
June 5th	3.6	3.6	2.2	4.4	0.4	1.3
June 20th	2.9	2.7	1.8	1.9	1.1	2.9
July 5th	2.5	2.7	1.1	0.3	2.7	5.5
July 20th	1.8	1.1	1.5	4.2	3.9	6.2
August 5th	1.0	0.8	3.5	6.8	7.8	5.6

For Jaya, rainy days experienced was lowest during heading to 50% flowering of June 20th planting and booting to heading stage of July 20th and August 5th planting and a highest value was recorded during 50% flowering to grain filling stage of June 5th and June 20th planting. For Jyothi, a minimum number of rainy days was recorded during booting to heading stage of June 5th, June 20th, July 20th and August 5th planting and a higher number of rainy days was recorded during 50% flowering to grain filling stage of June 5th planting.

In Jyothi forenoon relative humidity ranged from 90.8% to 98.5%. The lowest and highest values were recorded during heading to 50% flowering stages of August 5th and June 5th planting respectively. The afternoon relative humidity experienced by Jaya ranged between 60.0% - 88.1%. The lowest and highest values were experienced during heading to booting stage of August 5th planting and active tillering to panicle initiation stage of July 5th planting respectively. For Jyothi a lowest value of 65.0% was experienced during booting to heading stage of August 5th planting and highest value of 83.8% was experienced during the same stage of July 5th planting.

Wind speed experienced during the crop period ranged between 0.9 km hr^{-1} to 2.2 km hr^{-1} for Jaya and 1.0 km hr^{-1} to 2.4 km hr^{-1} for Jyothi. For Jaya lowest wind speed was recorded during heading to 50% flowering stage of August 5th planting and highest value was recorded during booting to heading stage of June 5th planting. For Jyothi lowest wind speed was recorded during heading to 50% flowering of August 5th planting and booting to heading stage of June 20th planting. Maximum wind speed was recorded during heading to 50% flowering of June 5th planting.

Lowest amount of sunshine hours recorded was 0.2 hrs during heading to 50% flowering stage of June 5th planting. Highest amount (6.8 hrs) was recorded during booting to heading stage of August 5th planting for the variety Jaya. In case of Jyothi a lowest amount of sunshine hours was received during booting to heading stage of July 5th planting and a highest value was recorded during heading to 50% flowering stage of August 5th planting.

5.2 Effect of weather on growth and development of rice varieties

5.2.1 Plant height

A significant variation in plant height was observed among five different dates of planting at weekly interval. Plant height was more during July 5th dates of planting compared to other dates of planting. Plant height recorded during June 5th planting was found to be lower than other planting. Increased maximum temperature during vegetative stage of first dates of planting may have caused the reduction in plant height (Fig. 5.1). This was in agreement with the results of Vysakh *et al.* (2015) who suggested that increase in maximum temperature may reduce plant height . Plant height recorded in Jyothi was higher compared to Jaya. This was in agreement with the results of Haritharaj *et al.* (2019). She recorded a maximum height in Jyothi compared to Jaya.

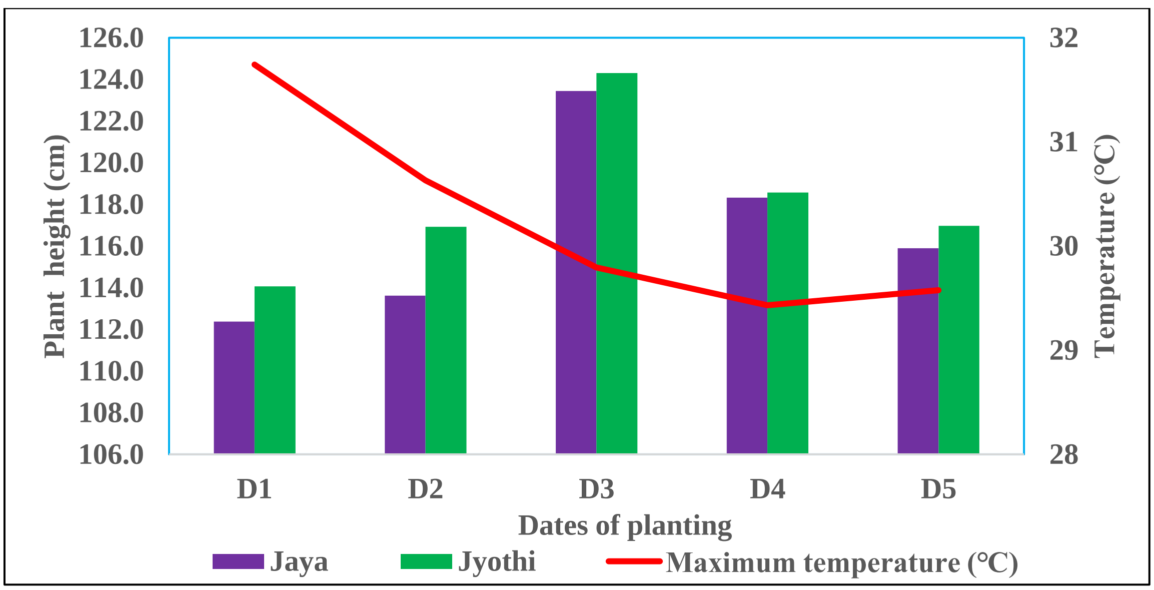


Fig. 5.1. Influence of maximum temperature on plant height

5.2.2 Dry matter accumulation

In both the varieties Jaya and Jyothi, dry matter accumulation was maximum during August 5th planting. Lower value of dry matter accumulation was reported during July 5th planting. In both the varieties maximum dry matter accumulation was reported at 75 days after planting. Maximum temperature experienced during vegetative period showed negative influence in dry matter production, while rainfall experienced during vegetative period showed a positive influence in dry matter production in Jaya. Afternoon relative humidity showed a positive influence with dry matter production in both Jaya and Jyothi (Table 5.17). This was in agreement with the study conducted by Haritharaj *et al.* (2019), Ravindran *et al.* (2018) and Singh *et al.* (2012).

They observed a positive influence of rainfall and relative humidity and a negative influence of maximum temperature on dry matter accumulation. August 5th planting experienced a higher rainfall and after noon relative humidity during transplanting to panicle initiation stage. Maximum temperature experienced during August 5th planting was less compared to early planting. These two factors may have led to the maximum dry matter production in August 5th planting (Fig. 5. 2).

Table 5.17. Correlation coefficients between weather parameters and dry matter accumulation

Variety	Tmax	Tmin	RHI	RHII	Rainfall
Jaya	-0.235	-0.447	0.460*	0.591**	0.557*
Jyothi	-0.132	-0.380	0.384	0.512*	0.163

5.3. Effect of weather on yield and yield attributes

Effect of dates of planting on yield and yield attributes like number of tillers per m^2, number of spikelet per panicle, number of filled grains per panicle and thousand grain weight was found to be significant (Fig. 5.3 to 5.7). Interaction effect of dates of planting and variety was also found to be significant. The pair wise comparisons were done and plotted using R- software (Fig 5.8.a. to 5.12. b.).

5.3.1 Number of tillers per m^2

A significant effect of dates of planting was seen on number of tillers per m^2. Maximum number of tillers was seen during August 5th planting and June 5th planting. Weather parameters and number of tillers were not found to be correlated. Similar results

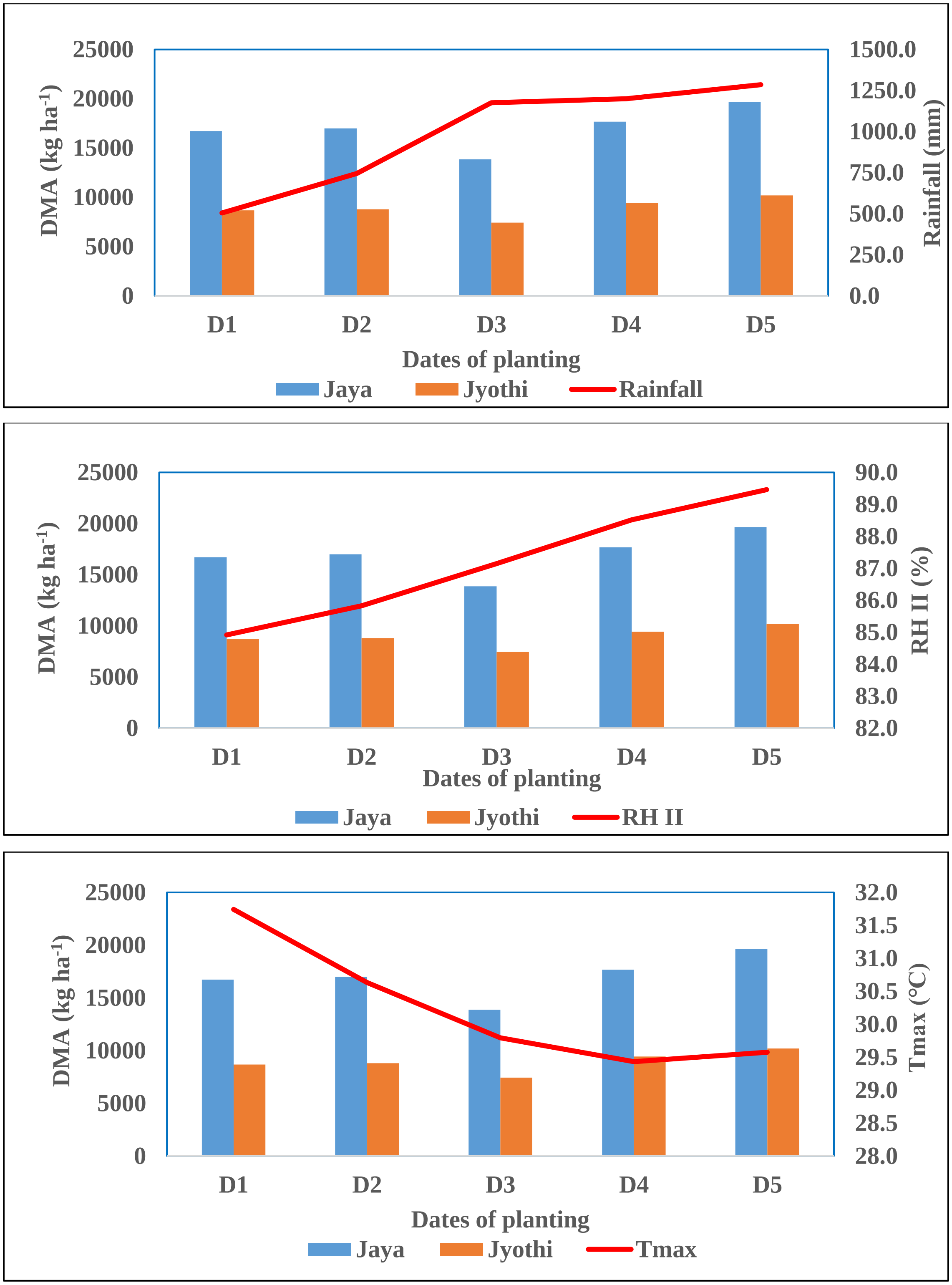


Fig. 5.2. Influence of weather parameters in dry matter accumulation

DMA – Dry matter accumulation

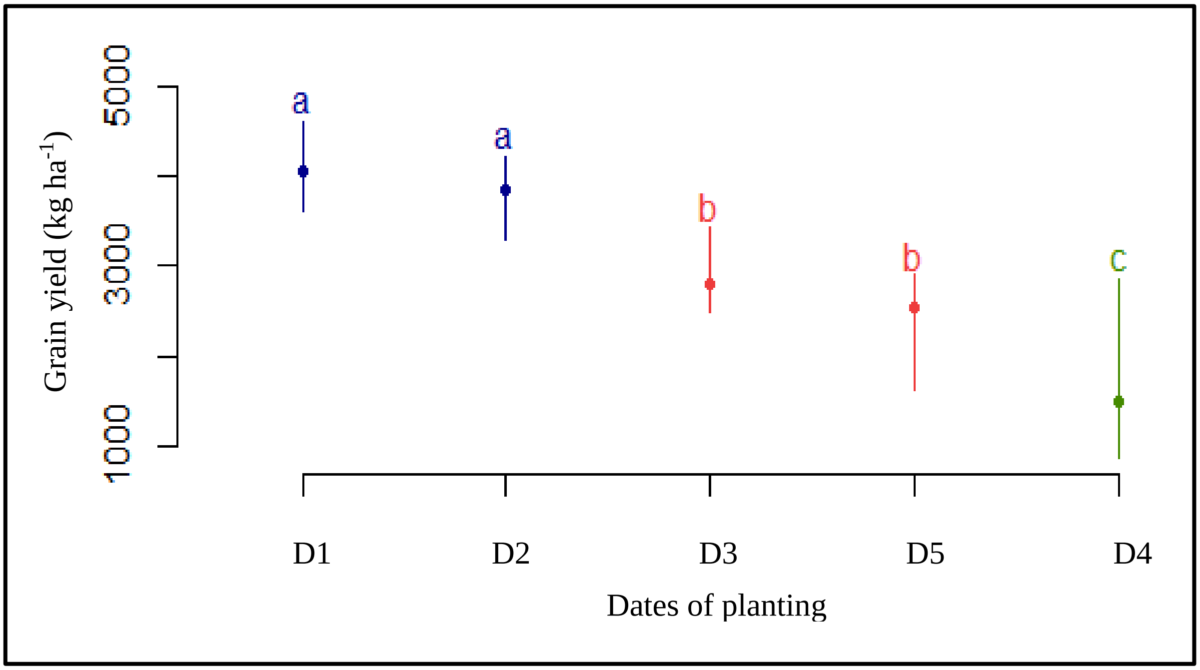


Fig . 5.3. Effect of dates of planting on grain yield

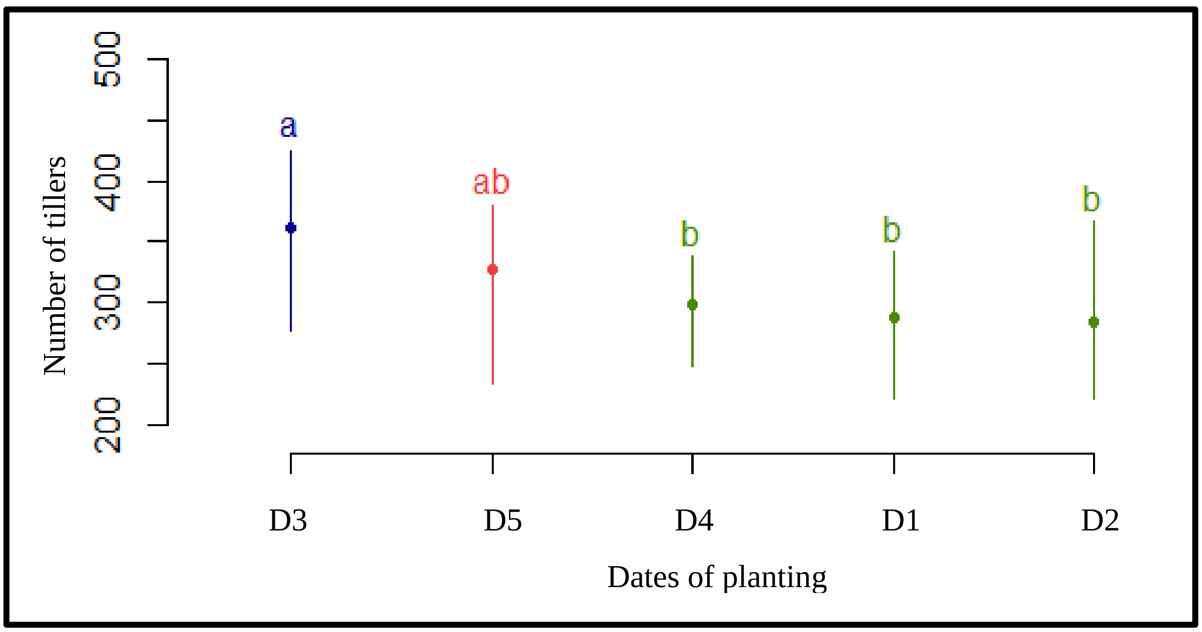


Fig. 5.4. Effect of dates of planting on number of tillers

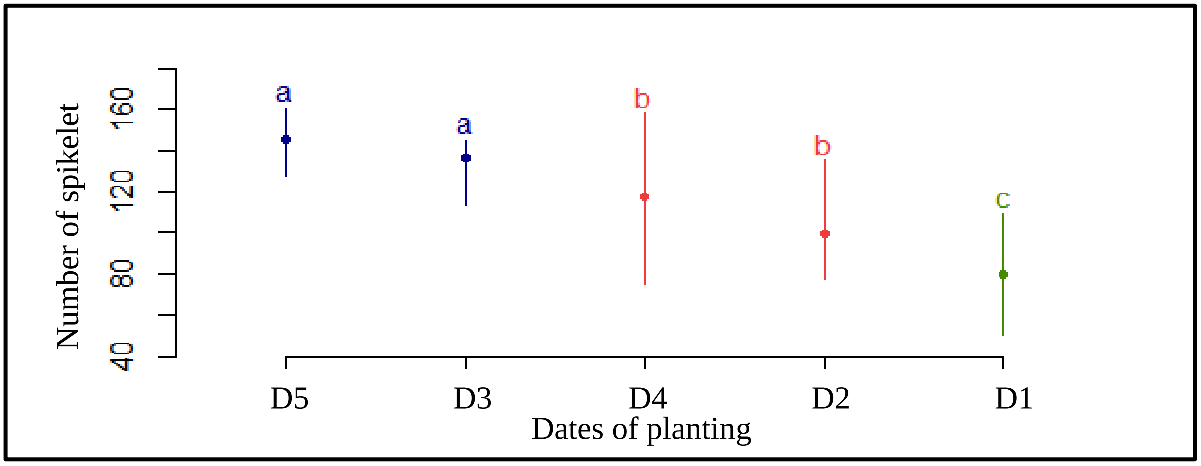


Fig. 5.5. Effect of dates of planting on number of spikelet

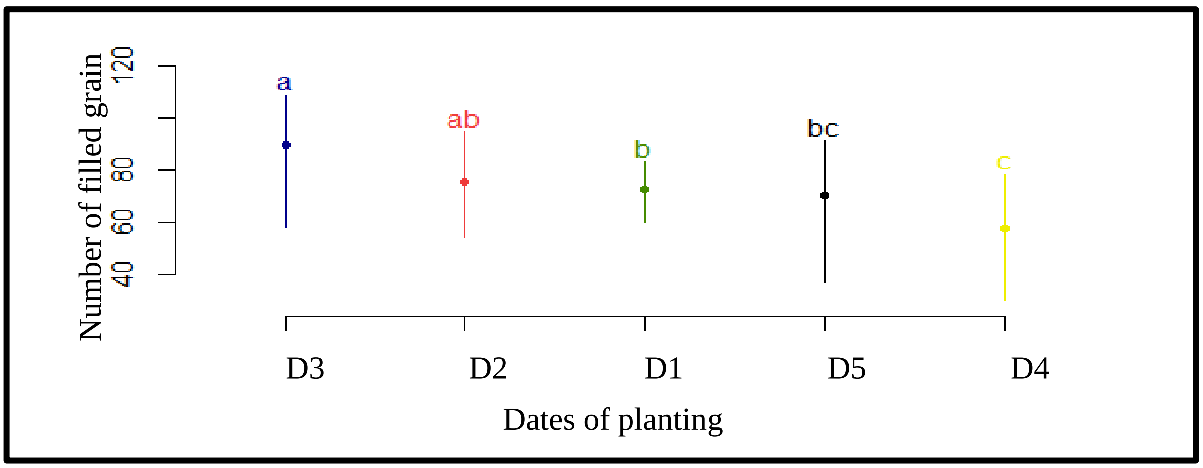


Fig. 5.6. Effect of dates of planting on number of filled grain

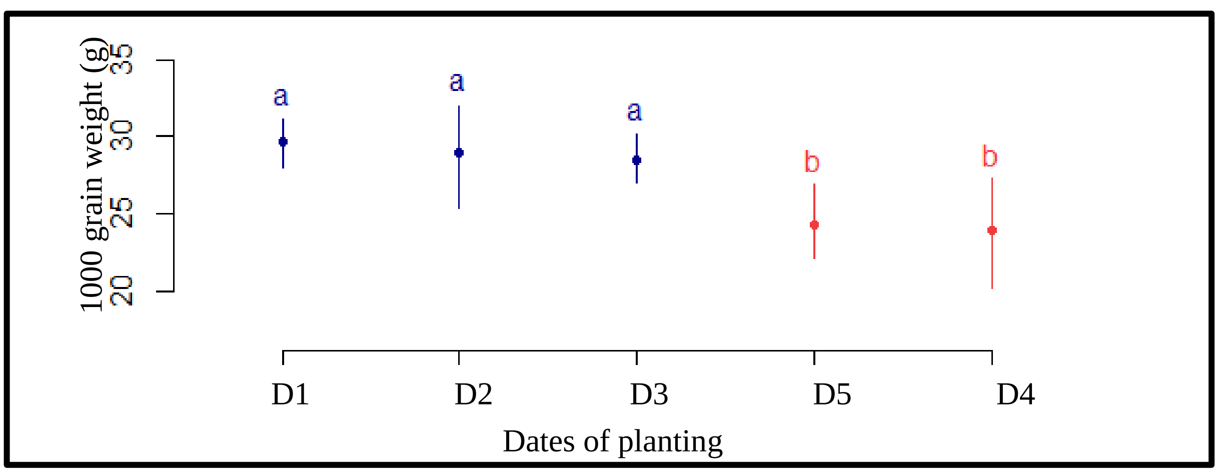


Fig. 5.7. Effect of dates of planting on 1000 grain weight

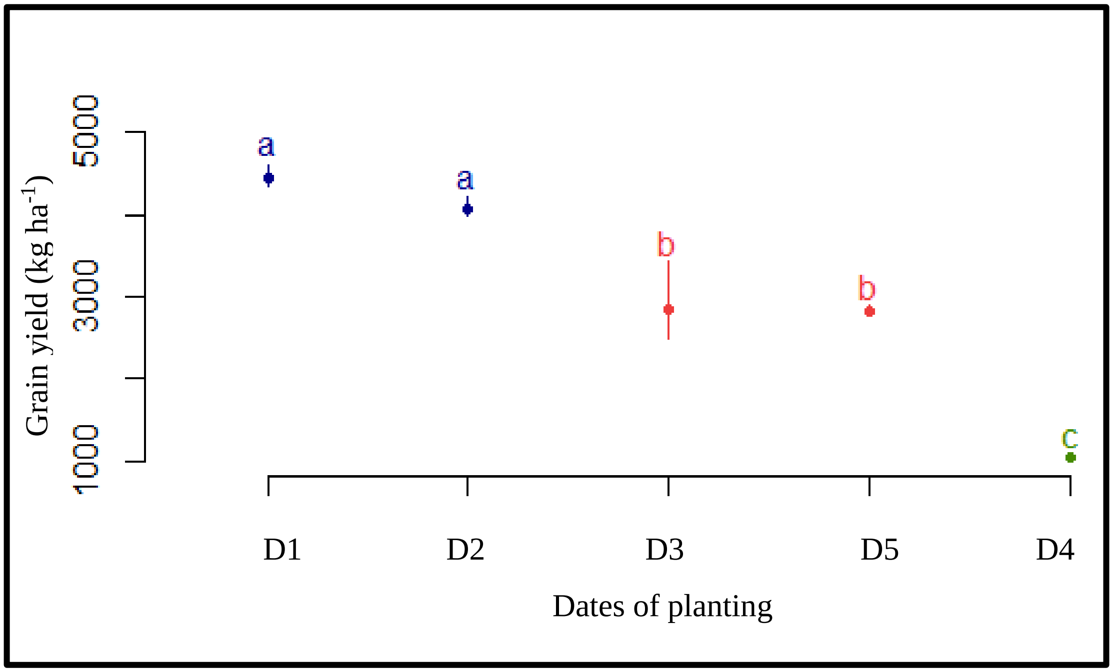


Fig. 5.8. a. Interaction effect of dates of planting and variety on grain yield (Jaya)

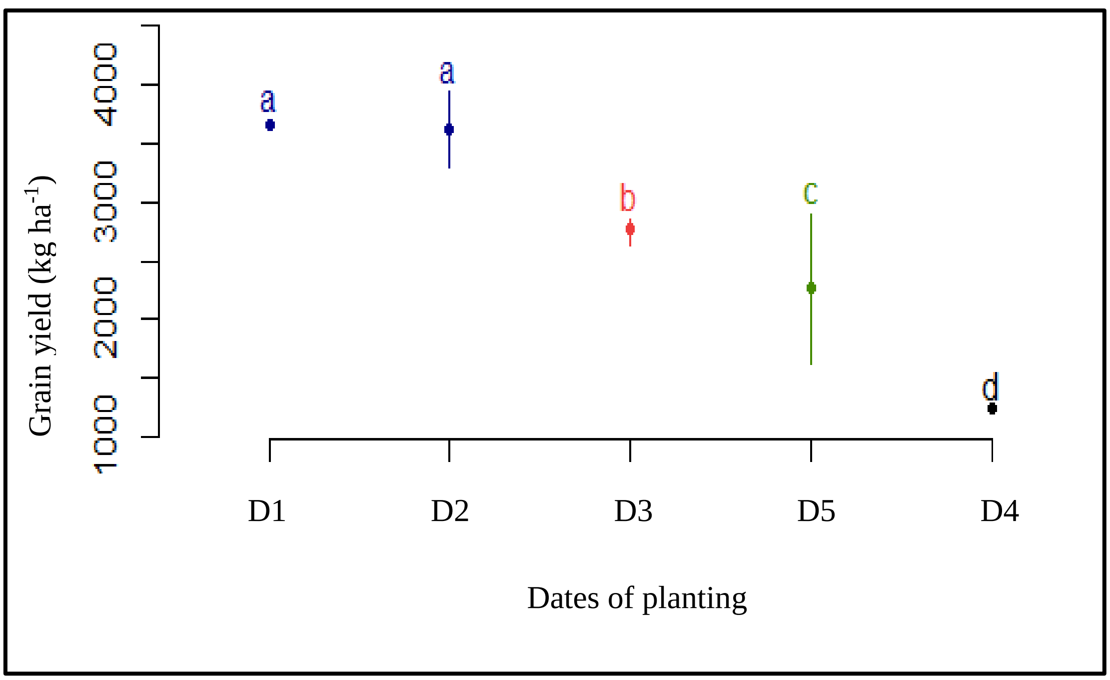


Fig. 5.8. b. Interaction effect of dates of planting and variety on grain yield (Jyothi)

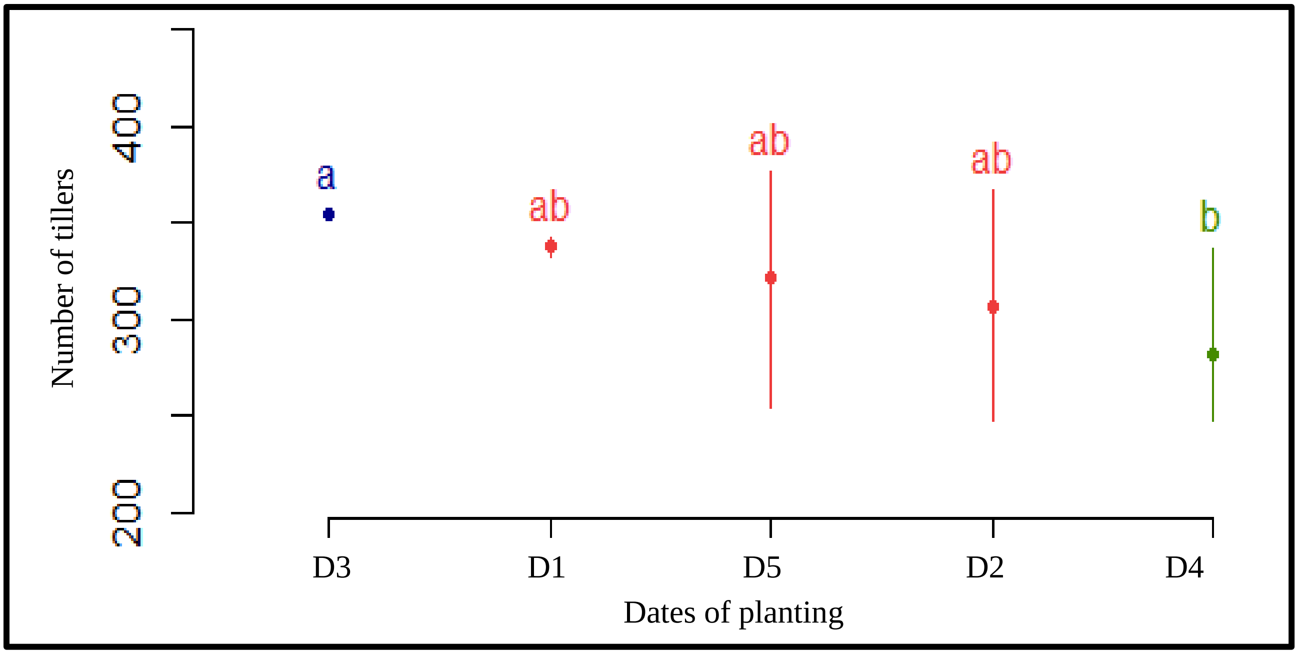


Fig. 5.9. a. Effect of dates of planting and variety on number of tillers (Jaya)

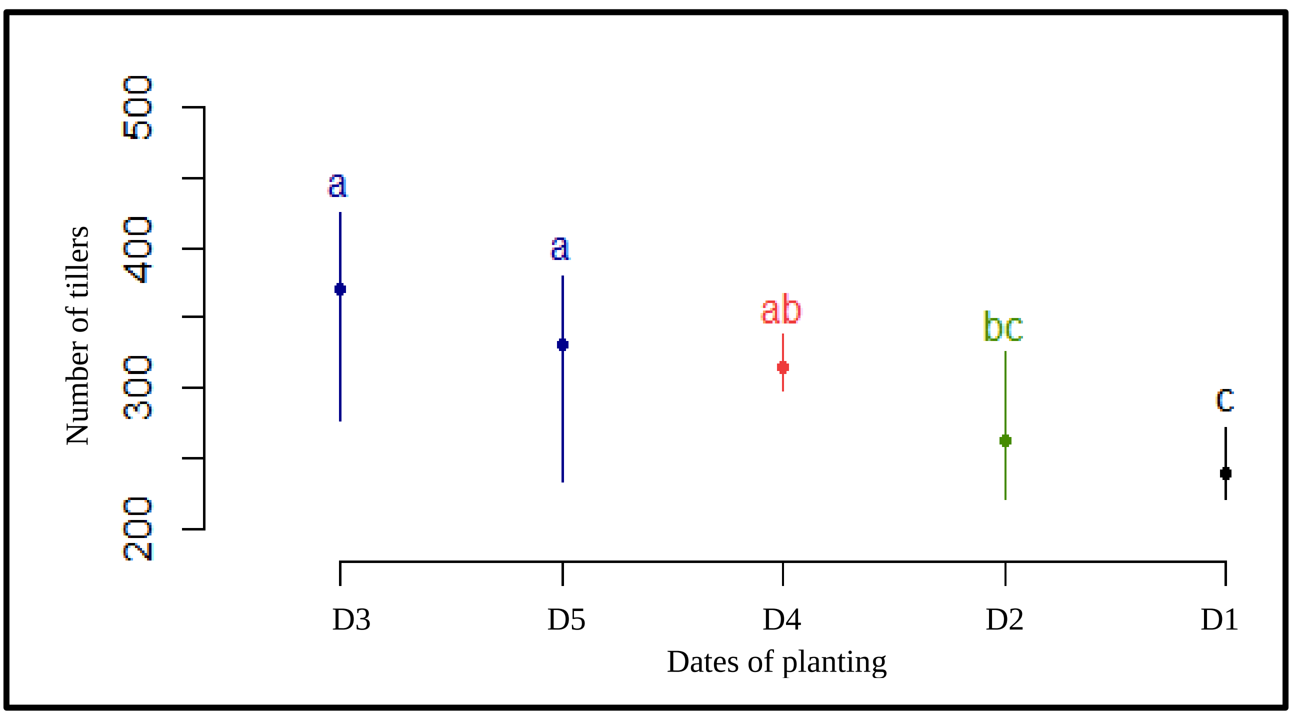


Fig. 5.9. b. Effect of dates of planting and variety on number of tillers (Jyothi)

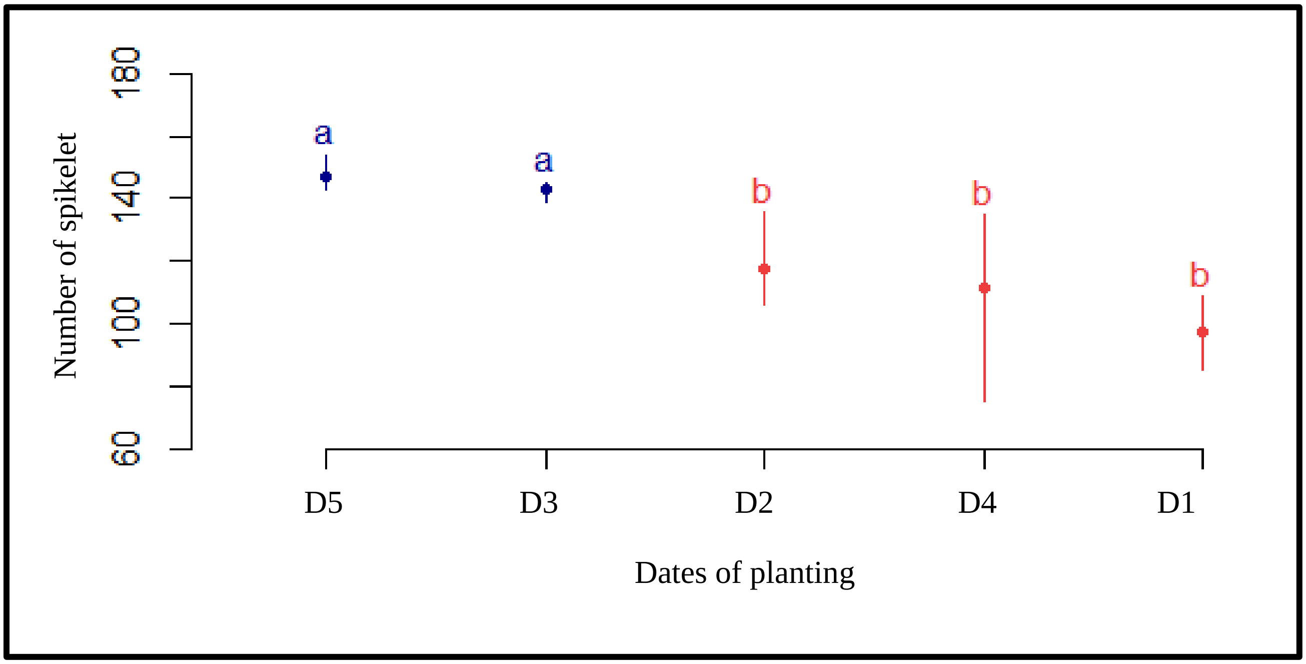


Fig. 5.10. a. Effect of dates of planting and variety on number of spikelet (Jaya)

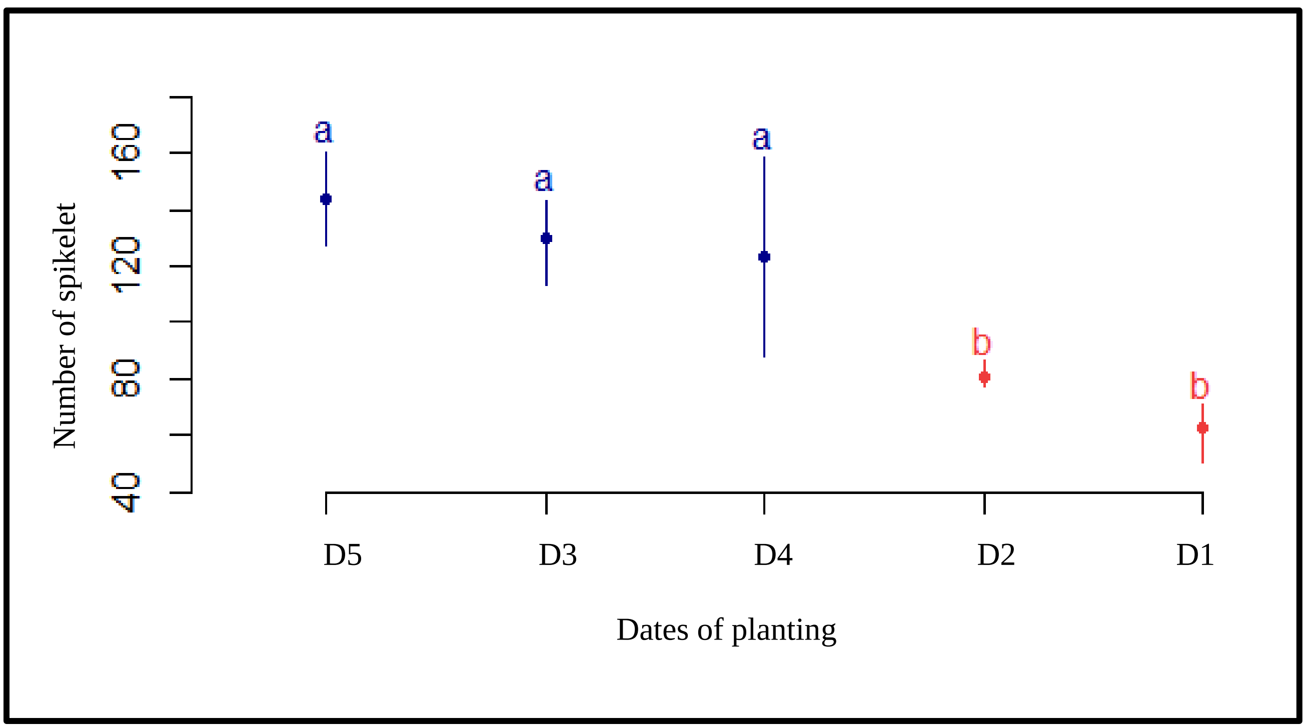


Fig. 5.10. b. Effect of dates of planting and variety on number of spikelet (Jyothi)

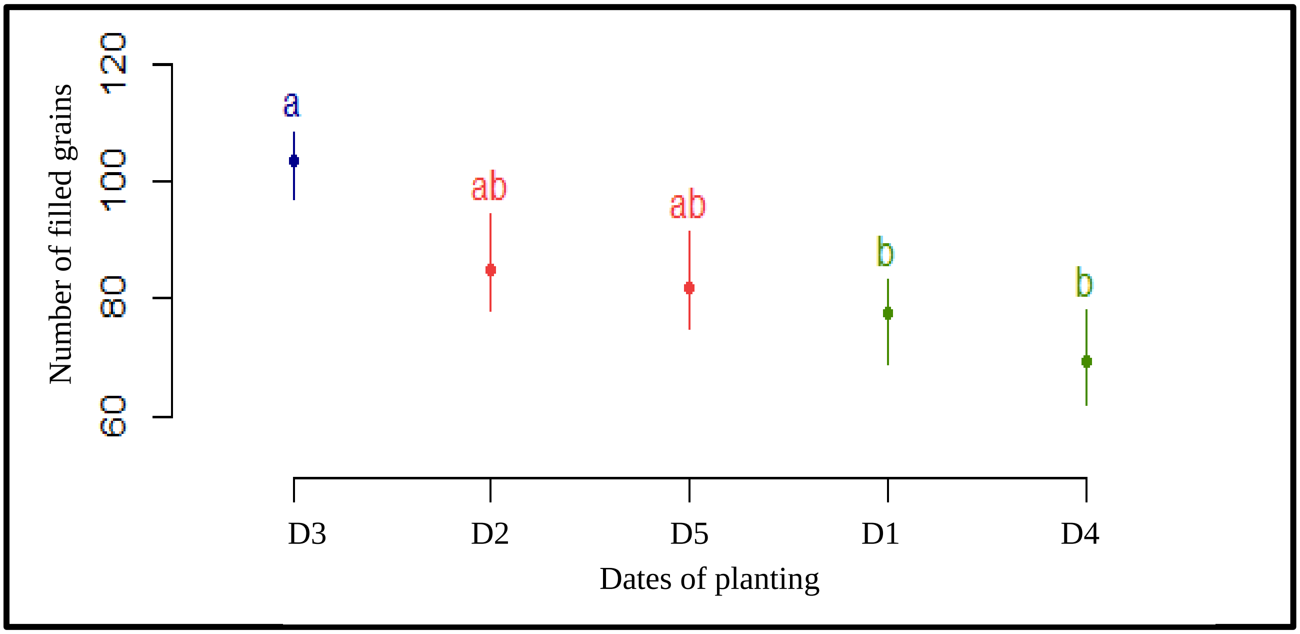


Fig. 5.11. a. Effect of dates of planting and variety on number of filled grain (Jaya)

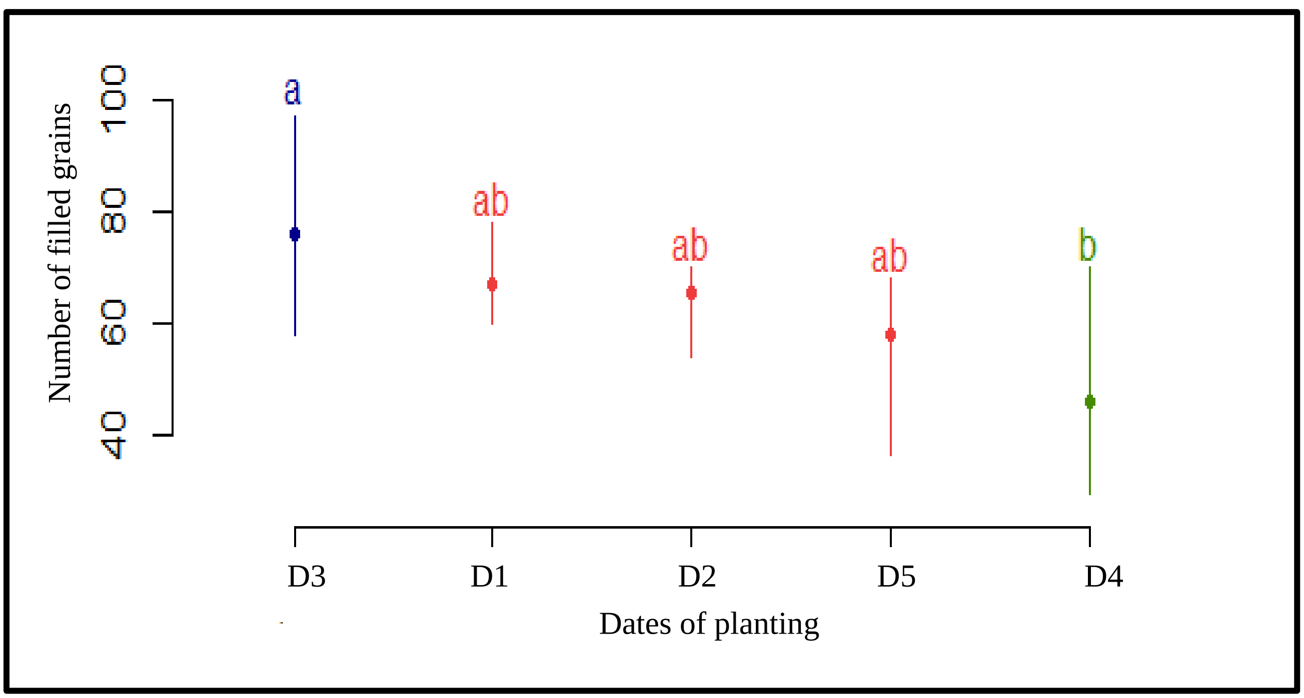


Fig. 5.11. b. Effect of dates of planting and variety on number of filled grain (Jyothi)

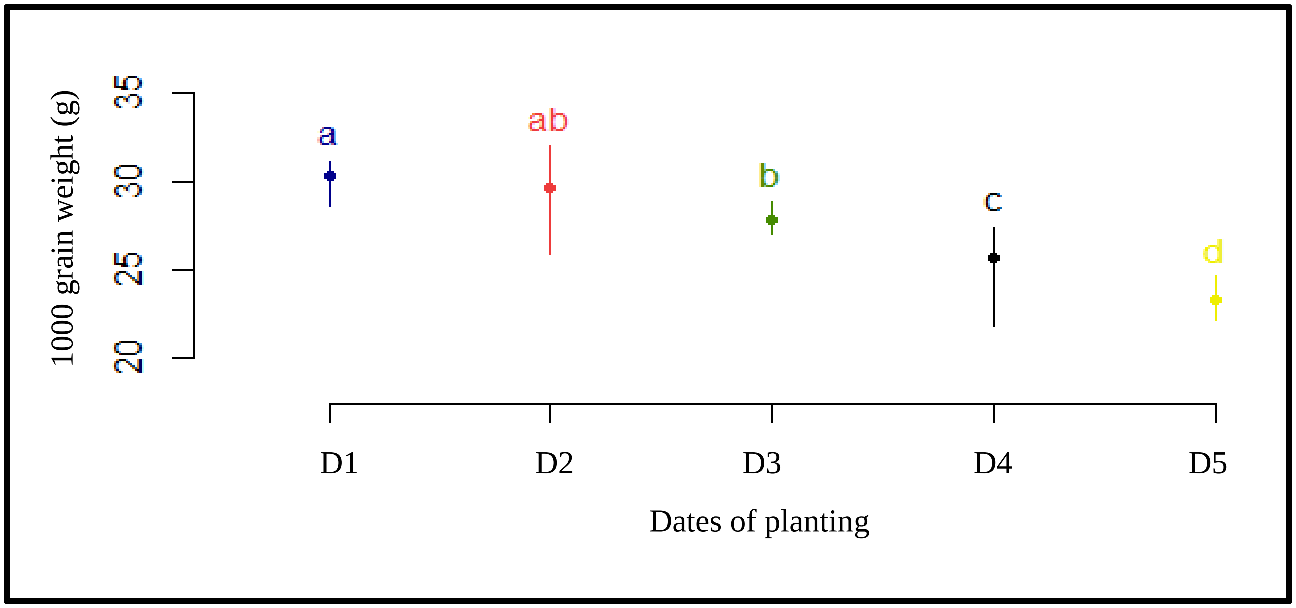


Fig. 5.12. a. Effect of dates of planting and variety on 1000 grain weight (Jaya)

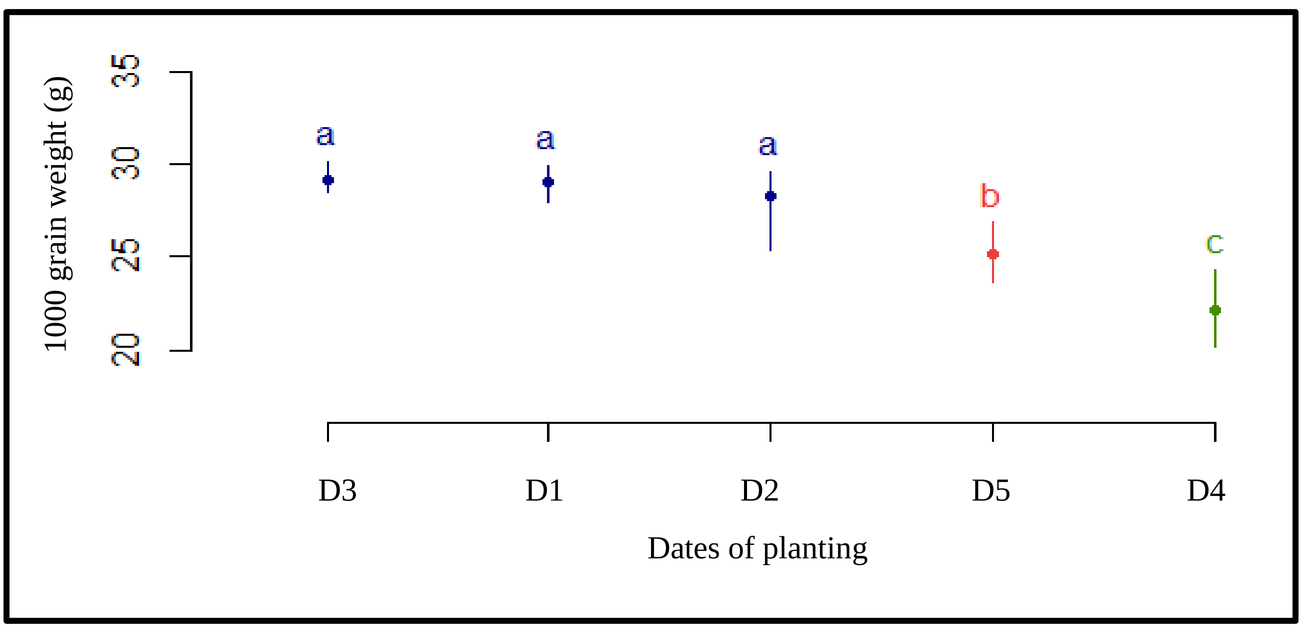


Fig. 5.12. b. Effect of dates of planting and variety on 1000 grain weight (Jyothi)

were noticed by Haritharaj *et al.* (2019) who found no correlation between number of tillers and weather variable.

5.3.2 Number of spikelet per panicle

Number of spikelet per panicle varied significantly between different dates of planting. A maximum spikelet number was experienced during 5th August planting and 5th July planting. Maximum number of spikelet recorded during August 5th planting was due to higher amount of bright sunshine received (Fig. 5.13) and a minimum number of spikelet recorded during June 5th planting was due to higher mean temperature (Fig 5.14). Similar result was suggested by Yoshida and Paravo (1976). They suggested that a high solar radiation combined with relatively low temperature produced more spikelet.

5.3.3 Number of filled grains per panicle

A significant influence of planting dates was observed on number of filled grains. A highest value of number of filled grain was observed during July 5th planting. Temperature experienced during flowering stage was found to be influential for number of filled grains. Higher value of maximum (Fig. 5.15) and minimum temperature (Fig. 5.16) experienced during heading to flowering was responsible for the reduction in number of filled grains per panicle during August 5th planting. This result was in agreement with Yoshida *et al.*. (1981) and Shimono and Ishii (2012) they observed a poor grain growth under higher temperatures during ripening stage of rice.

5.3.4 1000 grain weight

Thousand grain weight recorded was maximum during early sowing *i. e.* June 5th dates of planting and it was found to be decreasing with delayed dates of planting and a minimum value was recorded during July 20th planting. The higher value of 1000 grain weight was due to minimum temperature during grain filling stage (Fig 5. 17). Increase in 1000 grain weight attributed to minimum temperature was due to increased grain filling period and slow rate of translocation of photosynthates to grain. This result was agreement with the findings of Pazhanisamy *et al.* (2020). Thousand grain weight recorded in Jaya was higher than Jyothi which was in agreement with Haritharaj *et al.* (2019).

5.3.5 Grain yield

Grain yield was significantly affected by different dates of planting in both Jaya and Jyothi. Maximum grain yield was achieved during June 5th planting in case of both the varieties. High yield obtained under June 5th planting was due to low maximum temperature (Fig. 5.18) and high rainfall (Fig. 5.19) during the crop growth period which go in line with Wahid *et al.* (2007).

Rainfall experienced during panicle initiation to booting and 50% flowering to physiological maturity was found to be augmenting crop yield (Fig. 5.20 & 5.21). Yield was found to be increased with minimum temperature during panicle initiation to booting (Fig. 5.22) and it decreased with maximum temperature during 50% flowering to physiological maturity (Fig. 5.23).

Low amount of rainfall was received during panicle initiation to booting and 50% flowering to physiological maturity stage of July 5th and August 5th planting. So a water stress was experienced during critical stages and it might be the reason for the declined yield during July 20th and August 5th planting. Similar results were seen by Jha *et al.* (2020), who proposed that water stress during reproductive stage showed a 43% yield reduction. Among the yield attributes thousand grain weight and number of filled grains showed significant correlation with yield . The maximum yield obtained under June 5th planting was attributed to maximum thousand grain weight recorded. This results was in accordance with Liu *et al*. (2019). They suggested that greater values of number of tillers and 1000 grain weight have accounted for high yield.

Table 5.18. Correlation between yield attributes and yield

Yield attribute	1000 grain weight	Filled grains	Number of panicle	Straw yield	Number of spikelet	Number of tillers
Correlation coefficient	0.657**	0.345*	0.136	-0.005	-0.463	0.039

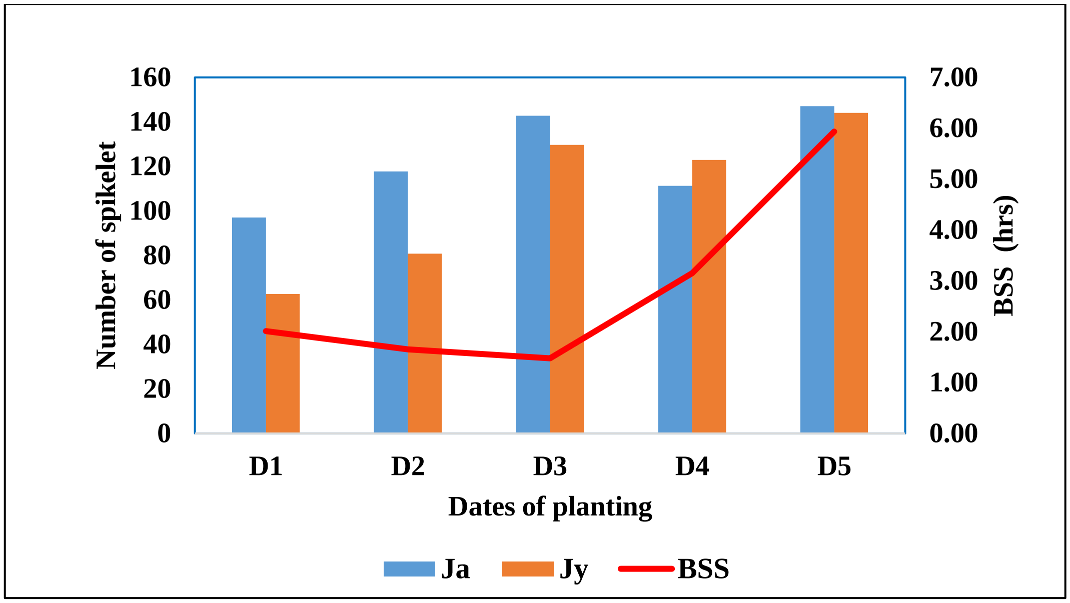


Fig 5.13. Influence of bright sunshine hours on number of spikelet

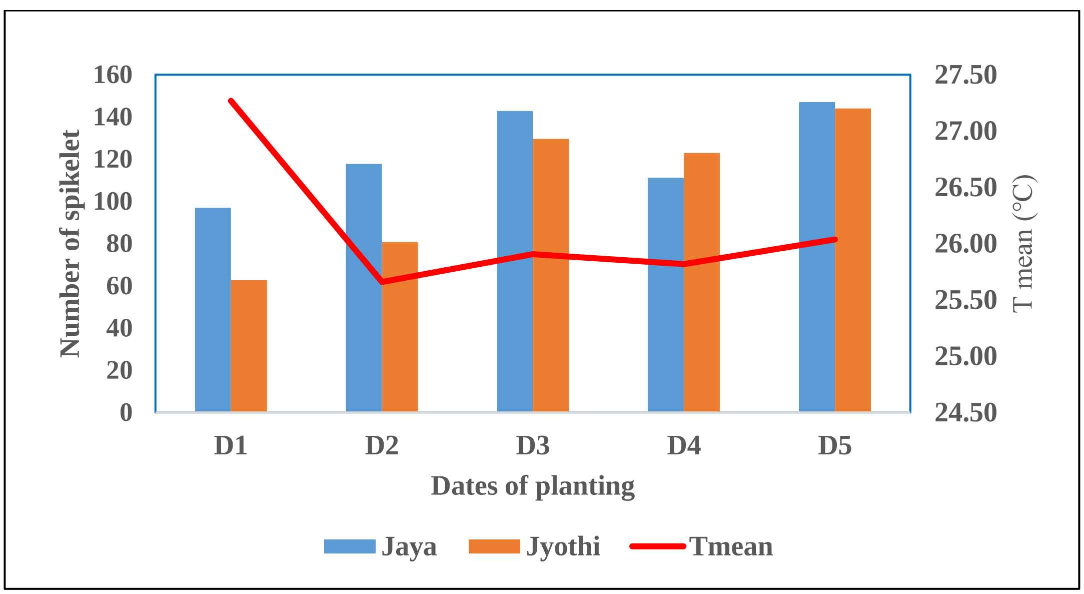


Fig 5.14. Influence of temperature on number of spikelet

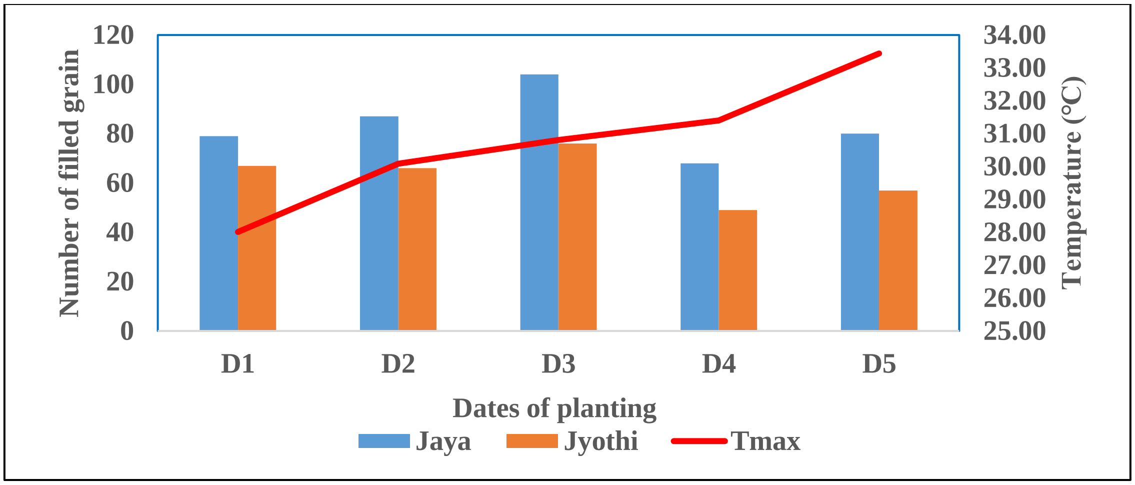


Fig: 5.15. Influence of maximum temperature on number of filled grains

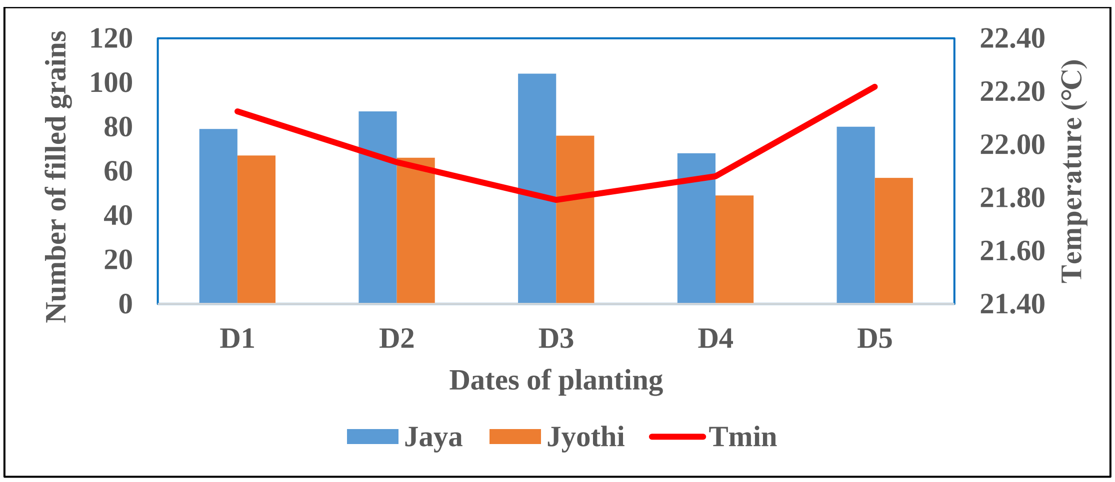


Fig: 5.16. Influence of minimum temperature on number of filled grains per panicle

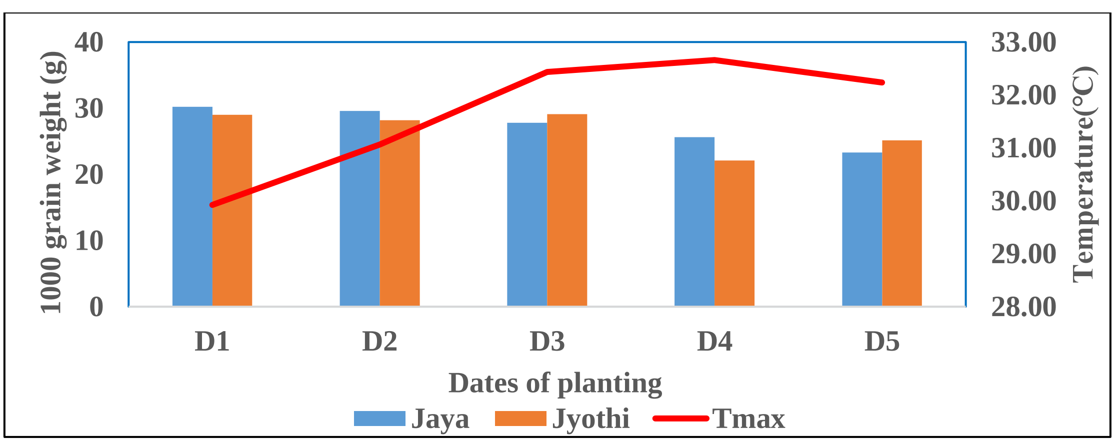


Fig. 5.17. Effect of maximum temperature on 1000 grain weight

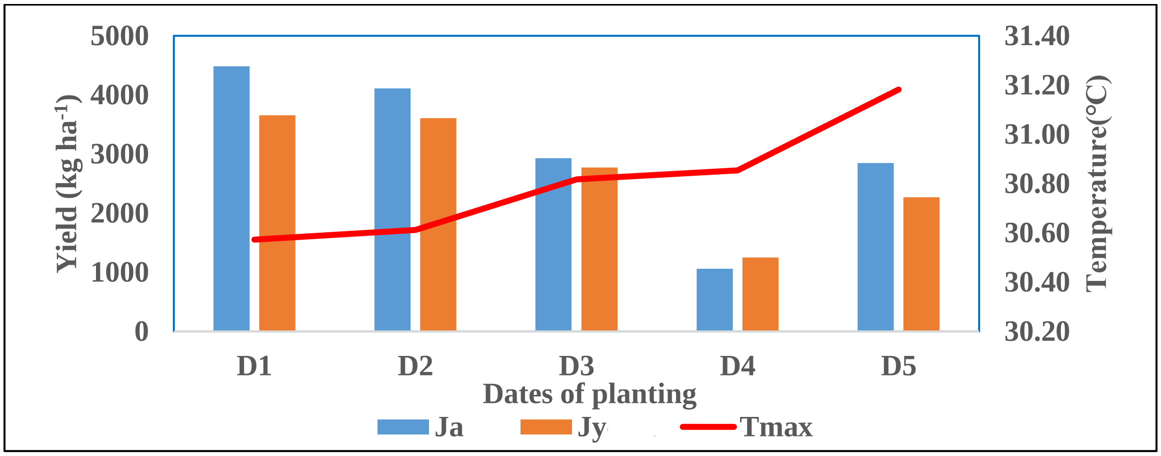


Fig 5.18. Influence of maximum temperature on grain yield

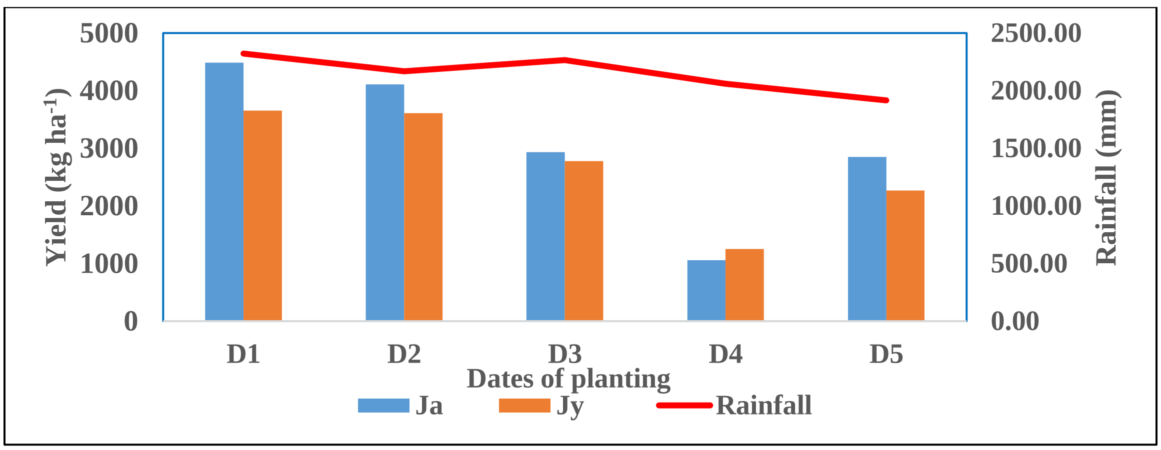


Fig 5.19. Influence of total rainfall received during crop period on grain yield

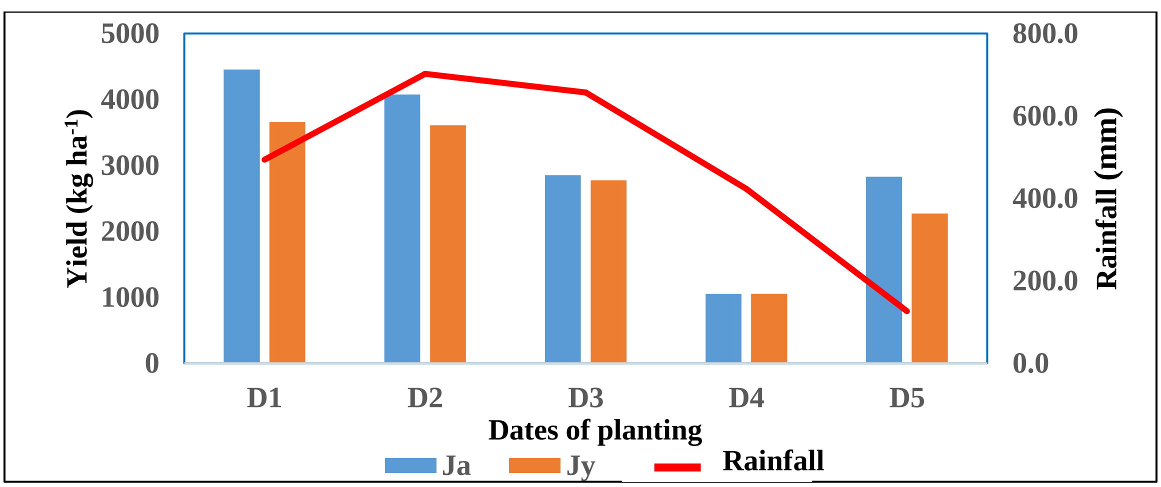


Fig : 5.20. Influence of rainfall received during panicle initiation to booting on grain yield

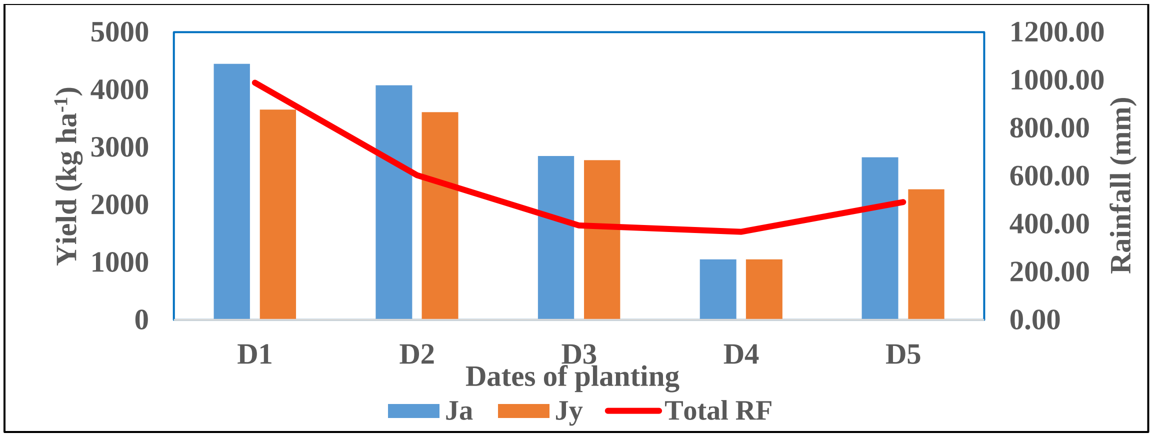


Fig 5.21. Influence of rainfall received during 50% flowering to maturity on grain yield

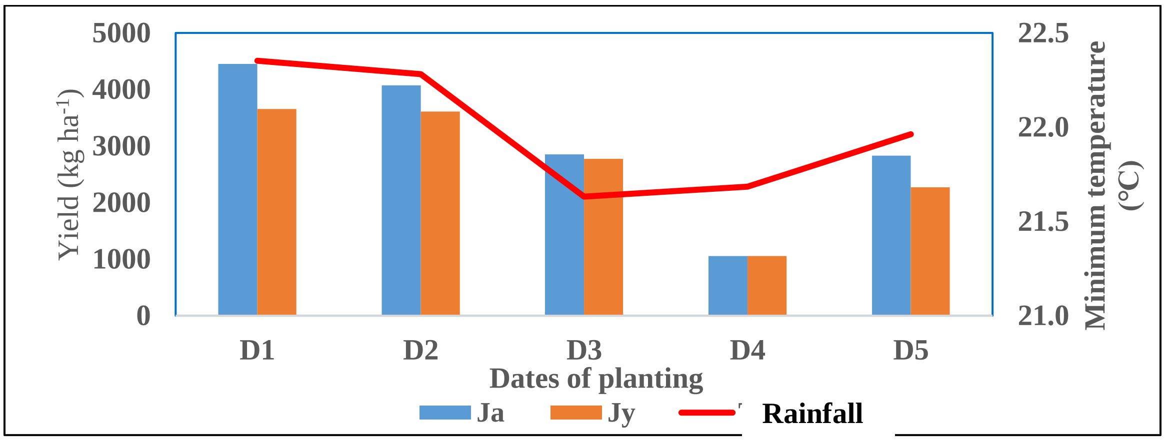


Fig : 5.22. Influence of minimum temperature during panicle initiation to booting on grain yield

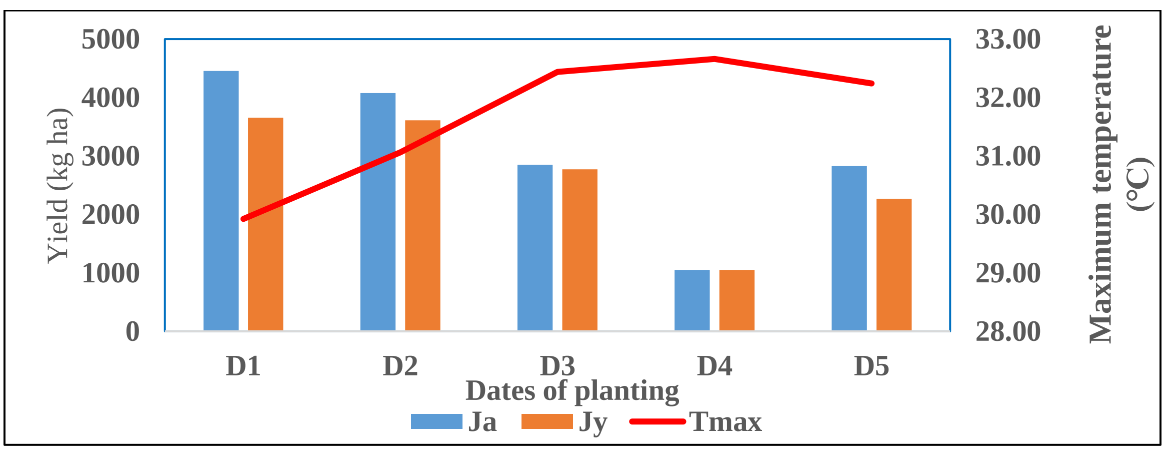


Fig 5.23. Influence of maximum temperature received during 50% flowering to maturity on grain yield

5.4. Effect of weather on phenology

Duration taken for each phenological stage differs among different dates of planting and variety (Fig. 5.24). Total crop duration was found to be decreasing with delayed dates of planting. The difference in duration among different dates of planting was due to prevailed weather conditions during each phenophases in each variety. This result was in confirmation with Vysakh *et al.* (2015), Ravindran *et al.* (2018) and Haritharaj *et al.* (2019).

Duration of Jaya and Jyothi varied since Jyothi is a short duration variety and Jaya is a medium duration variety. A higher duration was observed during June 20th planting for both Jaya and Jyothi. A lower duration for Jaya was observed during July 20th and August 5th planting and for Jyothi it was observed during July 20th planting.

After the correlation analysis it was understood that maximum temperature experienced during transplanting to active tillering, panicle initiation to booting, 50% flowering to physiological maturity reduced number of days taken to reach each phenophases while relative humidity and rainfall showed a positive influence on duration. A decline in the number of days taken to reach physiological maturity was noticed with delay in transplanting. This result was in line with Begum *et al.* (2000).

Duration of each phenophase was dependent on temperature. Number of days taken to reach physiological maturity was more during early planting due to the comparatively lower temperature prevailed during the crop growth period especially from panicle initiation to physiological maturity period. This result was in accordance with Mahmood *et al*. (1996). According to him the length of growing season increases with decline in air temperature as there was a longer time requirement for the accumulation of heat to complete physiological cycles.

5.5. Growth indices

5.5.1. Leaf area index (LAI)

Maximum value of leaf area index was seen at 75 days after planting. Leaf area index was minimum during initial stages due to poor number of leaves as crop growth stage progress the canopy development starts and it attains its maximum during 75 days after planting after that competition among tillers and the drying of leaves reduced leaf area index (Fig. 5.25 a & b), similar results were noticed by Azharpour *et al*. (2014) and Medhi *et al.* (2016).

5.5.2. Leaf area duration (LAD)

Leaf area duration showed a similar trend like that of leaf area index (Fig. 26. (a & b)). Maximum duration was seen at 75 days after planting there after leaf area duration showed a decrease towards maturity. This was in accordance with Devendra *et al.* (1983)

5.5.3. Crop growth rate (CGR)

Crop growth rate was found to be increasing and reached a maximum value at 45 to 60 days after planting in both Jaya and Jyothi. Crop growth rate then shows a decreasing trend towards maturity and reaches a negative value (Fig. 27(a & b). Similar results were noticed by Taleshi *et al*. (2013). The whole plant receive maximum light during initial stages. As crop growth proceeds mutual shading of leaves occur and light intercepted by crop also decreases as a result the crop growth rate decreases at later stages of crops. These results were in line with Mani and Noori, (2015).

5.5.4. Net assimilation rate (NAR)

Net assimilation rate was found to be higher during initial stages of crop *i e.* 15 to 30 days after planting, later on it was found to be decreasing and reached a negative value during 75 to 90 days after planting (Fig.28 (a&b). This was in accordance with the findings

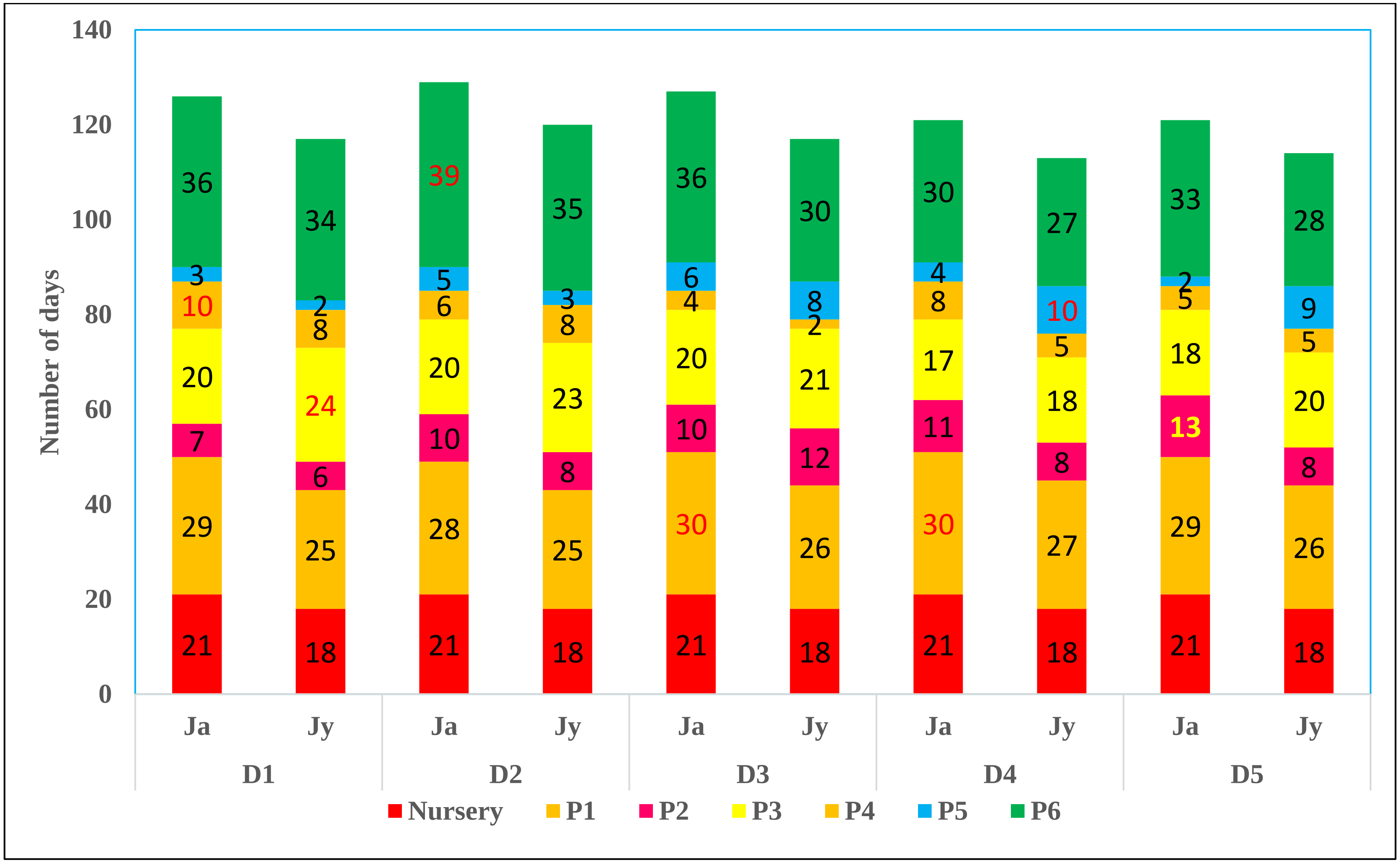


Fig. 5. 24. Phenology of Jaya and Jyothi

Ja – Jaya , Jy - Jyothi

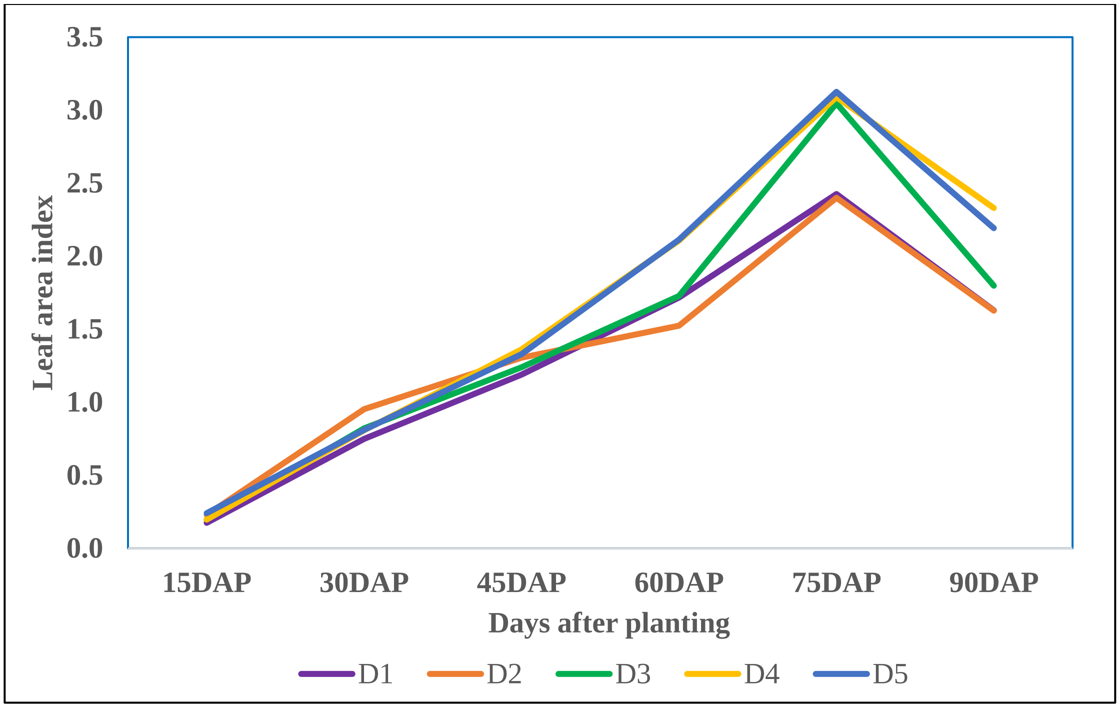


Fig. 5.25 (a) Trend of Leaf area index in different dates of planting in Jaya

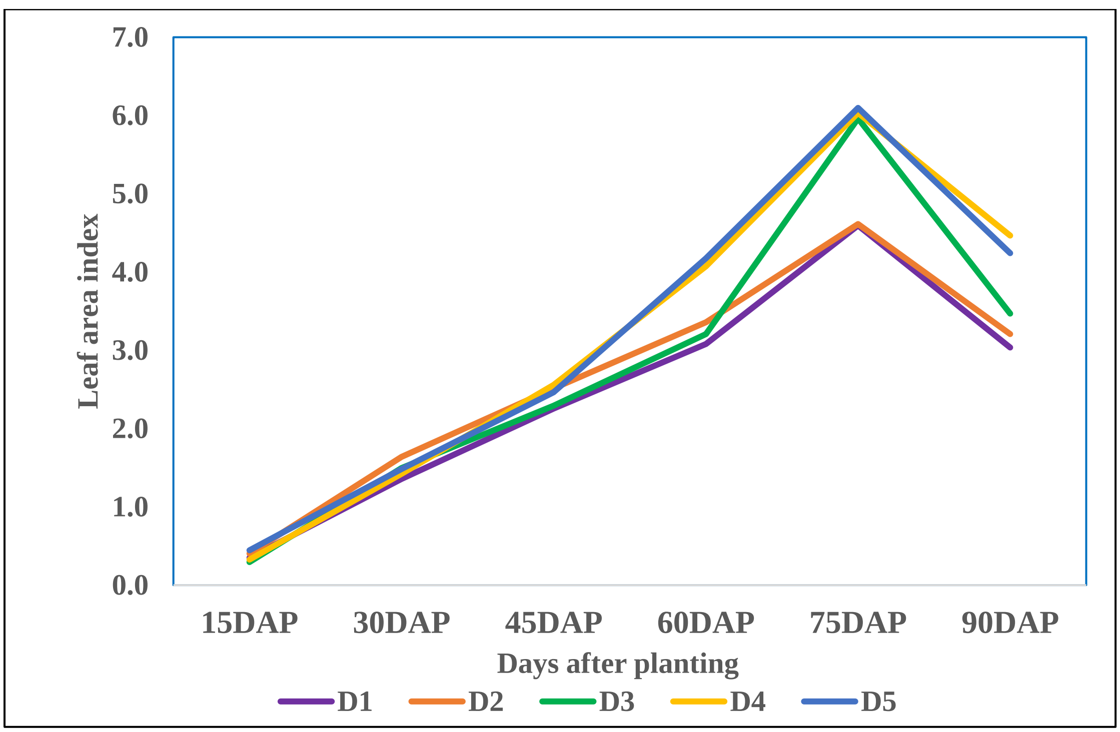


Fig. 5.25 (b) Trend of Leaf area index in different dates of planting in Jyothi

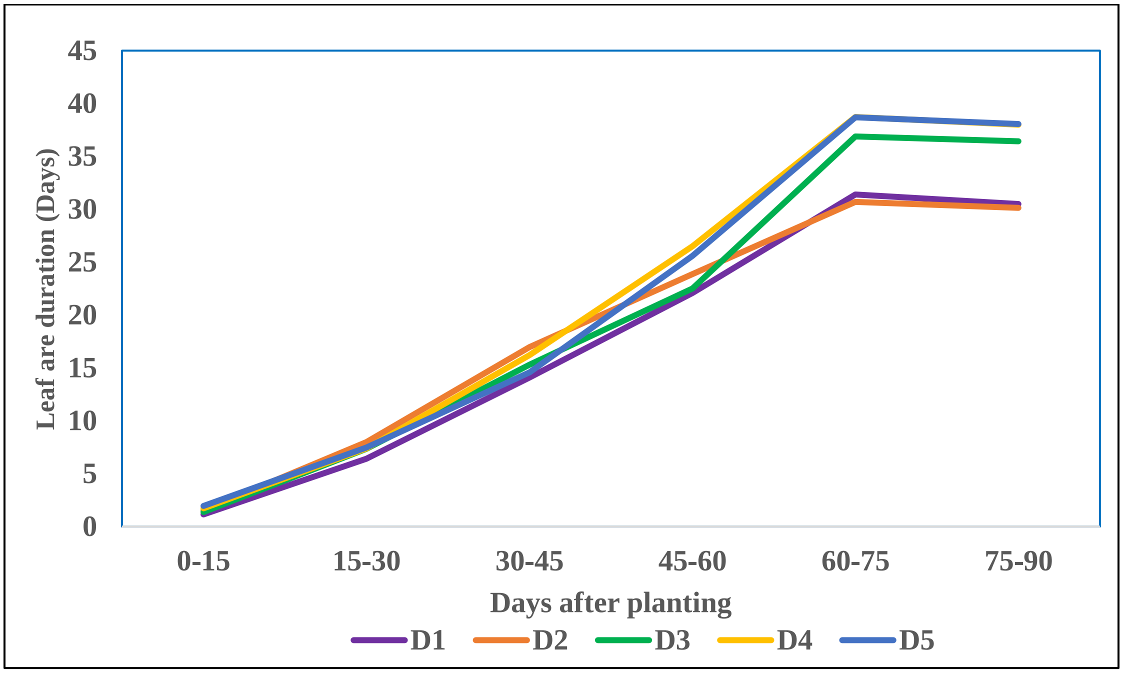


Fig. 5.26. (a) Leaf area duration in different dates of planting in Jaya

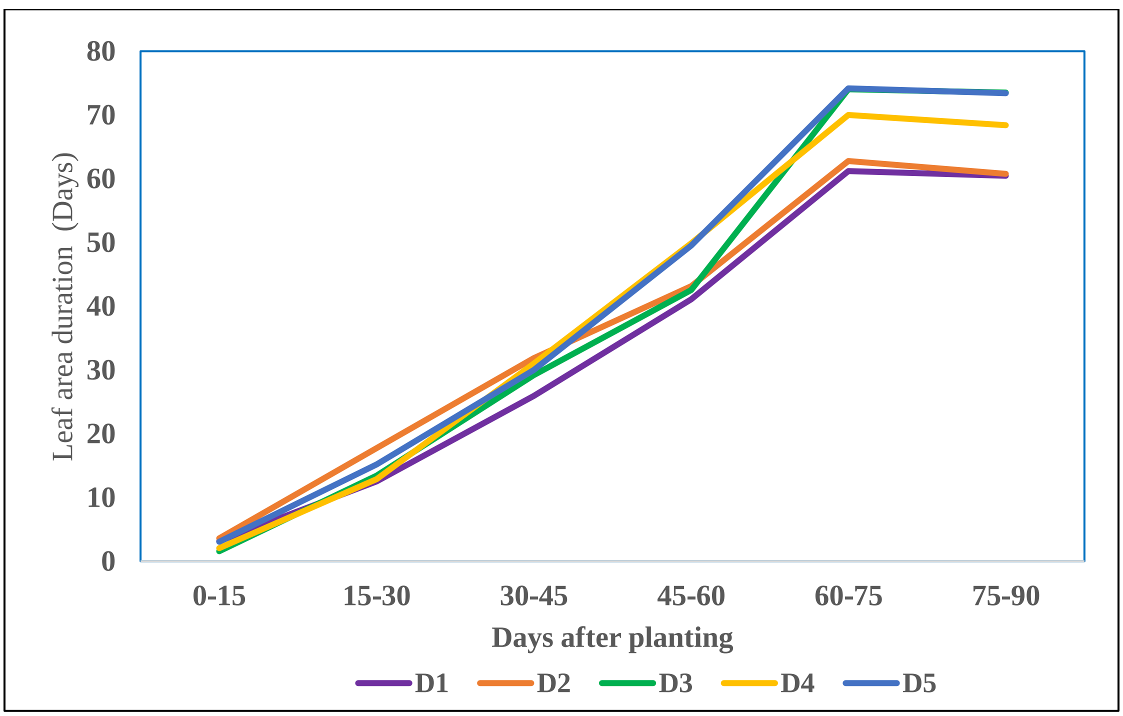


Fig. 5.26 (b) Leaf area duration in different dates of planting in Jyothi

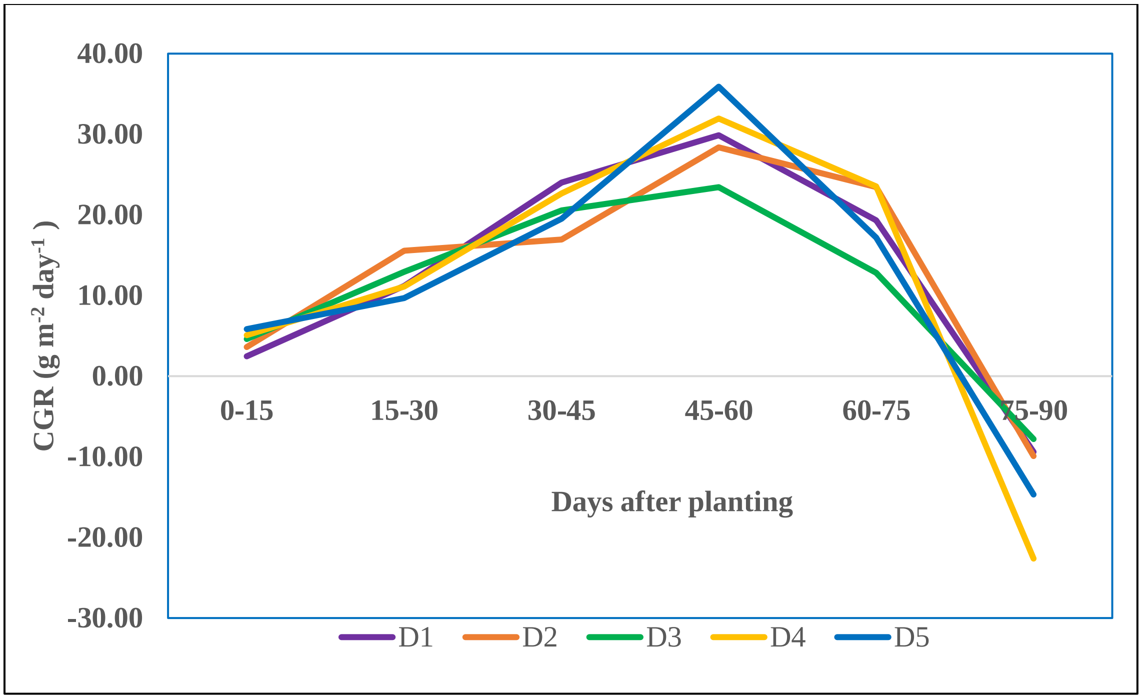


Fig. 5.27. (a) Crop growth rate in different dates of planting in Jaya

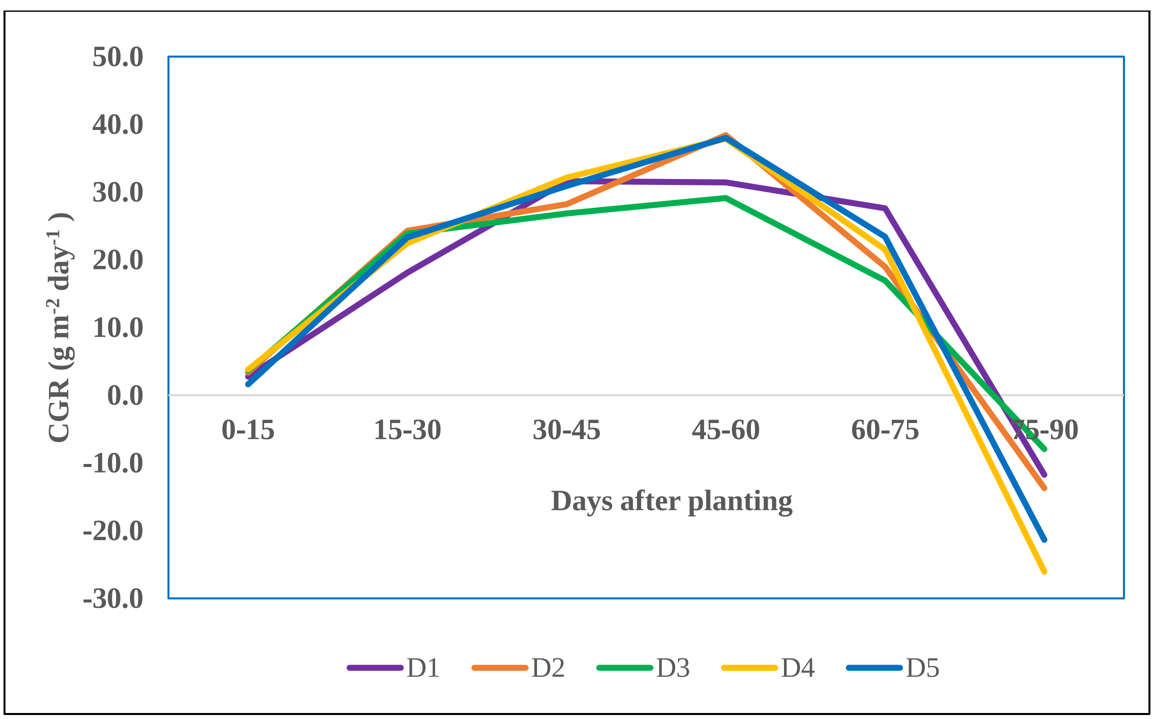


Fig. 5.27. (b) Crop growth rate in different dates of planting in Jyothi

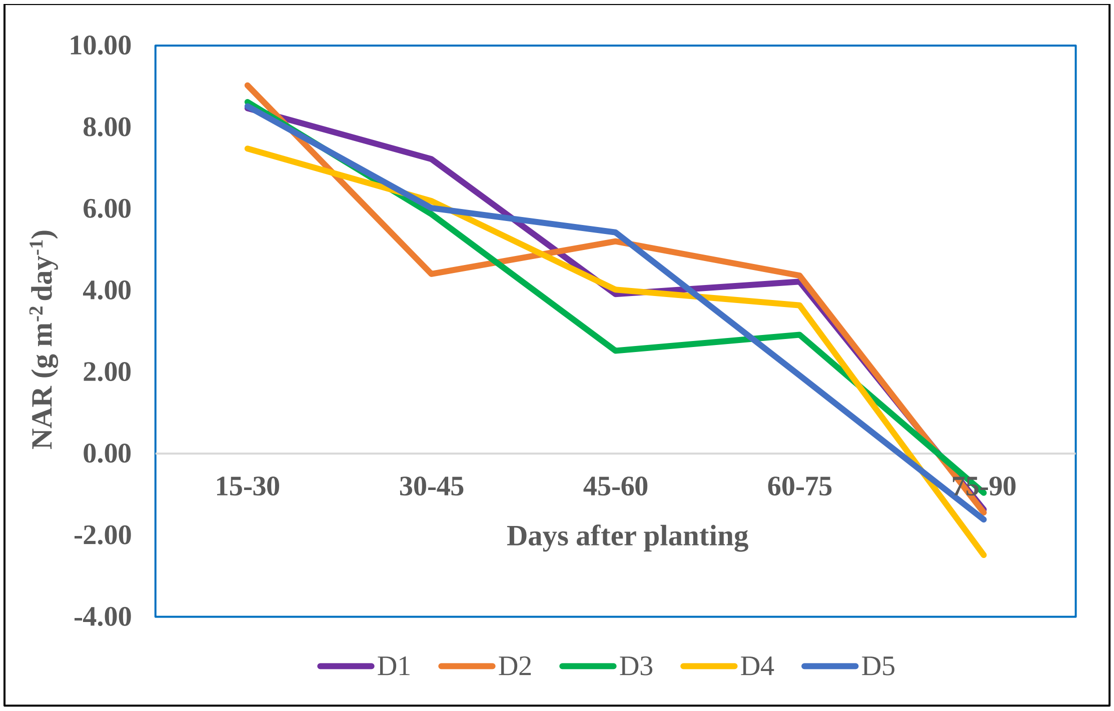


Fig. 5.28. (a) Net assimilation rate in different dates of planting in Jaya

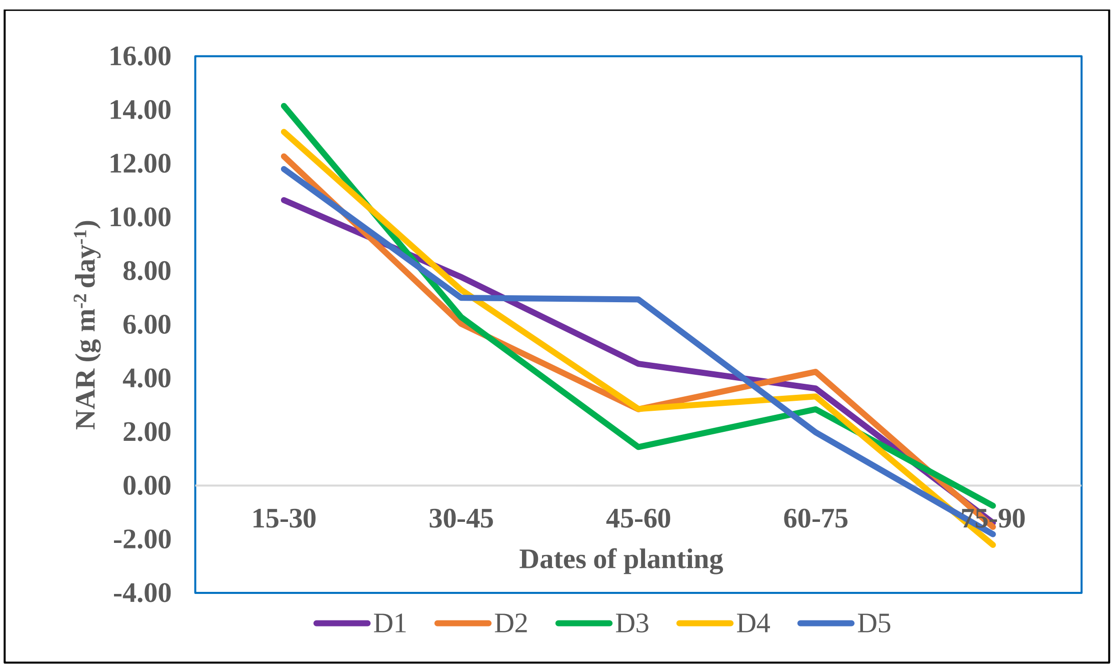


Fig. 5.28. (b) Net assimilation rate in different dates of planting in Jyothi

of Gardner *et al*. (2017). According to him initial stages the proportion of photosynthetic tissues will be higher compared to respiratory tissues as a result net assimilation rate was more as crop growth proceeds the proportion of respiratory tissue increases. At a point proportion of photosynthetic tissues and respiratory tissues came to be same. Then net assimilation rate will be zero. There after proportion of respiratory tissues will be higher and dry matter consumed for respiration was greater than that assimilated by photosynthesis as a result net assimilation rate becomes negative.

5.4 CERES rice model

CERES rice model was used to simulate crop yield and different phenophases like days to anthesis, days to panicle initiation, days to physiological maturity. The simulated yield and phenophases were compared with the values recorded from the experimental field. Low accuracy was observed in case of already calibrated genetic coefficients, hence fine tuning of model should be done (Akinble, 2013). The genetic coefficients calibrated for Jyothi during 2014-2015 and for Jaya during 2017-2018 were used for calibrating genetic coefficients for the year 2019-2020. Genetic coefficients were fine tuned with 6000 iterations using DSSAT v. 46 a. The model performance was assessed using two statistics, Root Mean Square Error (RMSE) and d-stat index . A model is said to be performing good if the d-stat index should approach unity and RMSE value should approach zero (Willmott, 1982). The validation of model with grain yield and phenology were discussed

5.4.1 Simulation of Grain yield

In case of Jaya model predicted the grain yield with RMSE value of 1488 and d-stat index of 0.57 respectively which showed a good agreement with the observed yield (Fig. 5.29). In case of Jyothi the simulated grain yield was in good agreement with observed yield (Fig. 5.30) with an RMSE value of 1043 and d-stat index of 0.61. Similar findings were reported by Jha *et al.* (2020) who predicted the grain yield which was in good agreement with observed yield with an RMSE value of 4.4% and d-stat index of

0.67. With delay in planting, a wide variation in observed and simulated yield was noticed. Similar results were observed by Vysakh *et al.* (2015).

5.4.2 Simulation of Phenology

There was rationally a good agreement with simulated and observed phenology of both Jaya and Jyothi except for duration of physiological maturity in Jyothi (Fig. 5.31 & 5.32). Simulated anthesis day was sensibly in good agreement with observed anthesis dates. In Jaya model predicted anthesis dates with RMSE value of 1.84 and d-stat value of 0.49 and in Jyothi it predicted anthesis dates with RMSE value of 1.673 and d- stat value of 0.686. Predicted panicle initiation showed a good agreement with observed panicle initiation dates with a RMSE value of 3.72 for Jaya and 1.94 for Jyothi and a d-stat value of 0.584 for Jaya and 0.643 for Jyothi. Simulated maturity dates and observed maturity dates showed a good agreement in Jaya with a RMSE value of 3.55 and a d-stat value of 0.584. Similar results were reported by Haritharaj, (2019).

5.5 Yield gap analysis

Yield gap analysis was carried out by estimating different production levels *i. e* potential yield, attainable yield and actual yield. Using CERES rice model a no stress condition for water and nutrients were simulated. Yield simulated by the model under this condition was considered as potential yield. The simulated value of potential yield was 5797 kg ha^{-1} for Jaya and 5687 kg ha^{-1} for Jyothi. According to FAO (2004) total yield gap was calculated by the difference between potential yield and actual yield. This total yield gap was further divided into yield gap I and yield gap II. A total yield gap of 3457 kg ha^{-1} and 3357 kg ha^{-1} was estimated for Jaya and Jyothi respectively. Yield gap I estimated for Jaya was 1740 kg ha^{-1} and for Jyothi it was 2078 kg $ha^{-1.}$ Yield gap II estimated for Jaya was 1717 kg ha^{-1} and for Jyothi it was 1279 kg ha^{-1} (Fig. 33). Timsina *et al*. (2004) also used CERES rice model to calculate yield gap. They used models to analyze the gap between potential and actual yield at three different locations (Ludhiana, Delhi and Modipuram) and varieties (PR114, Pusa 44 and Saket 4) and total yield gap calculated

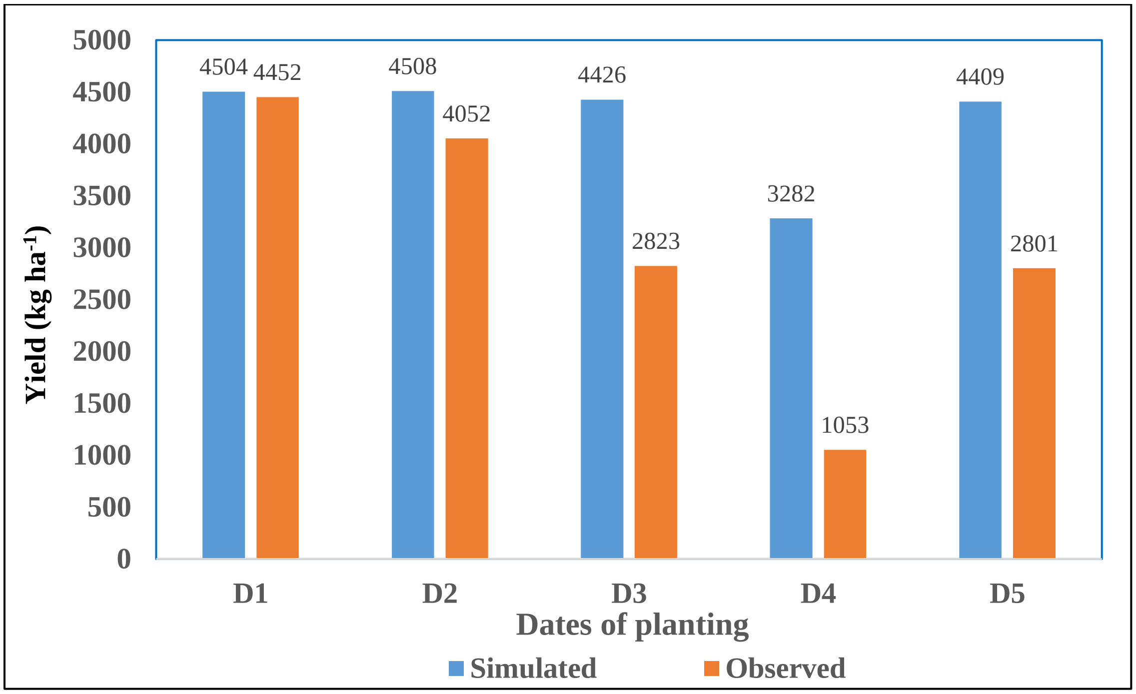


Fig. 5.29. Simulated and observed yield in Jaya

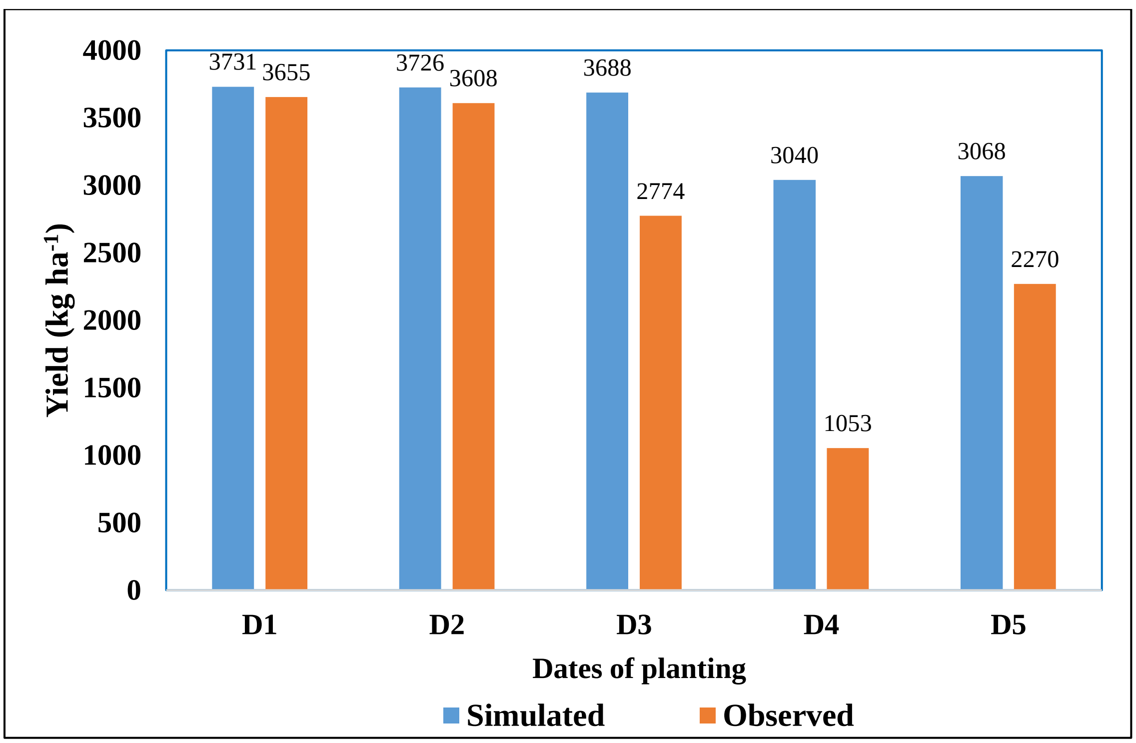


Fig. 5.30. Simulated and observed yield in Jyothi.

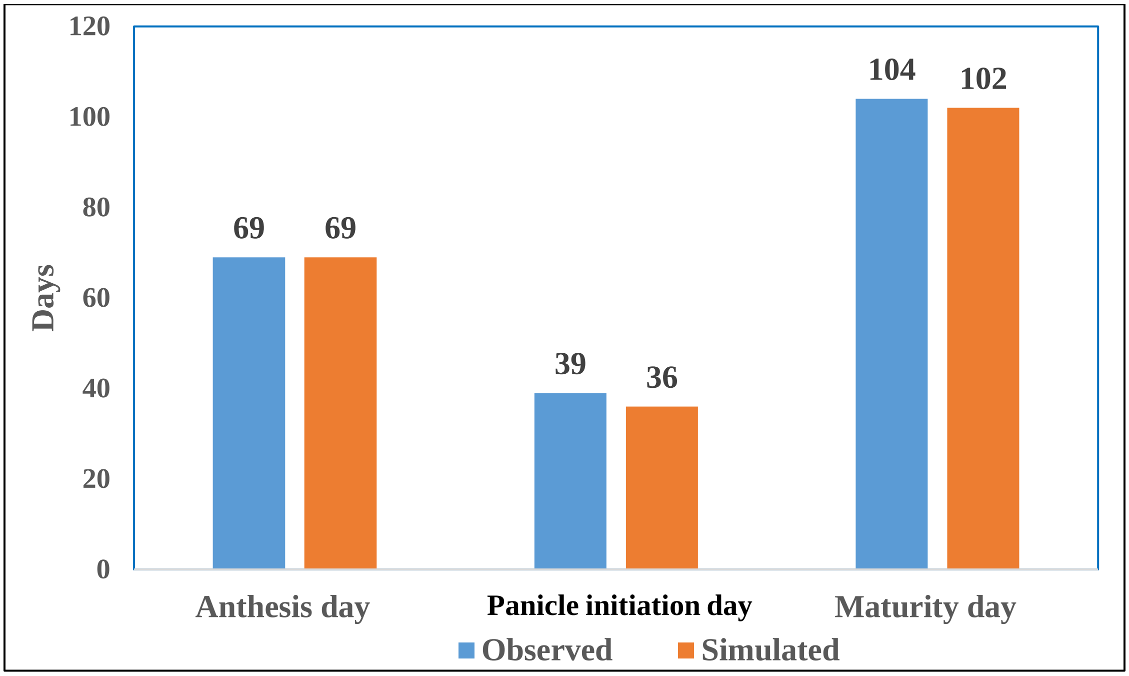


Fig. 5.31. Simulated and observed phenophase in Jaya

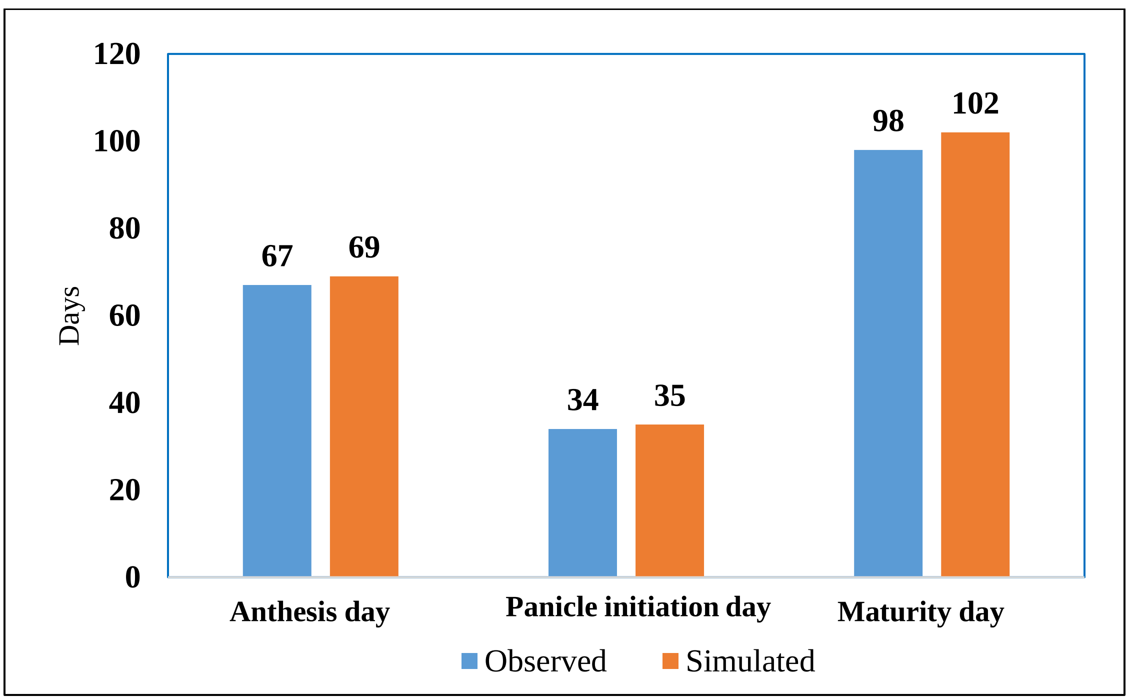


Fig. 5.32. Simulated and observed phenophase in Jyothi

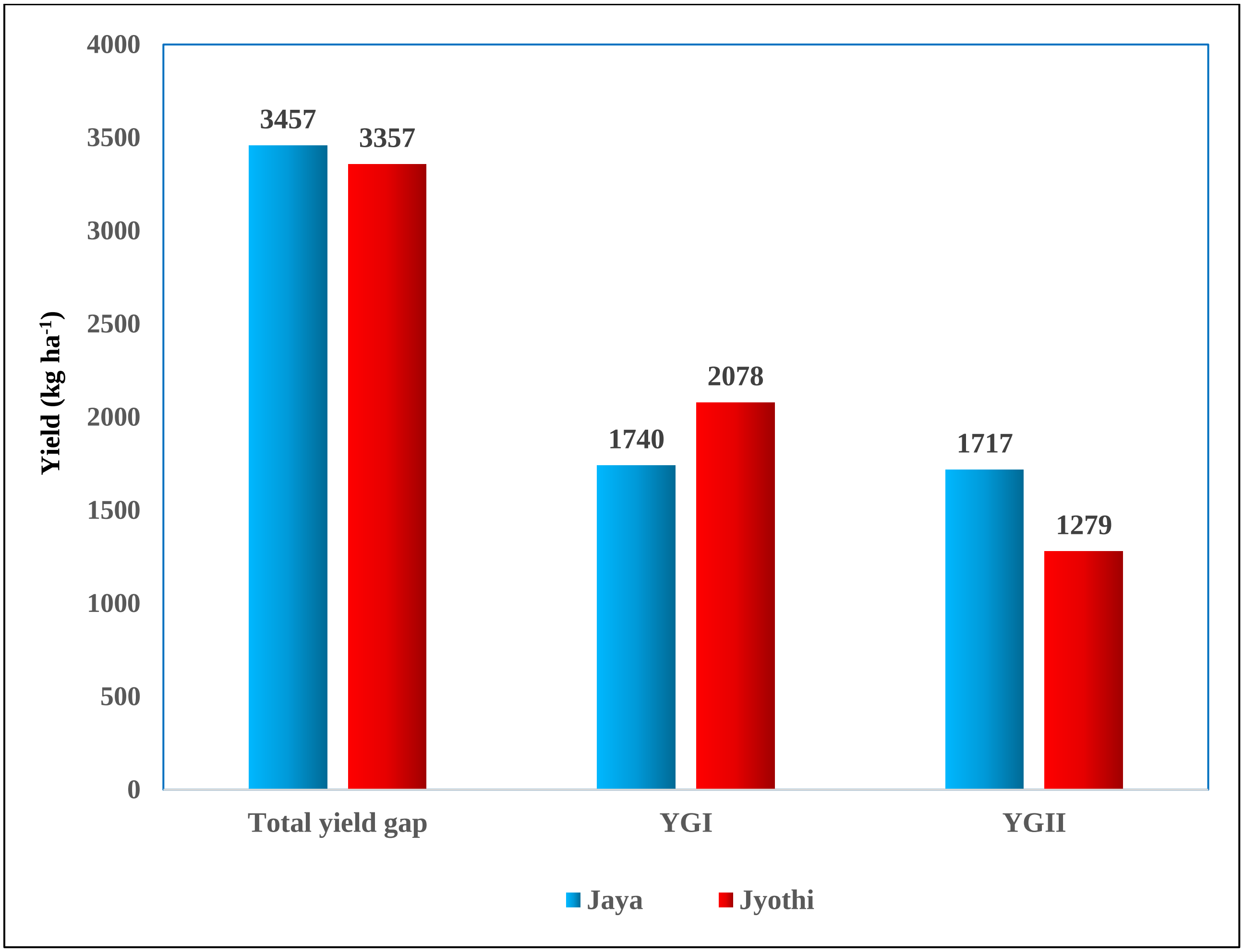


Fig. 5.33 Different levels of yield gap calculated in each rice varieties

varied from 48 to 68 % of potential yield. Similar type of studies were conducted by Singh *et al.*, 2015. They computed potential yield, attainable yield and actual yield over a period of 1990 to 2010 at different districts. Maximum potential yield of 4742 kg ha^{-1} was simulated by model in the variety Shatabadi at Kalyani district.

5.6 Management strategies to reduce gap

The yield gap analysis revealed that there was a huge yield gap in rice production. There was a plenty of scope to increase yield by improving crop management conditions. Using CERES rice model yield of two varieties were simulated under various nitrogen fertilizer management practices. Yield simulated by the model was found to be increasing with increase in nitrogen input and reaches a plateau when the nitrogen input was 130 kg ha^{-1} both Jaya and Jyothi. The yield obtained under the 130 kg ha^{-1} nitrogen input was 5572 kg ha^{-1} for Jaya 5387 kg ha^{-1} for Jyothi. The graph was drawn by plotting nitrogen input on x axis and yield on y axis (Fig. 5.34 a&b). The slope of the graph (yield/nitrogen input) represented nitrogen use efficiency. Nitrogen use efficiency simulated was 50.1% and 53.2% for Jaya and Jyothi when the general recommended nitrogen was applied (90 kg ha^{-1} for Jaya and 70 kg ha^{-1} for Jyothi). Nitrogen use efficiency under 130 kg ha^{-1} nitrogen input was found to be declined to 42.9% and 41.4% in Jaya and Jyothi respectively. Nitrogen use efficiency was found to be decreased under increased nitrogen input. Model also simulated yield responses of two varieties under different split doses of nitrogen. Even though the same amount of fertilizer were applied, yield simulated by model under three split doses of nitrogen was higher than two split doses of nitrogen.

A similar type of study was conducted by Hameed, (2019) who simulated yield under different nitrogen fertilizer rates and with different nitrogen splits using ORYZA model. He observed a linear increment in yield with additional input of nitrogen and after the application of 300 kg N ha^{-1} there was no increase in yield at all. He also added that at zero nitrogen input nitrogen use efficiency was higher and it tend to decrease with increase in nitrogen rates. Model also simulated lowest yield under single split nitrogen application and highest yield under four split nitrogen application. According to him proper rate of nitrogen when applied in different splits will increase productivity.

Increse in yield was simulated by model with increase in number of split doses. This was in agreement with a field study conducted by Djman *et al.* (2018). He found out that yield from hybrid rice was more under four split doses of nitrogen compared to three split doses of nitrogen.

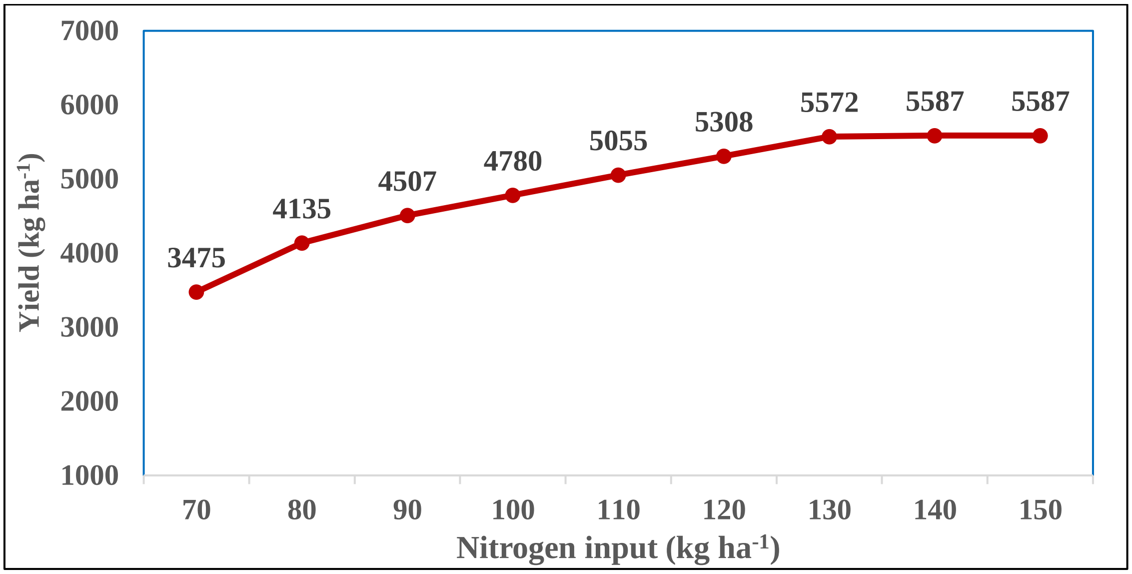


Fig 5.34 (a). Simulated yield response with increased N application in Jaya

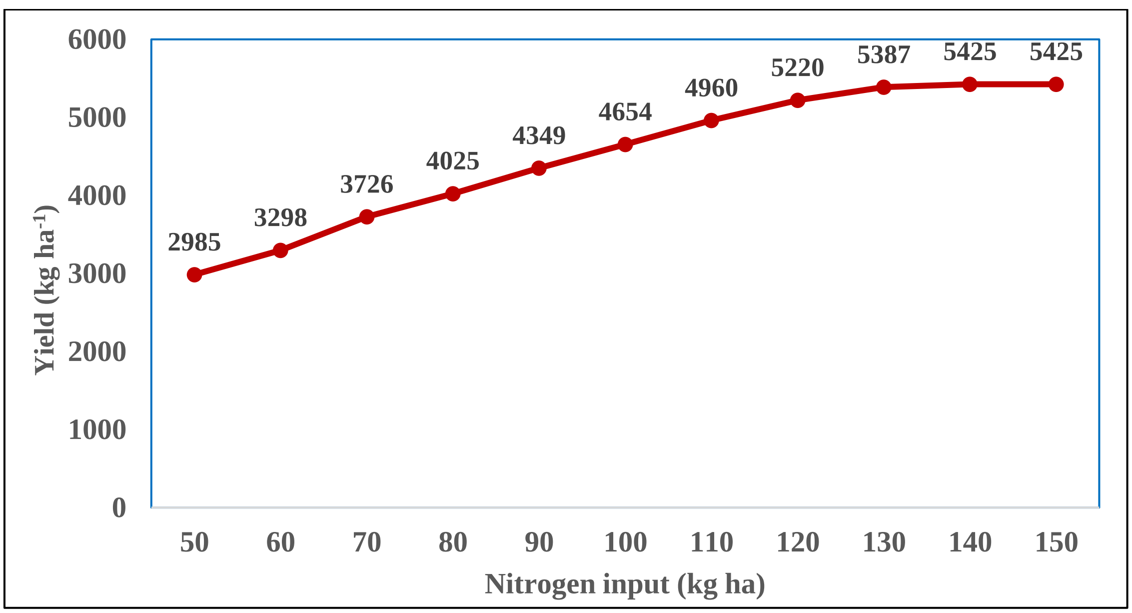


Fig 5.34 (b). Simulated yield response with increased N application in Jyothi

Summary

6. SUMMARY

The present study on "Analysis of potential yield and yield gap of rice (*Oryza sativa*) using CERES rice model" was conducted at Department of Agricultural Meteorology, College of Horticulture, Vellanikkara during 2019. Yield gap was analyzed by estimating different production levels. Crop management strategies were evaluated using the model to reduce the yield gap.

Weather observations were recorded on daily basis. Biometric, phenological, yield and yield attributes were noted during different planting. Biometric observations taken at fortnightly intervals were used to calculate growth indices like leaf area index, leaf area duration and crop growth rate. Production levels during June 20th planting were used for calculating yield gap. The potential yield was simulated by CERES rice model. Yield obtained from experimental plot was taken as attainable yield. Yield obtained from farmers field was taken as actual farmers yield. The model was used to evaluate different crop management strategies which can be used to reduce the gap. The results of this research work are summarized here:

- Plant height was found to be significantly influenced by dates of planting in every week. Effect of variety on plant height was also found to be significant except for 2nd, 3rd and 11th week
- Compared to Jaya, plant height recorded in Jyothi was higher during all the weeks. The interaction effect of dates of planting and variety was also found to be significant
- Effect of dates of planting on dry matter accumulation was found to be significant in every fortnightly interval except for 45 days after planting. Maximum dry matter accumulation was recorded during 75 days after planting. Dry matter accumulation was maximum during August 5th planting
- A significant difference in dry matter accumulation was seen between varieties. Compared to Jaya, dry matter accumulation was more in Jyothi

- A significant difference was found between different dates of planting in case of number of tillers recorded per unit area. Number of tillers recorded during June 5th planting was on par with August 5th planting which were higher than other dates of planting
- Effect of dates of planting on number of spikelet per panicle was found to be significant in both varieties. Number of spikelet per panicle recorded during July 5th planting was found to be on par with August 5th planting. Number of spikelet recorded in Jaya was higher than Jyothi
- Number of filled grain recorded during July 5th planting was higher compared to other dates of planting. Number of filled grains recorded in Jaya was higher than Jyothi
- A significant difference was seen for 1000 grain weight between different dates of planting in both varieties. Thousand grain weight recorded during June 5th planting was on par with June 20th planting and July 5th planting which were higher than other two dates of planting
- Grain yield recorded was found to be significantly influenced by dates of planting. Grain yield recorded during June 5th planting was on par with June 20th planting which were higher than other dates of planting
- The maximum number of days to reach physiological maturity from transplanting was recorded during June 20th planting for both varieties. The minimum number of days to reach physiological maturity was recorded during July 20th and August 5th in case of Jaya and July 20th in case of Jyothi
- Leaf area index was found to be increasing towards 75 days after planting. From 75 days after planting to physiological maturity LAI decreases. Leaf area duration also showed a similar trend. Effect of dates of planting on leaf area index and leaf area duration were found to be significant
- Crop growth rate was found to be maximum during 45-60 days after planting. As per the analysis of variance carried out, effect of dates of planting on crop growth rate was significant for both the varieties

- Effect of dates of planting on net assimilation rate was also found to be significant. Maximum net assimilation rate was recorded during 15-30 days after planting
- Correlation studies showed that duration of phenophases, yield and yield attributes were significantly influenced by weather parameters experienced during each phenophases
- Yield gap was analyzed with the help of CERES rice model
- No stress conditions of water and nitrogen were simulated using the model and the corresponding yield was taken as potential yield
- Yield obtained from experimental plot during June 20th planting was considered as attainable yield
- Actual yield was obtained from farmers field and ECOSTAT report, 2019
- Yield gap analysis showed that there exist a sizeable yield gap in rice production.
- Total yield gap (Potential yield – Actual yield) of 3457 kg ha^{-1} and 3357 kg ha^{-1} were found out in Jaya and Jyothi respectively
- With the help of model, it was found out that the yield gap can be reduced by adopting proper fertilizer management practices
- Yield response under different management practices was simulated using model
- With an additional nitrogen supply, yield was found to be increasing. The optimum dose of nitrogen was found to be 130 kg ha^{-1}
- Yield can be increased by three split doses of nitrogen application compared to two split dose of nitrogen
- A comparison done between different fertilizer application method, using model, revealed that yield increased when nitrogen was applied through irrigation water compared to broad casting and urea super granule method

References

REFERENCES

Aberra, K. 2011. The impact of climate variability on crop production in Ethiopia: Which crop is more vulnerable to rainfall variability [abstract]. In: 9th International Conference of Ethiopian Economic Association (EEA). Ethiopian Economic Association, Addis Ababa, p.12.

Aggarwal, P. K., Hebbar, K. B., Venugopalan, M. V., and Wani, S. P. 2008. *Quantification of yield gaps in rain-fed rice, wheat, cotton and mustard in India.* Global Theme on Agroecosystems Report No. 43, Patancheru, Andhra Pradesh, 39p.

Akinbile, C. O. 2013. Assessment of the CERES-Rice model for rice production in Ibadan, Nigeria. *Agric. Eng. Int. CIGR. J.* 15(1): 19-26.

Amgain, L.P., Dhakal, B., Shrestha, U. and Marasini, S., 2019. Agronomic management and climate change scenario simulations on productivity of rice, maize and wheat in central Nepal using DSSAT ver 4.5 crop model. *J. Agric. Nat. Resour*. *2*(1): 193-214.

Azharpour, E., Moraditochaee, M., and Bozorgi, H. R. 2014. Effect of nitrogen fertilizer management on growth analysis of rice cultivars. *Int. J. Biosci.* 4(5): 35-47. Available: http://www.innspub.net.pdf. [08 March].

Baite, M.S., Raghu, S., Prabhukarthikeyan, S. R., Keerthana, U., Jambhulkar, N. N. and Rath, P. C. 2020. Disease incidence and yield loss in rice due to grain discolouration. *J. Plant Dis. Prot*. *127*(1): 9-13.

Baloch, M. S., Awan, I. U., and Hassan, G. 2006. Growth and yield of rice as affected by transplanting dates and seedlings per hill under high temperature of Dera Ismail Khan, Pakistan. *J. Zhejiang Univ. Sci.* 7(7): 572-579.

Begum, A. A., Altaf, H. S. M., and Moin-us- Salam. 2000. Growth duration, temperature sum, photoperiod and yield of rice as influenced by dates of transplanting. *Bengladesh J. Agric. Sci*. 27(2): 191-197.

Bhattacharya, T. and Pandey R. K. 2013. Effect of climate change on rice yield at Kharagpur, West Bengal. *Int. J. Food, Agric. Vet. Sci*. *4*(2): 6-12.

Bhuvaneswari, K., Geethalakshmi, V., Lakshmanan, A., Anbhazhagan, R. and Sekhar, D. N. U. 2014. Climate change impact assessment and developing adaptation strategies for rice crop in western zone of Tamil Nadu. *J. Agrometeorol*. 16: 38-43.

Biswas, R., Banerjee, S., and Bhattacharya, B. 2018. Impact of temperature increase on performance of *kharif* rice at Kalyani, West Bengal using WOFOST model. *J. Agrometeorol*. 20(1): 28-30.

Chan, C. S. and Cheong, A. W. 2001. Seasonal weather effects on crop evapotranspiration and rice yield. *J. Trop. Agric. Food Sci*. *29*: 77-92.

Chaudhari, N. V., Kumar, N., Parmar, P. K., Dakhore, K. K., Chaudhari, S. N. and Chandrawanshi, S. K. 2019. Assessment of Impact of Temperature and CO_2 on Growth and yield of Rice Crop using DSSAT Model. *Int. J. Curr. Microbiol. App. Sci*, *8*(2): 776-783.

Chaudhari, A.K. 2019. Epidemiological study of false smut of rice (*Oryza sativa* L.) in Gujarat. *Int. J. Microbiol. Res.* 11(6): 975-5276.

Chopra, N. K., Chopra, N., Yadav, R. N. and Nagar, K. C. 2006. Effects of transplanting dates on seed yield and quality of paddy cv. Pusa 44. *Seed res. 34*(2): 218.

Debnath, S., Mishra, A., Mailapalli, R. D. and Raghuwanshi, S. N. 2018. Quantifying yield gap for rice cropping systems in lower gangetic plains. *Paddy Water Environ*. 16 (3): 601-615.

Devendra, R., Veeraraj, Y. S., Udayakumar, M., ans Sastry, K. S. K. 1983. Leaf area duration and its relationship to productivity in early cultivars of rice. *Proc. Indian. Natl. Sci. Acad.* pp. 692 – 696.

De Wit, C. T. 1965. *Photosynthesis of leaf canopies*. Agricultural Research Report No. 663 PUDOC, Wageningen, The Netherlands. 56p.

Dhaliwal, L. K. 2020. Variability in meteorological parameters during *kharif* season and its impact on rice crop at Ludhiana, Punjab, India. *J. Agrometeorol. 22*(1): 92-96.

Dias, M. P. N. M., Navaratne, C. M., Weerasinghe, K. D. N., and Hettiarachchi, R. H. A. N. 2015. Application of DSSAT crop simulation model to identify the changes of rice growth and yield in Nilwala river basin for mid-centuries under changing climatic conditions. *Proc. Food Sci.*6: 159-163.

Directorate of Rice Development [DRD]. 2014. Status Paper on Rice. Government of India, New Delhi. 326p.

Djaman, K., Mel, V. C., Ametonou, F. Y., El-Namaky, R., Diallo, M. D. and Koudahe, K., 2018. Effect of nitrogen fertilizer dose and application timing on yield and nitrogen use efficiency of irrigated hybrid rice under semi-arid conditions. *J. Agri. Sci. Food Res*. 9: 2

Fadzillah, N. M., Gill, V., Finch, R. P., and Burdon, R. H. 1996. Chilling, oxidative stress and antioxidant responses in shoot cultures of rice. *Planta.* 199: 552–556.

Fisher, R. A. 1947. *The design of experiments* (4th Ed.). Oliver and Boyd, Edinburg. 235p.

Fischer, R. A. 2015. Definitions and determination of crop yield, yield gaps, and of rates of change. *Field Crops Res.* 182: 9-18.

Food and Agricultural Organization [FAO]. 2004. Rice and narrowing the yield gap. Available at www.rice2004.org/fao.org/rice2004/- en/f-sheet/factsheet 5.pdf

Gardner, F. P., Pearce, R. B. and Mitchell, R. L. 2017. *Physiology of Crop Plants* (2nd Ed.). Scientific Publishers. 327p.

Ghosh, M., Mandal, B. K., Mandal, B. B., Lodh, S. B., and Dash, A. K. 2004. The effect of planting dates and nitrogen management on yield and quality of aromatic rice (*Oryza sativa*). *J. Agric. Sci.* 142(2): 183-191.

Grassini, P., Thorburn, J., Burr, C., and Cassman, K. G. 2011. High yield irrigated maize in the Western U.S. Corn-Belt. *Field Crop Res.* 120: 142-150.

Gupta, R. and Mishra, A. 2019. Climate change induced impact and uncertainty of rice yield of agro-ecological zones of India. *Agric. Syst.* 173: 1-11.

Halder, D., Kheroar, S., Srivastava, R. K. and Panda, R. K., 2020. Assessment of future climate variability and potential adaptation strategies on yield of peanut and *kharif* rice in eastern India. *Theor. Appl. Climatol*. 8: 1-16.

Hall, A. J., Feoli, C., Ingaramo, J. and Balzarini, M. 2013. Gaps between farmer and attainable yields across rain fed sunflower growing regions of Argentina. *Field Crops Res.* 143: 119-129.

Haritharaj. S. 2019. Crop weather relationship of rice varieties under different growing environments. MSc. (Ag) thesis, Kerala Agricultural University, Thrissur, 199p.

Hameed, F., Xu, J., Rahim, S., F., Wei, Q., Rehman, A., Khalil and Liao, Q. 2019. Optimizing nitrogen options for improving nitrogen use efficiency of rice under different water regimes. *Agron.* 9 (39): 1-18.

Hoogenboom, G., Wilkens, P. W., Thornton, P. K., Jones, J. W., Hunt, L. A. and Imamura, D. T. 1999. Decision support system for agro technology transfer V 3.5. In: DSSAT Version 3 (Eds. : Hoogenboom, G., Wilkens, P. W. and Tsuji, G. .Y), , University of Hawaii, Honolulu, HI. pp: 1-36.

Hunt, L. A. and Boote, K. J. 1994. Data for model operation, calibration and validation. In: Tsuji, G. Y., Hoogenboom, G., and Thornton, P. K. (eds), IBSNAT*:* A system approach to research and decision making. University of Hawaii, Honolulu, Hawaii, USA, pp. 9-40.

IPCC. 2013. Climate Change 2013: The Physical Science Basis - Anthropogenic and Natural Radiative Forcing Supplementary Material. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 1523p.

Islam, A. N., Khanikar, P. G., Deka, R. L. and Goswami, B. 2017. Impact of weather parameters on winter rice productivity in the upper Brahmaputra valley zone of Assam. *J. Agrometeorol.* 19:75-79.

Jain, A., Chaudhary, J. L., Beck, M. K. and Kumar, L. 2019. Developing regression model to forecast the rice yield at Raipur condition. *J. Pharmacogn. Phytochem.* 8(1):72-76.

Jagatap, D.N., Rajemahadik, V.A., Chavan, S.A. and Mahadkar, U.V. 2018. Effect of different weather parameters on the growth and yield attributes and yield of rice (*Oryza sativa* L.). *J. Indian Soc. Coastal Agric. Res.* 36(1): 80-83.

Jasrotia, P., Khippal, A., Yadav, J., Kashyap, P. L., Kumar, S., and Singh, G. P. 2019. Effect of weather variables on the incidence of yellow stem borer (*Scirpophaga incertulas*) and leaf folder *(Cnaphalocrocis medinalis*) in rice. *J. Cereal Res. 11*(3): 247-251.

Jha, R. K., Kalita, P. K. and Jat, R., 2020. Development of production management strategies for a long-duration rice variety: Rajendra Mahsuri-using crop growth model, DSSAT, for the state of Bihar, India. *Paddy and Water Environ.* 18: 531-545.

Jones, J. W., Hoogenboom, G., Porter, C. H., Boote, K. J., Batchelor, W. D., Hunt, L. A. and Ritchie, J. T. 2003. The DSSAT cropping system model. European *J.* Agron. 18: 235-265.

Kant, K., Bora, P. K. and Saikia, U. S. 2018. Calibration of DSSAT-CERES-Rice model for rice cultivars under different N-levels in Meghalaya, India. *J. Agrometeorol. 20*(4): 322.

KAU [Kerala Agricultural University]. 2016. *Package of Practices Recommendations: Crops* (15^{th} Ed.). Kerala Agricultural University, Thrissur, 392p.

Kaur, S and Singh, M. 2020. Modeling the crop growth - A review. *Mausam*. 71:103-114

Kim, J., Shon, J., Lee, C. K., Yang, W., Yoon, Y., Yang, W. H., Kim, Y. G. and Lee, B. W. 2011. Relation between grain filling duration and leaf senescence of temperature rice under high temperature. *Field Crops Res.*122(3): 207-213.

Korres, N. E., Norsworthy, J. K., Burgos, N. R. and Oosterhuis, D. M. 2017. Temperature and drought impacts on rice production: An agronomic perspective regarding short-and long-term adaptation measures. *Water resour. rural dev.* 9: 12-27.

Kumari, A., Prasad, R. and Prasad, D. 2018. Effect of weather parameters on incidence and abundance of gall midge (*O. oryzae*) in rice (var TN-I) grown in Ranchi, Jharkhand. *J. Entomol. Zool. Stud.* 6(4): 1329-1331.

Lee, D. J., Shim, I. S., Seo, J. H., Cho K. J and Chae, J. C. 1994. Growth and grain yield of infant seedling in rice as affected by different planting dates in Southern Alpine area.. *J. Agric. Sci. Rice*. 36(1): 1-7.

Liu, X., Huang, Z., Li, Y., Xie, W., Li, W., Tang, X., Ashraf, U., Kong, L., Wu, L., Wang, S., Mo, Z. 2019. Selenium-silicon (Se-Si) induced modulations in physio-biochemical responses, grain yield, quality, aroma formation and lodging in fragrant rice. *Ecotoxicol. Environ. Saf*. 15: 110:196.

Liu, S., Xu, X., He, P., Pampolino, M.F., Li, Y., Xie, J., Hou, Y. and Zhou, W. 2016. Narrowing yield gaps and increasing nutrient use efficiencies using the Nutrient Expert system for maize in Northeast China. *Field Crops Res.* 194:75-82.

Lobell, D. B., Field, C. B. 2007. Global scale climate - crop yield relationships and the impacts of recent warming. *Environ. Res. Lett*. 2: 14–21.

Magunmder, S. K. G., Ali, M. P., Choudhury, T. R., and Rahin, S. A. 2013. Effect of variety and transplanting dates on the incidence of insect pests and their natural enemies. *World J. Agric. Sci.* 1(5): 158-167.

Mahajan, Gulshan, T. S. Bharaj, and J. Timsina. 2009. Yield and water productivity of rice as affected by time of transplanting in Punjab, India. *Agric. Water Manag.* 96 (3): 525-532.

Mahmood, N., Hussain, A., Akhtar, B., Ahmad, A. H. and Saleem, M. 1995. Effect of transplanting date and irrigation on rice paddy yield. *Sci. Tech. Dev*. 14(3): 49-52.

Mani, M. and Noori, A. 2015. The effect of sowing date and plant density on growth analysis parmeters of cowpeas. *Indian J. Fundamentals Appl. Life Sci*.[e-journal] 5(1). Available: http://www.cibtech.org/jls.html. [Jan-Mar 2015]

Mannan, M.A., Bhuiya, M.S.U., Akhand, M.I.M. and Rana, M.M., 2012. Influence of dates of planting on the growth and yield of locally popular traditional aromatic rice varieties in boro season. *J. Sci. foundation*. 10(1): 20-28.

Matthew, B. E., Kenneth, G. C., Yung, H., and Grassini. 2016. Yield gap analysis in US rice production system shows opportunities in US rice production system shows opportunities for improvement. *Field Crop Res*. 196: 276-283.

Medhi, A. K., Chetia, S. K., Dey, P. C., and Ghose, T. J. 2016. Physiological analysis of growth characteristics, dry matter partitioning and productivity in hybrid rice (*Oryza sativa* L.). *Res. Crops*. 17(1): 16-20.

Monteith, J. L. 1996. The quest for balance in crop modelling. *Agron. J.* 88: 695-697.

Mousanejad, S., Alizadeh, A., and Safaie, N. 2009. Effect of weather factors on spore population dynamics of rice blast fungus in Guilan Province. *J. Plant Prot. Res.* 49(3): 319-329.

Nahar, K., M. Hasanuzzaman and R. R. Majumder. 2009. Effect of low temperature stress in transplanted aman rice varieties mediated by different transplanting dates. *Acad. J. Plant Sci.* 2(3): 132-138.

Nakagawa, H., Horie, T. and Matsui, T. 2003. Effects of climate change on rice production and adaptive technologies. In International Rice Research Conference,, Beijing, China, 16-19 September 2002. International Rice Research Institute. pp. 635-658.

Naziya. 2014. Simulation of environmental and varietal effects in rice using CERES model. MSc. (Ag) thesis, Kerala Agricultural University, Thrissur, 148p.

Orcutt, D. M. and Nelson, E. T. 2000. The physiology of plants under stress, soil and biotic factors. John Wiley and Sons, Inc., 605 3rd Avenue, New York, NY, pp. 683.

Pandey, K. K., Rai, V. N., Sisodia, B. V. S., Singh, S. K. 2015. Effect of weather variables on rice crop in eastern Uttar Pradesh, India. *Plant Arch.*15(1) : 575-579.

Patel, A. R., Patel, M. L., Patel, R. K., Mote, B. M. 2019. Effect of different sowing dates on phenology, growth and yield of rice– a review. *Plant Arch.* 19(1):12-16.

Patel, H. R., 2004. Simulation modelling of wheat (cv. gw-496) yield using CERES-wheat model in varied environmental and moisture regimes of middle Gujarat agro-climatic region. (Doctoral dissertation, Anand Agricultural University, Anand). 273p.

Pattnayak, A. and Kumar, K. K. 2014. Does weather sensitivity of rice yield vary across sub-regions of a country? Evidence from Eastern and Southern India. *J. Asia Pacific Econ.*3: 1-22.

PAU [Punjab Agricultural University]. 2020. Package of Practices for The Crops in Punjab. Punjab Agricultural University, Ludhiana. 180p.

Pazhanisamy, S., Narayanan, A., Sridevi, V., Singh, A and Singh, A., K. 2020. Effect of weather parameters on yield and yield attributes under aerobic rice cultivation during navarai season. *Curr. J. Appl. Sci. Technol.* 39(7): 115-121.

Pinnschmidt, H. O., Chamarerk, V., Cabulisan, N., Pena, F. D., Long, N. D., Savary, S., Klein-Gebbinck, H. W. and Teng, P. S. 1997. Yield gap analysis of rain fed lowland systems to guide rice crop and pest management. In: Applications of systems approaches at the field. *Springer*. Pp.321-338

Power, J. F., Willis, W. O., Grunes, D. C., and Reichman, G. A. 1967. Effect of soil temperature, phosphorus and plant age on growth analysis of barley. *Agron J.* 59: 231-234.

Rabbinge, R. 1993. The ecological background of food production. In Ciba Foundation Symposium . pp. 1-2

Ramaraj, A. P., Jagannathan, R. and Dheebakaran, G. 2013. Impact of climate change on rice and groundnut yield using précis regional climate model and DSSAT crop simulation model. ISPRS Archives XXXVIII-8/W3. Workshop Proceedings: Impact of Climate Change on Agriculture. pp: 143-146.

Rana, R., Singh, G., Tanwar, A. K. and Kumar, R. 2017. Effect of weather parameters on the infestation of yellow stem borer, *Scirpophaga incertulas* Walker in basmati rice. *J. Entomol. Zool. Stud*. 5(3): 24-27.

Rani B. A., and Maragatham, N. 2013. Effect of Elevated Temperature on Rice Phenology and Yield. *Int. J. Sci. Technol*. 6(8): 5095-5907

Ravindran, A. 2018. Comparison of different weather based models for forecasting rice yield in central zone of Kerala. MSc. (Ag) thesis, Kerala Agricultural University, Thrissur. 213p.

Ray, M., Roul, P. K., and Baliarsingh, A. 2018. Application of DSSAT crop simulation model to estimate rice yield in Keonjhar district of Odisha (India) under changing climatic conditions. *Int. J. Curr. Microbiol. App. Sci.* 7 (4): 659-667.

Reza, F., H.R. Mobasser, A. A. Dehpor and Kochaksarai, S. T. 2011. *Afr. J. Agric. Res.* 6(11): 2571-2575.

Sadras, V. O., Cassman, K., Grassini, P., Bastiaanssen, W. G. M., Laborte, A. G., Milne, A. E., Sileshi, G. and Steduto, P. 2015. *Yield gap analysis of field crops: Methods and case studies*. FAO Water Reports No. 41, Rome, Italy. 50p.

Saseendran, S. A., Singh, K. K., Rathore, L. S., Singh, S.V. and Sinha, S. K. 2000. Effects of climate change on rice production in the tropical humid climate of Kerala, India. *Clim. Change 44*(4): 495-514.

Satish, J. V., Ajithkumar, B., Laly John, C., and Vysakh, A. 2017.Heat units requirement for different rice varieties in the central zone of Kerala.*Contemporary Res. India*,

Shahid, M. Q., Li, Y. J., Saleem, M. F., Naeem, M., Wei, C. M. and Liu, X. D. 2013. Yield and yield components in auto tetraploid and diploid rice genotypes (*indica* and *japonica*) sown in early and late seasons. *Aust. J. Crop Sci.* 7(5): 632-641.

Shakoor, U., Saboor, A., Baig, I., Afzal, A. and Rahman, A. 2015. Climate variability impacts on rice crop production in Pakistan. Pak. *J. Agric. Res.* 28: 1-8.

Sharma, K. R., Raju, S.V. S., Singh, K. N. and Roshan, D. R. 2019. Effects of environmental factors on population dynamics of rice ear head bug and their management with newer insecticide combinations and sole insecticide. *Bangladesh J. Bot. 48*(4): 973-979.

Sheehy, J. E., Elmido, A., Centeno, G. and Pablico, P. 2005. Searching for new plant for climate change. *J. Agrometeorol*. 60: 463–468.

Shimono, H. and Ishii, A., 2012. Poor grain growth in rice under high temperatures affected by water temperature during vegetative stage. *J. Agric. Meteorol. 68*(4): 205-214.

Shyamrao, I. D. and Raghuraman, M. 2019. Effect of abiotic factors on incidence of leaf folder, *Cnaphalocrocis medinalis* (L.) in rice ecosystem of Varanasi region. The *Pharma Innovation J.* 8(3): 31-34

Singh, P. K., Singh, K. K., Baxla, A. K., Kumar, B., Bhan, S. C. and Rathore, L. S. 2013. Crop yield prediction using CERES-Rice vs 4.5 model for the climate variability of different agro climatic zone of south and north-west plane zone of Bihar (India). *Mausam*. 65(4):529-538

Singh, S., Singh, R. K., and Singh, R.2013. Enhancing rice and wheat production by bridging yield gap in western Uttar Pradesh of India. *J. Wheat Res*. 5(2): 43-47.

Sridevi, V. and Chellamuthu, V. 2015. Impact of weather on rice – A review. *Int. J. Appl. Res*. 1(9): 825-831.

Subramanyam, G., Sunil, K. M., Ajithkumar, B. and Ajayan, K. V. 2019. Climate Change Impact on kharif Rice Production in Central Agro-Climatic Zone of Kerala under Different Representative Concentration Pathways. *Environ. Ecol*. 37: 143-148.

Sun, Q., Zhao, Y., Zhang, Y., Che, X., Yang, Z., Song, Y. and Zheng, X. 2020. Improvement of the CERES-Rice model using controlled experiments and a Meta-analysis.

Taleshi, K., Nooshin, Osoli, and Moradi, M. 2013. Rice Growth Pattern Analysis in Fish-Rice Culture. *World Appl. Sci. J.* 22(7): 1019-1023.

Thiyagarajan, T.M. and Selvaraju, R. 2001, April. Water saving in rice cultivation in India. In Proceedings of an international workshop on water saving rice production systems. Nanjing University, China. 9: 15-45.

Timsina, J., Pathak, H., Humphreys, E., Godwin, D., Singh, B., Shukla, A. K., and Singh, U. 2004. Evaluation of, and yield gap analysis in rice using, CERES Rice Ver. 4.0 in northwest India. In: Pathak, H. (ed), New directions for a diverse planet. Proceedings of the 4th international crop science congress Brisbane, Australia, pp.1-7

Timsina, J and Humphrey, E. 2010. Application of CERES rice and CERES wheat in research policy and climate change studies in Asia: A Review. *Int. J. Agric. Sci*.5(8): 587-610.

Van Ittersun, M.K., Cassman, K.G., Grassini, P., Wolf, J., Tittonell, P. and Hochman, Z. 2013. Yield gap analysis with local to global relevance—a review. *Field Crops Res.* 143:4-17.

Vysakh, A., Ajithkumar, B., and Rao, A. V. M. S. 2015. Evaluation of CERES-Rice model for the selected rice varieties of Kerala. *J. Agrometeorol.* 18(1): 120-123.

Wahid, A., Gelani, S., Ashraf, M., and Foolad, M. R. 2007. Heat tolerance in plants: an overview. *Environ. Exp. Bot.* 61:199–223.

Wani, S. A., Qayoom, S., Bhat, M. A., Lone, B. A. and Nazir, A. 2016. Influence of sowing dates and nitrogen levels on growth yield and quality of scented rice cv. Pusa Sugandh 3 in Kashmir valley. *J. Appl. Nat. Sci.* 8(3): 1704-1709.

Wart, J., Kersebaum, K. C., Peny, S., Milna, M., and Cassman, K. 2013. Estimation of crop yield potential at regional to national scale. *Field Crops Res*. 143:34-43.

Wassmann, R., Jagadish, S. V. K., Sumfleth, K., Pathak, H., Howell, G., Ismail, A., Serraj, R., Redona, E., Singh, R. K. and Heuer, S. 2009. Regional vulnerability of climate change impacts on Asian rice production and scope for adaptation. *Adv. Agron*., 102: 91-133.

Watson, D. J. 1956. The dependence of net assimilation rate on leaf area index. *Ann. Bot.* 18: 29-31.

Williams, R. F. 1946. The physiology of plant growth with special reference to the concept of net assimilation rate. *Ann. Bot.* 10: 41-72.

Willmott, C. J. 1982. Some comments on the evaluation of model performance. *Bull. Am. Meteorol. Soc. 63*(11): 1309-1313.

Yadav, M., Prasad, R., Kumar, P. and D Pandey, C. 2018. Effect of dates of transplanting on the incidence of green leaf hopper (GLH), *Nephotettix virescens* (Distant) & N. *nigropictus* (Stal) in rice field, Jharkhand. *J. Pharmacogn. Phytochem*. 7(SP1): 897-900.

Yashoda, H., Anahosur, K. H., and Srikant, K. 2000. Influence of weather parameters on the incidence of false smut of rice. *Adv. Agric. Res. India*. 14: 161-165.

Yin, X. and Kropff, M. J. 1996. The effect of temperature on leaf appearance in rice. *Ann. Bot.* 77(3): 215-221.

Yoshida, S. and Parao, F.T., 1976. Climatic influence on yield and yield components of lowland rice in the tropics. *Clim. rice*. 20: .471-494.

Yoshida, S., Satake, T. and Mackill, D.S., 1981. High-temperature stress in rice [study conducted at IRRI, Philippines]. *IRRI Research Paper Series (Philippines)*. 15p.

Zhang, H., Tao, F. and Zhou, G., 2019. Potential yields, yield gaps, and optimal agronomic management practices for rice production systems in different regions of China. *Agric. Syst.* 171:100-112.

Appendices

Appendix I

Abbreviations and units used

Weather parameters

Tmax : Maximum temperature

Tmin : Minimum temperature

Trange : 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

Epan : Pan evaporation

BSS : Bright sunshine hours

Phenophases

T – AT : Transplanting – active tillering

T – PI : Transplanting – panicle initiation

T – B : Transplanting – booting

T – H : Transplanting - heading

T – F : Transplanting - flowering

T - PM: Transplanting- Physiological maturity

Varieties

Jy – Jyothi

Ja - Jaya

Units

g : gram

kg : kilogram

km hr^{-1}: kilometre per hour

^0C : degree Celsius

kg ha^{-1} : kilogram per hectare

% : %

Growth indices

LAI – Leaf area index

LAD – Leaf area duration

CGR – Crop growth rate

NAR- Net assimilation rate

Appendix II

ANOVA of different plant growth characters of 2019 experiment

Plant height at different weeks after planting

Source of variation	DF	Mean sum of squares							
		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
Dates of planting	4	53.66***	188.70***	506.16***	651.36***	692.23***	905.09***	721.89***	553.34***
Error(a)	12	1.40	4.22	7.99	5.57	3.95	1.59	4.09	3.05
Variety	1	8.79*	0.006 NS	6.03 NS	46.89*	77.53***	14.22*	85.81***	59.39***
DOP x Variety	4	7.72**	4.39 NS	51.05***	24.71*	80.85***	8.94**	77.87***	46.32***
Error(b)	15	1.15	2.80	5.68	6.83	2.58	1.70	3.87	2.54

Source of variation	DF	Mean sum of squares				
		Week 9	Week 10	Week 11	Week 12	Week 13
Dates of planting	4	275.99***	191.7***	159.75***	133.75***	131.93***
Error(a)	12	3.50	2.48	2.44	1.11	1.15
Variety	1	54.46***	36.73***	3.35 NS	7.93**	20.57***
DOP x Variety	4	35.93***	13.91***	6.60**	1.44 NS	2.70**
Error(b)	15	1.56	1.34	1.30	0.70	0.49

DF – degrees of freedom -***Significant at 0.1% level -** Significant at 1% level -* Significance at 5% level

Appendix II (contd.)

Dry matter accumulation at fortnightly intervals

Source of variation	DF	Mean sum of squares					
		15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT
Dates of planting	4	52297***	6982***	1124292 NS	31446140***	19216944***	9625410***
Error(a)	12	3169	757158	1972631	336968	249462	545877
Variety	1	4792 NS	55629***	210857120***	391569850***	651060040***	480533903***
DOP x Variety	4	86974***	47226993*	975473 NS	3412849***	2325937***	847454***
Error(b)	15	1763	113874	1502360	160666	92446	78220

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

Source of variation	DF	Mean sum of squares						
		Grain yield	Panicles per m^2	Spikelets per panicle	Number of filled grains per panicle	1000 grain weight	Straw yield	Tillers per m^2
Dates of planting	4	10807008***	327773 NS	5735.0***	1063.6**	60.119***	1450666 NS	8352.7*
Error(a)	12	76177	1537.8	303.0	118.3	5.081	968186	2519.9
Variety	1	1158650**	7209.2*	2303.6**	4351.2***	3.306 NS	849723 NS	2829.9 NS
DOP x Variety	4	315625*	2758.0	851.8**	82.5 NS	9.579**	33590 NS	5935.8*
Error(b)	15	70693	1285.2	162.5	115.6	1.363	327773	1299.5

DF – degrees of freedom -***Significant at 0.1% level -** Significant at 1% level -* Significance at 5% level DAT – days after planting

Appendix II (Contd.)

Leaf area index at fortnightly intervals

Source of variation	DF	Mean sum of squares					
		15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT
Dates of planting	4	0.013*	0.064 NS	0.08 NS	1.120***	2.660***	1.8491***
Error(a)	12	0.003	0.064	0.038	0.048	0.136	0.1126
Variety	1	0.246***	4.244***	12.818***	30.334***	0.136***	31.2877***
DOP x Variety	4	0.003 NS	0.002 NS	0.010 NS	0.185*	0.341***	0.1955***
Error(b)	15	0.001	0.004	0.011	0.038	0.024	0.0160

Leaf area duration at fortnightly intervals

Source of variation	DF	Mean sum of squares				
		15-30 DAT	30-45 DAT	45-60 DAT	60-75 DAT	75-90 DAT
Dates of planting	4	23.847 NS	47.23 NS	366.556***	1427.996***	460.505***
Error(a)	12	27.791	51.58	86.504	115.072	16.424
Variety	1	366.025***	1787.569***	4646.18***	10817.52***	10946.17***
DOP x Variety	4	1.482 NS	3.156 NS	59.236**	171.809***	54.277***
Error(b)	15	4.353	15.165	42.079	73.92	2.846

DF – degrees of freedom -***Significant at 0.1% level -** Significant at 1% level -* Significance at 5% level DAT – days after planting

Appendix II (contd.)

Crop growth rate at fortnightly intervals

Source of variation	**DF**	**Mean sum of squares**				
		15-30 DAT	30-45 DAT	45-60DAT	60-75 DAT	75-90 DAT
Dates of planting	4	32.07***	41.42 NS	1764.77***	280.5**	351.31**
Error(a)	12	2.73	16.49	29.65	31.70	51.86
Variety	1	1063.26***	849.31NS	0.00NS	345.46 NS	107.89***
DOP x Variety	4	13.16***	9.99***	56.10***	18.15***	11.23 NS
Error(b)	15	1.59	5.42	5.64	10.77	6.09

Net assimilation rate at fortnightly intervals

Source of variation	**DF**	**Mean sum of squares**				
		15-30 DAT	30-45 DAT	45-60DAT	60-75 DAT	75-90 DAT
Dates of planting	4	3.62	5.69*	8.33***	18.41***	2.35*
Error(a)	12	2.70	1.22	0.43	1.67	0.68
Variety	1	159.00**	8.74	0.41	2.42	.01
DOP x Variety	4	4.84*	0.45*	0.13	4.79***	0.08
Error(b)	15	1.16	0.59	0.19	0.57	0.05

DF – degrees of freedom -***Significant at 0.1% level -** Significant at 1% level -* Significance at 5% level DAT – days after planting

ANALYSIS OF POTENTIAL YIELD AND YIELD GAP OF RICE (*Oryza sativa* L.) USING CERES RICE MODEL

by
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ABSTRACT OF THE THESIS

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ABSTRACT

Rice has shaped the culture, diet and wealth of millions of people. For more than half of population around the globe "Rice is life". It is the staple food for more than half of the global population. A world population that will exceed 9 billion by 2050 will require an estimated 60 % more food. World production of rice was 495.9 million metric tons during 2019. There is an urgent need to boost current agricultural productivity. Assessing the yield gap of existing cropped lands will indicate the possible extend of yield increase from current value. Crop weather models are a promising tool for estimating yield gap, identifying causes of yield gap and evaluating proper management strategies to reduce the gap.

The present study was aimed to analyze potential yield and yield gap among two rice varieties and to suggest proper management practices to reduce gap. Two varieties of rice, Jyothi and Jaya were raised at Agricultural Research Station, Mannuthy during *kharif* season by adopting split-plot design. Five planting dates such as June 5th, June 20th, July 5th, July 20th and August 5th were used as main plot treatments and the two varieties were used as subplot treatments. The replication number used for this experiment was four.

During the field experiment, daily weather data were collected like maximum temperature, minimum temperature, relative humidity, rainfall, bright sunshine hours, wind speed and evaporation. Biometric observations like plant height, leaf area, dry matter accumulation, number of tillers per unit area, number of panicles per unit area, number of spikelet per panicle, number of filled grains per panicle, thousand grain weight, straw yield and grain yield were observed. Duration of different phenophases was noted. Duration of phenophases, yield and yield attributes were found to be significantly influenced by weather parameters recorded during each phenophases. Considerable variation among biometric observations was noticed during the field experiment. Plant height was higher for Jyothi compared to Jaya and it showed variation among different planting dates. Maximum dry matter accumulation was recorded during 75 days after planting and it was higher for August 5th planting. Compared to Jaya dry matter accumulation was more in Jyothi. Effect of dates of

planting was significant in all yield attributes except for the number of panicle and straw yield. The grain yield obtained during June 5th (4418 kg ha^{-1}) and June 20th (4029 kg ha^{-1}) planting were on par irrespective of variety.

The potential yield was simulated by CERES model. Attainable yield was the yield obtained from the experimental plot, where management practices as suggested by KAU was followed. Actual farmer's yield was collected from the survey and ECOSTAT report, 2019. Total yield gap was calculated by taking the difference between potential yield and actual farmer's yield. Total yield gap was split into two components, yield gap I (YGI = Potential yield – Attainable yield) and yield gap II (YGII = Attainable yield – Actual yield). Total yield gap estimated for Jaya was 3457 kg ha^{-1} and for Jyothi was 3357 kg ha^{-1}. YGI calculated for Jaya and Jyothi was 1740 kg ha^{-1} and 2078 kg ha^{-1} respectively. YGII calculated for Jaya and Jyothi was 1717 kg ha^{-1} and 1279 kg ha^{-1} respectively.

Yield responses under various nitrogen management conditions were simulated using CERES model. Yield simulated under three split doses of nitrogen was more in all dates of planting in the case of Jaya. In case of Jyothi, yield increase under 3 split nitrogen doses was more under first three dates of planting whereas during last two dates of planting it was less. The model simulated yield was found to be increased with an additional supply of nitrogen input. As per the model output, the optimum dose of nitrogen to get higher yield (5572 kg ha^{-1} for Jaya and 5387 kg ha^{-1} for Jyothi) was found to be 130 kg ha^{-1}. The model was used to compare the fertilizer application methods like broadcasting, using urea super granules and together with irrigation water. As per the model output the yield simulated for general amount of nitrogen applied (90 kg ha^{-1} for Jaya and 70 kg ha^{-1} for Jyothi was) was more when fertilizer was applied through irrigation water.