# Crop weather relationship of rice varieties under different growing environments

By
**HARITHARAJ S.**
**(2017-11-094)**

**THESIS**

**Submitted in partial fulfillment of the requirement for the degree of**

***MASTER OF SCIENCE IN AGRICULTURE***

**Faculty of Agriculture**

**Kerala Agricultural University**

**Department of Agricultural Meteorology**

**COLLEGE OF HORTICULTURE**

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

**2019**

# DECLARATION

I hereby declare that this thesis entitled **"Crop weather relationship of rice varieties under different growing environments"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

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# CERTIFICATE

Certified that this thesis entitled **"Crop weather relationship of rice varieties under different growing environments"** is a bonafide record of research work done independently by **Ms. Haritharaj S. (2017-11-094)** 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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We, the undersigned members of the advisory committee of **Ms. Haritharaj S. (2017-11-094)**, a candidate for the degree of **Master of Science in Agriculture** with major field in Agricultural Meteorology, agree that this thesis entitled **"Crop weather relationship of rice varieties under different growing environments"** may be submitted by **Ms. Haritharaj S.** in partial fulfillment of the requirement for the degree.

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## ACKNOWLEDGEMENT

*This thesis is the end of my journey in gaining my degree on M.Sc. Agricultural Meteorology, fulfilling my passion towards the subject. It was rough and tough, that ensured innumerous troubles in this journey, which was well figured out, with enormous support and inspiration from various people. Time and determination being the most valuable things we can offer someone, all these people fed me with both which I value to be precious throughout the last two years. At the end of this, I would like to thank all those people who made this thesis possible and a memorable experience for me. It is a pleasant task to express my thanks to all those who made contribution in this memoir of hard work and effort.*

*First and foremost, I owe my heartful gratitude towards the almighty, for showering his boundless grace towards the testing situations of this period.*

*I would primarily like to express sincere gratitude whole-heartedly to my esteemed guide* **Dr. B. Ajithkumar**, *Assistant Professor of Agricultural meteorology, for guiding me in getting an opportunity to work as a research scholar under his valued and meticulous leadership. I always respected his unique approach, constant encouragement, valuable suggestions, intellectual freedom that has led me in the right direction in all ways.*

*It is with my heartfelt feelings, I wish to express my deep sagacity of gratitude and sincere thanks to* **Dr. P. Lincy Davis**, **Dr. P. Shajeesh Jan** *and* **Dr. Latha A.**

*I extend my sincere thanks to* **Dr. Laly John C**. *Professor and Head, Department of Agricultural statistics for her meticulous care, scientific advice and mentor for my M.Sc. study. Her guidance helped me throughout research. I thank her for having shaped me to take up a good carrier in Agricultural Meteorology.*

*I owe a great deal of appreciation and gratitude to thank my dearest friends and staffs of the department* **Deen chechi, Suchitra chechi**, **Likhitha chechi**, **Shahimol itha**, **Mini chechi** *and* **Anu chechi** *in providing their efforts during my on field and off field studies. I shall be missing something if do not extend my admiration and appreciation to* **Mr. Arjun Vysakh** *in his master guidance to the technical world of crop modelling. The mention and special thanks shall be valued for* **Biju Kuruvila** *for his assistance, and the labours of ARS in the physical support they provided me.*

Thanks should really be extended towards the modest efforts put forwarded by my dear friends **Radhika, Anitta, Anasooya, Aliya, Anunayana, Linu, Reshmi, Sajay, Anirudh, Alan, Syam**, **Amal, Anil** in the valuable efforts for me. I would also like to thank some people from early days of my research tenure who immensely supported me both physically and mentally, my dear **Jyothish, Harithalekshmi, Aswathy, Vinu, Hubaib, Jesma, Agina, Anusha, Amrita, Pournamy, Krishna veni, Kailas** and **Vivek ettan.**

I express my thanks to office staff members of our department very particularly to **Mr. Gangadharan, Mr. Poulose, Sreejith** and beloved seniors **Athira chechi, Navya chechi** and **Aswathy chechi** for their support during my research programme. Thanks are extended to the expert dignitaries **Dr. Berin Pathrose** for his valuable guidance. I would like to record my special thanks to **Shakeela mam, Aravindettan** and **Rajitha chechi** for their valuable support during the thesis

I acknowledge the whole-hearted co-operation and gracious help rendered by each and every member of the **College of Horticulture** during the period of study.

Finally, yet importantly, I extend my heartiest and sincere sense of gratitude to my beloved father Mr. **Rajendran**, mother Mrs. **Sujatha**, brother **Vighnesh** and my dear **Ani chettan** and **Remya chechi** for their prayers and mental support for the tough days. For the whole journey, my head bows to Kerala Agricultural University for letting my dreams come true…

**Haritharaj S.**

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# Introduction

# 1. INTRODUCTION

The most important sector of Indian Economy is Agriculture. Indian agriculture sector accounts for 18 per cent of India's gross domestic product (GDP) and more than 50% of population is depend on agriculture as it provides employment to 50% of the countries workforce. According to the reports provided by Department of Agriculture, Cooperation and Farmers Welfare, New Delhi (2017-2018) the production of food grains is 277.49 million tonnes which is increased when compared to (2016-2017) 275.11 million tonnes.

In India, rice production is an important part of the national economy. India is the second largest producer in the world with approximately 43 million hectare planted area, accounting for 22% of the total rice production in this world. Rice is a basic food crop of India and being a tropical plant, it grows in hot and humid climate. Rice is grown in rainfed areas with heavy annual rainfall. Therefore it is fundamentally considered as a *kharif* crop. With assured irrigation it can be cultivated throughout the season.

Weather plays an important role in agricultural production. It has a profound influence on growth, development and yields of crop; on the incidence of pests and diseases; on water needs; and on fertilizer requirements. All physiological functions depends on weather. Weather aberrations may cause physical damage to crops and permits soil erosion. In addition, the quality of crop produce during the movement from field to storage and at the time of transport to market depends on weather conditions. Bad weather may affect negatively to the quality of produce during transport, the viability and vigour of seeds, and planting material during storage. Duration of the crop also depends on weather. Even on a climatological basis, weather factors cause spatial variations in an area at a given time, temporal variations for a given place, and year-to-year variations for a given place and time.

Agricultural research is needed to supply useful information to farmers, policy makers and other decision makers on how to accomplish sustainable agriculture using minimum resources over these wide variations in climate around the world. In this aspect prediction plays an important role in the management of crop practices in response to climate and soil related factors. Quantitative prediction of complex systems is possible only through the integration of available information related to that system. The principal approach for this happens by the construction of statistical and simulation models. Simulating a system with the defining parameters will help to assess the situations going to be faced and can change the route to an appropriate way to get the useful outcome. This is the yield forecasting if we are preparing the simulation models for crops. Reliable crop yield forecasts are important for national food security, including early determination of the import/export plan and price. It is also important in providing timely information for optimum management of growing crops.

A model is a schematic representation of the conception of a system or an act of mimicry or a set of equations, which represents the behaviour of a system. Its purpose is usually to help in explaining, understanding or improving performance of a system. For agriculture, crop simulation models are more important. There are different types of simulation models useful according to the crop type which we are using. Decision support system for agro technology transfer (DSSAT) and its crop simulation models (eg. CERES-Rice model) can be used for this purpose as a research and teaching tool. In the case of rice, the most commonly used model is CERES-Rice model (Crop Estimation through Resource and Environment Synthesis) and is applicable for a range of areas, including crop management and shifting weather patterns. 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.

Different crop weather studies were conducted earlier in Department of Agrl. Meteorology, College of Horticulture, Vellanikkara. This study titled "crop weather relationship of rice varieties under different growing environments" is aimed to identify the influence of weather parameters on short and medium duration rice varieties and to validate the DSSAT and statistical models, essential for the forecasting of rice yields and climate change impact studies.

# Review of Literature

# 2. REVIEW OF LITERATURE

Since rice is the basic food crop of India, the importance of rice production should be considered in this changing climatic conditions as it necessary to feed the entire country. Here comes the significance of prediction which will be useful in reducing the hazardous situations which may affect the yield. This study giving attention to the prediction side through which we can save the outcome. 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. Growth indices
5. Weather influences on the incidences of pests and diseases
6. Crop simulation models
7. Statistical models

## 2.1. Significance of rice cultivation

Rice is the important second most cereal crop in the world. Approximately 495.87 million metric tonnes of milled rice were produced in the last year worldwide. Asian countries have the largest share in worldwide production of rice. According to the latest information, China is the world's chief rice producer with a production of over 210 million metric tonnes in 2017, followed by India.

Rice is produced in more than a hundred countries and have a total harvested area of about 158 million hectares, producing more than 700 million tonnes annually (470 million tonnes of milled rice). The production status of Sub-Saharan Africa is about 19 million tonnes and Latin America is around 25 million tonnes. In the case of Asia and Sub-Saharan Africa, the major rice production is concentrated in the small farms of 0.5–3 ha.

In the year 2009-10r, rice production of India had dropped to 89.14 million tonnes from record 99.18 million tonnes of previous year production due to the incidence of severe drought in major parts of the country. India attained a record rice production of 100 million tonnes during 2010-11 crop year due to high monsoon rainfall received in this year. A record production of 104.32 million tonnes was attained in the crop year 2011-2012 (July–June).

In 2014-15, the total global consumption of milled rice came around 485 million metric tonnes. The consumption rate of China is around 148.4 million tonnes of milled rice per year. On an average, 57.5 kilograms of rice is consumed annually by every human in this world.

From the total world's production, only around 4% is used for international trade (Khush, 1997). World's leading rice exporter is India, marketing about 12.5 million metric tonnes in 2018-19. Thailand is the second largest exporter with 10.3 million metric tonnes exported rice. China, Philippines and Nigeria are the major importers, with 4.5, 2.3 and 2.2 million metric tonnes respectively in the year 2018-19.

The significance of rice varies according to the countries. It comes around 70% of calorie intake per day in countries like Bangladesh, Cambodia, Laos, and Myanmar while it accounts only 40% in countries like China and India who consume more wheat in northern areas. In Western countries, premium price is given for brown or unpolished rice however rice is polished wherever it is staple food. Since the layers of its bran hold oils (free fatty acids) that become rancid if the surface is scraped. So brown rice cannot be kept for more than a week. The digestion and absorption of brown rice is lesser compared to white rice. On the other hand, brown rice contain more B vitamins and 1% more protein.

### 2.2. Effect of weather parameters on growth and yield of rice

Dingkunh *et al.* in 1995 observed that there was a delay in heading and near total sterility of spikelet when there was a drop in minimum temperature below $18^0$C.

In Andhra Pradesh, Lalitha *et al.* (2000) stated the effect of temperature on the duration of tillering in lowland rice varieties. They found that there was a direct influence of prevailing temperature on tillering period during the tillering stage. The daily mean temperature between 22.9 to 25.8°C improved the duration of tillering stage up to 8 weeks whereas after the transplanting, the temperature not less than 26°C reduced the period of tillering to 5 weeks.

Chan and Cheong (2001) conducted a study to know the effect of seasonal weather on crop evapotranspiration and yield of rice. The results showed that there is no significant effect of seeding rate on evapotranspiration (ET). Lower seeding rates were compensated with production of more tillers in each hills. In the main season, the average value of ET/Epan ratio was 1.56 throughout crop growth and during off-season it was about 1.75. There was a difference in ET values between rice varieties and was distinctly higher in the off-season. Direct seeded crop showed a lower yield in the off-season. Crop establishment is more productive by direct seeding than by transplanting in the main season.

Laza *et al.* in 2004 through the experiment conducted in wet season at IRRI found that all rice cultivars during that time possessed small to intermediate panicle size having a range from 63 to 114 spikelets per panicle and panicle size showed the closest relation with the grain yield of rice. They concluded that there is a possibility of increasing the yield by crossing the cultivars with larger panicle size.

Lakshmanan *et al.* (2005) evaluated the effects of duration of variety and nitrogen fertilization on yield and uptake of micronutrients at IARI, New Delhi. Zn, Fe, Mn and Cu uptake was significantly more in medium duration variety PB-1 than in short duration variety PJD-1, mainly due to higher grain and straw yield of the former. Nitrogen fertilization increased the concentration and uptake of Zn, Fe, Mn and Cu by rice.

The impact of high temperature was noticed by Wahid *et al.* (2007) on growth stages of rice and reported that if the growth stage exposed to more high temperature, it results more damages. It was also concluded that, during vegetative as well as reproductive stages the low and high temperatures will lead to reduced tillering, less productive tillers and poor seed set in rice.

Zhang *et al.* (2008) investigated the performance of yield in terms of quality and quantity and water use efficiency (WUE). The activities like root oxidation, photosynthetic rate, and activities of major enzymes in sucrose-to-starch conversion in grains showed significant increase in the grain filling period under the non-flooded wheat straw mulching (SM) compared to traditional flooding, whereas a significant reduction was observed under the non-flooded plastic film mulching (PM) and non-flooded no mulching treatments. They concluded that both SM and PM could significantly increase WUE, while the SM could also maintain a higher grain yield and improve rice quality.

Murthy and Rao (2010) conducted an experiment during two consecutive seasons of *Kharif* 2003 and 2004 at Regional Agricultural Research Station, Jagtial to study the influence of low temperature stress on phenology and yield of *Kharif* rice. Results indicated that the varieties produced significantly higher yield under early sown conditions and the yield progressively declined as the sowings were delayed.

Field experiment was conducted by Sreenivas *et al.* (2010) to study the phenology and, heat and radiation use efficiency of aerobic rice. Results showed that, an accumulated mean growing degree days of 2017+55 and heliothermal units of 11526+817 with coefficient of variation of 3% and 7%, respectively were exhibited by Jagtiala Sannalu from emergence to physiological maturity Whereas Polasa Prabha was accumulated a mean growing degree days of 2102+33 and heliothermal units of 12031+716 from emergence to physiological maturity with 2 % and 6% as coefficient of variation respectively. Both the cultivars were showed a higher heat use efficiency (6.61 and 6.29), heliothermal use efficiency (1.30and 1.19) and radiation use efficiency (6.28 and 5.88) during June $16^{th}$ sowing.

Elanchezhian *et al.* (2012) analyzed the impact of climate change on growth and yield of three rice varieties differing in duration using simulation model InfoCrop at Bihar. The reproductive development of rice delayed by elevated $CO_2$ Higher Crop Growth Rate and Leaf Area Index were recorded in short and medium duration variety under future climate change scenario and in long duration variety maximum yield projected at 2020.

Mahajan *et al.* (2012) proved that with the application of P and K fertilizers at 120 kg N ha$^{-1}$, grain yield with irrigation threshold increasing from 10 to 20 kPa did not decrease, which leading to substantial savings in irrigation water at Ludhiana during summer season. Application of P and K fertilizers along with 120kg N ha$^{-1}$ at the soil moisture potential of 20 kPa, resulted in an increase of 14% rice yield. It was inferred that, in dry-seeded rice, the addition of P and K with N could compensate for the yield loss under water-stress conditions.

To know the effect of prevailing environments and genotype on the phenology and performance of rice Singh *et al.* (2012) conducted an experiment for two years. They proved that for better growth, development and more biomass, first year was more favourable. Moreover for maximum economic produce (grain yield) second year was better probably due to the favourable environmental conditions during the reproductive phase. Thermal time requirements (TTR) were maximum during the first year for the period between sowing to tillering (1142.4 heat units) and were recorded minimum (486.5 heat units) for the period between anthesis to maturity with last date of transplanting.

Effects of change in weather conditions on the yields of Basmati 370 and IR 2793-80-1 cultivated under System of Rice Intensification (SRI) in Mwea and Western Kenya irrigation schemes were evaluated (Nyang'Au *et al.*, 2014) through sensitivity analysis using the CERES-Rice model v 4.5 of the DSSAT modeling system. The study showed that an increase of both maximum and minimum temperatures affects Basmati 370 and IR 2793- 80-1 grain yield under SRI. An increased grain yield was observed for both Basmati and IR 2793-80-1 under SRI due to an increase in atmospheric CO2 concentration as well as an increase in solar radiation.

Pandey *et al.* (2015) determined the individual and combined effect of weather variables on rice yield. They found that individually sun shine (hrs) is more important with 67.57 subsequently wind velocity and rainfall with 48.63 and 46.74 respectively, on the basis of R2. The combined effect of weather variables is also playing an imperative role in case of rice crop. According to R2 more important combination is rainfall & wind velocity with 82% followed by rainfall & sunshine hours and wind velocity & sun shine hours 63% and 53.8, respectively.

**2.3. Effect of dates of planting on growth and yield of rice**

The rice varieties planted on 5 to 10th January and 20 to 25th December produced more and yield of 3.7 and 2.6 t $ha^{-1}$ were observed during 1985 1986 respectively (Maity and Mahapatra, 1988). Yield was reduced due to the high temperature prevailed during early and late transplanting stages.

In 2003, Slaton *et al.* determined the influence of seeding date on rice yield for two geographical areas in USA. Yield data were collected from Stuttgart, AR, and Crowley, LA, and were compared with modern cultivars for studies conducted in the 1990s and from the 1960s and 1970s with older cultivars. Maximum grain yield was produced by modern rice cultivars when seeded from 16 February at Crowley, LA, and 29 March at Stuttgart, AR. In 1960s and early 1970s, older cultivars showed similar yield, but slightly later optimum seeding dates.

Ghosh *et al.* in 2004 determined the effect of two planting dates and four fertilizer levels on aromatic rice cultivars during the dry seasons of 1995/96 and 1996/97, while nine cultivars were evaluated during the wet seasons of 1996 and 1997. It was observed that delayed planting (23 February) significantly reduced the grain yield by 0·88 t/ha, amylose content by 0·5% and duration by 10 days whereas it increased the summed heliothermal units. Thus, the cultivars became less capable (27%) in heat use with delay in planting from 2 to 23 February.

Baloch *et al.* in 2006 found the effect of transplanting time and seedlings $hill^{-1}$ on the productivity of rice in Dera Ismail Khan District, Pakistan. They used 1, 2, 3 or 4 seedlings $hill^{-1}$ as subplot treatments against four transplanting dates viz. 20th and 27th of June and 4th and 11th of July as main plots. June 20th transplanted crop gave highest yield and net return with 1 seedling $hill^{-1}$. Based on the experiment

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they concluded that 1 seedling hill$^{-1}$ is most suitable for timely sowing and 4 seedlings hill$^{-1}$ used to compensate for the yield gap in late transplanted rice.

Mahajan *et al.* in 2009 aimed at investigating the effect of transplanting date in four rice cultivars (short-duration RH-257 and PR-115, and medium-duration PR-113 and PAU-201) on yield and water productivity. A delay in date of transplanting from 15$^{th}$ June to 25$^{th}$ June or 5$^{th}$ July resulted in a yield reduction of four cultivars by 7.2% and 15.9% respectively. Short-duration cultivars, saved 18.9% and 16.6% of water, compared to medium-duration cultivar PR-113 irrespective of date of transplanting. With delay in transplanting, both yield and water productivity showed a reduction for all photoperiod insensitive cultivars, whereas for a photoperiod sensitive cultivar, yields remained statistically similar and water productivity were higher.

To evaluate the effect of sowing dates on yield and yield components of the direct sown coarse rice, a field experiment was conducted by Bashir *et al.* in 2010 during *kharif* season of 2008, at University of Agriculture, Faisalabad. The experiment was carried out with six sowing dates i.e. 31$^{st}$ May, 10$^{th}$ June, 20$^{th}$ June, 30$^{th}$ June, 10$^{th}$ July and 20$^{th}$ July. Results showed that for obtaining maximum grain yield and net return, direct seeded rice sown on June 20$^{th}$ proved to be the best among the six sowing dates. This also gave maximum number of productive (panicle bearing) tillers, number of kernels per panicle, 1000-grain weight and benefit-cost ratio.

In order to investigate the effect of planting date and planting density on rice, a field experiment was carried out by Moradpour *et al.* in 2013. Results showed that grain yield was increased with an increase in plant density and there was a decrease in grain yield with delayed planting date. Most grain yield was related to May 30$^{th}$ and June 9$^{th}$ planting dates (6357 and 6264 kg ha$^{-1}$ respectively). Minimum grain yield was obtained during June 19$^{th}$ planting (5576 kg ha$^{-1}$). With increasing planting density, total dry matter, crop growth rate, leaf area index were increased. With delayed planting date, total plant dry matter, leaf area index and crop growth rate were increased.

Dharmarathna *et al*. (2014) simulated the effect of change in planting date on the yield of dry season rice using the software Decision Support System for Agrotechnology Transfer (DSSAT 4.5) for four rice varieties grown in Sri Lanka under probable climate change. Results showed that the yield of seasonally averaged dry season rice would rise compared to the base condition when the planting date is advanced by 1 month whereas the seasonally averaged rice yield would decline compared to the base condition when there is a delay in planting date by 1 month for all four varieties. Advancing the rice planting date by 1 month for all four rice varieties can be identified as a non-cost climate change adaptation strategy for rice production.

Ali *et al.* (2015) analyzed the response of different rice cultivars to different transplanting dates through an experiment conducted at Allahabad. In case of cultivars transplanted during mid of July, a higher yield was recorded when there was an observed temperature of $35^0$C. But the lowest yield was recorded for the cultivars transplanted during first week of August and the temperature was $30^0$C. They inferred that it is unfavourable for planting rice during late season.

There was a reduction of 5-10% yield of rice transplanted in normal date ($4^{th}$ week of May) with increase in temperature up to $2^0$C (Biswas *et al.*, 2018). They proved that the decrease in yield occurred primarily due to lower LAI all over the growth stages of crop and reduced crop growth period under raised thermal condition. They suggested that for getting higher yield in *kharif* rice for the study area, there should be sowing of rice before $15^{th}$ July.

## 2.3. Growth indices

Wilson in 1966 concluded that ideal temperature for net assimilation rate was between 20° and 30°C, and it was lower for rape and higher for maize. Net assimilation rate showed a variation with temperature by ± 10 per cent between 12° and 30°C for rape and for maize, in between 23° and 36°C in moderate to warm conditions. He suggests that the importance of temperature is less compared to light in controlling net assimilation rate.

The increased rate of N fertilizers will enhance the leaf expansion before stem elongation and will lead to high pre-anthesis leaf area duration (LAD) due to improved tiller growth in barley, oat and wheat (Sainio *et al.,* 1997) and higher tillers per main shoot in wheat. Application of high N fertilizer rate and green manuring also caused more post-anthesis LAD.

Zhong *et al.* (2002) through a field study at IRRI during dry seasons of 1997 and 1998 under irrigated situations found that there was an exponential decrease of relative tillering rate (RTR) with an increase of LAI at a known N input level. A high N input caused an increased LAI. When nitrogen was not limiting, the tillering was prevented at LAI values of 3·36 to 4·11 whereas under limited N, LAI reduced to as low as 0·98. They also observed little effect of spacing and number of seedlings per hill on LAI.

Roy *et al.* (2012) observed a significant increase of root biomass, leaf area index (LAI) and net assimilation rate (NAR) under elevated $CO_2$ (EC) (550 $\mu mol\ mol^{-1}$) than control chamber by 28, 19 and 40%, respectively. In elevated $CO_2$, net assimilation rate increased by 40% than ambient $CO_2$ level.

There was a slight increase in the leaf area index value of rice planted at early stages and it showed a higher increase during later stages (Azarpour *et al.*, 2014). The maximum leaf area index was observed during the flowering stage (65 DAP) while the falling of lower leaves and wilting of them leads to decrease in Index value.

Medhi *et al.* (2016) in *rabi* season of 2012 and 2013 studied the partitioning of dry matter, growth characteristics and productivity of hybrid rice and found that, there was an increase of leaf area and leaf area index after 60 days of transplanting whereas it decreased when the harvesting was approached. They also concluded that towards the crop maturity, the leaf area index was reduced only because of senescence of early leaves which leads to lesser leaf number.

**2.4. Weather influences on the incidences of pests and diseases**

A field experiment (Yashoda *et al.*, 2000) was conducted during the kharif seasons of 1996-97 and 1997-98 to study the influence of weather parameters on incidence of false smut (caused by *Claviceps oryzae-sativae*) in rice cultivars HR-12 and Amrut. They found that during 50% flowering, weather parameters had a significant effect on false smut disease development in rice. The favourable conditions like low maximum temperature, (<31°C), low rainfall (<5 mm), high minimum temperature (19°C) and high relative humidity (>90%) experienced during this stage leads to the disease development.

Sheath rot incidence of rice was more in kharif season than in *rabi* season (Reddy *et al.*, 2001). A positive correlation was observed between relative humidity and disease index whereas temperature and sunshine are negatively correlated. Even though there was disease development at 50 per cent maximum RH, it was quick at above 80 per cent and slow between 60-80 per cent. Correlation analysis revealed that there was no relationship between the insect population got in light trap and disease development in the field.

Mousanejad *et al.* (2009) considered the effect of weather factors on the changes in spore population *Pyricularia grisea* and the occurance of that disease. It was revealed that the weather factors such as pressure, maximum temperature, mean relative humidity and sunshine hours are the most significant factors in forecasting rice blast disease. Also, enough precipitation, increased daily mean relative humidiity, decreased daily maximum temperature and sunshine hours result in better spore population and occurrence of blast during next 7–10 days.

In sowing-date experiments with rice crops, the higher spread of rice black-streaked dwarf disease was observed during the earliest sowings and it suffered from maximum yield losses (Wang *et al.*, 2009). There was no loss observed during the last sowing (25 days after the first). Yield reduction of 0·80% for every 1% increase in disease incidence was noticed in early *indica* rice and more loss of 0·92% in the late *japonica* crop. Changes in recent winter weather and cropping practices have contributed to the development of virus diseases in Eastern China.

Hafeez *et al.* in 2010 proved that in adult leaf folders, only RH mean and minimum temperature showed a significant positive correlation on light trap catch and the weather factors showed 68.2% influence during this light trap catch. There was no correlation observed between the buildup of larval population and weather parameters but weather factors exhibited 50.0% effect on larval population. It is also concluded that weather factors had no significant impact on leaf infestation.

Through the experiment (Sabale *et al.*, 2010) conducted at Pattambi research station, three peak periods were observed for the incidence of green leaf hoppers (*Nephotettix nigropictus* and *Nephotettix virescens*) such as during $38^{th}$ to $41^{st}$, $45^{th}$ and $52^{nd}$ to $2^{nd}$ standard meteorological weeks. The stage in between tillering to panicle initiation were more affected by these two species. The main meteorological parameters that were more favoured for incidence and spread include lower minimum temperature, low rainfall and sufficient sunshine were found to be favouring the incidence and spread of green leaf hoppers.

Magunmder *et al.* (2013) observed that early planted rice less affected by pests and natural enemy's population compared to later-transplanted rice. Lower insect population was found in the varieties Binasail and Binadhan-4 compared other varieties. They concluded that there was lower incidence of plant and leaf sucking pests in early planted rice varieties.

Dhaliwal *et al.* (2018), found that there was a significant correlation between minimum temperature and evening relative humidity with the incidence of brown leaf spot disease. They concluded that the incidence will be more in higher plant population compared to lesser plant population, since there is more relative humidity within dense plant population.

**2.5. Crop simulation models**

Aggarwal P.K. (1991) conducted a study for estimating optimal duration of wheat in a rice-wheat system using crop simulation at IARI, New Delhi. It is estimated that for normal sowing (November 15), the early maturing types are more suitable in areas like Punjab, medium maturing types in New Delhi and Uttar Pradesh and late maturing types in West Bengal and Bihar.

Ohnishi *et al.* (1997) formulated a simplified dynamic model, based on the simulation model for Rice-Weather Relationships (SIMRIW), to simulate leaf area index (LAI) and dry matter production for irrigated, transplanted rice. The model explained all observed LAI and dry weight data with minimum errors. The shapes of response curves of component growth functions to environments and the values of optimized parameters were physiologically reasonable and were similar to published values. It is inferred that this model can be integrated with an N uptake model to simulate the growth and yield of rice in relation to soil-plant N dynamics in the future.

The CERES-Rice v3 crop simulation model, calibrated and validated to know the suitability to simulate rice production in tropical humid climate, Kerala state of India, by Saseendran *et al.* (2000). Over the state on an average, the maturity period of rice is projected to shorten by 8% and an increase in yield by 12%. If the temperature elevations only are considered, the crop simulations showed 8% decrease in crop maturity period and 6% in yield. This reveals that the increase in yield due to elevated $CO_2$ effect on fertilization and increased rainfall as projected in the climate change scenario nearly makes up for the negative impact on yield due to rise in temperature in rice.

Calibration and validation of CERES-Wheat model were done by Patel *et al.* (2010) for the variety GW-496 by using data obtained from experiments conducted during 1995-2007 at Anand under varying management practices. By using three sowing dates and irrigation levels as treatments, they found that performance of model was good under optimum date of sowing and optimum irrigation compared to early/late sowing and moisture stress environments.

In 2012, Ahmad *et al.* evaluated the performance of (CSM)-CERES-Rice which is a cropping system model for simulating the growth and development of an aromatic rice variety under irrigated semiarid environment of Pakistan and to know the effect of various plant densities and nitrogen (N) application rates on grain yield.and economic return. The results showed that the management with two

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seedlings per hill and 200 kg N $ha^{-1}$ was the best for higher yield and monitory return of these rice under irrigated semiarid conditions.

The objective of a study conducted by Lamsal *et al.* (2013) was to identify whether CSM-CERES-Rice model is useful in Nepalese condition and to evaluate the model sensitivity with the impact of climate change on rice production using interactive sensitivity analysis mode in DSSAT. Among the evaluated scenario, temperature (± 40°C), CO2 concentration (+20 ppm) with change in solar radiation (±1MJ m-2 day-1) resulted in increased yield at the maximum level (by 62, 41 and 42%) under decreasing climatic scenarios and sharp decline in yield (by 80, 46 and 40%) was observed during increased climate change scenarios, in Prithivi, Masuli and Sunaulo Sugandha cultivars respectively. Finally it was observed that there was sharp decrease in the yield due to change in temperature, CO2 and solar radiation.

Jeong *et al.* (2014) in the research work conducted for assessing the effect of nitrogen fertilizer rate and split nitrogen application on rice yields grown in the field irrigated with reclaimed waste water using DSSAT v4.5 model found that the optimal N fertilizer rate for rice irrigated with reclaimed waste water is 20-50 % less than the normal recommended rate and by adjusting the split dose of N application resulted in an additional 10-20kg$ha^{-1}$ reduction in the amount of N fertilizer used.

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

Kadiyala *et al.* (2015) conducted a study to identify a good water saving rice production system grown in sandy loam soils in semiarid conditions using calibrated CERES rice and maize models of DSSAT with two different establishment methods viz. aerobic and flooded rice. It is estimated that application of 180kgN$ha^{-1}$ in four splits and automatic irrigation with 40mm, when soil available water (ASW) in top 30cm fell below to 60% was the best combination for aerobic rice, saving 41% of water for producing 96% of the yield attainable under flooded conditions. In the case of maize, the application of 120kg N$ha^{-1}$ and irrigation with 30mm of water at 40% ASW in the top 30cm soil was the most suitable management option. The results showed that DSSAT model is a useful tool for evaluating different management options aimed at maintaining yield and saving water in rice–maize systems in semi-arid regions.

In earlier experiments conducted at the Department of Agrl. Meteorology, College of Horticulture Vellanikkara, phenology, growth and yield of selected short duration rice varieties were simulated, their genetic coefficients were calibrated and the CERES-Rice model was validated using the field experiment data (Vysakh *et al.,* 2015).

A study was conducted by Dias *et al.*(2016) to identify the yield and growth changes of most popular two rice varieties (At362 and Bg357) cultivated in Nilwala river basin at Yala season under the global climate change scenario Representative Concentrate Pathway (RCP) 8.5. In mid-centuries the Decision Support System for Agro technology Transfer (DSSAT) software is used to forecast the rice yield for Yala season. It was found that, both yield and growth of rice affected by increasing temperature and solar radiation and decreasing rainfall in mid-centuries. For both the varieties grain yield in mid-centuries shows decreasing trend by 25% to 35% than the yield at 2014 and there will be lesser growth period than the present conditions.

Modeling was done by Rao *et al.* (2016) in rice phenology, growth phase, and yield by using "Decision Support System for Agro technology Transfer (DSSAT) CERES rice model" and obtained the predicted yield under altered carbon dioxide concentrations at four locations in Eastern India which include three irrigated and one rainfed location.

Gumel *et al.* in 2017 conducted a study in three rice growing areas, Barat Laut Selangor and MADA (Muda Agricultural Development Authority), Kedah in the west coast and KADA (Kemubu Agricultural Development Authority), Kelantan in the east coast of Peninsular Malaysia to assess the seasonal potential effect of temperature and rainfall variability on MR219 using CERES-Rice model v4.6.1.0 of the DSSAT modelling system. The sensitivity analysis revealed that there is a decrease in yield from -0.2 to -4.5% for MADA and KADA during the main season because of +10°C rise in the maximum temperature. If the maximum temperature goes up to +50°C, the yield will be decreased from -3.3 to -14.3 % for all the areas. +10°C increase of minimum temperature resulted in decreased yield ranging from -1.3 to -3.5%. During the off season, yield reduction from -0.5 to -2.3% is observed when the temperature rise is +10°C for MADA. For all the areas, a rise in +30°C maximum temperature resulted in a yield reduction from -2.5 to -7.5%.

## 2.3. Statistical models

Takahashi *et al.* in 2000 examined different multivariate regression models to develop precise models for predicting dry weight and nitrogen accumulation of rice crops from the maximum tillering to the meiosis stage. The results found that the principal component regression with hyper-spectra gave improved fits and predictability compared to using specific wavelengths.

Sarma *et al.* in 2008 inferred that there was no linear variation of rice yield with rainfall of Andhra Pradesh but showed good relation with growing degree days and the satellite derived vegetation index, INDVI using statistical agrometeorological model. They also found a high impact of sea surface temperature of Nino 3 region on the yield of rice compared to southern oscillation index.

Calibration of empirical linear regression models were carried out with yield data of wheat at Canadian Prairies to forecast spring wheat yield (Qian *et al.*, 2009). Using the data up to harvesting stage they observed yield variances of 77%, 64%, 63% and 70% respectively for Alberta, Saskatchewan, Manitoba and the entire Prairie region during 1976-2006. The accuracy of prediction was lower for early in the season than late in the season.

Lobell and Burke (2010) suggested that time-series models are best suited in predicting response to precipitation compared to temperature, while for temperature, panel or cross-section models are useful. According to climate variable and spatial scale, the performance of statistical models will differ, with time-series statistical models capably reproducing site-specific response of yield to change in precipitation, but less performing for temperature responses.

Pre-harvest forecast models were prepared by Agnihotri and Sridhara (2014) for forecasting the yield of rice for the districts of Dakshin Kannada, Uduppi and Uttar Kannada. This models were capable of explaining the annual variation of rice production to an extent of 86, 95, and 74% for Dakshin Kannada, Uduppi and Uttar Kannada respectively. The most important property of this model was the ability of this to forecast rice yield before two months of its harvest.

A forecast model of post-harvest stage of rice were developed by Jain (2016) for Raipur condition. Weighted and un-weighted indices were obtained using the weather data collected from $22^{nd}$ to $46^{th}$ standard meteorological weeks for the regression analysis. From the validation of regression model with the use of SPSS (Statistical Packages for Social Sciences) revealed that for the last ten years the accuracy rate of the model was 88% when it generally was beyond 95%.

For Chattisgarh plains, the prediction of rice yield was done by Murari (2017) with the help of statistical and crop simulation models. He found that there was an accuracy of 96.7 per cent for the statistical model created using weekly weather data during pre-harvest stage with 3.3 per cent error whereas, CERES-Rice model produced an accuracy of 93 per cent through its validation which require further modifications in genetic coefficients.

# Materials and Methods

# 3. MATERIALS AND METHODS

The study on "Crop weather relationship of rice varieties under different growing environments" was carried out during 2018-2019 at the Department of Agricultural Meteorology, College of Horticulture, Vellanikkara.

## 3.1 DETAILS OF THE EXPERIMENT

### 3.1.1. Location of experiment

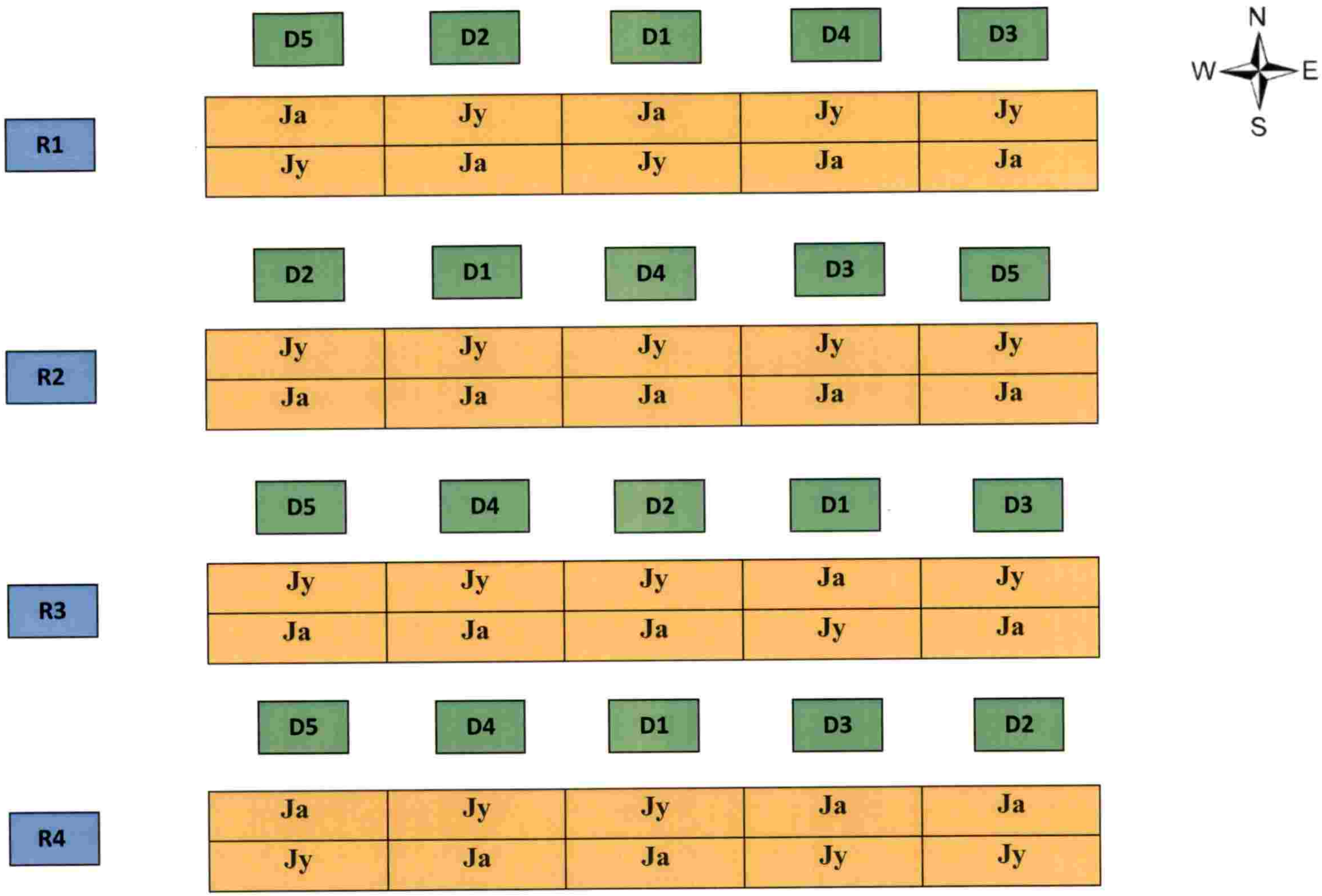
The field experiments were conducted during May 2018 to December 2018 at Agricultural Research Station, Mannuthy, Kerala Agricultural University, Thrissur. The station is located at $10^0$ 32' N latitude and $76^0$ 20' E longitudes at an altitude of 22m above mean sea level.

### 3.1.2. Soil Characters

It was found that the soil texture of the experimental field was sandy loam. Table 3.1 shows the physical properties of soil.

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 |




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

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

### 3.1.3 **Climate**

The area selected for the experiment is a typical warm humid tropical region. Both southwest and northeast monsoons provide rain to the area and this location experienced a mean maximum temperature of 31.2 $^{0}$C and a mean minimum temperature of 23.0$^{0}$C during the experimental period. The maximum rainfall was obtained during the month of August which was recorded to be 928 mm. the average sunshine received during experiment was 4.3 hrs/ day. The mean forenoon relative humidity was 91.5% and the mean afternoon relative humidity was 69.2%. The average wind speed was 2.1 kmh$^{-1}$. Table 3.2 represents the details of the weekly weather parameters during the experiment.

### 3.1.4 **Season of the experiment**

The field experiment was conducted from May 2018 to December 2018 during *kharif* season.

## 3.2 EXPERIMENTAL MATERIALS AND METHODS

### 3.2.1 **Variety**

The experiment was conducted using two most popular rice varieties Jyothi and Jaya. Jyothi is a short duration variety with 110-125 days duration and Jaya is a medium duration variety with 130 days duration.

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 improved local strain and IR 8, the internationally famous high yielding genotype.

Jaya is recommended for general cultivation all over the country either in *kharif* or *rabi* season. It is a cross variety which is evolved from a cross between Taichung (Native) 1 and the tall local photosensitive variety T-141 of Orissa

Table 3.2 Weekly weather parameters during the period of experiment 2018

| Week No. | Tmax (°C) | Tmin (°C) | RH I (%) | RH II (%) | VPD I (mm Hg) | VPD II (mm Hg) | WS (km hr$^{-1}$) | BSS (hrs) | RF (mm) | RD (days) | EVP (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 23 | 30.3 | 23.6 | 96 | 82 | 23.6 | 23.8 | 1.9 | 1.7 | 230.7 | 5 | 2.0 |
| 24 | 29.4 | 23.5 | 97 | 82 | 23.4 | 23.8 | 1.7 | 1.3 | 236.0 | 5 | 2.3 |
| 25 | 28.3 | 22.5 | 96 | 87 | 21.9 | 22.4 | 1.4 | 1.6 | 142.7 | 6 | 2.1 |
| 26 | 30.2 | 22.7 | 95 | 76 | 22.4 | 22.7 | 1.2 | 3.0 | 98.0 | 5 | 2.4 |
| 27 | 31.5 | 22.8 | 94 | 94 | 22.6 | 22.1 | 2.0 | 3.5 | 65.5 | 2 | 3.2 |
| 28 | 28.0 | 21.7 | 98 | 98 | 21.5 | 23.8 | 1.5 | 0.3 | 304.2 | 7 | 2.5 |
| 29 | 28.8 | 22.1 | 95 | 86 | 21.8 | 23.0 | 1.5 | 0.1 | 256.1 | 6 | 1.9 |
| 30 | 29.5 | 23.1 | 96 | 77 | 23.1 | 22.8 | 1.8 | 1.0 | 110.5 | 5 | 2.5 |
| 31 | 29.9 | 23.1 | 96 | 76 | 23.1 | 22.8 | 1.4 | 1.5 | 103.6 | 5 | 2.5 |
| 32 | 28.7 | 22.0 | 97 | 84 | 22.3 | 23.2 | 1.5 | 0.4 | 208.6 | 7 | 2.0 |
| 33 | 27.1 | 21.7 | 96 | 89 | 21.5 | 21.8 | 2.2 | 0.4 | 629.0 | 7 | 1.5 |
| 34 | 30.6 | 22.2 | 95 | 70 | 21.9 | 21.6 | 1.9 | 6.1 | 12.9 | 7 | 3.0 |
| 35 | 30.2 | 22.7 | 94 | 68 | 22.4 | 21.2 | 1.7 | 2.9 | 32.6 | 4 | 2.7 |
| 36 | 31.6 | 22.0 | 92 | 59 | 21.9 | 19.9 | 2.1 | 9.6 | 0.5 | 0 | 3.5 |
| 37 | 31.9 | 22.3 | 90 | 61 | 21.9 | 20.4 | 1.5 | 7.6 | 0.0 | 0 | 3.8 |
| 38 | 32.5 | 22.4 | 92 | 57 | 22.1 | 20.3 | 1.6 | 7.6 | 0.9 | 0 | 3.1 |
| 39 | 33.6 | 22.5 | 91 | 63 | 22.3 | 24.8 | 1.6 | 5.0 | 27.6 | 2 | 3.1 |
| 40 | 33.2 | 22.6 | 88 | 67 | 22.1 | 23.3 | 3.3 | 4.9 | 131.0 | 4 | 3.0 |
| 41 | 32.5 | 24.0 | 95 | 70 | 23.3 | 23.5 | 1.3 | 5.0 | 65.7 | 2 | 2.8 |
| 42 | 32.0 | 23.2 | 96 | 70 | 22.3 | 22.3 | 1.2 | 4.8 | 146.5 | 5 | 2.8 |
| 43 | 33.3 | 22.3 | 79 | 45 | 18.9 | 16.8 | 2.6 | 7.8 | 39.8 | 1 | 3.5 |
| 44 | 32.8 | 23.8 | 85 | 54 | 21.3 | 19.4 | 4.0 | 6.1 | 1.0 | 0 | 3.3 |
| 45 | 33.7 | 22.8 | 81 | 49 | 19.8 | 18.0 | 3.0 | 7.2 | 0.0 | 0 | 3.6 |
| 46 | 32.7 | 23.4 | 89 | 57 | 21.4 | 20.1 | 2.1 | 6.5 | 4.1 | 2 | 2.6 |
| 47 | 32.9 | 23.3 | 85 | 57 | 20.7 | 20.0 | 4.0 | 6.8 | 58.8 | 0 | 3.6 |

Tmax – Maximum temperature
Tmin – Minimum temperature
RH I – Forenoon relative humidity
RH II – Afternoon relative humidity
BSS – Bright sunshine hours

VPD I – Forenoon vapour pressure deficit
VPDII – Afternoon vapour pressure deficit
WS – Wind speed
RF - Rainfall
RD – Rainy days
Epan – Pan evaporation

### 3.2.2. Design and Layout

Split plot design was used for the experiment with five dates of planting (from 5$^{th}$ June to 5$^{th}$ August) 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 of 4x4 $m^2$size each. A spacing of 15x10 cm was maintained for Jyothi and 20x15 cm was maintained for Jaya.

### 3.2.3. Treatments

The treatments included were five dates of planting starting from 5$^{th}$ June to 5$^{th}$ 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** |
| 5$^{th}$ June | Jyothi |
| | Jaya |
| 20$^{th}$ June | Jyothi |
| | Jaya |
| 5$^{th}$ July | Jyothi |
| | Jaya |
| 20$^{th}$ July | Jyothi |
| | Jaya |
| 5$^{th}$ August | Jyothi |
| | Jaya |

## 3.3 CROP MANAGEMENT

### 3.3.1. Nursery Management

Nurseries were made eighteen days before transplanting for Jyothi and twenty days before for Jaya. 2-3 seedlings were transplanted per hill and for adequate irrigation and drainage all the necessary provisions were taken. In addition, plant protection measures are also taken in the field.


**Plate I. General view of the experimental field**

**Plate II. Nursery preparation**

Plate III. Transplanting

Plate IV. Harvesting

**Plate V. Threshing**

**3.3.2. Land Preparation and planting**

According to the package of practices recommended (KAU, 2016) for Jyothi and Jaya, the experimental field was cleared properly, ploughed well using tractor and puddled. After that plots were prepared according to the layout.

**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 (70N: 35 $P_2O_5$: 35 $K_2O$ kg ha $^{-1}$ for short duration and 90N: 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

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

3.4.1. **Biometric characters**

***3.4.1.1. Plant height***

The plant height 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 was 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 $80^0$C to a constant weight. Then the biomasses were recorded in gram per plant.

*3.4.1.4. Number of tillers / unit area*

Number of tillers per plant were counted randomly from five plants at active tillering stage.

*3.4.1.5. Number of panicles / unit area*

Number of panicles per plant were counted randomly from five plants at the time of harvest.

*3.4.1.6. Number of spikelets / panicle*

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

*3.4.1.7. Number of filled grains / 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 percent 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 was 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 put forward by Williams in 1946.

***3.4.3.2 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 $^{-1}$.

***3.4.3.3. 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

***3.4.3.4. 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 $\rho$ is the ground area on which $W_1$ and $W_2$ are noted.

**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 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.

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Table 3.4. Chemical properties of the soil

| Sl. No. | Parameter | Sampling depth in cm | |
|---|---|---|---|
| | | 0 - 15 | 15 - 30 |
| 1 | Organic carbon (%) | 0.94 | 0.95 |
| 2 | Soil pH | 4.24 | 4.33 |
| 3 | Available nitrogen (kg $ha^{-1}$) | 103.38 | 121.41 |
| 4 | Available phosphorous (kg $ha^{-1}$) | 194.42 | 186.34 |
| 5 | Available potassium (kg $ha^{-1}$) | 404.77 | 397.04 |

Table 3.5. Weather parameters used in the experiment

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

## 3.5 STATISTICAL ANALYSIS

Statistical analysis of the experimental data was done using the standard procedure for split plot design given by Fisher (1947). The existence of significant difference between main plot treatments (dates of planting) and sub plot treatments (varieties) and their interaction were analyzed by performing ANOVA. When significant difference was found between the above, the computed critical differences were used for the pair wise comparison.

Critical difference for comparing two main plot treatments (dates of planting) was calculated as,

$$CD_1 = t_1 \times SE_1$$

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 for the comparison of two subplot treatments (varieties)

$$CD_2 = t_2 \times SE_2$$

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

$SE_2$ = Standard error of difference between two sub plot treatments

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

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 two main plot treatment means at the same or different levels of sub plot treatment was found as

$$CD_3 = t \times SE_3$$

Where,

$$t = \frac{(b-1)E_2 t_2 + E_1 t_1}{(b-1)E_2 + E_1}$$

$t_1$ = 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

To study the impact of weather parameters on biometric and phenological characters of the crop, correlation analysis was carried out. Critical growth stage wise weather variables were worked out from the daily data and correlated with the important crop growth and yield characters obtained from field experiment.

Various statistical analyses were carried out using different software packages like Microsoft – excel, SPSS and WASP.

## 3.6. CROP GROWTH SIMULATION

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

DSSAT 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 whereas the cultivar or variety information is to be given by the user in a separate file. The crop simulation models has to be integrated with the weather, soil and crop management files provided by the user to give simulated output. DSSAT also evaluates the simulated outputs with that of experimental data.

### 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 2018 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.

#### *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.

### 3.6.2. Running the Crop Model

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

Table 3.6. Input files of CERES-Rice model

| Internal file name | | External description | Name |
|---|---|---|---|
| Experiment | FILEX | Experiment details file for a specific experiment (e.g., rice at AGVK): Contains data on treatments, field conditions, crop management and simulation controls | AGVK1701.RIX |
| Weather and soil | FILEW | Weather data, daily, for a specific (e.g., ATRA) station and time period (e.g., for one year) | ATRA1701.WTH |
| | FILES | 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 | FILEC | Cultivar/variety coefficients for a particular crop species and model; e.g., rice for the 'CERES' model, version 046 | RICER046.CUL[1] |
| | FILEE | Ecotype specific coefficients for a particular crop species and model; e.g., rice for the 'CERES' model, version 046 | RICER046.ECO[1] |
| | FILEG | Crop (species) specific coefficients for a particular model; e.g., rice for the 'CERES' model, version 046 | RICERO46.SPE[1] |
| Experiment data files | FILEA | Average values of performance data for a rice experiment. (Used for comparison with summary model results.) | AGVK1701.RIA |
| | FILET | 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. | | | |

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 |

### 3.6.3. Model calibration and evaluation

The adjustment of parameters 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. Validation of crop weather models based on Statistical techniques for Jyothi

Four methods were adopted by Ravindran (2018) to develop yield forecasting models for Jyothi and Kanchana with better accuracy. The models were developed based on weekly weather variables, fortnightly weather variables, crop stage wise weather variables and composite weather variables.

### 3.7.1. Crop weather models based on weekly weather variables

Here, the weekly weather parameters were used to fit the regression model which was arranged according to standard meteorological weeks. Weekly weather variables from 1st to 8th weeks after transplanting were used to carry out step wise regression which further aided in fitting regression model. This 8 week model had lower MAPE value and Higher Adjusted-$R^2$ value and will coincide with the booting stage. The model is given below.

$$\mathbf{Y = 20.736 - 0.385X_{25} + 0.045X_{41} + 0.493X_{54} - 0.357X_{57} - 0.563X_{58} - 0.263X_{63}}$$

(Adjusted $R^2$ = 85.4%  MAPE = 5.19%)

$X_{25}$ - minimum temperature during 5th week

$X_{41}$ - afternoon relative humidity during 1st week

$X_{54}$ - forenoon vapour pressure deficit during 4th week

$X_{57}$ - forenoon vapour pressure deficit during 7th week

$X_{58}$ - forenoon vapour pressure deficit during 8th week

$X_{63}$ - bright sunshine hours during 3rd week

### 3.7.2. Crop weather models based on fortnightly weather variables

In this method, fortnightly averaged weather variables from 1st to 3rd, 1st to 4th and 1st to 5th fortnights after transplanting were used for step wise regression analysis and fitted the model. The best model was formulated with the data of 1st to 5th fortnight for better yield forecast as given below.

$$\mathbf{Y = 16.774 - 0.370X_{15} - 0.137X_{34} + 0.110X_{41} + 0.106X_{44} + 0.238X_{64} - 1.605X_{84}}$$

(Adjusted $R^2$ = 91.2%  MAPE = 4.00%)

$X_{15}$ – Maximum temperature of 5th fortnight

$X_{34}$ – Forenoon relative humidity of 4th fortnight

$X_{41}$ – Afternoon relative humidity of 1st fortnight

$X_{44}$ - Afternoon relative humidity of 4th fortnight

$X_{64}$ – Bright sunshine hours of 4th fortnight

$X_{84}$ – Pan evaporation of 4th fortnight

### 3.7.3. Crop weather models based on crop stage-wise weather variables

The weather variables experienced during six phenophases of rice variety such as transplanting to active tillering, active tillering to panicle initiation, panicle initiation to booting, booting to heading, heading to 50% flowering, and 50% flowering to physiological maturity were used for step wise regression analysis and the model was fitted. The model with weather variables of P4 (booting to heading) stage which coincide with booting stage was selected as best one in predicting the model. The form of the model is,

$$\mathbf{Y = 19.873 - 0.670X_5 + 0.006X_7}$$

(Adjusted $R^2$ = 51.3%  MAPE = 10.49%)

$X_5$ – Forenoon vapour pressure deficit

$X_7$ – Rainfall

### 3.7.4. Crop yield forecasting using composite weather parameters

Partial crop season data were used to fit this model. The model with generated weather variables of seven-week weather variables used for yield forecast in Jyothi and the model is,

$$\mathbf{Y = -8.034 + 0.71Z_{40} + 0.218Z_{41}}$$

(Adjusted $R^2$ = 61.4%, MAPE = 8.93%)

$Z_{40}$ – Un-weighted index of afternoon relative humidity

$Z_{41}$ – Weighted index of afternoon relative humidity

Here un-weighted index is the simple sum of weather variables in different weeks and the weighted index is the weighted total where weights used are the correlation coefficients between the yield and weather parameter recorded during respective weeks.

The validation of these four models were done using the weather data collected from the experimental field of Jyothi variety during 2018 year.

### 3.8. Crop weather models using Principal Component Analysis for Jyothi and Jaya

To fit a regression model for Jyothi and Jaya, initially principal component analysis (PCA) was carried out using different weather observations experienced during the crop period along with the yield data for computing the best principal components. PCA helps in minimizing the complexity of a data set to a lower appropriate dimension the contributions of which will be more towards the system that we analyzing. By this method, principle components were obtained and were used for fitting regression models of both the varieties using SPSS software for better yield forecasting. This was also evaluated using the experimental data collected from field during 2018.

# Results

# 4. RESULTS

Results obtained from the study "Crop weather relationship of rice varieties under different growing environments" are described here.

## 4.1. PHENOPHASES

The study of periodic plant cycle events as influenced by the plant environment and climatic conditions represents the phenology. By knowing the timing of different phenological events and their variations with respect to the weather conditions, we can adopt more suitable crop management practices to get a good output in terms of quantity as well as quality.

In the case of rice crop, the total life cycle is having six different growth phases from transplanting to physiological maturity (Satish *et al.*, 2017) which are known as phenophases and these are listed below.

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)

In addition, vegetative period, reproductive period and ripening period are denoted by P7, P8 and P9 respectively and are used to group the above mentioned phenophases. Vegetative period include P1-P2, the phenophases P3-P4 included in reproductive period and P5-P6 are included in the ripening period

Phenological calendar for both Jyothi and Jaya are given below (Fig. 4.1(a) and (b)). It shows the duration of phenophases P1- P6 for five different dates of planting (June $5^{th}$ to August $5^{th}$) for both the varieties during *kharif* season 2018. Each

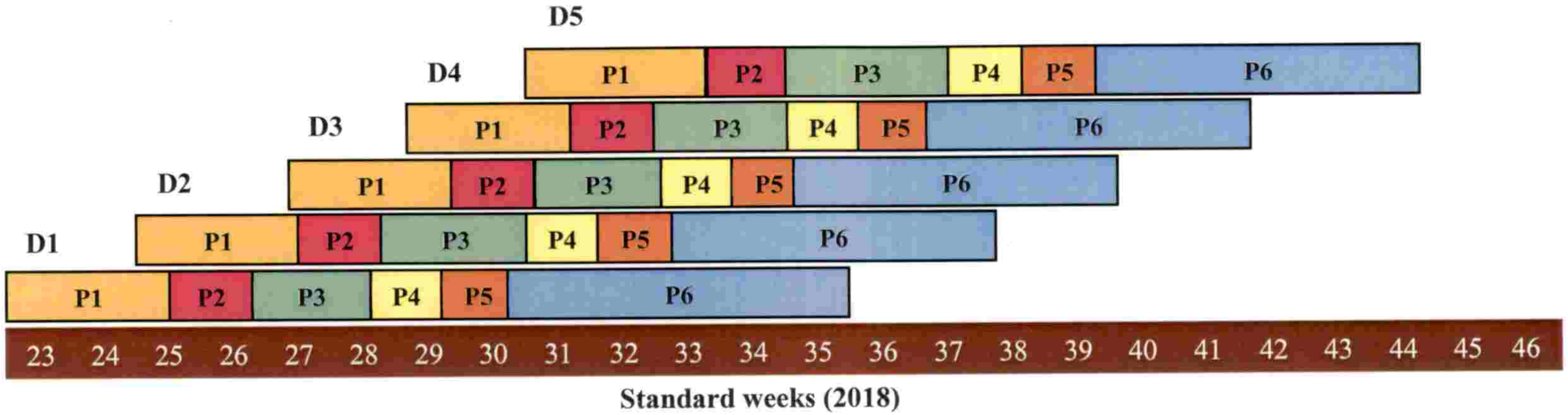


Fig. 4.1(a) Phenological calendar of Jyothi

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

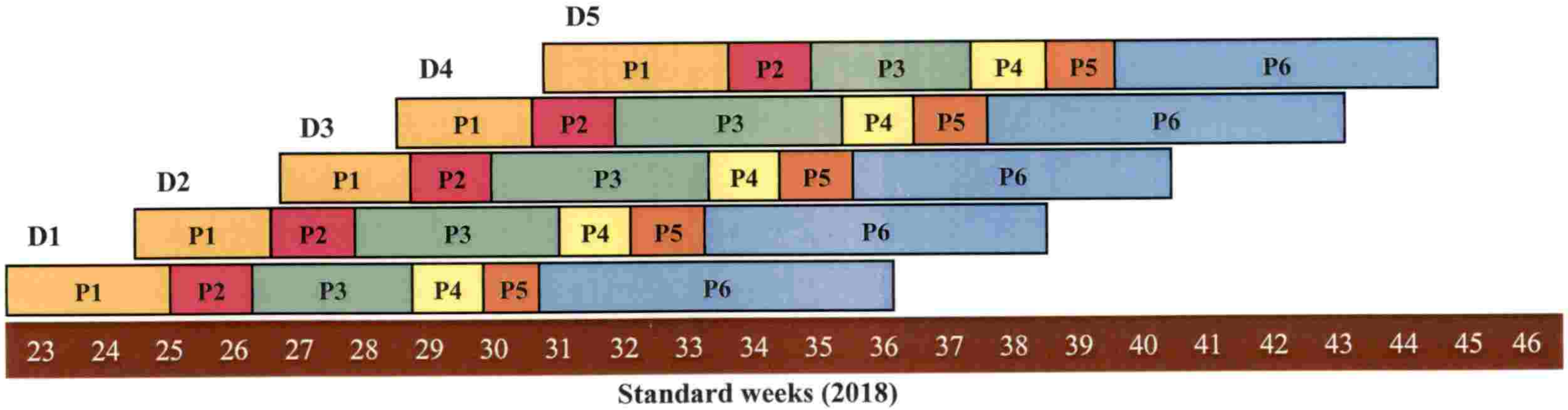


Fig. 4.1(b) Phenological calendar of Jaya

phenophase was plotted against the standard meteorological weeks. Variation was observed in the duration of phenophases for varieties as well as for dates of planting. Jaya took more duration compared to Jyothi.

## 4.2. WEATHER PREVAILED DURING CROP GROWTH PERIOD

Weather prevailed during the field experiment for the year 2018 were recorded on daily basis and the different meteorological parameters include maximum temperature, minimum temperature, relative humidity, vapour pressure deficit, rainfall, number of rainy days, bright sunshine hours, wind speed and pan evaporation. The averaged parameters over different meteorological weeks for both the varieties, Jyothi and Jaya, are represented graphically from Fig. 4.2 to 4.7.

### 4.2.1. Air temperature

The weekly maximum temperature, minimum temperature, mean temperature and temperature range were plotted graphically against each standard meteorological weeks which were experienced over entire crop growing period (Fig. 4.2). A non-linear relationship was observed in the case of maximum and minimum temperature. Both of them showed a decreasing trend towards the August 5$^{th}$ planting and after this an increasing trend was observed with a maximum value of 33.7°C for maximum temperature and 28.3°C for minimum temperature. The mean temperature measured during the study period was varying in between 21.7 °C and 24.0 °C. The temperature range (TR) calculated during the crop growth period showed a range from 5.4°C to 11.1°C and the value was not stable at any of the growth stages.

### 4.2.2. Relative humidity (RH)

Weekly forenoon and afternoon relative humidity along with the weekly mean relative humidity over different standard meteorological weeks recorded during the entire crop period were depicted in Fig. 4.3.

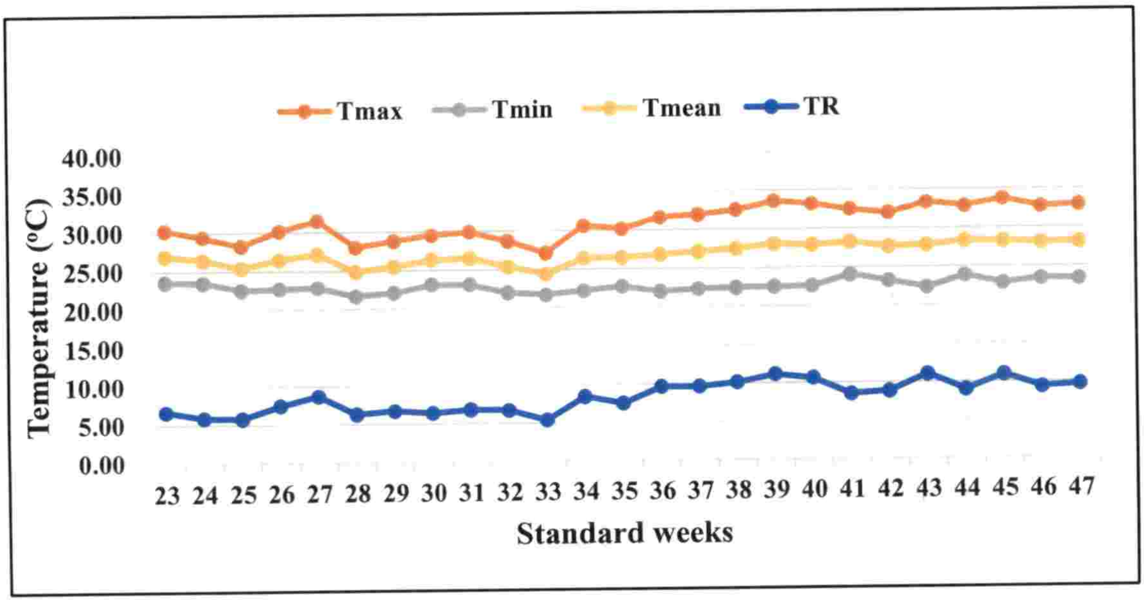


Fig. 4.2. Weekly air temperature during crop period

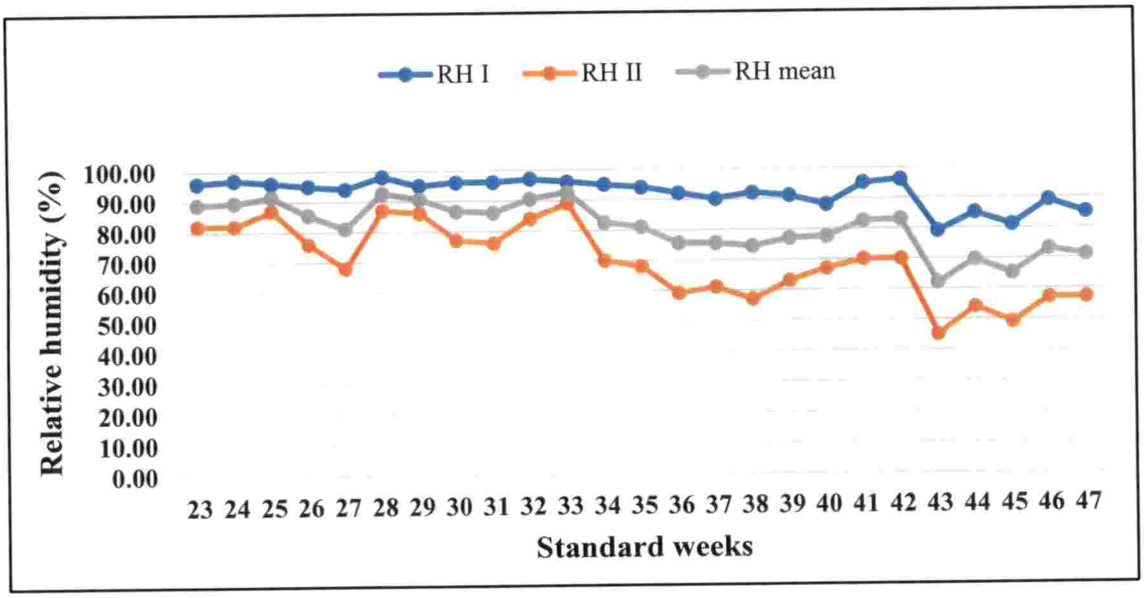


Fig. 4.3. Weekly relative humidity (RH) during crop period

The forenoon and afternoon relative humidity did not show much variation till the last planting date (August 5$^{th}$) and afterwards a decreasing trend was noticed. Mean relative humidity also showed the same trend. Near values of forenoon and afternoon relative humidity was observed during the initial plantings with a maximum value of 98%. The forenoon and afternoon humidity values ranged between 79-98% and 45-98% respectively.

### 4.2.3. Vapour pressure deficit (VPD)

Dry bulb as well as wet bulb temperature readings were used to calculate the forenoon and afternoon vapour pressure deficit which was experienced throughout the crop growth period. The vapour pressure deficit values were also averaged over standard meteorological weeks and were plotted graphically (Fig.4.4).

Vapour pressure deficits showed a decreasing trend towards the last date of planting and after that it was fluctuating. The forenoon and afternoon vapour pressure deficits over the crop period varied between 18.9-23.8 mm Hg and 16.8-24.8 mm Hg respectively.

### 4.2.4. Pan evaporation (Epan)

According to standard meteorological weeks, pan evaporation experienced over the cropped area was averaged and it was plotted graphically which was shown in Fig.4.5.

A non-linear progress of evaporation was observed during this period. It showed an increasing trend towards the 3$^{rd}$ planting then it decreased towards the early stages of 4$^{th}$ planting. Then it again decreased after the 5$^{th}$ planting of crop. The lowest value of 1.5mm was observed during 33$^{rd}$ week and a highest value of 3.8 was noticed on 37$^{th}$ week which was the later stages of crop growth.

### 4.2.5. Bright sunshine hours (BSS)

The bright sunshine hours prevailed during the crop period averaged on weekly basis and are plotted against standard meteorological weeks as shown in the Fig.4.5.

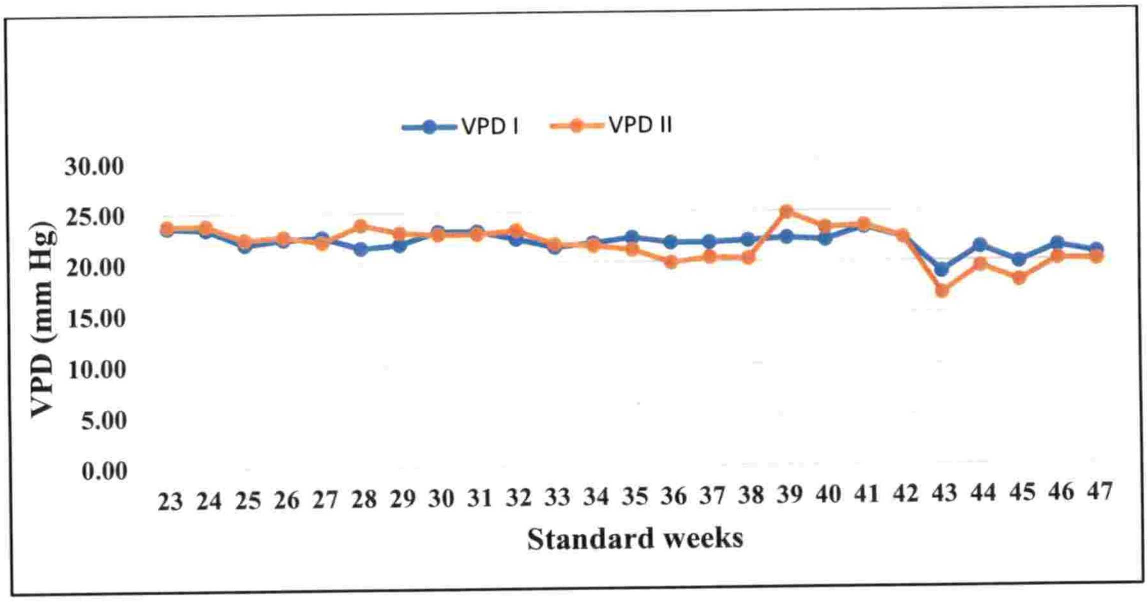


Fig. 4.4. Weekly vapour pressure deficit (VPD) during crop period

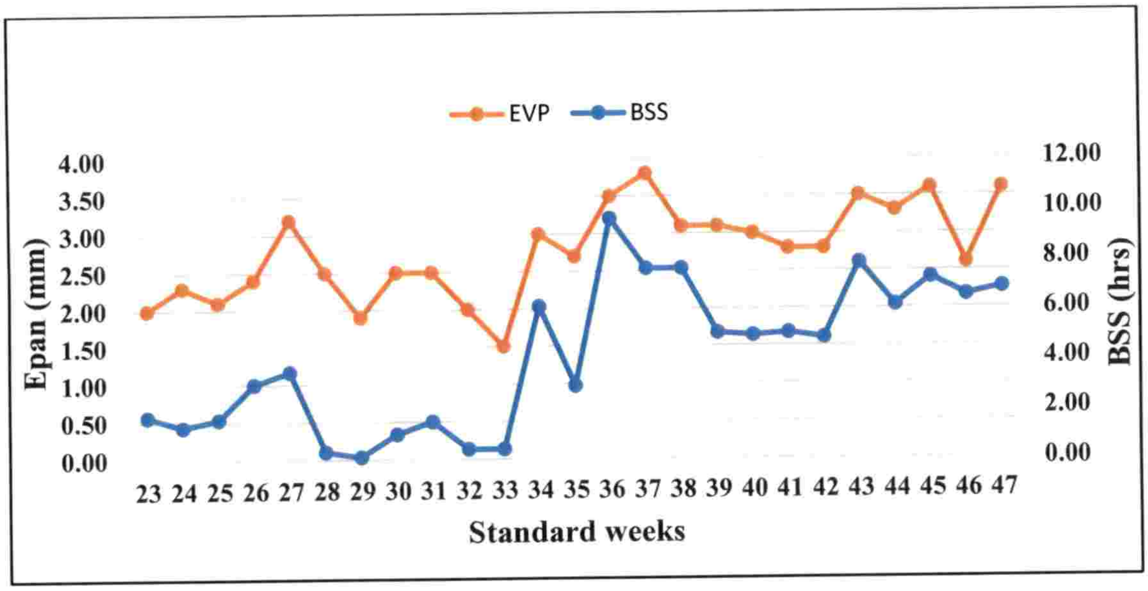


Fig. 4.5. Weekly bright sunshine hours (BSS) and evaporation (Epan) during crop period

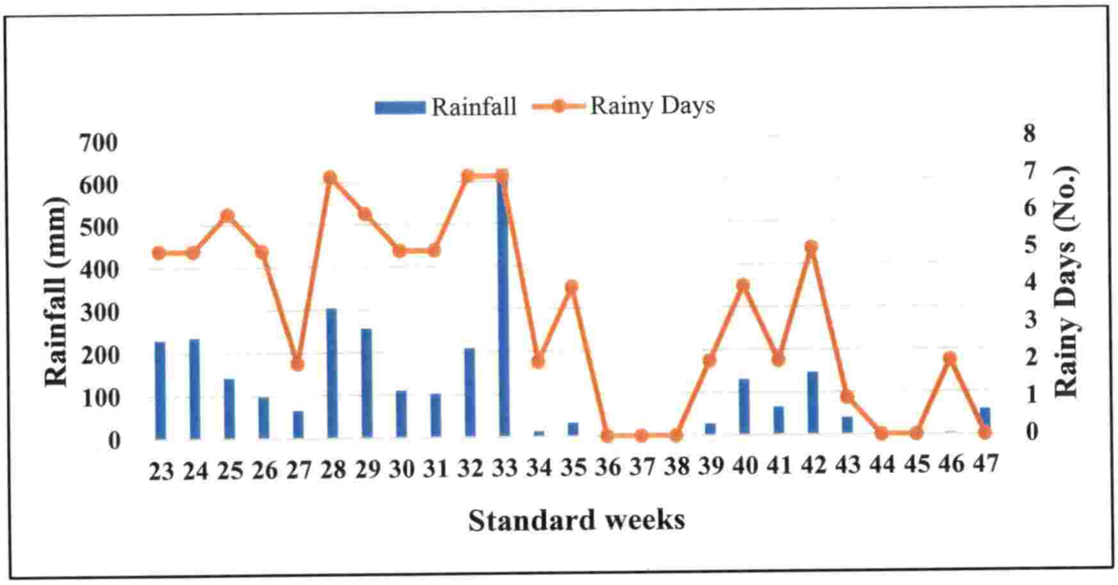


Fig. 4.6. Weekly rainfall (RF) and rainy days (RD) during crop period

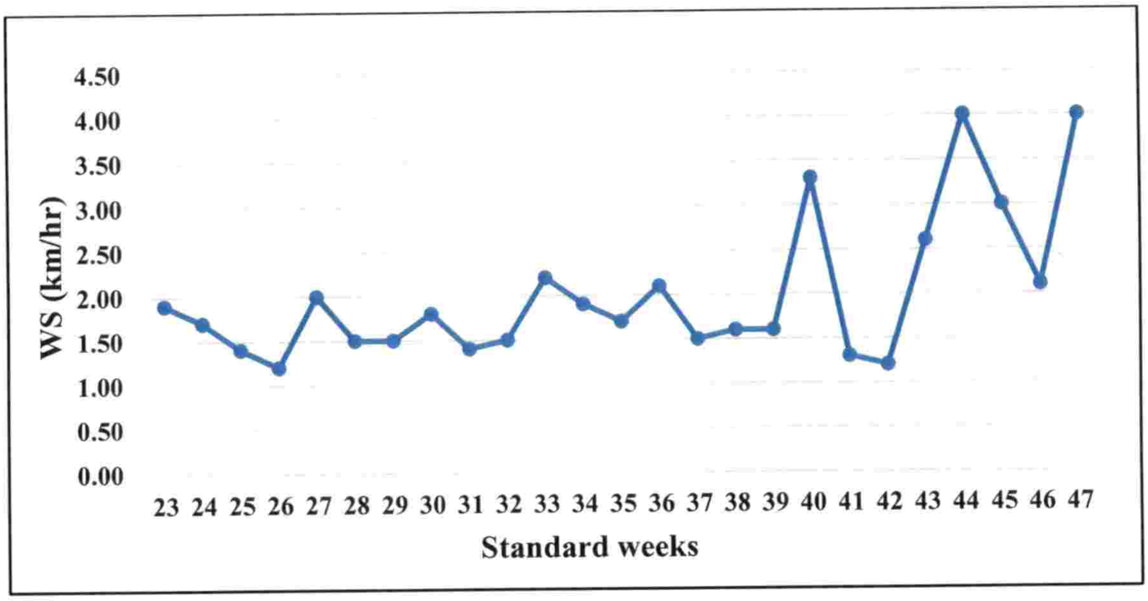


Fig. 4.7. Weekly wind speed during crop period

The BSS were increasing during the initial crop stages then it showed a decrease in the early growth stages of 3rd planting. The maximum value of 9.6 hrs $day^{-1}$ was observed when the maturity phase is approached. Bright sunshine duration varied from 0.1-9.6 hrs $day^{-1}$ over the entire crop period.

### 4.2.6. Rainfall and rainy days (RF and RD)

Fig.4.6. represents the weekly rainfall and rainy days recorded during the crop period from 23rd week to 47th week. Higher rainfall was recorded during the early stages of crop growth with a maximum value of 629mm $day^{-1}$ experienced in the early stages of 5th planting date. A decreasing trend of rainfall was observed when the crop approaches its maturity stage. Number of rainy days showed a decreasing trend after 5th planting while a maximum of 7 days were recorded in the early stages of 5th planting.

### 4.2.7. Wind speed (WS)

Graph representing the averaged wind speed and standard weeks showed an increasing trend towards the end of the crop period (Fig.4.7). Lower wind speed were recorded during the early stages of the crop growth. While reaching to the maturation period of the last planting, an increasing trend was observed where 4 km $hr^{-1}$ was recorded as maximum in the 44th and 47th weeks.

## 4.3. PHENOLOGICAL OBSERVATIONS OF CROP GROWTH AND DEVELOPMENT

The duration of each phenophases *viz.* transplanting to active tillering, active tillering to panicle initiation, panicle initiation to booting, booting to heading, heading to 50% flowering and 50% flowering to physiological maturity were noted for the varieties Jyothi and Jaya for all dates of planting. The observations are given in the Table 4.1.

### 4.3.1. Number of days for active tillering

Number of days for active tillering of Jyothi was more for August 5th planting (33 days) and it was lesser for July 20th planting. In the case of Jaya, more duration for active

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 | |
| | Jy | Ja | Jy | Ja | Jy | Ja | Jy | Ja | Jy | Ja |
| Active tillering | 30 | 31 | 29 | 31 | 31 | 32 | 28 | 30 | 33 | 34 |
| Panicle initiation | 40 | 41 | 39 | 42 | 41 | 43 | 38 | 44 | 42 | 47 |
| Booting | 61 | 65 | 59 | 66 | 62 | 67 | 60 | 69 | 62 | 70 |
| Heading | 69 | 75 | 67 | 73 | 69 | 75 | 68 | 74 | 70 | 74 |
| 50% flowering | 73 | 79 | 72 | 78 | 74 | 80 | 72 | 77 | 73 | 76 |
| Physiological maturity | 107 | 115 | 111 | 118 | 109 | 113 | 105 | 111 | 103 | 108 |
| Total duration | 125 | 136 | 129 | 139 | 127 | 134 | 123 | 132 | 121 | 129 |

Jy – Jyothi      Ja – Jaya

tillering was observed in August 5th (34 days) planting and lesser was noted in July 20th planting. Compared to Jyothi, Jaya took more days for attaining active tillering.

### 4.3.2. Number of days for panicle initiation

For attaining panicle initiation, the lower duration of 38 days were taken by Jyothi variety in July 20th planting and for Jaya, the lower duration of 41 days were needed to complete the stage in June 5th planting. Higher duration of 47 days were noticed in August 5th planting for Jaya. Maximum duration for panicle initiation of Jyothi also observed in August 5th planting.

### 4.3.3. Number of days for booting

Number of days for attaining booting was almost near for all planting dates for Jyothi in which lower number of days (59 days) was observed in June 20th planting. In Jaya, an increasing trend was noticed where in August 5th planting showed a higher duration of 70 days and lower days needed in June 5th planting (65 days).

### 4.3.4. Number of days for heading

For attaining heading stage, Jyothi took more days in August 5th planting (70 days) while lower days were noticed in June 20th planting (67 days). From June 5th to August 5th planting, difference in number of days was observed for Jaya in which the higher number of days recorded were 75 days.

### 4.3.5. Number of days for 50% flowering

Higher duration of 74 days were observed in Jyothi variety for attaining 50% flowering in July 5th planting and lower days of 72 were noted in the case of June 20th and July 20th plantings. In Jaya variety, 80 days of July 5th planting was noticed as the maximum duration attained for this stage whereas other plantings showed lower number of days.

### 4.3.6. Number of days for Physiological maturity

Number of days taken for attaining physiological maturity was higher (111 days) for June 20$^{th}$ planting in Jyothi while lower duration was observed in August 5$^{th}$ planting (103 days). Similar to Jyothi, Jaya also showed higher duration in June 20$^{th}$ planting (118 days) and lower number of 108 days in August 5$^{th}$ planting. The total duration was maximum in June 20$^{th}$ planting in both the varieties (129 for Jyothi and 139 days for Jaya) and was lower during August 5$^{th}$ planting.

## 4.4. WEATHER CONDITIONS PREVAILED DURING DIFFERENT GROWTH STAGES

Weather conditions prevailed during different stages of crop growth are 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

#### *4.4.1.1. Temperature (Maximum temperature, Minimum temperature, Mean temperature and Temperature range)*

Highest value of maximum temperature, 29.9°C and 29.7°C in June 5$^{th}$ planting and lowest value of 28.1°C and 28.0°C in August 5$^{th}$ planting were observed for Jyothi and Jaya respectively. During June 20$^{th}$ and July 20$^{th}$ plantings, the maximum temperature observed were same for both the varieties. Higher minimum temperature of the varieties recorded were similar for June 5$^{th}$, June 20$^{th}$ and July 20$^{th}$ plantings whereas the lowest minimum temperature was noticed during July 5$^{th}$ and August 5$^{th}$ plantings with values 22.0°C and 22.1°C for Jyothi and Jaya. Mean temperature values ranged from 25.0°C to 26.7°C wherein lowest value was recorded during August 5$^{th}$ planting and the highest during June 5$^{th}$ planting. The highest temperature range value 7.1°C in July 5$^{th}$ planting and lowest value of 5.9°C in August 5$^{th}$ planting were observed for Jyothi and Jaya respectively.

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

| Weather variable | Date of transplanting | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | June $5^{th}$ | | June $20^{th}$ | | July $5^{th}$ | | July $20^{th}$ | | August $5^{th}$ | |
| | Jyothi | Jaya | Jyothi | Jaya | Jyothi | Jaya | Jyothi | Jaya | Jyothi | Jaya |
| Tmax ($^{0}$C) | 29.9 | 29.7 | 28.9 | 28.9 | 29.1 | 29.0 | 29.5 | 29.5 | 28.1 | 28.0 |
| Tmin ($^{0}$C) | 23.6 | 23.6 | 22.5 | 22.5 | 22.0 | 22.1 | 22.9 | 22.9 | 22.0 | 22.1 |
| Tmean ($^{0}$C) | 26.7 | 26.6 | 25.7 | 25.7 | 25.5 | 25.6 | 26.2 | 26.2 | 25.0 | 25.0 |
| Trange ($^{0}$C) | 6.4 | 6.1 | 6.4 | 6.4 | 7.1 | 6.9 | 6.6 | 6.6 | 6.1 | 5.9 |
| VPD I (mm Hg) | 23.6 | 23.7 | 22.1 | 22.1 | 21.6 | 21.8 | 22.9 | 22.9 | 22.0 | 21.9 |
| VPD II (mm Hg) | 23.9 | 24.1 | 22.7 | 22.7 | 23.2 | 23.2 | 23.0 | 23.0 | 22.5 | 22.5 |
| RH I (%) | 97 | 97 | 95 | 95 | 97 | 97 | 95 | 95 | 97 | 96 |
| RH II (%) | 84 | 85 | 81 | 81 | 86 | 85 | 77 | 77 | 86 | 87 |
| RH mean (%) | 90 | 91 | 88 | 88 | 91 | 91 | 86 | 86 | 91 | 92 |
| RF (mm) | 440 | 439.3 | 120.7 | 120.7 | 567.5 | 496.8 | 140.8 | 140.8 | 840.2 | 837.6 |
| RD | 9 | 9 | 9 | 9 | 11 | 10 | 7 | 7 | 14 | 13 |
| BSS (hrs) | 1.7 | 1.1 | 1.8 | 1.8 | 1.0 | 1.1 | 0.7 | 0.7 | 0.5 | 0.3 |
| Epan (mm) | 2.3 | 2.2 | 2.1 | 2.1 | 2.6 | 2.6 | 2.4 | 2.4 | 1.8 | 1.8 |
| WS (km $hr^{-1}$) | 1.9 | 1.8 | 1.1 | 1.1 | 1.8 | 1.8 | 1.7 | 1.7 | 1.8 | 1.8 |

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

Forenoon relative humidity varied from 95% to 97% in which the lowest humidity was recorded during June 20th and July 20th plantings for both the varieties and the higher value recorded during June 5th and July 5th plantings. Afternoon relative humidity was lowest for July 20th planting in both the varieties with a value of 77% and the higher value of 87% was recorded for Jaya variety during August 5th planting. Mean relative humidity ranged from 86% to 92%. Higher mean relative humidity value was recorded for August 5th planting in Jaya and the lowest recorded during July 20th planting for both varieties.

Forenoon vapour pressure deficit showed a decreasing trend up to June 20th planting and it showed an increasing trend till July 20th planting, then again decreased. Maximum value of forenoon vapour pressure deficit was observed during June 5th planting with the values 23.6mm Hg for Jyothi and 23.7mm Hg for Jaya while minimum value of 21.6mm Hg was recorded for Jyothi during July 5th planting. Afternoon vapour pressure values ranged from 22.5mm Hg to 24.1mm Hg wherein the lowest value noticed in August 5th planting for both the varieties and higher value was recorded for Jaya during June 5th planting.

*4.4.1.3. Rainfall (RF) and Rainy days (RD)*

Amount of rainfall received was higher during the August 5th planting with a quantity of 840.2 mm for Jyothi and 837.6 mm for Jaya. June 20th planting received the lower amount of 120.7 mm rainfall in both varieties.

Rainy days showed an increasing trend towards July 5th planting and decreased for July 20th planting, then again increased. Maximum rainy days were recorded during August 5th planting with 14 days for Jyothi and 13 days for Jaya. In Jyothi and Jaya, the minimum rainy days recorded was 7 days during July 20th planting.

*4.4.1.4. Bright sunshine hours (BSS)*

Bright sunshine hours exhibited an increasing trend towards June 20$^{th}$ planting and showed a decreasing trend with delayed planting. A higher value of 1.8 hrs bright sunshine hours were noticed during June 20$^{th}$ planting in Jyothi and Jaya whereas lower values of 0.5 hrs and 0.3 hrs were recorded in August 5$^{th}$ planting for Jyothi and Jaya respectively.

*4.4.1.5. Pan Evaporation (Epan)*

Pan evaporation showed a range in between 1.8 mm to 2.6 mm. the values showed a decreasing trend towards June 20$^{th}$ planting and increased during July 5$^{th}$ planting, then again decreased with planting dates. The higher value of 2.6 mm and lower value of 1.8 mm were recorded during July 5$^{th}$ and August 5$^{th}$ plantings respectively for both the varieties.

*4.4.1.6. Wind speed (WS)*

Wind speed was higher during June 5$^{th}$ planting with a maximum value of 1.9 km hr$^{-1}$ recorded for the variety Jyothi. Minimum value of wind speed was recorded during June 20$^{th}$ planting with 1.1 km hr$^{-1}$ for both the varieties.

**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, Mean temperature and Temperature range)*

From transplanting to panicle initiation stage the maximum temperature of different planting dates showed a variation from 28.9$^0$C to 29.7$^0$C. The maximum value for the variety Jyothi was observed during June 20$^{th}$ planting with a value 29.7$^0$C and for Jaya it was 29.5$^0$C during all planting dates except for July 5$^{th}$ and August 5$^{th}$ plantings. Lower values of 29.0$^0$C and 28.9$^0$C were noticed for Jyothi and Jaya

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

| **Weather variable** | **Date of transplanting** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | June 5th | | June 20th | | July 5th | | July 20th | | August 5th | |
| | Jyothi | Jaya | Jyothi | Jaya | Jyothi | Jaya | Jyothi | Jaya | Jyothi | Jaya |
| Tmax ($^0$C) | 29.5 | 29.5 | 29.7 | 29.5 | 29.0 | 28.9 | 29.5 | 29.5 | 29.2 | 29.1 |
| Tmin ($^0$C) | 23.2 | 23.2 | 22.7 | 22.6 | 22.2 | 22.2 | 22.9 | 22.9 | 22.1 | 22.1 |
| Tmean ($^0$C) | 26.3 | 26.3 | 26.2 | 26.1 | 25.6 | 25.6 | 26.2 | 26.2 | 25.6 | 25.6 |
| TR ($^0$C) | 6.3 | 6.3 | 7.0 | 6.9 | 6.8 | 6.7 | 6.7 | 6.7 | 7.1 | 7.0 |
| VPD I (mm Hg) | 22.8 | 22.8 | 22.4 | 22.3 | 22.0 | 21.9 | 22.9 | 22.9 | 21.9 | 22.0 |
| VPD II (mm Hg) | 23.3 | 23.3 | 22.7 | 22.7 | 22.9 | 22.9 | 23.0 | 23.0 | 22.1 | 22.1 |
| RH I (%) | 96 | 96 | 95 | 95 | 96 | 96 | 96 | 96 | 96 | 96 |
| RH II (%) | 83 | 84 | 78 | 79 | 83 | 83 | 78 | 79 | 78 | 79 |
| RH mean (%) | 90 | 90 | 87 | 87 | 89 | 90 | 87 | 87 | 87 | 87 |
| RF (mm) | 609.6 | 606.1 | 363.2 | 411.3 | 727.2 | 725.3 | 401.4 | 421.6 | 882.6 | 883.1 |
| RD | 18 | 17 | 13 | 14 | 18 | 18 | 15 | 17 | 23 | 25 |
| BSS (hrs) | 1.7 | 1.8 | 2.9 | 2.7 | 0.7 | 0.6 | 1.0 | 0.9 | 2.6 | 2. 3 |
| Epan (mm) | 2.3 | 2.3 | 2.5 | 2.5 | 2.4 | 2.4 | 2.3 | 2.3 | 2.3 | 2.3 |
| WS (km $hr^{-1}$) | 1.7 | 1.7 | 1.4 | 1.4 | 1.6 | 1.7 | 1.6 | 1.6 | 1.9 | 1.9 |

respectively during July 5th planting. Minimum temperature showed a decreasing trend towards July 5th planting and increased during July 20th planting, then again decreased during August 5th planting. Higher value of 23.2$^0$C and a lower value of 22.1$^0$C were obtained as minimum temperature during June 5th and August 5th plantings respectively for both the varieties. Mean temperature values ranged from 25.6$^0$C to 26.3$^0$C in which maximum value was recorded during June 5th planting. Temperature range also showed variation from 6.2$^0$C to 7.1$^0$C and it varied according to different dates of planting.

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

Forenoon relative humidity was found to be higher for Jyothi (96%) and Jaya (96%) for all the plantings except for June 20th planting which had lower values of 95% for Jyothi and 95% for Jaya. Afternoon relative humidity varied from 78% to 84% in which lowest value was recorded for June 20th, July 20th and August 5th (78% for Jyothi and 79% for Jaya) plantings and higher values recorded for the varieties (83% for Jyothi and 84% for Jaya) during June 5th planting. Mean relative humidity showed a range from 87% to 90% and showed decreasing as well as increasing trend as the planting date was delayed.

Forenoon vapour pressure deficit showed a decreasing trend till July 5th planting and later it increased during July 20th planting, then again showed a decrease during August 5th planting. Maximum value of forenoon vapour pressure deficit was observed during July 20th planting (22.9mm Hg) whereas maximum value of afternoon vapour pressure deficit was observed during June 5th planting (23.3mm Hg). Afternoon vapour pressure deficit was more compared to forenoon vapour pressure deficit.

*4.4.2.3. Rainfall (RF) and Rainy days (RD)*

The quantum of rainfall received exhibited a wide variation among different dates of planting. Maximum amount of rainfall was received during August 5$^{th}$ planting in which Jyothi received 882.6 mm and that for Jaya was 883.1 mm rainfall. Least amount of rainfall was recorded during July 20$^{th}$ planting (401.4 mm for Jyothi and 421.6 mm for Jaya).

Rainy days recorded was in a range between 13 to 25 days. August 5$^{th}$ planting have recorded maximum number of rainy days for both the varieties *viz.* 23 days for Jyothi and 25 days for Jaya. The lowest rainy days of 13 and 14 days were recorded in June 20$^{th}$ planting for Jyothi and Jaya respectively.

*4.4.2.4. Bright sunshine hours (BSS)*

Bright sunshine hours showed an increasing trend towards June 20$^{th}$ planting and decreased during July 5$^{th}$ planting, thereafter it was increasing towards the last planting date. It was varying from a value 0.6 hrs to 2.9 hrs. A higher bright sunshine hours recorded during June 20$^{th}$ planting with 2.9 hrs for Jyothi and 2.7 hrs for Jaya. July 5$^{th}$ planting experienced minimum values of 0.7 hrs in Jyothi and 0.6 hrs in Jaya varieties.

*4.4.2.5. Pan Evaporation (Epan)*

Almost nearer values of pan evaporation were recorded during the crop period from transplanting to panicle initiation. An evaporation of 2.5 mm was experienced for June 20$^{th}$ planting and that was 2.4 mm during July 5$^{th}$ planting whereas all other planting dates were experienced by an evaporation of 2.3 mm for both the varieties.

*4.4.2.6. Wind speed (WS)*

Wind speed exhibited a range from 1.4 km hr$^{-1}$ to 1.9 km hr$^{-1}$ from transplanting to panicle initiation. The lowest speed of 1.4 km hr$^{-1}$ was experienced during June 20$^{th}$

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planting and higher speed of 1.9 km $hr^{-1}$ were recorded during the last planting (August $5^{th}$). All other planting dates were experienced by a wind speed of 1.6 – 1.7 km $hr^{-1}$.

### 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, Mean temperature and Temperature range)*

A decreasing trend of maximum temperature was observed towards July $5^{th}$ planting, thereafter it showed an increasing trend with delayed planting. 29.9$^0$C and 30.0$^0$C were the higher values of maximum temperature recorded for Jyothi and Jaya respectively and it was experienced during August $5^{th}$ planting while 28.9$^0$C were obtained as the lower value recorded for both the varieties during July $5^{th}$ planting. Minimum temperature varied from 22.2$^0$C to 22.9$^0$C wherein higher value and lower value were recorded during June $5^{th}$ and August $5^{th}$ plantings respectively for both the varieties. Mean temperature showed a decreasing trend towards July $5^{th}$ planting and increased during July $20^{th}$ planting, then again showed a decrease during August $5^{th}$ planting. 26.2$^0$C and 25.6$^0$C were recorded as the higher and lower mean temperature values during June $5^{th}$ planting and July $5^{th}$ planting respectively in Jyothi and Jaya. For first four planting dates, the temperature range values were in between 6.6$^0$C – 6.9$^0$C whereas for the last planting, higher values of 7.7$^0$C and 7.8$^0$C were obtained in Jyothi and Jaya respectively.

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

From transplanting to booting stage, higher forenoon relative humidity values were recorded which was greater than 94% for all the planting dates. Among different planting dates, except for August $5^{th}$ planting, all other plantings were noticed with higher forenoon humidity values of 96%. Afternoon relative humidity values varied

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

| **Weather variable** | **Date of transplanting** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | June $5^{th}$ | | June $20^{th}$ | | July $5^{th}$ | | July $20^{th}$ | | August $5^{th}$ | |
| | Jyothi | Jaya | Jyothi | Jaya | Jyothi | Jaya | Jyothi | Jaya | Jyothi | Jaya |
| Tmax ($^0$C) | 29.6 | 29.5 | 29.5 | 29.4 | 28.9 | 28.9 | 29.3 | 29.5 | 29.9 | 30.0 |
| Tmin ($^0$C) | 22.9 | 22.9 | 22.6 | 22.6 | 22.3 | 22.3 | 22.6 | 22.6 | 22.2 | 22.2 |
| Tmean ($^0$C) | 26.2 | 26.2 | 26.0 | 26.0 | 25.6 | 25.6 | 26.0 | 26.0 | 26.1 | 26.1 |
| TR ($^0$C) | 6.7 | 6.6 | 6.9 | 6.9 | 6.6 | 6. 6 | 6.8 | 6.8 | 7.7 | 7.8 |
| VPD I (mm Hg) | 22.6 | 22.6 | 22.3 | 22.3 | 22.2 | 22.1 | 22.6 | 22.6 | 22.0 | 22.0 |
| VPD II (mm Hg) | 23.1 | 23.1 | 22.8 | 22.8 | 22.9 | 22.9 | 22.6 | 22.5 | 21.5 | 21.5 |
| RH I (%) | 96 | 96 | 96 | 96 | 96 | 96 | 96 | 96 | 95 | 94 |
| RH II (%) | 82 | 83 | 80 | 79 | 83 | 83 | 78 | 77 | 73 | 72 |
| RH mean (%) | 89 | 90 | 88 | 88 | 90 | 90 | 87 | 87 | 84 | 83 |
| RF (mm) | 1250.9 | 1293.5 | 915.7 | 960.6 | 1674.8 | 1679.1 | 1110.2 | 1110.2 | 883.9 | 886.0 |
| RD | 32 | 34 | 30 | 34 | 38 | 40 | 37 | 37 | 25 | 25 |
| BSS (hrs) | 1.9 | 1.9 | 2.1 | 2.1 | 0.7 | 0.7 | 1.5 | 1.8 | 4.2 | 4.2 |
| Epan (mm) | 2.4 | 2.4 | 2.5 | 2.4 | 2.3 | 2.3 | 2.3 | 2.4 | 2.7 | 2.7 |
| WS (km $hr^{-1}$) | 1.7 | 1.7 | 1.5 | 1.5 | 1.6 | 1.7 | 1.7 | 1.7 | 1.9 | 1.8 |

from 72% to 83% and it was higher in July 5$^{th}$ planting while it was lower during August 5$^{th}$ planting. As in the case of afternoon relative humidity, higher and lower values of mean relative humidity were recorded during July 5$^{th}$ and August 5$^{th}$ plantings respectively and was in a range from 83% to 90%.

Forenoon vapour pressure deficit was in a range of 22.0mm Hg to 22.6mm Hg. Towards July 5$^{th}$ planting, forenoon vapour pressure deficit showed a decreasing trend and during July 20$^{th}$ planting the values were increased, but later on August 5$^{th}$ planting the values were decreased again. Maximum value of forenoon vapour pressure deficit were obtained during June 5$^{th}$ and July 20$^{th}$ planting with a value of 22.6mm Hg whereas the minimum value of 22.0mm Hg were recorded during August 5$^{th}$ planting. Afternoon vapour pressure deficit showed a higher value during June 5$^{th}$ planting (23.1mm Hg) and minimum value recorded during August 5$^{th}$ planting (21.5mm Hg) for both the varieties.

*4.4.3.3. Rainfall (RF) and Rainy days (RD)*

The total amount of rainfall received during transplanting to active tillering stage were found to be different for different dates of planting. The quantum of rainfall received was maximum during July 5$^{th}$ planting wherein 1674.8 mm were recorded for Jyothi and 1679.1 mm for Jaya. The lowest accumulated rainfall were observed during August 5$^{th}$ planting with 883.9 mm for Jyothi and 886.0 mm for Jaya.

Number of rainy days were noticed in between a range of 25-40 days in which maximum rainy days observed during July 5$^{th}$ planting (38 and 40 for Jyothi and Jaya respectively) and a minimum number of 25 days were recorded for August 5$^{th}$ planting in both the varieties.

*4.4.3.4. Bright sunshine hours (BSS)*

Bright sunshine hours showed a wide variation among different dates of planting. Both the varieties were experienced with same duration of bright sunshine hours except for July 20$^{th}$ planting. Maximum of 4.2 hrs and minimum of 0.7 hrs were experienced during August 5$^{th}$ and July 5$^{th}$ plantings respectively for Jyothi and Jaya.

*4.4.3.5. Pan Evaporation (Epan)*

Pan evaporation showed a slight variation for first four dates of planting within a range of 2.3-2.5 mm. Higher pan evaporation values were observed during the last planting (August 5$^{th}$) with an evaporation value of 4.7 mm for Jyothi as well as Jaya.

*4.4.3.6. Wind speed (WS)*

A range of 1.5 km hr$^{-1}$ to 1.9 km hr$^{-1}$ wind speed values were noticed during transplanting to booting stage of different planting dates. Highest wind speed value of 1.9 km hr$^{-1}$ were recorded in August 5$^{th}$ planting for Jyothi variety and the lower value of 1.5 km hr$^{-1}$ were obtained during June 20$^{th}$ planting for both varieties. Other dates of planting showed nearer values in the case of wind speed, experienced during this stage.

**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, Mean temperature and Temperature range)*

A specific trend was not observed in the case of maximum temperature. The maximum temperature varied from 29.3$^0$C to 31.0$^0$C. Higher value of 31.0$^0$C were obtained in Jaya during August 5$^{th}$ planting whereas minimum value of 29.3$^0$C was observed in Jyothi variety during June 5$^{th}$ and July 5$^{th}$ planting. Minimum temperature showed a decreasing trend towards July 5$^{th}$ planting and increased during July 20$^{th}$ planting, again decreased in the last planting date. Minimum temperature was higher

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

| Weather variable | Date of transplanting | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | June 5th | | June 20th | | July 5th | | July 20th | | August 5th | |
| | Jyothi | Jaya | Jyothi | Jaya | Jyothi | Jaya | Jyothi | Jaya | Jyothi | Jaya |
| Tmax ($^0$C) | 29.3 | 29.4 | 29.6 | 29.4 | 29.3 | 29.4 | 29.6 | 30.0 | 30.6 | 31.0 |
| Tmin ($^0$C) | 22.8 | 22.8 | 22.6 | 22.6 | 22.3 | 22.3 | 22.8 | 22.4 | 22.2 | 22.3 |
| Tmean ($^0$C) | 26.0 | 26.1 | 26.1 | 26.0 | 25.8 | 25.8 | 26.2 | 26.2 | 26.4 | 26.6 |
| TR ($^0$C) | 6.6 | 6.5 | 6.9 | 6.8 | 7.0 | 7.1 | 6.8 | 7.6 | 8.4 | 8.7 |
| VPD I (mm Hg) | 22.5 | 22.5 | 22.5 | 22.4 | 22.1 | 22.0 | 22.8 | 22.4 | 22.0 | 22.0 |
| VPD II (mm Hg) | 23.0 | 23.1 | 22.8 | 22.9 | 22.6 | 22.4 | 22.3 | 21.8 | 21.2 | 21.6 |
| RH I (%) | 96 | 96 | 96 | 96 | 96 | 96 | 96 | 95 | 94 | 93. |
| RH II (%) | 82 | 82 | 79 | 80 | 80 | 79 | 75 | 73 | 69 | 69 |
| RH mean (%) | 89 | 89 | 87 | 88 | 88 | 87 | 86 | 84 | 81 | 81 |
| RF (mm) | 1406.9 | 1384.2 | 1105.4 | 1155.1 | 1687.7 | 1687.7 | 1110.7 | 1110.7 | 887.2 | 887.2 |
| RD | 39 | 38 | 36 | 39 | 46 | 45 | 37 | 37 | 25 | 25 |
| BSS (hrs) | 1.5 | 1.5 | 2.0 | 1.7 | 2.0 | 2.3 | 1.6 | 3.7 | 4.9 | 4.7 |
| Epan (mm) | 2.3 | 2.3 | 2.4 | 2.4 | 2.4 | 2.5 | 2.4 | 2.7 | 2.9 | 2.8 |
| WS (km $hr^{-1}$) | 1.6 | 1.6 | 1.5 | 1.5 | 1.8 | 1.8 | 1.7 | 1.8 | 1.8 | 1.7 |

in June 5th planting (22.8$^0$C for both varieties) and in July 20th planting (for Jyothi) while it was found to be lower during August 5th planting (22.2$^0$C in Jyothi). Mean temperature varied from 25.8$^0$C (July 5th planting) to 26.6$^0$C (in Jaya during august 5th planting). Temperature range showed an increasing trend towards the last planting date in which higher values of 8.4$^0$C and 8.7$^0$C were observed during August 5th planting in Jyothi and Jaya respectively.

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

A lower forenoon relative humidity value of 93% recorded in Jaya variety during last planting whereas in Jyothi, it was 94 during the same planting time. Higher value recorded for all other plantings (96%) and it was recorded in both the varieties. Afternoon relative humidity and mean relative humidity were exhibited a decreasing trend towards as the planting date was delayed. Afternoon relative humidity values were higher in the 1st planting date for Jyothi and Jaya with recorded value of 82%. The lower values were reached up to 69% during last planting (August 5th). Mean relative humidity value ranged from 81% (during August 5th planting) to 89% (during June 5th planting).

Forenoon vapour pressure deficit did not show any trend among different planting dates whereas afternoon vapour pressure deficit showed a decreasing trend towards the August 5th planting. The higher values of forenoon and afternoon vapour pressure deficits were 22.8mm Hg (July 20th planting of Jyothi) and 23.1% (June 5th of Jaya) respectively whereas the lower values recorded were 22.0mm Hg (August 5th planting) and 21.2mm Hg (August 5th of Jyothi) respectively.

*4.4.4.3. Rainfall (RF) and Rainy days (RD)*

The accumulated rainfall of transplanting to heading stage among different planting dates revealed that larger quantity of 1687.7 mm was received during July $5^{th}$ planting and lower amount of 887.2 mm was received during August $5^{th}$ planting for Jyothi as well as Jaya varieties.

During July $5^{th}$ planting, the number of rainy days counted were higher compared to all other planting dates in which 46 days were recorded in Jyothi and 45 days in Jaya. The lower number of 25 days were noticed during August $5^{th}$ planting in both the varieties. Other planting dates varied from 36 to 39 in number of rainy days.

*4.4.4.4. Bright sunshine hours (BSS)*

Bright sunshine hours showed a range from 1.5 hrs to 4.9 hrs. An increasing trend was observed in bright sunshine hours as the planting date was delayed. Maximum of 4.9 hrs and 4.7 hrs were observed during the last planting date (August $5^{th}$) for Jyothi and Jaya respectively while minimum hours of 1.5 hrs was recorded in the June $5^{th}$ planting for both varieties.

*4.4.4.5. Pan Evaporation (Epan)*

Pan evaporation values showed slight changes during the initial four planting dates within a range of 2.3 mm to 2.5 mm whereas the last planting date (August $5^{th}$ planting) showed higher evaporation values of 2.9 mm and 2.8 mm for Jyothi and Jaya respectively.

*4.4.4.6. Wind speed (WS)*

Wind speed showed a variation in between 1.5 km $hr^{-1}$ to 1.8 km $hr^{-1}$. 1.5 km $hr^{-1}$ was recorded as the lower value from June $20^{th}$ planting. The maximum speed of 1.8 km $hr^{-1}$ was recorded during July $5^{th}$ (Jaya and Jyothi), July $20^{th}$ (Jaya) and August $5^{th}$ (Jyothi) plantings.

### 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, Mean temperature and Temperature range)*

A decreasing trend of maximum temperature was observed towards June 20th planting, thereafter it showed an increasing trend towards the last planting (August 5th). The maximum temperature noticed as higher during August 5th planting with values 31.3⁰C and 31.4⁰C for Jyothi and Jaya respectively whereas it was found to minimum during June 20th planting with 29.3⁰C for Jyothi and 28.9⁰C for Jaya. Minimum temperature showed a range from 22.2⁰C to 22.9⁰C. The higher values obtained during June 5th planting and the lower values were obtained during July 5th planting. Like maximum temperature, mean temperature values also found to be higher during the last planting (26.8⁰C and 26.9⁰C for Jyothi and Jaya). From the 1st planting to the last, the temperature range showed an increasing trend with a maximum value of 9.1⁰C which was recorded for Jaya.

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

In general, it was found that forenoon and afternoon relative humidity values were decreasing towards the last planting date with a range of 93% - 96% and 67% - 82% respectively. Forenoon relative humidity was higher during June 5th, June 20th and July 5th plantings whereas it was lower during August 5th planting. Higher value of 82% afternoon relative humidity was found in Jaya variety during June 20th planting and lower value of 67% was found in Jyothi cultivated during August 5th planting.

Slight changes were observed in the forenoon vapour pressure deficit in between different planting dates. Maximum of 22.7mm Hg and 22.6mm Hg forenoon vapour pressure deficits were noticed during August 5th planting in Jyothi and Jaya

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

| Weather variable | Date of transplanting | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | June 5th | | June 20th | | July 5th | | July 20th | | August 5th | |
| | Jyothi | Jaya | Jyothi | Jaya | Jyothi | Jaya | Jyothi | Jaya | Jyothi | Jaya |
| Tmax ($^0$C) | 29.5 | 29.4 | 29.3 | 28.9 | 29.4 | 29.4 | 30.1 | 30.4 | 31.3 | 31.4 |
| Tmin ($^0$C) | 22.9 | 22.8 | 22.5 | 22.4 | 22.2 | 22.2 | 22.6 | 22.4 | 22.3 | 22.4 |
| Tmean ($^0$C) | 26.2 | 26.1 | 25.9 | 25.7 | 25.8 | 25.8 | 26.3 | 26.4 | 26.8 | 26.9 |
| TR ($^0$C) | 6.64 | 6.6 | 6.8 | 6.5 | 7.1 | 7.2 | 7.6 | 8.1 | 9.0 | 9.1 |
| VPD I (mm Hg) | 22.7 | 22.6 | 22.4 | 22.2 | 22.1 | 21.9 | 22.5 | 22.2 | 22.0 | 22.1 |
| VPD II (mm Hg) | 23.1 | 22.9 | 22.8 | 22.7 | 22.4 | 22.4 | 21.9 | 21.4 | 21.5 | 22.7 |
| RH I (%) | 96 | 96 | 96 | 96 | 96 | 96 | 95 | 94 | 93 | 93 |
| RH II (%) | 81 | 80 | 80 | 82 | 78 | 78 | 72 | 70 | 67 | 69 |
| RH mean (%) | 88 | 88 | 88 | 88 | 87 | 87 | 83 | 82 | 80 | 81 |
| RF (mm) | 1434.3 | 1410.6 | 1195.7 | 1598.2 | 1720.3 | 1720.0 | 1110.7 | 1110.7 | 887.2 | 944.2 |
| RD | 41 | 39 | 41 | 44 | 50 | 49 | 37 | 37 | 25 | 27 |
| BSS (hrs) | 1.51 | 1.35 | 1.59 | 1.38 | 2.04 | 2.27 | 3.25 | 4.70 | 5.33 | 4.43 |
| Epan (mm) | 2.36 | 2.33 | 2.32 | 2.18 | 2.50 | 2.56 | 2.67 | 2.89 | 2.95 | 2.75 |
| WS (km $hr^{-1}$) | 1.66 | 1.64 | 1.46 | 1.58 | 1.74 | 1.75 | 1.74 | 1.77 | 1.75 | 1.73 |

respectively. Minimum of 21.9mm Hg were noted in the case of Jaya in July 5th planting. Afternoon vapour pressure values ranged from 21.4mm Hg (in Jaya of July 20th planting) to 23.1mm Hg (in Jyothi of June 5th planting).

*4.4.5.3. Rainfall (RF) and Rainy days (RD)*

The amount of rainfall received among different planting dates was varying without showing any specific pattern. More amount of rainfall was received in July 5th planting in which Jyothi recorded a rainfall of 1720.3 mm and for Jaya it was 1720.0 mm. During August 5th planting, Jyothi recorded the lowest amount of 887.2 mm rainfall compared to other planting dates.

A wide variation was observed in number of rainy days for different planting dates. A range of 25-50 days were noticed for all the planting dates. The minimum number of rainy days obtained during last planting date in which 25 days and 27 days were observed for Jyothi and Jaya respectively. Higher number of 50 rainy days were observed in Jyothi variety during July 5th planting.

*4.4.5.4. Bright sunshine hours (BSS)*

There was an increasing trend of bright sunshine hours from transplanting to 50% flowering in different dates of planting. The bright sunshine hours were lower during the first two plantings (1.38 hrs – 1.59 hrs) while the duration of bright sunshine was increasing towards the delayed planting. Jyothi variety exhibited the maximum bright sunshine hours of 5.33 hrs during August 5th planting.

*4.4.5.5. Pan Evaporation (Epan)*

Pan evaporation varied from 2.18 mm to 2.95 mm. the pan evaporation values were almost nearer during the first two plantings whereas it showed an increasing trend as the planting date was delayed. Maximum evaporation of 2.95 mm was recorded during August 5$^{th}$ planting in Jyothi variety and was minimum during June 20$^{th}$ planting (2.18 mm in Jaya).

*4.4.5.6. Wind speed (WS)*

Wind speed was ranging from 1.46 km hr$^{-1}$ to 1.77 km hr$^{-1}$. Wind speed showed a decreasing pattern towards June 20$^{th}$ planting where the lowest speed was observed, thereafter it was almost similar throughout all other planting dates.

**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, Mean temperature and Temperature range)*

From transplanting to physiological maturity, the maximum temperature showed an increasing trend from June 5$^{th}$ to August 5$^{th}$ planting. Jyothi and Jaya experienced a higher maximum temperature during August 5$^{th}$ planting with 31.5$^{0}$C and 31.7$^{0}$C respectively. The lowest maximum temperature of 29.2$^{0}$C were experienced in June 20$^{th}$ planting by Jaya variety and all other planting dates showed a slight change from this temperature. The higher value of minimum temperature were noticed during June 5$^{th}$ planting (22.8$^{0}$C) for both varieties whereas the lower value observed during July 5$^{th}$ planting with temperatures 22.3$^{0}$C and 22.2$^{0}$C for Jyothi and Jaya respectively. Mean temperature varied from 25.8$^{0}$C (June 20$^{th}$ planting) to a maximum of 27.1$^{0}$C (August 5$^{th}$ planting). There was an increasing trend of temperature range values towards the last planting. It was varying from 6.7$^{0}$C to 9.2$^{0}$C from June 5$^{th}$ to August 5$^{th}$ planting.

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

A gradual decrease of forenoon and afternoon relative humidity were noticed during transplanting to physiological maturity stage of different planting dates.

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

| Weather variable | Date of transplanting | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | June $5^{th}$ | | June $20^{th}$ | | July $5^{th}$ | | July $20^{th}$ | | August $5^{th}$ | |
| | Jyothi | Jaya | Jyothi | Jaya | Jyothi | Jaya | Jyothi | Jaya | Jyothi | Jaya |
| Tmax ($^{0}C$) | 29.5 | 29.5 | 29.5 | 29.2 | 29.9 | 29.9 | 30.5 | 30.8 | 31.5 | 31.7 |
| Tmin ($^{0}C$) | 22.8 | 22.8 | 22.5 | 22.4 | 22.3 | 22.2 | 22.6 | 22.4 | 22.4 | 22.5 |
| Tmean ($^{0}C$) | 26.1 | 26.1 | 26.0 | 25.8 | 26.1 | 26.1 | 26.6 | 26.6 | 26.9 | 27.1 |
| TR ($^{0}C$) | 6.7 | 6.7 | 7.04 | 6.8 | 7.6 | 7.7 | 7.9 | 8.4 | 9.1 | 9.2 |
| VPD I (mm Hg) | 22.6 | 22.5 | 22.3 | 22.2 | 22.1 | 21.9 | 22.5 | 22.2 | 21.9 | 22.0 |
| VPD II (mm Hg) | 22.9 | 22.8 | 22.5 | 22.4 | 22.2 | 22.2 | 21.9 | 21.6 | 21.5 | 22.5 |
| RH I (%) | 96 | 96 | 96 | 96 | 95 | 95 | 95 | 93 | 92 | 93 |
| RH II (%) | 81 | 79 | 78 | 80 | 75 | 75 | 70 | 69 | 66 | 68 |
| RH mean (%) | 88 | 88 | 87 | 88 | 85 | 85 | 83 | 81 | 79 | 80 |
| RF (mm) | 2403.7 | 2403.7 | 1845.1 | 1845.1 | 1825.6 | 1880.3 | 1369.0 | 1485.2 | 1295.1 | 1295.1 |
| RD | 71 | 71 | 59 | 59 | 54 | 56 | 46 | 50 | 39 | 39 |
| BSS (hrs) | 1.62 | 1.59 | 2.23 | 2.16 | 2.86 | 3.00 | 3.66 | 4.82 | 5.36 | 4.65 |
| Epan (mm) | 2.35 | 2.35 | 2.41 | 2.33 | 2.63 | 2.68 | 2.73 | 2.91 | 2.96 | 2.80 |
| WS (km $hr^{-1}$) | 1.67 | 1.66 | 1.53 | 1.62 | 1.73 | 1.79 | 1.75 | 1.77 | 1.83 | 1.78 |

Forenoon and afternoon relative humidity were higher during June 5$^{th}$ planting (96% and 81% respectively) and the lower values of both were detected during August 5$^{th}$ planting (92% and 66% respectively). The same trend was observed in the case of mean relative humidity which showed a range from 79% to 88%.

Forenoon as well as afternoon vapour pressure deficits showed little difference among different dates of planting. Forenoon vapour pressure deficit showed a range from 21.9 mm Hg - 22.6 mm Hg while afternoon vapour pressure deficit showed from 21.5 mm Hg -22.9 mm Hg. In both cases, lower values were observed during August 5$^{th}$ planting and higher values were observed during June 5$^{th}$ planting.

*4.4.6.3. Rainfall (RF) and Rainy days (RD)*

The total amount of rainfall received during transplanting to physiological maturity stage was higher for June 5$^{th}$ planting (2403.7 mm) and the lesser amount was noticed during August 5$^{th}$ planting (1295.1 mm). In the same way, more number of rainy days was recorded during June 5$^{th}$ planting (71 days) and lesser number was recorded during August 5$^{th}$ planting (39 days). The number of rainy days was decreasing towards the August 5$^{th}$ planting from June 5$^{th}$ planting date.

*4.4.6.4. Bright sunshine hours (BSS)*

During initial planting dates, the bright sunshine hours was less, after that was increasing towards last planting dates. It showed a range from 1.59 hrs (June 5$^{th}$ planting) to 5.36 hrs (August 5$^{th}$ planting).

*4.4.6.5. Pan Evaporation (Epan)*

An increasing trend of pan evaporation values were observed from transplanting to physiological maturity for Jyothi and Jaya. It ranged from 2.33 mm to 2.96 mm. In Jyothi the lowest value of 2.35 mm was observed in June 5$^{th}$ planting whereas in Jaya, it was during June 20$^{th}$ planting (2.33 mm). Higher evaporation value

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of Jyothi was noticed during August 5$^{th}$ planting (2.96 mm) and in the case of Jaya, it was observed during July 20$^{th}$ planting (2.91 mm).

*4.4.6.6. Wind speed (WS)*

A range of 1.53 km hr$^{-1}$ to 1.83 km hr$^{-1}$ was noticed for wind speed among different dates of planting. 1.53 km hr$^{-1}$ was the lowest speed observed during June 20$^{th}$ planting and 1.83 km hr$^{-1}$ was the higher speed noticed during August 5$^{th}$ planting.

4.5. CROP WEATHER RELATIONSHIP

For the varieties Jyothi and Jaya, correlation analysis was carried out between weather variables and duration of phenophases, yield and yield attributes using the data collected from the time of experimentation during 2018. The results obtained are given below.

**4.5.1. Influence of weather parameters on crop duration of Jyothi**

Table 4.8 represents the result of the correlation analysis carried out between weather variables and phenophases duration of Jyothi.

*4.5.1.1. Transplanting to active tillering (P1)*

Forenoon relative humidity, afternoon relative humidity, mean relative humidity, rainfall and rainy days showed a significant positive correlation with the number of days taken from transplanting to active tillering whereas maximum temperature, minimum temperature, mean temperature, forenoon vapour pressure deficit and evaporation showed a negative significant correlation.

*4.5.1.2. Active tillering to panicle initiation (P2)*

Minimum temperature, afternoon relative humidity, mean relative humidity, rainfall, forenoon as well as afternoon vapour pressure deficit exhibited positive significant correlation and temperature range, wind speed, bright sunshine hours and

Table 4.8 Correlation between duration of phenophases and weather variables in Jyothi

| Stages | Tmax | Tmin | Tmean | Trange | RHI | RHII | RHm | VPDI | VPDII | WS | BSS | RF | RD | Epan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1 | -0.674$^{**}$ | -0.561$^{*}$ | -0.645$^{**}$ | -0.249 | 0.737$^{**}$ | 0.902$^{**}$ | 0.888$^{**}$ | -0.464$^{*}$ | -0.261 | 0.443 | -0.428 | 0.972$^{**}$ | 0.982$^{**}$ | -0.459$^{*}$ |
| P2 | -0.441 | 0.836$^{**}$ | -0.087 | -0.729$^{**}$ | 0.243 | 0.811$^{**}$ | 0.791$^{**}$ | 0.645$^{**}$ | 0.980$^{**}$ | -0.810$^{**}$ | -0.701$^{**}$ | 0.860$^{**}$ | -0.431 | -0.627$^{**}$ |
| P3 | -0.524$^{*}$ | -0.625$^{**}$ | -0.600$^{**}$ | -0.427 | 0.448$^{*}$ | 0.390 | 0.400 | -0.464$^{*}$ | 0.186 | 0.548$^{*}$ | -0.282 | 0.619$^{**}$ | 0.683$^{**}$ | -0.522$^{*}$ |
| P4 | -0.543$^{*}$ | -0.226 | -0.598$^{**}$ | -0.418 | 0.578$^{**}$ | 0.502$^{*}$ | 0.560$^{*}$ | -0.049 | 0.504$^{*}$ | 0.711$^{**}$ | -0.172 | 0.037 | 0.725$^{**}$ | -0.350 |
| P5 | -0.909$^{**}$ | -0.301 | -0.944$^{**}$ | -0.798$^{**}$ | 0.825$^{**}$ | 0.742$^{**}$ | 0.780$^{**}$ | 0.048 | 0.139 | -0.523$^{*}$ | -0.581$^{**}$ | 0.865$^{**}$ | 0.775$^{**}$ | -0.629$^{**}$ |
| P6 | -0.032 | -0.034 | -0.033 | -0.028 | -0.114 | -0.120 | -0.120 | -0.379 | -0.553$^{*}$ | 0.347 | 0.221 | 0.099 | 0.012 | 0.157 |

*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

evaporation showed negative significant correlation with the number of days taken from active tillering to panicle initiation.

*4.5.1.3. Panicle initiation to booting (P3)*

Forenoon relative humidity, wind speed, rainfall and rainy days showed positive correlation while minimum temperature, maximum temperature, mean temperature, forenoon vapour pressure deficit and evaporation showed a negative correlation with the number of days taken from panicle initiation to booting.

*4.5.1.4. Booting to heading (P4)*

Forenoon relative humidity, afternoon relative humidity, mean relative humidity, afternoon vapour pressure deficit, wind speed and rainy days showed a positive correlation with the number of days taken from booting to heading while maximum and minimum temperature showed negative correlation.

*4.5.1.5. Heading to 50% flowering (P5)*

Rainfall, rainy days, forenoon, afternoon and mean relative humidity exhibited positive correlation whereas minimum temperature, maximum temperature, temperature range, wind speed, bright sunshine hours and evaporation exhibited negative correlation with the number of days taken from heading to 50% flowering.

*4.5.1.6. 50% flowering to physiological maturity (P6)*

Afternoon vapour pressure deficit showed negative correlation with number of days taken from 50% flowering to physiological maturity.

**4.5.2. Influence of weather parameters on crop duration of Jaya**

Table 4.9 represents the result of the correlation analysis carried out between weather variables and phenophases duration of Jyothi.

Table 4.9 Correlation between duration of phenophases and weather variables in Jaya

| Stages | Tmax | Tmin | Tmean | Trange | RHI | RHII | RHm | VPDI | VPDII | WS | BSS | RF | RD | Epan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1 | -0.871** | -0.654** | -0.799** | -0.437 | 0.523* | 0.811** | 0.779** | -0.583** | -0.440 | 0.250 | -0.535* | 0.993** | -0.566** | -0.566** |
| P2 | 0.760** | -0.339 | 0.496* | 0.809** | 0.177 | -0.861** | -0.789** | 0.369 | -0.551* | 0.660** | 0.540* | -0.431 | 0.691** | 0.532* |
| P3 | -0.873** | -0.336 | -0.892** | -0.844** | 0.759** | 0.701** | 0.713** | 0.273 | 0.533* | 0.420 | -0.675** | 0.901** | 0.869** | -0.858** |
| P4 | -0.821** | 0.076 | -0.853** | -0.776** | 0.863** | 0.720** | 0.764** | 0.596** | 0.260 | 0.172 | -0.465* | 0.807** | 0.683** | -0.564** |
| P5 | -0.397 | -0.899** | -0.511* | -0.253 | -0.330 | 0.197 | 0.106 | -0.947** | -0.651** | 0.654** | 0.320 | 0.483* | 0.241 | 0.106 |
| P6 | -0.766** | -0.824** | -0.820** | -0.663** | 0.823** | 0.629** | 0.695** | 0.702** | 0.129 | -0.624** | -0.420 | 0.422 | 0.526* | -0.447* |

*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

*4.5.2.1. Transplanting to active tillering (P1)*

Forenoon relative humidity, afternoon relative humidity, mean relative humidity and rainfall showed a positive correlation with the number of days taken from transplanting to active tillering while maximum temperature, minimum temperature, mean temperature, temperature range, forenoon vapour pressure deficit, bright sunshine hours, rainy days and evaporation showed a negative correlation.

*4.5.2.2. Active tillering to panicle initiation (P2)*

Maximum temperature, mean temperature, temperature range, wind speed, bright sunshine hours, rainy days and evaporation exhibited a positive correlation whereas afternoon relative humidity, mean relative humidity and afternoon vapour pressure deficit showed negative correlation with number of days taken from active tillering to panicle initiation.

*4.5.2.3. Panicle initiation to booting (P3)*

Forenoon relative humidity, afternoon relative humidity, mean relative humidity, afternoon vapour pressure deficit, rainfall and rainy days showed a positive correlation with number of days taken from panicle initiation to booting while maximum temperature, mean temperature, temperature range, bright sunshine hours and evaporation showed a negative correlation.

*4.5.2.4. Booting to heading (P4)*

Number of days taken from booting to heading had a positive correlation with forenoon relative humidity, afternoon relative humidity, mean relative humidity, forenoon vapour pressure deficit rainfall and rainy days while negatively correlated with maximum temperature, mean temperature, temperature range, bright sunshine hours and evaporation.

*4.5.2.5. Heading to 50% flowering (P5)*

Wind speed and rainfall showed a positive correlation with duration of heading to 50% flowering whereas minimum temperature, mean temperature, forenoon vapour pressure deficit and afternoon vapour pressure deficit showed negative correlation.

*4.5.2.6. 50% flowering to physiological maturity (P6)*

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

### 4.5.3. Correlation between weather variables and yield of Jyothi

The result of correlation analysis between weather variables and yield of Jyothi variety is given in the Table.4.10.

*4.5.3.1. Transplanting to active tillering (P1)*

Bright sunshine hours showed a positive correlation while wind speed showed a negative correlation with yield.

*4.5.3.2. Active tillering to panicle initiation (P2)*

Forenoon relative humidity and rainy days exhibited a significant negative correlation with yield and mean temperature showed a positive correlation.

*4.5.3.3. Panicle initiation to booting (P3)*

Positive correlation of afternoon relative humidity, mean relative humidity and afternoon vapour pressure deficit were observed with yield whereas wind speed and bright sunshine hours showed a negative correlation.

Table 4.10 Correlation between weather variables and yield in Jyothi

| Stages | Tmax | Tmin | Tmean | Trange | RHI | RHII | RHm | VPDI | VPDII | WS | BSS | RF | RD | Epan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1 | -0.118 | -0.181 | -0.155 | 0.099 | -0.319 | -0.022 | -0.076 | -0.338 | -0.233 | -0.807** | 0.635** | -0.398 | -0.098 | 0.036 |
| P2 | 0.418 | 0.352 | 0.520* | 0.252 | -0.584** | -0.087 | -0.183 | 0.159 | 0.200 | 0.227 | 0.268 | 0.333 | -0.890** | 0.418 |
| P3 | -0.364 | 0.284 | -0.300 | -0.422 | 0.402 | 0.463* | 0.453* | 0.424 | 0.582** | -0.647** | -0.567** | 0.156 | 0.193 | -0.317 |
| P4 | -0.295 | -0.055 | -0.301 | -0.252 | 0.361 | 0.446* | 0.469* | 0.084 | 0.607** | -0.111 | -0.192 | 0.674** | 0.531* | -0.345 |
| P5 | -0.760** | -0.120 | -0.754** | -0.705** | 0.637** | 0.808** | 0.778** | 0.039 | 0.442 | -0.849** | -0.734** | 0.939** | 0.856** | -0.819** |
| P6 | -0.391 | -0.678** | -0.461* | -0.283 | 0.282 | 0.062 | 0.121 | -0.218 | -0.851** | -0.165 | 0.150 | 0.207 | 0.097 | 0.053 |

*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, mean relative humidity, afternoon vapour pressure deficit, rainfall and rainy days were positively correlated with yield.

*4.5.3.5. Heading to 50% flowering (P5)*

Forenoon relative humidity, afternoon relative humidity, mean relative humidity, rainfall and rainy days exhibited positive effect on yield while maximum temperature, mean temperature, temperature range, wind speed, bright sunshine hours and evaporation were negatively correlated.

*4.5.3.6. 50% flowering to physiological maturity (P6)*

Negative correlation of yield was observed with minimum temperature, mean temperature and afternoon vapour pressure deficit.

### 4.5.4. Correlation between weather variables and yield of Jaya

The result of correlation analysis between weather variables and yield of Jaya variety is given in the Table.4.11.

*4.5.4.1. Transplanting to active tillering (P1)*

Maximum temperature, minimum temperature, mean temperature, forenoon vapour pressure deficit, afternoon vapour pressure deficit and bright sunshine hours during transplanting to active tillering showed appositive correlation with yield.

*4.5.4.2. Active tillering to panicle initiation (P2)*

Minimum temperature and afternoon relative humidity showed a positive correlation while rainy days showed a negative correlation with yield during active tillering to panicle initiation.

Table.4.11 Correlation between yield and weather variables in Jaya

| Stages | Tmax | Tmin | Tmean | Trange | RHI | RHII | RHm | VPDI | VPDII | WS | BSS | RF | RD | Epan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1 | 0.493* | 0.661** | 0.600** | -0.244 | 0.093 | 0.162 | 0.153 | 0.572** | 0.660** | -0.145 | 0.587** | -0.216 | -0.204 | 0.006 |
| P2 | -0.167 | 0.572** | 0.149 | -0.424 | -0.043 | 0.461* | 0.430 | -0.369 | 0.146 | -0.187 | 0.161 | 0.108 | -0.604** | 0.006 |
| P3 | -0.294 | -0.036 | -0.292 | -0.293 | 0.443 | 0.542* | 0.525* | 0.108 | 0.651** | -0.805** | -0.487* | 0.244 | 0.284 | -0.251 |
| P4 | -0.813** | 0.742** | -0.733** | -0.868** | 0.658** | 0.865** | 0.840** | 0.823** | 0.755** | -0.440 | -0.876** | 0.675** | 0.624** | -0.864** |
| P5 | -0.629** | 0.271 | -0.532* | -0.726** | 0.645** | 0.508* | 0.545* | 0.382 | -0.184 | 0.044 | -0.678** | 0.298 | 0.132 | -0.547* |
| P6 | -0.953** | -0.687** | -0.952** | -0.918** | 0.827** | 0.795** | 0.817** | 0.276 | -0.124 | -0.455* | -0.677** | 0.685** | 0.810** | -0.705** |

*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

*4.5.4.3.Panicle initiation to booting (P3)*

Afternoon relative humidity, mean relative humidity and afternoon vapour pressure deficit exhibited a significant positive correlation with yield during panicle initiation to booting while wind speed and bright sunshine hours showed a negative correlation.

*4.5.4.4. Booting to heading (P4)*

A significant positive effect was observed for minimum temperature, forenoon relative humidity, afternoon relative humidity, mean relative humidity, forenoon vapour pressure deficit, afternoon vapour pressure deficit, rainfall and rainy days with yield whereas maximum temperature, mean temperature, temperature range, bright sunshine hours and evaporation showed a negative correlation.

*4.5.4.5. Heading to 50% flowering (P5)*

Forenoon relative humidity, afternoon relative humidity and mean relative humidity were positively correlated with grain yield while maximum temperature, mean temperature, temperature range, bright sunshine hours and evaporation were negatively correlated.

*4.5.4.6.50% flowering to physiological maturity (P6)*

A positive influence of forenoon relative humidity, afternoon relative humidity, mean relative humidity, rainfall and rainy days were observed with the yield whereas maximum temperature, minimum temperature, mean temperature, temperature range, wind speed, bright sunshine hours and evaporation showed a negative influence.

**4.5.5. Correlation between weather variables and yield attributes of Jyothi**

For the yield attributes *viz*. thousand grain weight, number of panicles per $m^2$, number of spikelets per panicle and number of filled grains per panicle, correlation analysis were carried out with weather variables for the variety Jyothi in the year 2018 and the results obtained are given below from the Table 4.12 to 4.15.

*4.5.5.1. Correlation between weather variables and thousand grain weight in Jyothi*

Significant positive correlation of minimum temperature, mean temperature, forenoon vapour pressure deficit and bright sunshine hours with thousand grain weight was noticed during transplanting to active tillering. When afternoon relative humidity, mean relative humidity and rainfall showed appositive correlation with thousand grain weight of booting to heading and 50% flowering to physiological maturity, maximum temperature, temperature range, bright sunshine hours and evaporation showed a negative correlation. Afternoon vapour pressure deficit during booting to heading stage exhibited a positive influence on thousand grain weight. Minimum temperature, forenoon vapour pressure deficit and afternoon vapour pressure deficit were positively correlated with thousand grain weight during heading to 50% flowering. Forenoon relative humidity and rainy days of 50% flowering to physiological maturity showed a positive effect on thousand grain weight whereas mean temperature showed a negative correlation with this yield attribute.

*4.5.5.2. Correlation between weather variables and number of panicles per $m^2$ in Jyothi*

During transplanting to active tillering, rainfall and rainy days showed a significant positive influence on number of panicles per $m^2$ while bright sunshine hours showed a negative correlation for the same period. Minimum temperature, afternoon vapour pressure deficit and rainfall exhibited a negative correlation with number of panicles per $m^2$ during active tillering to panicle initiation. A significant positive effect of bright sunshine hours as well as significant negative effect of afternoon relative humidity, mean relative humidity and afternoon vapour pressure deficit on number of panicles per $m^2$ were observed during panicle initiation to booting and booting to heading periods. Maximum temperature, temperature range and evaporation during

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

| Stages | Tmax | Tmin | Tmean | Trange | RHI | RHII | RHm | VPDI | VPDII | WS | BSS | RF | RD | Epan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1 | 0.412 | 0.668** | 0.560* | -0.405 | -0.242 | -0.170 | -0.186 | 0.640** | 0.397 | -0.079 | 0.574** | -0.256 | -0.304 | -0.193 |
| P2 | 0.057 | 0.412 | 0.210 | -0.106 | 0.280 | 0.294 | 0.321 | -0.160 | 0.162 | -0.103 | 0.140 | 0.176 | 0.041 | 0.039 |
| P3 | 0.055 | -0.204 | 0.019 | 0.092 | 0.110 | 0.143 | 0.137 | -0.368 | 0.266 | -0.147 | -0.081 | -0.077 | -0.063 | 0.155 |
| P4 | -0.517* | 0.131 | -0.443 | -0.521* | 0.069 | 0.532* | 0.492* | 0.156 | 0.490* | -0.663** | -0.621** | 0.621** | 0.163 | -0.565** |
| P5 | -0.217 | 0.482* | -0.073 | -0.348 | 0.346 | 0.353 | 0.358 | 0.595** | 0.485* | 0.208 | -0.287 | 0.216 | 0.029 | -0.323 |
| P6 | -0.705** | -0.309 | -0.659** | -0.750** | 0.659** | 0.760** | 0.747** | 0.112 | 0.187 | -0.124 | -0.731** | 0.760** | 0.756** | -0.755** |

*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 4.13 Correlation between weather variables and number of panicles per $m^2$ in Jyothi

| Stages | Tmax | Tmin | Tmean | Trange | RHI | RHII | RHm | VPDI | VPDII | WS | BSS | RF | RD | Epan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1 | -0.355 | -0.349 | -0.367 | -0.039 | 0.422 | 0.401 | 0.412 | -0.262 | -0.161 | 0.391 | $-0.482^{*}$ | $0.551^{*}$ | $0.496^{*}$ | -0.161 |
| P2 | -0.089 | $-0.577^{**}$ | -0.303 | 0.139 | -0.152 | -0.266 | -0.272 | -0.340 | $-0.454^{*}$ | 0.213 | 0.072 | $-0.522^{*}$ | 0.378 | 0.045 |
| P3 | 0.395 | 0.269 | 0.419 | 0.358 | -0.430 | $-0.457^{*}$ | $-0.453^{*}$ | 0.178 | $-0.479^{*}$ | 0.117 | $0.450^{*}$ | -0.272 | -0.372 | 0.314 |
| P4 | $0.467^{*}$ | -0.311 | 0.330 | $0.539^{*}$ | $-0.490^{*}$ | $-0.447^{*}$ | $-0.494^{*}$ | -0.399 | $-0.496^{*}$ | 0.195 | $0.533^{*}$ | $-0.461^{*}$ | -0.221 | $0.561^{*}$ |
| P5 | $0.456^{*}$ | 0.099 | $0.460^{*}$ | 0.416 | $-0.446^{*}$ | -0.368 | -0.397 | -0.114 | -0.088 | 0.127 | 0.251 | -0.416 | -0.305 | 0.288 |
| P6 | 0.398 | 0.403 | 0.415 | 0.363 | -0.435 | -0.322 | -0.358 | -0.287 | 0.105 | 0.342 | 0.189 | -0.290 | -0.239 | 0.255 |

*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

booting to heading exhibited a positive influence on number of panicles per $m^2$ whereas forenoon relative humidity and rainfall were negatively correlated with the same yield attribute. Number of panicles per $m^2$ had a positive correlation with maximum temperature and mean temperature whereas negative correlation was observed in the case of forenoon relative humidity during heading to 50% flowering.

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

During transplanting to active tillering, significant positive correlation of maximum temperature, minimum temperature, mean temperature, forenoon vapour pressure deficit, afternoon vapour pressure deficit and bright sunshine hours were observed with number of spikelets per panicle. Forenoon as well as afternoon relative humidity exhibited a positive correlation during active tillering to panicle initiation with number of spikelets per panicle. Significant positive influence of afternoon relative humidity and mean relative humidity with number of spikelets per panicle were noticed during booting to heading, heading to 50% flowering and 50% flowering to physiological maturity whereas significant negative influence was noticed for maximum temperature, temperature range, bright sunshine hours and evaporation. Afternoon vapour pressure deficit of panicle initiation to booting showed a positive correlation with number of spikelets per panicle whereas wind speed showed a negative correlation. Rainfall and rainy days showed a positive effect only during booting to heading 50% flowering to physiological maturity. A positive correlation was observed for afternoon vapour pressure deficit of booting to heading, minimum temperature, forenoon relative humidity, forenoon vapour pressure deficit and afternoon vapour pressure deficit of heading to 50% flowering and forenoon relative humidity of 50% flowering to physiological maturity whereas negative correlation was noticed for

Table.4.14 Correlation between weather variables and number of spikelets per panicle in Jyothi

| Stages | Tmax | Tmin | Tmean | Trange | RHI | RHII | RHm | VPDI | VPDII | WS | BSS | RF | RD | Epan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1 | 0.541* | 0.606** | 0.597** | -0.068 | 0.080 | 0.098 | 0.096 | 0.533* | 0.633** | 0.038 | 0.730** | -0.085 | -0.275 | 0.119 |
| P2 | -0.259 | 0.359 | -0.101 | -0.377 | 0.032 | 0.549* | 0.513* | -0.253 | 0.286 | -0.311 | -0.126 | 0.133 | -0.088 | -0.186 |
| P3 | -0.139 | 0.130 | -0.111 | -0.166 | 0.359 | 0.381 | 0.377 | 0.007 | 0.521* | -0.504* | -0.324 | 0.251 | 0.110 | -0.093 |
| P4 | -0.705** | -0.222 | -0.751** | -0.567** | 0.075 | 0.759** | 0.698** | -0.133 | 0.696** | -0.419 | -0.566** | 0.674** | 0.571** | -0.598** |
| P5 | -0.478* | 0.598** | -0.288 | -0.634** | 0.628** | 0.597** | 0.618** | 0.778** | 0.594** | 0.110 | -0.590** | 0.394 | 0.338 | -0.544* |
| P6 | -0.810** | -0.617** | -0.807** | -0.793** | 0.797** | 0.769** | 0.790** | 0.207 | 0.029 | -0.403 | -0.688** | 0.733** | 0.715** | -0.724** |

*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

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mean temperature of booting to heading and for minimum and mean temperature of 50% flowering to physiological maturity.

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

Bright sunshine hours showed a significant positive correlation with the number of days taken from transplanting to active tillering. Afternoon vapour pressure deficit showed a positive correlation whereas wind speed showed a negative correlation with the number of days taken from panicle initiation to booting. Afternoon relative humidity, mean relative humidity, afternoon vapour pressure deficit, rainfall and rainy days exhibited a positive correlation with number of days taken from booting to heading while maximum temperature, mean temperature and evaporation showed a negative correlation. A positive effect of forenoon relative humidity, afternoon relative humidity, mean relative humidity, afternoon vapour pressure deficit, rainfall and rainy days were observed with number of days taken from heading to 50% flowering while maximum temperature, mean temperature, diurnal temperature range, bright sunshine hours and evaporation showed negative correlation. Forenoon relative humidity exhibited a significant positive correlation with number of days taken from 50% flowering to physiological maturity whereas maximum temperature, minimum temperature, mean temperature and diurnal temperature range showed a negative correlation.

### 4.5.6. Correlation between weather variables and yield attributes of Jaya

For the yield attributes *viz*. thousand grain weight, number of panicles per $m^2$, number of spikelets per panicle and number of filled grains per panicle, correlation analysis were carried out with weather variables for the variety Jaya in the year 2018 and the results obtained are given below from the Table 4.16 to 4.19.

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

| Stages | Tmax | Tmin | Tmean | Trange | RHI | RHII | RHm | VPDI | VPDII | WS | BSS | RF | RD | Epan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1 | 0.213 | 0.216 | 0.224 | 0.012 | -0.160 | -0.021 | -0.047 | 0.109 | 0.177 | -0.380 | 0.630** | -0.303 | -0.203 | 0.078 |
| P2 | 0.089 | 0.369 | 0.223 | -0.059 | -0.215 | 0.217 | 0.162 | 0.006 | 0.256 | -0.053 | 0.060 | 0.264 | -0.432 | 0.102 |
| P3 | -0.257 | 0.138 | -0.222 | -0.287 | 0.368 | 0.406 | 0.400 | 0.157 | 0.518* | -0.494* | -0.426 | 0.182 | 0.155 | -0.207 |
| P4 | -0.471* | -0.072 | -0.473* | -0.406 | 0.244 | 0.555* | 0.545* | 0.034 | 0.604** | -0.250 | -0.381 | 0.623** | 0.483* | -0.461* |
| P5 | -0.574** | 0.182 | -0.493* | -0.610** | 0.581** | 0.633** | 0.632** | 0.349 | 0.445* | -0.332 | -0.584** | 0.594** | 0.533* | -0.607** |
| P6 | -0.549* | -0.589** | -0.579** | -0.492* | 0.500* | 0.383 | 0.421 | 0.024 | -0.363 | -0.273 | -0.244 | 0.422 | 0.364 | -0.309 |

*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

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*4.5.6.1. Correlation between weather variables and thousand grain weight in Jaya*

Significant positive effect was noticed for maximum temperature, minimum temperature, mean temperature, forenoon vapour pressure deficit, afternoon vapour pressure deficit and bright sunshine hours with thousand grain weight during transplanting to active tillering. Afternoon relative humidity and mean relative humidity exhibited a positive effect on thousand grain weight whereas maximum temperature and temperature range showed a negative correlation for all the phenophases except transplanting to active tillering. Minimum temperature showed a positive effect on thousand grain weight of active tillering to panicle initiation and booting to heading stages while negatively correlated for 50% flowering to physiological maturity. Forenoon relative humidity of all phenophases after panicle initiation exhibited a positive correlation while mean temperature and bright sunshine hours of these phenophases showed a negative correlation. Forenoon vapour pressure deficit was positively correlated with thousand grain weight during booting to heading as well as 50% flowering to physiological maturity and afternoon vapour pressure deficit showed positive correlation during the phenophases in between transplanting to heading, while for heading to 50% flowering, afternoon vapour pressure was negatively correlated. With the same yield attribute, a positive influence of rainy days and rainfall was noticed during panicle initiation to booting, booting to heading and 50% flowering to physiological maturity whereas evaporation showed a negative effect during this period. Negative correlation of wind speed was observed with thousand grain weight during active tillering to panicle initiation, panicle initiation to booting and 50% flowering to physiological maturity.

*4.5.6.2. Correlation between weather variables and number of panicles per $m^2$ in Jaya*

Number of panicles per $m^2$ was positively influenced by maximum temperature and temperature range whereas afternoon relative humidity and mean relative humidity showed a negative correlation during active tillering to panicle initiation and 50%

Table 4.16 Correlation between weather variables and thousand grain weight in Jaya

| Stages | Tmax | Tmin | Tmean | Trange | RHI | RHII | RHm | VPDI | VPII | WS | BSS | RF | RD | Epan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1 | 0.681** | 0.621** | 0.681** | 0.157 | 0.162 | 0.039 | 0.061 | 0.511* | 0.746** | -0.067 | 0.663** | -0.255 | -0.210 | 0.403 |
| P2 | -0.486* | 0.569** | -0.134 | -0.692** | -0.010 | 0.735** | 0.694** | -0.282 | 0.449* | -0.518* | -0.236 | 0.361 | -0.689** | -0.323 |
| P3 | -0.616** | -0.085 | -0.613** | -0.613** | 0.719** | 0.792** | 0.780** | 0.292 | 0.838** | -0.644** | -0.733** | 0.626** | 0.619** | -0.589** |
| P4 | -0.889** | 0.469* | -0.858** | -0.898** | 0.752** | 0.772** | 0.783** | 0.604** | 0.482* | -0.041 | -0.663** | 0.595** | 0.762** | -0.672** |
| P5 | -0.694** | -0.039 | -0.642** | -0.736** | 0.556* | 0.454* | 0.483* | 0.118 | -0.457* | -0.104 | -0.562** | 0.153 | 0.088 | -0.362 |
| P6 | -0.835** | -0.775** | -0.869** | -0.757** | 0.805** | 0.688** | 0.732** | 0.519* | 0.024 | -0.508* | -0.518* | 0.446* | 0.547* | -0.540* |

*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 panicles per $m^2$ in Jaya

| Stages | Tmax | Tmin | Tmean | Trange | RHI | RHII | RHm | VPI | VPII | WS | BSS | RF | RD | EVP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1 | -0.429 | -0.480* | -0.474* | 0.050 | -0.410 | -0.256 | -0.288 | -0.466* | -0.651** | -0.388 | -0.049 | -0.088 | 0.100 | -0.185 |
| P2 | 0.455* | -0.212 | 0.292 | 0.489* | -0.114 | -0.467* | -0.457* | 0.401 | -0.070 | 0.218 | 0.196 | 0.101 | 0.078 | 0.362 |
| P3 | 0.188 | 0.262 | 0.212 | 0.160 | -0.226 | -0.306 | -0.292 | 0.068 | -0.305 | 0.337 | 0.201 | -0.287 | -0.152 | 0.167 |
| P4 | 0.354 | -0.307 | 0.321 | 0.375 | -0.173 | -0.257 | -0.245 | -0.183 | -0.217 | 0.067 | 0.287 | -0.004 | -0.258 | 0.243 |
| P5 | 0.094 | -0.294 | 0.038 | 0.157 | -0.236 | 0.045 | -0.005 | -0.404 | 0.146 | 0.433 | 0.228 | 0.294 | 0.203 | -0.005 |
| P6 | 0.481* | 0.214 | 0.454* | 0.501* | -0.464* | -0.550* | -0.534* | -0.311 | -0.257 | 0.175 | 0.535* | -0.556* | -0.515* | 0.516* |

*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

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flowering to physiological maturity. Significant negative effect of minimum temperature, mean temperature, forenoon vapour pressure deficit and afternoon vapour pressure deficit was noticed with number of panicles per $m^2$ during transplanting to active tillering. Mean temperature, bright sunshine hours and evaporation exhibited a significant positive correlation with number of panicles per $m^2$ while afternoon relative humidity, rainfall and rainy days negatively correlated with the same yield attribute at the time of 50% flowering to physiological maturity.

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

Forenoon relative humidity exhibited a negative significant correlation with number of spikelets per panicle during active tillering to panicle initiation while minimum temperature and afternoon vapour pressure deficit showed positive correlation with this yield attribute during panicle initiation to booting. During the phenophase booting to heading, forenoon relative humidity as well as rainy days exhibited a positive effect on number of spikelets per panicle. Forenoon relative humidity, afternoon relative humidity, mean relative humidity and rainy days were positively correlated with number of spikelets per panicle whereas maximum temperature, mean temperature, temperature range, bright sunshine hours and evaporation showed negative correlation from heading to 50% flowering. Wind speed showed a negative influence only during panicle initiation to booting stage. Minimum temperature and afternoon vapour pressure deficit during 50% flowering to physiological maturity had a negative influence on number of spikelets per panicle.

*4.5.6.4. Correlation between weather variables and filled grains per panicle in Jaya*

During active tillering to panicle initiation, forenoon relative humidity, forenoon vapour pressure deficit and rainy days showed a significant negative correlation with number of filled grains per panicle. Minimum temperature showed a positive correlation with number of filled grains per panicle while wind speed showed

Table 4.18 Correlation between weather variables and number of spikelets per panicle in Jaya

| Stages | Tmax | Tmin | Tmean | Trange | RHI | RHII | RHm | VPI | VPII | WS | BSS | RF | RD | EVP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1 | -0.149 | -0.322 | -0.244 | 0.279 | 0.340 | 0.396 | 0.395 | -0.407 | -0.009 | -0.168 | 0.396 | 0.109 | 0.244 | 0.237 |
| P2 | -0.214 | -0.286 | -0.338 | -0.039 | -0.668** | 0.110 | 0.008 | -0.428 | -0.007 | -0.007 | -0.080 | 0.056 | -0.423 | 0.087 |
| P3 | -0.225 | 0.614** | -0.154 | -0.297 | 0.309 | 0.311 | 0.311 | 0.705** | 0.403 | -0.470* | -0.374 | 0.237 | 0.186 | -0.330 |
| P4 | -0.257 | 0.298 | -0.221 | -0.284 | 0.518* | 0.363 | 0.401 | 0.087 | 0.310 | 0.033 | -0.276 | 0.259 | 0.628** | -0.289 |
| P5 | -0.474* | -0.182 | -0.464* | -0.473* | 0.626** | 0.572** | 0.596** | -0.086 | 0.147 | -0.110 | -0.593** | 0.298 | 0.662** | -0.508* |
| P6 | -0.132 | -0.539* | -0.222 | -0.005 | -0.094 | -0.187 | -0.163 | -0.218 | -0.531* | 0.322 | 0.285 | -0.248 | -0.175 | 0.287 |

*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 filled grains per panicle in Jaya

| Stages | Tmax | Tmin | Tmean | Trange | RHI | RHII | RHm | VPI | VPII | WS | BSS | RF | RD | EVP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1 | -0.094 | 0.038 | -0.031 | -0.230 | 0.196 | 0.427 | 0.396 | -0.036 | 0.142 | -0.253 | 0.430 | 0.119 | 0.273 | -0.173 |
| P2 | 0.074 | 0.010 | 0.070 | 0.057 | -0.513$^{*}$ | 0.002 | -0.072 | -0.491$^{*}$ | -0.206 | 0.211 | 0.345 | -0.128 | -0.446$^{*}$ | 0.351 |
| P3 | 0.010 | 0.465$^{*}$ | 0.060 | -0.043 | 0.142 | 0.198 | 0.188 | 0.380 | 0.356 | -0.748$^{**}$ | -0.229 | -0.052 | -0.030 | -0.035 |
| P4 | -0.407 | 0.701$^{**}$ | -0.311 | -0.483$^{*}$ | 0.521$^{*}$ | 0.644$^{**}$ | 0.632$^{**}$ | 0.545$^{*}$ | 0.717$^{**}$ | -0.473$^{*}$ | -0.686$^{**}$ | 0.544$^{*}$ | 0.557$^{*}$ | -0.675$^{**}$ |
| P5 | -0.508$^{*}$ | 0.222 | -0.428 | -0.586$^{**}$ | 0.741$^{**}$ | 0.635$^{**}$ | 0.670$^{**}$ | 0.286 | 0.266 | 0.082 | -0.753$^{**}$ | 0.429 | 0.486$^{*}$ | -0.713$^{**}$ |
| P6 | -0.528$^{*}$ | -0.551$^{*}$ | -0.562$^{**}$ | -0.461$^{*}$ | 0.245 | 0.235 | 0.242 | -0.264 | -0.550$^{*}$ | 0.104 | -0.166 | 0.192 | 0.312 | -0.181 |

*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

a significant negative correlation during panicle initiation to booting. Significant positive correlation was obtained for forenoon relative humidity, afternoon relative humidity, mean relative humidity and rainy days of booting to heading and heading to 50% flowering with number of filled grains per panicle while temperature range, bright sunshine hours and evaporation showed a negative effect during these phenophases. Minimum temperature, forenoon vapour pressure deficit, afternoon vapour pressure deficit and rainfall exhibited a positive effect on number of filled grains per panicle during booting to heading stage whereas wind speed showed a negative effect. During heading to 50% flowering, rainy days exhibited positive correlation while maximum temperature showed a negative correlation with number of filled grains per panicle. Maximum, minimum and mean temperatures along with temperature range and afternoon vapour pressure deficit showed a significant negative correlation with number of filled grains per panicle during 50% flowering to physiological maturity.

## 4.6. PLANT CHARACTERS

### 4.6.1. Weekly plant height

Analysis of variance were carried out for weekly plant height of different dates of planting up to the harvesting stage and are represented in Appendix II. The effects of date of planting and varieties on plant height are given in the Table 4.20 (a&b).

Significant difference of plant height were observed between different planting dates within the varieties, Jyothi and Jaya, for all the weeks except for 4$^{th}$,6$^{th}$ and 7$^{th}$ weeks in which the interactions were non-significant. On 2$^{nd}$ week, Jyothi did not show any significant difference in height among different dates of planting while Jaya exhibited significant difference even though the interaction was found to be significant. Likewise, on 5$^{th}$ week, Jaya do not exhibited any significant difference, but Jyothi showed. From 8$^{th}$ week on wards it was observed that, in general, last plantings showed a lower plant height compared to early plantings. Different planting dates showed

Table.4.20 (a) Effect of date of planting on plant height at weekly intervals

| Date of planting | Plant height (cm) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Week 1 | | | Week 2 | | | Week 3 | | | Week 4 | | | Week 5 | | |
| | Jy | Ja | Mean | Jy | Ja | Mean | Jy | Ja | Mean | Jy | Ja | Mean | Jy | Ja | Mean |
| 5th June | 16.48$^{b}$ | 18.36$^{ab}$ | 17.42$^{bc}$ | 27.39$^{a}$ | 27.26$^{a}$ | 27.32$^{a}$ | 40.72$^{a}$ | 34.08$^{ab}$ | 37.40$^{a}$ | 51.53 | 43.52 | 47.52$^{a}$ | 68.79$^{a}$ | 49.23$^{a}$ | 59.01 |
| 20th June | 20.44$^{a}$ | 19.94$^{a}$ | 20.19$^{a}$ | 27.35$^{a}$ | 24.31$^{ab}$ | 25.83$^{a}$ | 36.26$^{b}$ | 31.19$^{bc}$ | 33.72$^{ab}$ | 47.60 | 42.32 | 44.96$^{ab}$ | 54.82$^{b}$ | 50.06$^{a}$ | 52.44 |
| 5th July | 15.40$^{b}$ | 15.84$^{b}$ | 15.62$^{c}$ | 24.75$^{a}$ | 18.97$^{c}$ | 21.86$^{b}$ | 34.76$^{b}$ | 25.55$^{d}$ | 30.16$^{b}$ | 42.28 | 33.53 | 37.90$^{c}$ | 64.03$^{a}$ | 46.37$^{a}$ | 55.20 |
| 20th July | 20.73$^{a}$ | 16.86$^{b}$ | 18.79$^{ab}$ | 26.97$^{a}$ | 23.25$^{b}$ | 25.11$^{ab}$ | 34.42$^{b}$ | 28.36$^{cd}$ | 31.39$^{b}$ | 44.79 | 35.70 | 40.24$^{bc}$ | 57.48$^{b}$ | 44.55$^{a}$ | 51.01 |
| 5th August | 21.55$^{a}$ | 19.55$^{a}$ | 20.55$^{a}$ | 26.83$^{a}$ | 27.06$^{a}$ | 26.94$^{a}$ | 36.65$^{ab}$ | 36.56$^{a}$ | 36.60$^{a}$ | 45.40 | 44.13 | 44.76$^{ab}$ | 53.57$^{b}$ | 49.21$^{a}$ | 51.39 |
| CD | 2.57 | | 2.62 | 3.08 | | 3.48 | 4.10 | | 4.44 | NS | | 5.09 | 6.03 | | NS |

| Date of planting | Plant height (cm) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Week 6 | | | Week 7 | | | Week 8 | | | Week 9 | | |
| | Jy | Ja | Mean | Jy | Ja | Mean | Jy | Ja | Mean | Jy | Ja | Mean |
| 5th June | 82.86 | 71.15 | 77.00$^{a}$ | 91.05 | 76.34 | 83.70$^{a}$ | 96.73$^{a}$ | 81.78$^{a}$ | 89.26$^{a}$ | 101.54$^{a}$ | 87.64$^{a}$ | 94.59$^{a}$ |
| 20th June | 70.07 | 57.46 | 63.77$^{c}$ | 83.86 | 63.52 | 73.69$^{b}$ | 90.81$^{b}$ | 69.12$^{bc}$ | 79.96$^{bc}$ | 98.72$^{ab}$ | 74.98$^{b}$ | 86.85$^{bc}$ |
| 5th July | 77.91 | 56.23 | 67.07$^{b}$ | 84.46 | 65.80 | 75.13$^{b}$ | 89.96$^{b}$ | 74.15$^{b}$ | 82.05$^{b}$ | 96.48$^{ab}$ | 82.33$^{a}$ | 89.40$^{ab}$ |
| 20th July | 67.99 | 51.64 | 59.81$^{c}$ | 81.02 | 58.82 | 69.92$^{b}$ | 91.45$^{ab}$ | 65.68$^{c}$ | 78.56$^{bc}$ | 94.92$^{bc}$ | 72.13$^{b}$ | 83.52$^{bc}$ |
| 5th August | 64.17 | 54.58 | 59.37$^{c}$ | 72.29 | 60.01 | 66.15$^{c}$ | 82.81$^{c}$ | 67.84$^{c}$ | 75.33$^{c}$ | 89.31$^{c}$ | 73.79$^{b}$ | 81.55$^{c}$ |
| CD | NS | | 6.9 | NS | | 5.61 | 5.81 | | 6.25 | 6.28 | | 7.08 |

| Date of planting | Plant height (cm) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Week 10 | | | Week 11 | | | Week 12 | | | Week 13 | | |
| | Jy | Ja | Mean | Jy | Ja | Mean | Jy | Ja | Mean | Jy | Ja | Mean |
| 5$^{th}$ June | 110.47$^{a}$ | 94.25$^{a}$ | 102.36$^{a}$ | 115.28$^{a}$ | 100.36$^{a}$ | 107.82$^{a}$ | 117.93$^{a}$ | 106.77$^{a}$ | 112.35$^{a}$ | 119.16$^{ab}$ | 112.42$^{a}$ | 115.79$^{a}$ |
| 20$^{th}$ June | 105.87$^{ab}$ | 80.60$^{c}$ | 93.24$^{bc}$ | 111.65$^{a}$ | 86.51$^{c}$ | 99.08$^{bc}$ | 114.96$^{a}$ | 91.97$^{cd}$ | 103.46$^{b}$ | 117.40$^{abc}$ | 97.96$^{c}$ | 107.68$^{c}$ |
| 5$^{th}$ July | 105.17$^{ab}$ | 87.42$^{b}$ | 96.29$^{ab}$ | 111.25$^{ab}$ | 93.04$^{b}$ | 102.14$^{ab}$ | 117.36$^{a}$ | 101.31$^{b}$ | 109.34$^{a}$ | 119.87$^{a}$ | 108.82$^{ab}$ | 114.34$^{ab}$ |
| 20$^{th}$ July | 101.95$^{b}$ | 78.82$^{c}$ | 90.38$^{bc}$ | 106.21$^{bc}$ | 84.31$^{c}$ | 95.26$^{c}$ | 109.36$^{b}$ | 89.21$^{d}$ | 99.28$^{b}$ | 113.77$^{c}$ | 98.20$^{c}$ | 105.98$^{dc}$ |
| 5$^{th}$ August | 95.78$^{c}$ | 79.99$^{c}$ | 87.88$^{c}$ | 103.95$^{c}$ | 88.56$^{bc}$ | 96.26$^{c}$ | 109.95$^{b}$ | 96.74$^{bc}$ | 103.34$^{b}$ | 115.35$^{bc}$ | 105.60$^{b}$ | 110.48$^{bc}$ |
| CD | 5.79 | | 6.73 | 5.41 | | 5.69 | 5.00 | | 4.82 | 3.99 | | 3.91 |

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Table.4.20 (b) Comparison between varieties with respect to plant height at weekly intervals

| | Plant height (cm) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variety | 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 |
| Jyothi | 18.92 | 26.66$^{a}$ | 36.56$^{a}$ | 46.32$^{a}$ | 59.74$^{a}$ | 72.60$^{a}$ | 82.54$^{a}$ | 90.35$^{a}$ | 96.19$^{a}$ | 103.85$^{a}$ | 109.66$^{a}$ | 113.91$^{a}$ | 117.11$^{a}$ |
| Jaya | 18.11 | 24.17$^{b}$ | 31.15$^{b}$ | 39.84$^{b}$ | 47.88$^{b}$ | 58.21$^{b}$ | 64.90$^{b}$ | 71.71$^{b}$ | 78.17$^{b}$ | 84.22$^{b}$ | 90.56$^{b}$ | 97.20$^{b}$ | 104.60$^{b}$ |
| CD | NS | 1.14 | 1.63 | 2.85 | 2.42 | 2.84 | 2.52 | 2.33 | 2.35 | 2.04 | 2.24 | 2.27 | 1.78 |

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significant difference in height irrespective of the varieties from 1st to 4th and 6th to 13th week, whereas observations on 5th week was found to be non-significant. There was no any specific pattern observed in plant height among different planting dates irrespective of the varieties. While comparing the varieties, Jyothi was found to be superior in weekly plant height than Jaya from 2nd to 13th weeks and the difference in plant height was more towards the physiological maturity stage.

### 4.6.2. Dry matter accumulation at fortnightly intervals

Analysis of variance was carried out for dry matter accumulation at fortnightly intervals for different dates of planting and are presented in the Appendix II.

Significant difference was observed (Table 4.21(a&b)) between different dates of planting in the case of dry matter accumulation. On 15, 60, 75 and 90 days after planting, significant difference was observed among different planting dates irrespective of varieties. On 15 days after planting, more dry matter accumulation was noticed for June 20th, July 5th, July 20th and August 5th plantings, and were found to be on par with each other. Lower dry matter accumulation (259.88 kg $ha^{-1}$) was observed during June 5th planting and was on par with August 5th planting. On 60 days after planting, dry matter accumulation was more during June 5th and June 20th plantings which were found to be on par. After 75 days of transplanting, June 5th planting was obtained with higher dry matter accumulation (10824.08 kg $ha^{-1}$) and was on par with June 20th planting, whereas July 5th planting was recorded with lower dry matter accumulation (6779.54 kg $ha^{-1}$) and was on par with July 20th and August 5th planting. 90 days after transplanting, June 5th planting was noticed with higher dry matter which was on par with June 20th and July 20th plantings whereas lowest was recorded for July 5th planting and was on par with July 20th planting.

Interaction was found to be significant only during 60 days after planting. In Jaya, June 5th and June 20th plantings were found to be superior and was on par with

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Table 4.21 (a) Effect of dates of planting on dry matter accumulation at fortnightly intervals

| Date of planting | Dry matter accumulation (kg ha$^{-1}$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 15 DAP | | | 30 DAP | | | 45 DAP | | |
| | Jy | Ja | Mean | Jy | Ja | Mean | Jy | Ja | Mean |
| 5th June | 331.65 | 188.10 | 259.88$^{b}$ | 2805.63 | 1841.40 | 2323.51 | 4910.43 | 3613.50 | 4261.96 |
| 20th June | 775.01 | 348.98 | 561.99$^{a}$ | 3205.65 | 1681.35 | 2443.50 | 4715.58 | 3531.83 | 4123.70 |
| 5th July | 504.85 | 569.33 | 537.09$^{a}$ | 2618.63 | 1896.35 | 2257.49 | 3798.90 | 3223.90 | 3511.40 |
| 20th July | 640.40 | 515.88 | 578.14$^{a}$ | 2298.10 | 1395.00 | 1846.55 | 4120.15 | 1986.03 | 3053.09 |
| 5th August | 532.65 | 297.00 | 414.83$^{ab}$ | 1822.78 | 1570.35 | 1696.56 | 4025.40 | 3177.05 | 3601.23 |
| CD | NS | | 164.90 | NS | | NS | NS | | NS |

| Date of planting | Dry matter accumulation (kg ha$^{-1}$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 60 DAP | | | 75 DAP | | | 90 DAP | | |
| | Jy | Ja | Mean | Jy | Ja | Mean | Jy | Ja | Mean |
| 5th June | 7667.93$^{a}$ | 8229.38$^{a}$ | 7948.65$^{a}$ | 10267.75 | 11380.40 | 10824.08$^{a}$ | 8055.40 | 9554.85 | 8805.13$^{a}$ |
| 20th June | 5839.05$^{b}$ | 8299.93$^{a}$ | 7069.49$^{ab}$ | 9751.85 | 9828.10 | 9789.98$^{ab}$ | 8516.40 | 8667.25 | 8591.83$^{ab}$ |
| 5th July | 4200.60$^{c}$ | 4830.43$^{b}$ | 4515.51$^{c}$ | 5524.90 | 8034.18 | 6779.54$^{c}$ | 4349.98 | 7181.25 | 5765.61$^{c}$ |
| 20th July | 6701.03$^{ab}$ | 3585.75$^{b}$ | 5143.39$^{c}$ | 8326.55 | 8429.13 | 8377.84$^{bc}$ | 6950.63 | 7635.40 | 7293.01$^{abc}$ |
| 5th August | 6517.25$^{ab}$ | 4508.70$^{b}$ | 5512.98$^{bc}$ | 7135.40 | 7700.75 | 7418.08$^{c}$ | 6339.80 | 6833.48 | 6586.64$^{b}$ |
| CD | 1421.39 | | 1861.66 | NS | | 2246.48 | NS | | 2089.40 |

DAP – Days After Planting    Jy-Jyothi    Ja-Jaya

Table.4.21 (b) Comparison between varieties with respect to dry matter accumulation

| Variety | 15 DAP | 30 DAP | 45 DAP | 60 DAP | 75 DAP | 90 DAP |
|---|---|---|---|---|---|---|
| **Jyothi** | 556.91$^{a}$ | 2550.16$^{a}$ | 4314.09$^{a}$ | 6185.17 | 8201.29 | 6842.44$^{b}$ |
| **Jaya** | 383.86$^{b}$ | 1676.89$^{b}$ | 3106.46$^{b}$ | 5890.84 | 9074.51 | 7974.45$^{a}$ |
| **CD** | 130.41 | 447.52 | 634.82 | NS | NS | 1018.64 |

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each other. In Jyothi, June 5$^{th}$, July 20$^{th}$ and August 5$^{th}$ plantings were on par with higher dry matter accumulation, whereas July 5$^{th}$ was obtained with low dry matter accumulation (4200.60 kg ha$^{-1}$). Comparison was made between varieties. It was observed that, except for 60 and 75 days after planting, the varieties showed significant difference in which Jyothi was found to be superior in dry matter accumulation in 15, 30 and 45 DAP while Jaya found to be superior during 90 DAP.

### 4.6.3. Yield and yield attributes

Yield and yield attributes were used for doing analysis of variance and is presented in Appendix II. Table 4.22 (a&b) shows the mean values of different yield attributes and yield obtained for different planting dates.

#### 4.6.3.1. Number of tillers per m$^2$

Analysis of variance showed significant difference between different dates of planting, whereas, no significant difference was noticed between the varieties. Interaction between date of planting and variety was significant.

The comparison between different dates of planting is shown in Table 4.22(a). July 20$^{th}$ planting (370 tillers m$^{-2}$) was found to be on par with June 5$^{th}$ and August 5$^{th}$ plantings. Also June 20$^{th}$ planting was on par with July 5$^{th}$ planting. Comparison was made between dates of planting for Jyothi and Jaya. In Jyothi, higher number of tillers per m$^2$ was found in July 20$^{th}$ (401 tillers m$^{-2}$) and June 5$^{th}$ (386 tillers m$^{-2}$) plantings and were on par. Also June 20$^{th}$, July 5$^{th}$ and August 5$^{th}$ plantings were on par in this character. In Jaya, August 5$^{th}$ (410 tillers m$^{-2}$) planting was observed as superior compared to all other plantings.

#### 4.6.3.2. Number of panicles per m$^2$

From the ANOVA table, significant difference was observed between dates of planting as well as varieties. Interaction between date of planting and variety did not show any significant difference for number of panicles per m$^2$.

Table 4.22(a) Effect of dates of planting on yield and yield attributes

| Date 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 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jy | Ja | Mean | Jy | Ja | Mean | Jy | Ja | Mean | Jy | Ja | Mean |
| 5$^{th}$ June | 386.00$^{a}$ | 308.75$^{bc}$ | 347.37$^{ab}$ | 345.05 | 168.30 | 256.68$^{b}$ | 307.85$^{a}$ | 105.80$^{ab}$ | 206.83$^{a}$ | 109.70 | 85.00 | 97.35$^{ab}$ |
| 20$^{th}$ June | 305.50$^{b}$ | 285.25$^{c}$ | 295.37$^{c}$ | 298.15 | 255.75 | 276.95$^{b}$ | 176.75$^{b}$ | 127.70$^{ab}$ | 152.23$^{ab}$ | 135.00 | 87.95 | 111.48$^{a}$ |
| 5$^{th}$ July | 291.75$^{b}$ | 346.50$^{b}$ | 319.13$^{bc}$ | 407.35 | 219.45 | 312.40$^{ab}$ | 117.00$^{bc}$ | 144.70$^{a}$ | 130.85$^{bc}$ | 78.70 | 73.15 | 75.93$^{bc}$ |
| 20$^{th}$ July | 400.50$^{a}$ | 338.75$^{bc}$ | 369.63$^{a}$ | 351.75 | 245.85 | 298.80$^{ab}$ | 66.35$^{c}$ | 71.05$^{b}$ | 68.70$^{c}$ | 50.15 | 45.45 | 47.80$^{c}$ |
| 5$^{th}$ August | 310.25$^{b}$ | 409.5$^{a}$ | 359.87$^{ab}$ | 455.60 | 250.80 | 353.20$^{a}$ | 62.70$^{c}$ | 101.90$^{ab}$ | 82.30$^{c}$ | 47.85 | 72.15 | 60.00$^{c}$ |
| CD | 54.78 | | 48.88 | NS | | 61.01 | 70.79 | | 64.57 | NS | | 34.37 |

| Date of planting | 1000 grain weight (g) | | | Straw yield (kg ha$^{-1}$) | | | Grain yield (kg ha$^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Jy | Ja | Mean | Jy | Ja | Mean | Jy | Ja | Mean |
| 5$^{th}$ June | 28.75$^{a}$ | 29.33$^{a}$ | 29.04$^{a}$ | 4470.00$^{a}$ | 4340.00$^{a}$ | 4405.00$^{a}$ | 3021.25$^{bc}$ | 5527.00$^{a}$ | 4274.13$^{a}$ |
| 20$^{th}$ June | 26.90$^{ab}$ | 25.78$^{b}$ | 26.34$^{b}$ | 3595.00$^{ab}$ | 1857.50$^{d}$ | 2726.25$^{c}$ | 4698.00$^{a}$ | 4034.25$^{b}$ | 4366.13$^{a}$ |
| 5$^{th}$ July | 23.90$^{c}$ | 25.00$^{b}$ | 24.45$^{c}$ | 2227.50$^{c}$ | 3685.00$^{ab}$ | 2956.25$^{bc}$ | 3422.75$^{b}$ | 2449.75$^{c}$ | 2936.25$^{b}$ |
| 20$^{th}$ July | 25.63$^{bc}$ | 21.85$^{c}$ | 23.74$^{cd}$ | 4435.00$^{a}$ | 3000.00$^{bc}$ | 3717.50$^{ab}$ | 2598.25$^{c}$ | 1697.00$^{d}$ | 2147.63$^{c}$ |
| 5$^{th}$ August | 25.28$^{bc}$ | 20.40$^{c}$ | 22.13$^{d}$ | 3195.00$^{bc}$ | 2177.50$^{cd}$ | 2686.25$^{c}$ | 2795.75$^{c}$ | 1789.25$^{d}$ | 2292.50$^{c}$ |
| CD | 2.11 | | 1.76 | 1026.69 | | 926.29 | 536.09 | | 438.53 |

Table.4.22 (b) Comparison between varieties and yield attributes

| Variety | Tillers per m$^2$ | Panicles per m$^2$ | Spikelets per panicle | Filled grains per panicle | 1000 grain weight | Straw yield (kg ha$^{-1}$) | Grain yield (kg ha$^{-1}$) |
|---|---|---|---|---|---|---|---|
| Jyothi | 338.80 | 371.18$^{a}$ | 146.13$^{a}$ | 84.28 | 26.09$^{a}$ | 3584.50$^{a}$ | 3307.20 |
| Jaya | 337.75 | 228.03$^{b}$ | 110.23$^{b}$ | 72.74 | 24.19$^{b}$ | 3012.00$^{b}$ | 3099.45 |
| CD | NS | 51.48 | 33.46 | NS | 1.05 | 489.02 | NS |

Jy - Jyothi   Ja - Jaya

July 5$^{th}$, July 20$^{th}$ and August 5$^{th}$ plantings was on par in the case of number of panicles per $m^2$ on comparing different dates of planting (Table 4.22(a)). A lower value was recorded in June 5$^{th}$ planting which was on par with June 20$^{th}$, July 5$^{th}$ and July 20$^{th}$ plantings. On comparing the varieties, Jyothi was found to be superior to Jaya.

**4.6.3.3. Number of spikelets per panicle**

Number of spikelets per panicle for the two varieties in different planting dates are depicted in table 4.22(a). Significant difference was found between dates of planting and between the varieties. Interaction also found to be significant.

Spikelets per panicle was higher for June 5$^{th}$ planting and was on par with June 20$^{th}$ planting. A lower number was recorded for July 20$^{th}$ planting which was on par with July 5$^{th}$ and August 5$^{th}$ plantings. Among varieties Jyothi was found to be superior to Jaya. In Jyothi, June 5$^{th}$ planting showed higher value for this character and lower value was recorded for august 5$^{th}$ planting which was on par with July 5$^{th}$ and July 20$^{th}$ plantings. For Jaya, June 5$^{th}$, June 20$^{th}$, July 5$^{th}$ and August 5$^{th}$ plantings were on par.

**4.6.3.4. Number of filled grains per panicle**

Analysis of variance showed that there was significant difference between the dates of planting, whereas, no significant difference was observed between varieties and interaction was also non-significant. Table 4.22(a) shows that higher number of filled grains per panicle was observed in June 5$^{th}$ and June 20$^{th}$ plantings. July 20$^{th}$ planting had lower value which was on par with July 5$^{th}$ and August 5$^{th}$ plantings.

**4.6.3.5. Thousand grain weight**

There was significant difference between dates of planting and within varieties. Interaction of different dates of planting with varieties also significant. June 5$^{th}$ planting was found to be superior (Table 4.22(a)) compared to all other plantings and a gradual decrease was observed for succeeding plantings.

Among varieties a higher value was observed for Jyothi than Jaya. In Jyothi, June 5$^{th}$ and June 20$^{th}$ plantings found to be higher and a lower value observed in July 5$^{th}$ planting and was on par with July 20$^{th}$ and August 5$^{th}$ plantings. For Jaya, June 5$^{th}$ planting had highest value and lowest was recorded for August 5$^{th}$ planting and was on par with July 20$^{th}$ planting.

#### 4.6.3.6. Straw yield

Analysis of variance (Appendix II) showed significant difference between dates of planting and also among varieties. Straw yield had significant difference in the interaction between dates of planting and varieties.

Table 4.10(a) shows that a higher straw yield (4405 kg ha$^{-1}$) was observed in June 5$^{th}$ planting and was on par with July 20$^{th}$ planting (3715.5 kg ha$^{-1}$). June 20$^{th}$ planting was observed as on par with July 5$^{th}$ and August 5$^{th}$ plantings. On comparing different dates of planting for Jyothi, higher straw yield was observed in June 5$^{th}$ planting (4470 kg ha$^{-1}$) and was on par with June 20$^{th}$ and July 20$^{th}$ plantings. July 5$^{th}$ planting was observed as low yielding which was on par with August 5$^{th}$ planting. For Jaya, higher yield was noticed for June 5$^{th}$ and July 5$^{th}$ plantings and were on par. Also Jyothi was found to be superior to Jaya for this character.

#### 4.6.3.7. Grain yield

Grain yield for the two varieties in different planting dates are depicted in Table 4.10(a). Significant difference was found between dates of planting, whereas, no significant difference was found between varieties. Interaction was found to be significant.

Grain yield was found higher for June 20$^{th}$ planting (4366.13kg ha$^{-1}$) which was on par with June 5$^{th}$ planting (4274.13kg ha$^{-1}$). July 20$^{th}$ planting had lower yield (2147.63 kg ha$^{-1}$) which was on par with August 5$^{th}$ planting. Comparison was made between dates of planting for Jyothi and Jaya. In Jyothi, June 20$^{th}$ planting was found to be superior (4698.00 kg ha$^{-1}$) to all other plantings. June 5$^{th}$ and July 5$^{th}$ plantings

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were on par. For Jaya, June 5$^{th}$ planting showed highest yield (5527 kg ha$^{-1}$). July 20$^{th}$ planting (1697.00 kg ha$^{-1}$) had lower yield which was on par with August 5$^{th}$ planting.

## 4.7. GROWTH INDICES

Growth indices like leaf area index, net assimilation rate, 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 (Appendix II)

### *4.7.1. Leaf area index at fortnightly intervals*

Analysis of variance was carried out for leaf area index at fortnightly interval for different dates of planting and for varieties. Significant difference was observed in this index between dates of planting and between varieties. Interaction was also found to be significant (Table.4.23 (a&b)).

The leaf area index values calculated, except for 90 DAP, showed a significant difference among dates of planting irrespective of the varieties. During 15 DAP, June 20$^{th}$, July 5$^{th}$ and July 20$^{th}$ plantings found to be higher in leaf area index and were on par with each other whereas, June 5$^{th}$ and August 5$^{th}$ plantings showed lower leaf area index. In 30 DAP, all the plantings except July 20$^{th}$ planting exhibited higher leaf area index and were on par. June 5$^{th}$ and August 5$^{th}$ plantings were on par with higher leaf area index values during 45 DAP whereas all other plantings showed lower values. At 60 DAP, July 20$^{th}$ planting recorded greater leaf area index and was found to be on par with July 5$^{th}$ and August 5$^{th}$ planting while July 5$^{th}$ planting showed higher leaf area index during 75 DAP. Interaction between dates of planting and varieties was found to be significant only during 45 DAP and 60 DAP. In Jyothi, August 5$^{th}$ planting during 45 DAP and July 20$^{th}$ and August 5$^{th}$ plantings during 60 DAP were found to be higher. In Jaya, higher leaf area index was noticed for June 5$^{th}$ and August 5$^{th}$ plantings during 45 DAP whereas all the plantings were found to be same during 60 DAP.

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Table.4.23 (a) Effect of date of planting on leaf area index (LAI) at fortnightly intervals

| Date of planting | Leaf area index | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 15 DAP | | | 30 DAP | | | 45 DAP | | |
| | Jy | Ja | Mean | Jy | Ja | Mean | Jy | Ja | Mean |
| 5th June | 0.36 | 0.12 | $0.24^{b}$ | 1.55 | 0.86 | $1.20^{a}$ | $2.41^{b}$ | $1.47^{a}$ | $1.94^{a}$ |
| 20th June | 0.51 | 0.16 | $0.34^{a}$ | 1.63 | 0.85 | $1.24^{a}$ | $2.23^{bc}$ | $1.18^{b}$ | $1.70^{b}$ |
| 5th July | 0.51 | 0.26 | $0.38^{a}$ | 1.58 | 0.96 | $1.27^{a}$ | $2.05^{c}$ | $1.14^{b}$ | $1.59^{b}$ |
| 20th July | 0.49 | 0.24 | $0.36^{a}$ | 1.24 | 0.37 | $0.80^{b}$ | $1.98^{c}$ | $1.15^{b}$ | $1.57^{b}$ |
| 5th August | 0.29 | 0.19 | $0.24^{b}$ | 1.71 | 0.82 | $1.26^{a}$ | $2.73^{a}$ | $1.24^{ab}$ | $1.98^{a}$ |
| CD | NS | | 0.06 | NS | | 0.25 | 0.28 | | 0.22 |

| Date of planting | Leaf area index | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 60 DAP | | | 75 DAP | | | 90 DAP | | |
| | Jy | Ja | Mean | Jy | Ja | Mean | Jy | Ja | Mean |
| 5th June | $3.41^{c}$ | $1.84^{a}$ | $2.62^{bc}$ | 4.17 | 2.30 | $3.23^{c}$ | 3.14 | 1.52 | 2.33 |
| 20th June | $3.23^{c}$ | $1.65^{a}$ | $2.44^{c}$ | 4.14 | 2.31 | $3.22^{c}$ | 3.42 | 1.48 | 2.45 |
| 5th July | $4.11^{b}$ | $1.62^{a}$ | $2.86^{abc}$ | 5.42 | 2.52 | $3.97^{a}$ | 3.52 | 1.60 | 2.56 |
| 20th July | $4.75^{a}$ | $1.61^{a}$ | $3.18^{a}$ | 4.71 | 2.33 | $3.52^{bc}$ | 3.33 | 1.49 | 2.41 |
| 5th August | $4.41^{ab}$ | $1.61^{a}$ | $3.01^{ab}$ | 4.89 | 2.33 | $3.61^{b}$ | 3.26 | 1.62 | 2.44 |
| CD | 0.53 | | 0.46 | NS | | 0.34 | NS | | NS |

DAP – Days After Planting Jy-Jyothi Ja-Jaya

Table.4.23 (b) Comparison of leaf area index (LAI) of varieties at fortnightly intervals

| Varieties | Leaf area index | | | | | |
|---|---|---|---|---|---|---|
| | 15 DAP | 30 DAP | 45 DAP | 60 DAP | 75 DAP | 90 DAP |
| Jyothi | $0.43^{a}$ | $1.54^{a}$ | $2.28^{a}$ | $3.98^{a}$ | $4.67^{a}$ | $3.33^{a}$ |
| Jaya | $0.19^{b}$ | $0.77^{b}$ | $1.23^{b}$ | $1.66^{b}$ | $2.36^{b}$ | $1.54^{b}$ |
| CD | 0.05 | 0.12 | 0.14 | 0.26 | 0.25 | 0.16 |

DAP – Days After Planting

Comparison was made between varieties and the result showed that in all cases higher leaf area index was observed for Jyothi variety compared to 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.4.24 (a&b)). The interaction effects of dates of planting and varieties was also found to be significant.

Leaf area duration for 15-30 DAP showed that except July 20$^{th}$ planting, all the planting dates observed as superior whereas during 30-45 DAP, higher leaf area duration recorded for August 5$^{th}$ planting and was on par with June 5$^{th}$ and June 20$^{th}$ plantings. For these two periods, July 20$^{th}$ planting was observed as inferior in leaf area duration. During 60-75 DAP, July 5$^{th}$ planting showed higher leaf area duration and was on par with July 20$^{th}$ and August 5$^{th}$ plantings while June 5$^{th}$ and June 20$^{th}$ plantings were on par with lower leaf area duration. July 5$^{th}$ planting during 75-90 DAP was higher in leaf area duration than other plantings and lower duration recorded foe June 5$^{th}$ and June 20$^{th}$ plantings. Interaction was found significant only during 45-60 and 60-75 DAP. In Jyothi, august 5$^{th}$ and July 20$^{th}$ plantings were superior in leaf area duration in 45-60 DAP and for 60-75 DAP, July 5$^{th}$, July 20$^{th}$ and August 5$^{th}$ plantings were showed higher leaf area duration. There was no significant difference for this index in Jaya variety for these periods. Among the two varieties, Jyothi was found to be superior than Jaya.

### *4.7.3. Crop growth rate at fortnightly intervals*

For crop growth rate also ANOVA was carried out at fortnightly intervals. Significant difference was observed between varieties. Table 4.25(a&b) shows the results obtained. The dates of planting and interaction effects were found to be significant only during 45-60 DAP.

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Table.4.24 (a) Effect of date of planting on leaf area duration (LAD) at fortnightly intervals

| Date of planting | Leaf area duration (days) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 15 - 30 DAP | | | 30 - 45 DAP | | | 45 – 60 DAP | | |
| | Jy | Ja | Mean | Jy | Ja | Mean | Jy | Ja | Mean |
| 5th June | 14.29 | 7.34 | $10.81^{a}$ | 29.67 | 17.42 | $23.54^{ab}$ | $43.66^{cd}$ | $24.76^{a}$ | 34.21 |
| 20th June | 16.04 | 7.59 | $11.81^{a}$ | 28.92 | 15.23 | $22.08^{ab}$ | $40.94^{d}$ | $21.21^{a}$ | 31.08 |
| 5th July | 15.65 | 9.14 | $12.39^{a}$ | 27.21 | 15.74 | $21.47^{b}$ | $46.22^{bc}$ | $20.66^{a}$ | 33.44 |
| 20th July | 12.94 | 4.49 | $8.71^{b}$ | 24.10 | 11.39 | $17.75^{c}$ | $50.41^{ab}$ | $20.69^{a}$ | 35.55 |
| 5th August | 14.99 | 7.54 | $11.27^{a}$ | 33.20 | 15.42 | $24.31^{a}$ | $53.45^{a}$ | $21.36^{a}$ | 37.40 |
| CD | NS | | 1.96 | NS | | 2.68 | 4.68 | | NS |

| Date of planting | Leaf area duration (days) | | | | | |
|---|---|---|---|---|---|---|
| | 60 – 75 DAP | | | 75 – 90 DAP | | |
| | Jy | Ja | Mean | Jy | Ja | Mean |
| 5th June | $56.81^{b}$ | $31.00^{a}$ | $43.90^{b}$ | 54.74 | 28.60 | $41.67^{d}$ |
| 20th June | $55.27^{b}$ | $29.64^{a}$ | $42.45^{b}$ | 56.62 | 28.36 | $42.49^{cd}$ |
| 5th July | $71.48^{a}$ | $31.05^{a}$ | $51.26^{a}$ | 67.05 | 30.89 | $48.97^{a}$ |
| 20th July | $70.92^{a}$ | $29.53^{a}$ | $50.22^{a}$ | 60.32 | 28.68 | $44.50^{bc}$ |
| 5th August | $69.73^{ab}$ | $29.56^{a}$ | $49.64^{a}$ | 61.17 | 29.59 | $45.38^{b}$ |
| CD | 5.86 | | 5.20 | NS | | 2.30 |

DAP – Days After Planting    Jy-Jyothi    Ja-Jaya

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Table 4.24(b) Comparison of leaf area duration (LAD) of varieties at fortnightly intervals

| Varieties | Leaf area duration | | | | |
|---|---|---|---|---|---|
| | 15 - 30 DAP | 30 - 45 DAP | 45 - 60 DAP | 60 - 75 DAP | 75 - 90 DAP |
| Jyothi | 14.78[a] | 28.62[a] | 46.94[a] | 64.84[a] | 59.98[a] |
| Jaya | 7.22[b] | 15.04[b] | 21.74[b] | 30.15[b] | 29.22[b] |
| CD | 1.06 | 1.67 | 2.15 | 2.82 | 3.59 |

DAP – Days After Planting

Table. 4.25(a) Effect of date 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 | | |
| | Jy | Ja | Mean | Jy | Ja | Mean | Jy | Ja | Mean |
| 5th June | 11.00 | 3.67 | 7.33 | 9.36 | 5.78 | 7.57 | 12.26[ab] | 8.41[a] | 10.34[a] |
| 20th June | 10.80 | 2.97 | 6.88 | 6.71 | 4.67 | 5.69 | 8.94[bc] | 9.75[a] | 9.35[a] |
| 5th July | 9.40 | 2.95 | 6.17 | 5.25 | 3.97 | 4.61 | 3.40[c] | 6.56[a] | 4.98[b] |
| 20th July | 7.37 | 1.96 | 4.66 | 8.10 | 2.67 | 5.38 | 16.54[a] | 5.45[a] | 10.99[a] |
| 5th August | 5.74 | 2.83 | 4.28 | 9.79 | 3.57 | 6.68 | 17.13[a] | 4.79[a] | 10.96[a] |
| CD | NS | | NS | NS | | NS | 5.69 | | 3.56 |

| Date of planting | Crop growth rate (g $m^{-2}$ $day^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | 60 – 75 DAP | | | 75 - 90 DAP | | |
| | Jy | Ja | Mean | Jy | Ja | Mean |
| 5th June | 11.56 | 7.01 | 9.28 | -9.83 | -4.06 | -6.94 |
| 20th June | 13.45 | 6.73 | 10.09 | -5.49 | -2.58 | -4.04 |
| 5th July | 3.75 | 7.12 | 5.43 | -4.69 | -1.90 | -3.29 |
| 20th July | 8.82 | 8.61 | 8.72 | -4.98 | -1.77 | -3.37 |
| 5th August | 9.86 | 7.09 | 8.47 | -6.69 | -2.28 | -4.48 |
| CD | NS | | NS | NS | | NS |

DAP – Days After Planting    Jy-Jyothi    Ja-Jaya

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Table.4.25 (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 |
| Jyothi | $8.86^{a}$ | $7.84^{a}$ | $11.65^{a}$ | 9.49 | $-6.34^{b}$ |
| Jaya | $2.87^{b}$ | $3.55^{b}$ | $5.82^{b}$ | 7.08 | $-2.51^{a}$ |
| CD | 1.64 | 2.40 | 3.16 | NS | 2.04 |

DAP – Days After Planting

Table.4.26 (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 | | |
| | Jy | Ja | Mean | Jy | Ja | Mean | Jy | Ja | Mean |
| 5$^{th}$ June | 6.04 | 4.14 | 5.09 | 2.11 | 2.92 | 2.52 | 1.86$^{a}$ | 2.75$^{a}$ | 2.31$^{a}$ |
| 20$^{th}$ June | 4.95 | 3.29 | 4.12 | 1.51 | 1.72 | 1.61 | 0.78$^{b}$ | 2.34$^{a}$ | 1.56$^{a}$ |
| 5$^{th}$ July | 4.32 | 2.38 | 3.35 | 1.25 | 1.24 | 1.24 | 0.44$^{b}$ | 1.15$^{b}$ | 0.79$^{b}$ |
| 20$^{th}$ July | 4.45 | 2.75 | 3.60 | 2.39 | 0.85 | 1.62 | 2.09$^{a}$ | 1.15$^{b}$ | 1.62$^{a}$ |
| 5$^{th}$ August | 3.13 | 2.87 | 3.00 | 1.85 | 1.57 | 1.71 | 2.24$^{a}$ | 0.90$^{b}$ | 1.57$^{a}$ |
| CD | NS | | NS | NS | | NS | 1.01 | | 0.75 |

| Date of planting | Net assimilation rate (g m$^{-2}$ day$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | 60 - 75 DAP | | | 75 – 90 DAP | | |
| | Jy | Ja | Mean | Jy | Ja | Mean |
| 5$^{th}$ June | 1.37 | 1.51 | 1.44 | -1.18 | -0.96 | -1.07$^{b}$ |
| 20$^{th}$ June | 1.98 | 0.81 | 1.39 | -0.62 | -0.60 | -0.61$^{a}$ |
| 5$^{th}$ July | 0.49 | 1.54 | 1.01 | -0.47 | -0.41 | -0.44$^{a}$ |
| 20$^{th}$ July | 0.96 | 2.14 | 1.55 | -0.54 | -0.41 | -0.47$^{a}$ |
| 5$^{th}$ August | 0.94 | 1.58 | 1.26 | -0.72 | -0.59 | -0.65$^{a}$ |
| CD | NS | | NS | NS | | 0.24 |

DAP – Days After Planting    Jy-Jyothi    Ja-Jaya

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Table.4.26 (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 |
| Jyothi | 4.58$^{a}$ | 1.82 | 1.48 | 1.15 | -0.70 |
| Jaya | 3.09$^{b}$ | 1.66 | 1.85 | 1.57 | -0.59 |
| CD | 1.24 | NS | NS | NS | NS |

DAP –Days After Planting

In Jyothi, higher crop growth rate was observed for August 5$^{th}$ planting and was on par with June 5$^{th}$ and July 20$^{th}$ plantings. Lowest crop growth rate values recorded for July 5$^{th}$ planting and was on par with June 20$^{th}$ planting. But in the case of Jaya, June 20$^{th}$ planting showed a higher growth rate and was on par with June 5$^{th}$, July 5$^{th}$, July 20$^{th}$ and August 5$^{th}$ plantings during 45-60 DAP. Among dates of planting, only July 5$^{th}$ planting showed a lowest crop growth rate while all other planting were on par with higher crop growth rate values. While comparing the varieties, in almost all cases Jyothi was found to be superior in this index whereas for 75-90 DAP, a lower decrease in growth rate was observed for Jaya than Jyothi.

### *4.7.4. Net assimilation rate at fortnightly intervals*

Table 4.26(a&b) shows the results of ANOVA carried out for the net assimilation rate at fortnightly intervals. This was found to be significant for dates of planting, varieties and for the interaction effects.

During 45-60 DAP, all dates of planting except for July 5$^{th}$ planting showed a higher net assimilation rate and was on par with each other while during 75-90 DAP, lower negative rate was observed for June 20$^{th}$, July 5$^{th}$, July 20$^{th}$ and August 5$^{th}$ plantings and were on par with each other. Interaction was found to be significant only during 45-60 DAP. In Jyothi, higher rate was noticed for August 5$^{th}$ planting and was on par with June 5$^{th}$ and July 20$^{th}$ plantings while in Jaya, June 5$^{th}$ and June 20$^{th}$ plantings were on par with higher net assimilation rate and other plantings were inferior in net assimilation rate. Among varieties, during 15-30 DAP, Jyothi was observed as superior whereas no significant difference was observed for the later periods.

## 4.8. CROP WEATHER MODELS

According to the objective of this study, the validation of different statistical models and one crop simulation model (DSSAT-CERES-Rice model) were done for the two varieties, Jyothi and Jaya. For validation, four statistical models (Ravindran, 2018) were used for Jyothi and one for Jaya.

### 4.8.1. Validation of different statistical models for Jyothi

To validate the statistical models for Jyothi, the experimental data of *kharif* season during the year 2018 was used. There was mainly four different models prepared based on,

1. Weekly weather variables
2. Fortnightly weather variables
3. Crop stage wise weather variables
4. Composite weather variables

These four models were validated with the weather variables collected during the crop period from Department of Agricultural Meteorology, College of Horticulture, Vellanikkara. The results obtained are presented below.

#### *4.8.1.1. Statistical model based on weekly weather variables*

Here, minimum temperature during 5$^{th}$ week ($X_{25}$), afternoon relative humidity during 1$^{st}$ week ($X_{41}$), forenoon vapour pressure deficit during 4$^{th}$ week ($X_{54}$), forenoon vapour pressure deficit during 7$^{th}$ week ($X_{57}$), forenoon vapour pressure deficit during 8$^{th}$ week ($X_{58}$) and bright sunshine hours during 3$^{rd}$ week ($X_{63}$) of five different dates of planting were used to fit the model that is given below.

$$\mathbf{Y = 20.736 - 0.385X_{25} + 0.045X_{41} + 0.493X_{54} - 0.357X_{57} - 0.563X_{58} - 0.263X_{63}}$$

The model output (predicted yield) and the observed yield are given in Table 4.27. It was observed that the June 20$^{th}$ planting showed an observed yield nearer to the predicted yield. For all other planting dates the predicted yield showed a large difference from the observed yield.

### *4.8.1.2. Statistical model based on fortnightly weather variables*

Fortnightly averaged weather data of 1st to 5th fortnights were used for forecasting the yield. Maximum temperature of 5th fortnight ($X_{15}$), forenoon relative humidity of 4th fortnight ($X_{34}$), afternoon relative humidity of 1st fortnight ($X_{41}$), afternoon relative humidity of 4th fortnight ($X_{44}$), bright sunshine hours of 4th fortnight ($X_{64}$) and pan evaporation of 4th fortnight ($X_{84}$) of different planting dates were obtained from different weather variables for forecasting the yield.

$$\mathbf{Y = 16.774 - 0.370X_{15} - 0.137X_{34} + 0.110X_{41} + 0.106X_{44} + 0.238X_{64} - 1.605X_{84}}$$

From the Table 4.27, it was clear that the model output showed a wide variation from the observed yield. Among different planting dates, the yield of August 5th planting was comparatively nearer to the predicted yield.

### *4.8.1.3. Statistical model based on crop stage wise weather variables*

The model with weather variables of booting to heading stage was used for validation. For this model only forenoon vapour pressure deficit ($X_5$) and rainfall ($X_7$) of booting to heading stage of five planting dates were needed.

$$\mathbf{Y = 19.873 - 0.670X_5 + 0.006X_7}$$

Comparison of observed yield and predicted yield using this statistical model were made (Table 4.27). Comparing the former two models, this model showed a predicted yield somewhat near to the observed yield. The difference between observed yield and predicted yield were lower than the models based on weekly weather data and based on fortnightly weather data. Here also June 20th planting showed a closer yield to the predicted yield.

Table 4.27 Validation of statistical models for Jyothi using the data of the experimental year 2018

| Dates of planting | Model based on 8 weeks weather variables | | | Model based on 5 fortnights weather variables | | | Model based on $P_4$ crop stage weather variables | | |
|---|---|---|---|---|---|---|---|---|---|
| | Observed yield | Predicted yield | Error % | Observed yield | Predicted yield | Error % | Observed yield | Predicted yield | Error % |
| D1 | 3021.25 | 5482.50 | -81.46 | 3021.25 | 7108.40 | -135.28 | 3021.25 | 5868.00 | -94.22 |
| D2 | 4698.00 | 4634.90 | 1.34 | 4698.00 | 6938.85 | -47.70 | 4698.00 | 5609.58 | -19.40 |
| D3 | 3422.75 | 7429.30 | -117.06 | 3422.75 | 8406.75 | -145.61 | 3422.75 | 5243.90 | -53.21 |
| D4 | 2598.25 | 6524.40 | -151.11 | 2598.25 | 4327.00 | -66.54 | 2598.25 | 4131.00 | -58.99 |
| D5 | 2795.75 | 5847.40 | -109.15 | 2795.75 | 3274.55 | -17.13 | 2795.75 | 5124.09 | -83.28 |

| Dates of planting | Model based on 7 weeks composite weather variables | | |
|---|---|---|---|
| | Observed yield | Predicted yield | Error % |
| D1 | 3021.25 | 4401.10 | -45.67 |
| D2 | 4698.00 | 4329.31 | 7.85 |
| D3 | 3422.75 | 4393.37 | -28.36 |
| D4 | 2598.25 | 3993.97 | -53.72 |
| D5 | 2795.75 | 3679.05 | -31.59 |

$$Error\ \%\ for\ statistical\ models = \frac{observed\ yield - Predicted\ yield}{observed\ yield} \times 100$$

#### *4.8.1.4.Statistical model based on composite weather variables*

Yield forecasting using composite weather variables uses weighted and un-weighted indices of weather parameters. Here, the model used the un-weighted and weighted indices of afternoon relative humidity ($Z_{40}$ and $Z_{41}$). The model used is,

$$\mathbf{Y = -8.034 + 0.71Z_{40} + 0.218Z_{41}}$$

The model output was compared with the actual yield of five plantings (Table 4.27). In this model, the predicted yield was much more closer to the observed yield than the previous three models and not much difference was observed between the predicted and the observed yield. The predicted yield showed a decreasing trend towards the delayed planting. In the case of June 20$^{th}$ planting, the observed yield was more than the predicted yield.

From the validation of four different statistical models for Jyothi, the model based on composite weather variables was in good agreement with the observed yield for different planting dates. So it can be used as the best yield forecasting model for Jyothi variety using afternoon relative humidity for seven weeks.

### 4.8.2. Crop weather models using Principal Component Analysis in Jyothi and Jaya

For fitting a model for Jyothi and Jaya, principal component analysis was carried out to determine the best suited components whose contribution was more towards the dependent variable. Weather variables such as maximum temperature, minimum temperature, forenoon relative humidity, afternoon relative humidity, forenoon vapour pressure deficit, afternoon vapour pressure deficit, rainfall, rainy days, wind speed, bright sunshine hours and evaporation were used along with the yield data from the year 2018.

#### *4.8.2.1. Crop weather model using Principal Component Analysis in Jyothi*

In Jyothi, principal component analysis was carried out with required weather data and five components were identified with varying proportions. The proportion of variance of the various components are given in the Table 4.28.

Table 4.28 Importance of components obtained after PCA analysis for Jyothi

| | Component 1 | Component 2 | Component 3 | Component 4 | Component 5 |
|---|---|---|---|---|---|
| Standard deviation | 2.489848 | 1.680294 | 1.205781 | 0.948069 | 0.156616 |
| Proportion of variance | 0.543802 | 0.247666 | 0.127536 | 0.078845 | 0.002152 |
| Cumulative proportion | 0.543802 | 0.791468 | 0.919003 | 0.997848 | 1 |

From the table it was observed that, a cumulative proportion of 91.9% was obtained for first three components (component 1, component 2 and component 3). Component 1 showed a proportion of variance of 54.38%, component 2 with 24.77% and that for component 3 was 12.75%. From component 4 and 5, the proportion of variance was very less. So for the yield prediction of Jyothi, only first three components were used in fitting the regression equation. The importance of different weather parameters in forming the three components were depicted in the variables factor map obtained after PCA analysis are given in the Fig. 4.8. and the loadings of different weather variables are shown in the Table 4.29. The parameters that are closer to the yield in the variables factor map showed more contribution in forming the components and those which had a loading value greater than 0.5 were more influential in the formation of corresponding components. The regression equation was fitted and comparison was made between estimated yield and observed yield (Table 4.31).

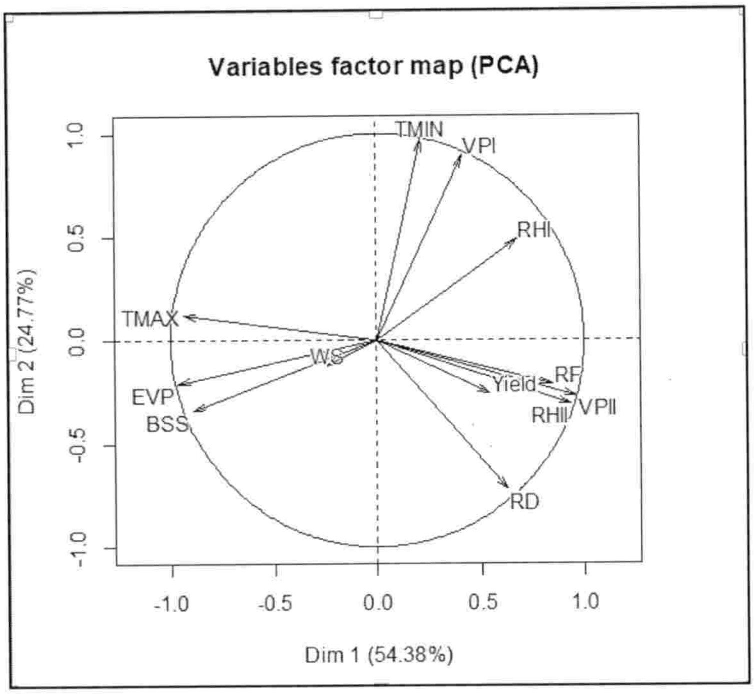


Fig.4.8. Variables factor map obtained after PCA in Jyothi

Table 4.29 Importance of different weather variables in forming principal components

| Variables | Component 1 | Component 2 | Component 3 |
|---|---|---|---|
| Maximum temperature | 0.540208 | -0.26084 | 0.030826 |
| Minimum temperature | -0.93721 | 0.11999 | -0.08747 |
| Forenoon relative humidity | 0.213409 | 0.97107 | -0.05008 |
| Afternoon relative humidity | 0.672825 | 0.486814 | 0.538431 |
| Forenoon vapour pressure deficit | 0.93441 | -0.31069 | 0.002204 |
| Afternoon vapour pressure deficit | 0.409529 | 0.892834 | 0.119038 |
| Wind speed | 0.960422 | -0.27153 | 0.041133 |
| Bright sunshine hours | -0.2421 | -0.12102 | 0.962315 |
| Rainfall | -0.89173 | -0.34035 | 0.148166 |
| Rainy days | 0.846391 | -0.21453 | -0.42269 |
| Evaporation | 0.624995 | -0.72186 | 0.294742 |

After the regression analysis using SPSS software, the yield prediction model for Jyothi was developed with three components and the form of model is given below.

**Yield= 3307.20 + 170.15$X_1$ + 121.74$X_2$ + 20.05$X_3$**

$X_1$- Score of principal component 1 (MAPE= 13.28%)

$X_2$- Score of principal component 2

$X_3$- Score of principal component 3

### *4.8.2.2. Crop weather model using Principal Component Analysis in Jaya*

From PCA analysis 12 components were identified with varying proportions. The details of the components with corresponding cumulative proportion values are given in the Table 4.30(a).

Table 4.30(a) Importance of components obtained after PCA analysis for Jaya

| | Component 1 | Component 2 | Component 3 | Component 4 | Component 5 | Component 6 |
|---|---|---|---|---|---|---|
| Standard deviation | 2.9082 | 1.4093 | 0.7454 | 0.6034 | 0.1912 | 1.1895 |
| Proportion of variance | 0.7419 | 0.1742 | 0.0487 | 0.0319 | 0.0032 | 1.2411 |
| Cumulative proportion | 0.7419 | 0.9161 | 0.9649 | 0.9968 | 1.0000 | 1.0000 |
| | Component 7 | Component 8 | Component 9 | Component 10 | Component 11 | Component 12 |
| Standard deviation | 1.0621 | 8.1159 | 7.9911 | 7.2087 | 1.4603 | 0.0000 |
| Proportion of variance | 9.8951 | 5.7778 | 5.6015 | 4.5583 | 1.8706 | 0.0000 |
| Cumulative proportion | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

From the table it was observed that, a cumulative proportion of 92% was obtained using first two components (component 1 and component 2). Component 1 have 74.2% proportion of variance and that of component 2 was 17.42%. From component 3 onwards the proportion of variance is only less than 5%. Therefore, for the yield prediction of Jaya, first two components were selected for fitting regression equation. The importance of different weather parameters in forming the components were studies by plotting the variables factor map (Fig 4.9). With the aid of loadings, the contribution of each weather variable in forming the principal components were also studied and are given in the Table 4.30(b). The regression equation was fitted withcomponent 1 and 2. Comparison was made between estimated yield and observed yield(Table 4.31).

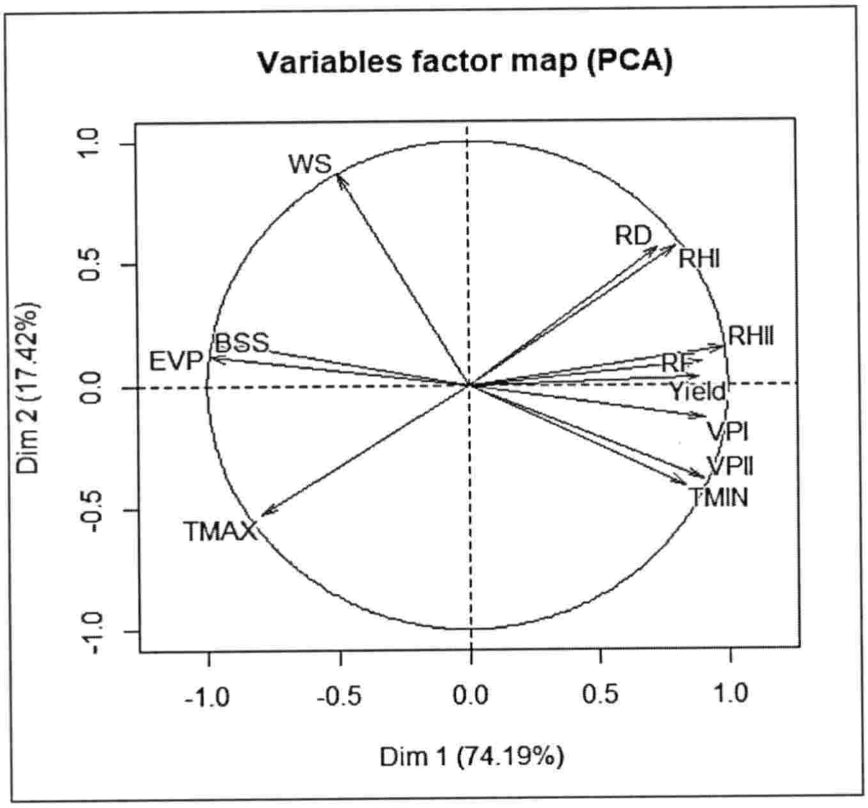


Fig. 4.9 Variables factor map obtained after PCA in Jaya

Table 4.30(b) Importance of different weather variables in forming principal components

| Variables | Component 1 | Component 2 |
|---|---|---|
| Maximum temperature | -0.79455 | -0.53196 |
| Minimum temperature | 0.834051 | -0.41013 |
| Forenoon relative humidity | 0.800778 | 0.567698 |
| Afternoon relative humidity | 0.987119 | 0.152353 |
| Forenoon vapour pressure deficit | 0.907028 | -0.1386 |
| Afternoon vapour pressure deficit | 0.903872 | -0.38541 |
| Wind speed | -0.49823 | 0.866238 |
| Bright sunshine hours | -0.98006 | 0.18888 |
| Rainfall | 0.89664 | 0.093018 |
| Rainy days | 0.732142 | 0.562513 |
| Evaporation | -0.99198 | 0.11887 |

The yield prediction model for Jaya was fitted using principal component 1 and component 2 and the model is given below.

$$\textbf{Yield} = \mathbf{3099.45 + 470.41X_1 + 34.34X_2}$$

Where, (MAPE= 14.75%)

$X_1$- Score of principal component 1
$X_2$- Score of principal component 2

Table 4.31 Comparison of predicted yield and observed yield of rice varieties after PCA

| Dates of planting | Model using PCA in Jyothi | | | Model using PCA in Jaya | | |
|---|---|---|---|---|---|---|
| | Estimated yield | Observed yield | Error % | Estimated yield | Observed yield | Error % |
| D1 | 3823.74 | 3021.25 | -0.26562 | 4631.636 | 5527.00 | 0.161998 |
| D2 | 3723.21 | 4698.00 | 0.20749 | 4863.443 | 4034.25 | -0.20554 |
| D3 | 3443.87 | 3422.75 | -0.00617 | 2545.027 | 2449.75 | -0.03889 |
| D4 | 2902.35 | 2598.25 | -0.11704 | 1424.631 | 1697.00 | 0.1605 |
| D5 | 2606.91 | 2795.75 | 0.067544 | 2094.352 | 1789.25 | -0.17052 |

### 4.8.3. CERES-Rice Simulation Model

Weather file, soil file, crop management file and experimental files were prepared initially for running the CERES-Rice model for Jyothi and Jaya during the experiment year 2018. The genetic coefficients calibrated from the Department of Agricultural Meteorology were used to simulate the yield for Jyothi and Jaya separately (Table 4.32).

Table 4.32 Genetic coefficients of Jyothi and Jaya used in CERES-Rice model

| Variety | P1 | P2R | P5 | P2O | G1 | G2 | G3 | G4 | PHINT |
|---|---|---|---|---|---|---|---|---|---|
| **Jyothi** | 533.3 | 20.2 | 443.0 | 12.0 | 54.0 | 0.0187 | 1.10 | 1.10 | 82.0 |
| **Jaya** | 815.0 | 99.0 | 200.0 | 11.4 | 40.0 | 0.0295 | 1.00 | 0.80 | 83.0 |

From the DSSAT CERES-Rice model, the average yield simulated for Jyothi was 4642 kg $ha^{-1}$ and for Jaya was 4795 kg $ha^{-1}$ which were higher than the observed yield from the experiment, i.e. 3307 kg $ha^{-1}$ for Jyothi and 3099 kg $ha^{-1}$ for Jaya. The d-stat value of Jyothi was 0.287 and that of Jaya was 0.349 in the case of yield (Table 4.33)

Table 4.33 Observed and simulated yield from CERES model of two varieties

| Variety name | Observed | Simulated | RMSE | d-Stat |
|---|---|---|---|---|
| Jyothi | 3307 | 4642 | 1713.7 | 0.287 |
| Jaya | 3099 | 4795 | 2518.7 | 0.349 |

The observed phenophase duration showed a good agreement with the simulated duration. The number of days taken for anthesis, panicle initiation and physiological maturity were simulated with a good Root Mean Square Error (RMSE) and d-stat value. The observed number of days and the simulated duration are given in the Table 4.34 with the corresponding RMSE and d-stat values.

Table 4.34 Observed and simulated phenophase duration of varieties

| Variety | Phenophases | Observed | Simulated | RMSE | d-Stat | MAPE |
|---|---|---|---|---|---|---|
| Jyothi | Anthesis | 66 | 69 | 3.4 | 0.346 | 4.26 |
| | Panicle initiation | 31 | 34 | 4.5 | 0.502 | 14.31 |
| | Physiological maturity | 102 | 104 | 2.4 | 0.516 | 1.61 |
| Jaya | Anthesis | 104 | 108 | 4.8 | 0.520 | 4.27 |
| | Panicle initiation | 73 | 72 | 2.9 | 0.347 | 3.53 |
| | Physiological maturity | 125 | 128 | 6.5 | 0.677 | 4.45 |

### 4.9. Pest and Disease Incidence

Incidence of pests and diseases were studied during the crop period in 2018 (Table 4.35). Pest incidence was more compared to diseases. Pest incidence was lower during the initial stages of planting and was more as the planting date was delayed. Later for last plantings, again the pest incidence was decreased. The major pests observed were Leaf folder (*Cnaphalocrocis medinalis),* Case worm (*Parapoynx stagnalis*), Stem borer (*Scirphophaga incertulus*) and Rice bug (*Leptocorisa acuta*). The only major disease noticed was Sheath blight (*Rhizoctonia solani*).

In addition to this, false smut disease (*Ustilaginoidea virens*) was observed in Jyothi variety during June 5$^{th}$ planting. Jyothi variety was more affected by the incidence of pests especially rice bug and leaf roller in which more leaf roller attack was detected for June 5$^{th}$ (18 $m^{-2}$)and June 20$^{th}$ (15 $m^{-2}$) plantings during the September month. Rice bug incidence was higher after the cessation of rainfall.

Table 4.35 Pests and disease incidence during the experiment period

| Pests/Diseases | D1 | D2 | D3 | D4 | D5 |
|---|---|---|---|---|---|
| Leaf folder | √ | √ | √ | √ | – |
| Case worm | √ | √ | √ | √ | √ |
| Stem borer | √ | – | – | √ | – |
| Rice bug | √ | √ | √ | √ | √ |
| Sheath blight | – | √ | √ | – | – |

# Discussion

# 5. DISCUSSION

This experiment was aimed at studying the crop weather relationship of rice varieties under different growing environments and to validate different statistical models and simulation model for two varieties, Jyothi and Jaya.

## 5.1. WEATHER PREVAILED DURING THE CROP PERIOD

During the experimental period, weather observations were taken in terms of maximum temperature, minimum temperature, forenoon relative humidity, afternoon relative humidity, forenoon vapour pressure deficit, afternoon vapour pressure deficit, wind speed, rainfall, rainy days, bright sunshine hours and evaporation. For each phenophases, weather conditions experienced were different and are depicted in the Table 5.1 to Table 5.16.

Higher maximum temperature was observed during transplanting to physiological maturity period of August 5$^{th}$ planting for Jyothi and Jaya with values 31.5°C and 31.7 °C respectively. A lower value of maximum temperature of 28.1 °C and 28.0 °C were noticed for Jyothi and Jaya respectively for August 5$^{th}$ planting from transplanting to active tillering stage. July 5$^{th}$ and August 5$^{th}$ planting showed lower minimum temperature for both the varieties (22.0 °C for Jyothi and 22.1°C for Jaya) whereas higher minimum temperature values of 23.6 °C was recorded for June 5$^{th}$ planting during transplanting to active tillering stage for both the varieties. In Jyothi, forenoon relative humidity ranged from 92%-97% whereas afternoon relative humidity ranged from 66%-86%. In Jaya, the range of forenoon and afternoon relative humidity were from 93%-97% and 68%-87% respectively. In both the varieties, lower forenoon relative humidity values recorded during August 5$^{th}$ planting from transplanting to physiological maturity stage and higher values for July 5$^{th}$ planting was observed during transplanting to active tillering stage. Higher afternoon relative humidity was noticed during transplanting to active tillering stage of

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

| | T - AT | T – PI | T - B | T - H | T - F | T - PM |
|---|---|---|---|---|---|---|
| D1 | 29.9 | 29.5 | 29.6 | 29.3 | 29.5 | 29.5 |
| D2 | 28.9 | 29.7 | 29.5 | 29.6 | 29.3 | 29.5 |
| D3 | 29.1 | 28.9 | 28.9 | 29.3 | 29.4 | 29.9 |
| D4 | 29.5 | 29.5 | 29.3 | 29.6 | 30.1 | 30.5 |
| D5 | 28.1 | 29.2 | 29.9 | 30.6 | 31.3 | 31.5 |

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

| | T - AT | T – PI | T - B | T - H | T - F | T - PM |
|---|---|---|---|---|---|---|
| D1 | 23.6 | 23.2 | 22.9 | 22.8 | 22.9 | 22.8 |
| D2 | 22.5 | 22.7 | 22.6 | 22.7 | 22.5 | 22.5 |
| D3 | 22.0 | 22.2 | 22.3 | 22.3 | 22.2 | 22.3 |
| D4 | 22.9 | 22.9 | 22.6 | 22.8 | 22.6 | 22.6 |
| D5 | 22.0 | 22.1 | 22.2 | 22.3 | 22.3 | 22.4 |

Table 5.3. Forenoon relative humidity (%) experienced by Jyothi during the crop period

| | T - AT | T - PI | T - B | T - H | T - F | T - PM |
|---|---|---|---|---|---|---|
| D1 | 97 | 96 | 96 | 96 | 96 | 96 |
| D2 | 95 | 95 | 96 | 96 | 96 | 96 |
| D3 | 97 | 96 | 96 | 96 | 96 | 95 |
| D4 | 95 | 96 | 96 | 96 | 95 | 95 |
| D5 | 97 | 96 | 95 | 94 | 93 | 92 |

Table 5.4. Afternoon relative humidity (%) experienced by Jyothi during the crop period

| | T - AT | T – PI | T - B | T - H | T - F | T - PM |
|---|---|---|---|---|---|---|
| D1 | 84 | 83 | 82 | 82 | 81 | 80 |
| D2 | 81 | 78 | 80 | 79 | 80 | 78 |
| D3 | 86 | 83 | 83 | 80 | 78 | 75 |
| D4 | 77 | 78 | 78 | 75 | 72 | 70 |
| D5 | 86 | 78 | 73 | 69 | 67 | 66 |

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

| | T - AT | T – PI | T - B | T - H | T - F | T - PM |
|---|---|---|---|---|---|---|
| D1 | 440.0 | 609.6 | 1250.9 | 1406.9 | 1434.3 | 2403.7 |
| D2 | 120.7 | 363.2 | 915.7 | 1105.4 | 1195.7 | 1845.1 |
| D3 | 567.5 | 727.2 | 1674.8 | 1687.7 | 1720.3 | 1825.6 |
| D4 | 140.8 | 401.4 | 1110.2 | 1110.7 | 1110.7 | 1369.0 |
| D5 | 840.2 | 882.6 | 883.9 | 887.2 | 887.2 | 1295.1 |

Table 5.6. Number of rainy days experienced by Jyothi during the crop period

| | T - AT | T – PI | T - B | T - H | T - F | T - PM |
|---|---|---|---|---|---|---|
| D1 | 9 | 18 | 32 | 39 | 41 | 71 |
| D2 | 9 | 13 | 30 | 36 | 41 | 59 |
| D3 | 11 | 18 | 38 | 46 | 50 | 54 |
| D4 | 7 | 15 | 37 | 37 | 37 | 46 |
| D5 | 14 | 23 | 25 | 25 | 25 | 39 |

Table 5.7. Bright sunshine hours (hrs) experienced by Jyothi during the crop period

| | T - AT | T - PI | T - B | T - H | T - F | T - PM |
|---|---|---|---|---|---|---|
| D1 | 1.7 | 1.7 | 1.9 | 1.5 | 1.5 | 1.6 |
| D2 | 1.8 | 2.9 | 2.1 | 1.9 | 1.6 | 2.2 |
| D3 | 1.0 | 0.7 | 0.7 | 1.9 | 2.0 | 2.9 |
| D4 | 0.7 | 1.0 | 1.5 | 1.6 | 3.3 | 3.7 |
| D5 | 0.5 | 2.6 | 4.2 | 4.9 | 5.3 | 5.4 |

Table 5.8. Wind speed (km $hr^{-1}$) experienced by Jyothi during the crop period

| | T - AT | T – PI | T - B | T - H | T - F | T - PM |
|---|---|---|---|---|---|---|
| D1 | 1.9 | 1.7 | 1.7 | 1.6 | 1.7 | 1.7 |
| D2 | 1.1 | 1.4 | 1.5 | 1.5 | 1.5 | 1.5 |
| D3 | 1.8 | 1.6 | 1.6 | 1.8 | 1.7 | 1.7 |
| D4 | 1.7 | 1.6 | 1.7 | 1.7 | 1.7 | 1.8 |
| D5 | 1.8 | 1.9 | 1.9 | 1.8 | 1.8 | 1.8 |

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Table 5.9. Maximum temperature (°C) experienced by Jaya during the crop period

| | T - AT | T - PI | T - B | T - H | T - F | T - PM |
|---|---|---|---|---|---|---|
| D1 | 29.7 | 29.5 | 29.5 | 29.4 | 29.4 | 29.5 |
| D2 | 28.9 | 29.5 | 29.4 | 29.4 | 28.9 | 29.2 |
| D3 | 29.0 | 28.9 | 28.9 | 29.4 | 29.4 | 29.9 |
| D4 | 29.5 | 29.5 | 29.5 | 30.0 | 30.4 | 30.8 |
| D5 | 28.0 | 29.1 | 30.0 | 31.0 | 31.4 | 31.7 |

Table 5.10. Minimum temperature (°C) experienced by Jaya during the crop period

| | T - AT | T - PI | T - B | T - H | T - F | T - PM |
|---|---|---|---|---|---|---|
| D1 | 23.6 | 23.2 | 22.9 | 22.8 | 22.8 | 22.8 |
| D2 | 22.5 | 22.6 | 22.6 | 22.6 | 22.4 | 22.4 |
| D3 | 22.1 | 22.2 | 22.3 | 22.3 | 22.2 | 22.2 |
| D4 | 22.9 | 22.9 | 22.6 | 22.4 | 22.4 | 22.4 |
| D5 | 22.1 | 22.1 | 22.2 | 22.3 | 22.4 | 22.5 |

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

| | T – AT | T – PI | T – B | T – H | T – F | T – PM |
|---|---|---|---|---|---|---|
| D1 | 97 | 96 | 96 | 96 | 96 | 96 |
| D2 | 95 | 95 | 96 | 96 | 96 | 95 |
| D3 | 97 | 96 | 96 | 96 | 96 | 95 |
| D4 | 95 | 96 | 96 | 95 | 94 | 93 |
| D5 | 96 | 96 | 94 | 93 | 93 | 93 |

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

| | T - AT | T - PI | T - B | T - H | T - F | T - PM |
|---|---|---|---|---|---|---|
| D1 | 85 | 84 | 83 | 82 | 80 | 79 |
| D2 | 81 | 79 | 79 | 80 | 82 | 80 |
| D3 | 85 | 83 | 83 | 79 | 78 | 75 |
| D4 | 77 | 78 | 77 | 73 | 69 | 69 |
| D5 | 87 | 79 | 72 | 69 | 69 | 68 |

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Table 5.13. Rainfall (mm) experienced by Jaya during the crop period

| | T - AT | T - PI | T - B | T - H | T - F | T - PM |
|---|---|---|---|---|---|---|
| D1 | 439.3 | 606.1 | 1293.5 | 1384.2 | 1410.6 | 2403.7 |
| D2 | 120.7 | 411.3 | 960.6 | 1155.1 | 1598.2 | 1845.1 |
| D3 | 496.8 | 725.3 | 1679.1 | 1687.7 | 1720.0 | 1880.3 |
| D4 | 140.8 | 421.6 | 1110.2 | 1110.7 | 1110.7 | 1485.2 |
| D5 | 837.6 | 883.1 | 886.0 | 887.2 | 944.2 | 1295.1 |

Table 5.14. Number of rainy days experienced by Jaya during the crop period

| | T - AT | T - PI | T - B | T - H | T - F | T - PM |
|---|---|---|---|---|---|---|
| D1 | 9 | 17 | 34 | 38 | 39 | 71 |
| D2 | 9 | 14 | 34 | 39 | 44 | 59 |
| D3 | 10 | 18 | 40 | 45 | 49 | 56 |
| D4 | 7 | 17 | 37 | 37 | 37 | 50 |
| D5 | 13 | 25 | 25 | 25 | 27 | 39 |

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

| | T - AT | T - PI | T - B | T - H | T - F | T - PM |
|---|---|---|---|---|---|---|
| D1 | 1.1 | 1.8 | 1.9 | 1.5 | 1.4 | 1.6 |
| D2 | 1.8 | 2.7 | 2.1 | 1.7 | 1.4 | 2.2 |
| D3 | 1.1 | 0.6 | 0.7 | 2.3 | 2.3 | 3.0 |
| D4 | 0.7 | 0.9 | 1.8 | 3.7 | 4.7 | 4.8 |
| D5 | 0.3 | 2.3 | 4.2 | 4.7 | 4.4 | 4.7 |

Table 5.16. Wind speed (km $hr^{-1}$) experienced by Jaya during the crop period

| | T - AT | T - PI | T - B | T - H | T - F | T - PM |
|---|---|---|---|---|---|---|
| D1 | 1.8 | 1.7 | 1.7 | 1.7 | 1.6 | 1.7 |
| D2 | 1.1 | 1.4 | 1.5 | 1.5 | 1.6 | 1.6 |
| D3 | 1.8 | 1.7 | 1.7 | 1.8 | 1.8 | 1.8 |
| D4 | 1.7 | 1.6 | 1.7 | 1.8 | 1.8 | 1.8 |
| D5 | 1.8 | 1.9 | 1.8 | 1.7 | 1.7 | 1.8 |

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August 5$^{th}$ planting for both the varieties. In Jyothi, during transplanting to physiological maturity stage, higher rainfall was received by June 5$^{th}$ planting (2403.7mm) whereas lower amount of rainfall was recorded for August 5$^{th}$ planting (1295.1mm). Similar trend was observed for Jaya also. During transplanting to active tillering stage, June 20$^{th}$ planting received lower rainfall and August 5$^{th}$ planting received higher rainfall for both the varieties. Maximum rainy days of 71 and minimum of 31 days were recorded for June 5$^{th}$ and August 5$^{th}$ plantings respectively and was similar for both the varieties. On comparing different planting dates, it was observed that August 5$^{th}$ planting received maximum sunshine hours in Jyothi and July 20$^{th}$ planting showed maximum for Jaya from transplanting to physiological maturity stage while June 5$^{th}$ planting experienced with minimum sunshine hours during the same period in both the varieties. Higher wind speed was noticed during transplanting to active tillering stage for June 5$^{th}$ planting (1.9 km hr$^{-1}$for Jyothi and 1.8 km hr$^{-1}$for Jaya) and lower wind speed was recorded for June 20$^{th}$ planting during the same period (1.1 km hr$^{-1}$ for both varieties).

The different phenophases and the corresponding temperature and rainfall were depicted in the Fig. 5.1 (a&b) and Fig. 5.2 (a&b) for Jyothi and Jaya.

From the Fig. 5.1 (a), it was clear that for June 5$^{th}$ planting in Jyothi the maximum temperature was lower during the entire crop period except for a small duration in the last phenophase (50% flowering to physiological maturity). June 20$^{th}$ planting experienced with higher maximum temperature only after 50% flowering. July 5$^{th}$ planting experienced higher maximum temperature from heading onwards and that for July 20$^{th}$ planting was panicle initiation onwards. In the case of August 5$^{th}$ planting, a major part of the crop duration were experienced with a higher maximum temperature.

In Jaya, June 5$^{th}$ planting experienced with higher maximum temperature towards the maturity phase. For June 20$^{th}$ planting, a higher temperature was noticed

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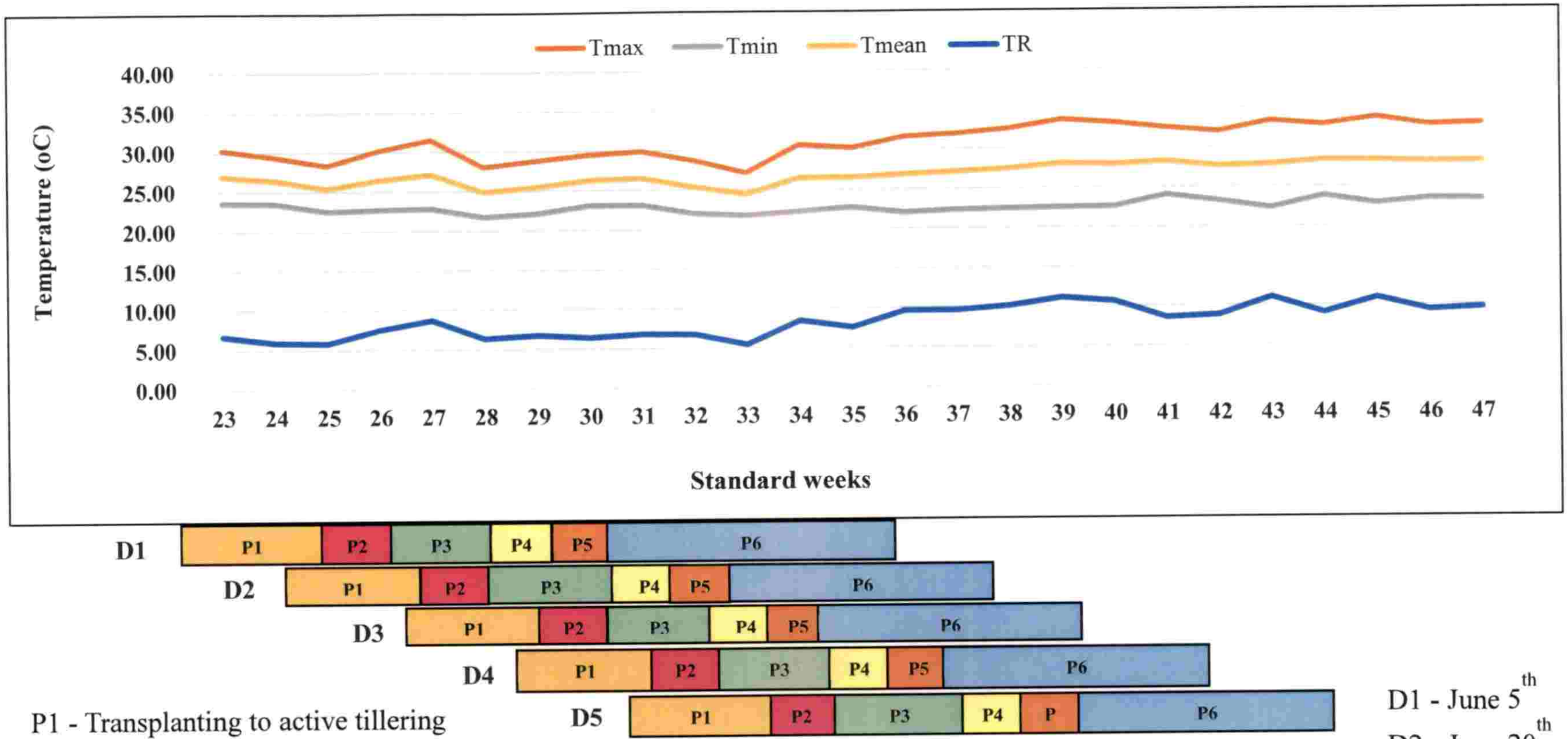
after heading stage. In the case of July 5th planting, it was booting onwards and that for July 20th planting it was after panicle initiation. As that of Jyothi, Jaya also experienced with higher maximum temperature during its major part of crop duration for August 5th planting. These increased temperature affected the yield and duration of the crop with delayed planting.

From the observations on rainfall (Fig. 5.2 (a)), in Jyothi, a water stress was observed during 27th meteorological week for June 5th planting which reduced the dry matter accumulation during that period. June 20th planting also experienced with a water stress condition during the tillering stage and physiological maturity stage. July 5th planting was most affected by the heavy rainfall and a rainfall deficit situation was observed during the maturity period. While comparing July 20th and August 5th plantings, deficiency of rainfall was noticed from heading stage of July 20th planting and some amount of rainfall was received only during the maturity stage whereas in August 5th planting, rainfall deficiency was observed after panicle initiation and more rainfall was received from heading onwards which increased the yield of August 5th planting than the previous one.

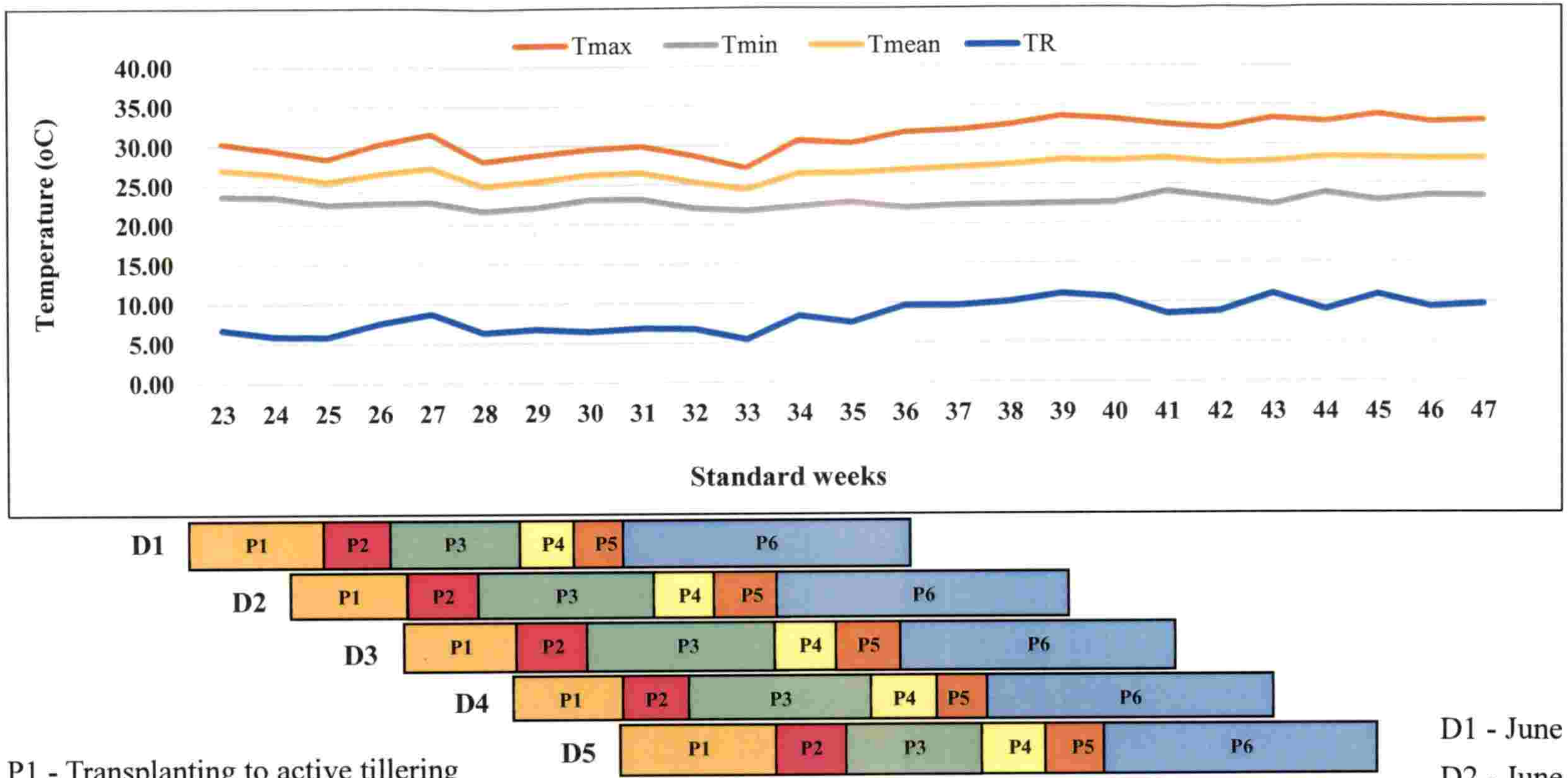
In Jaya (Fig. 5.2 (b)), the case of June 5th and June 20th plantings were same as that of Jyothi. During the July 5th planting, major crop duration was experienced by heavy rainfall. For July 20th planting, rainfall deficiency was observed from booting to 50% flowering stage which decreased the yield of July 20th planting compared to August 5th planting. Rainfall deficiency was also experienced by August 5th planting from panicle initiation stage and more rainfall was received after booting stage positively influenced the yield.




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

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

**Fig. 5.1 (a) Temperature (°C) experienced during different phenophases of Jyothi**




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

D1 - June 5$^{th}$
D2 - June 20$^{th}$
D3 - July 5$^{th}$
D4 - July 20$^{th}$
D5 - August 5$^{th}$

**Fig. 5.1 (b) Temperature (°C) experienced during different phenophases of Jaya**

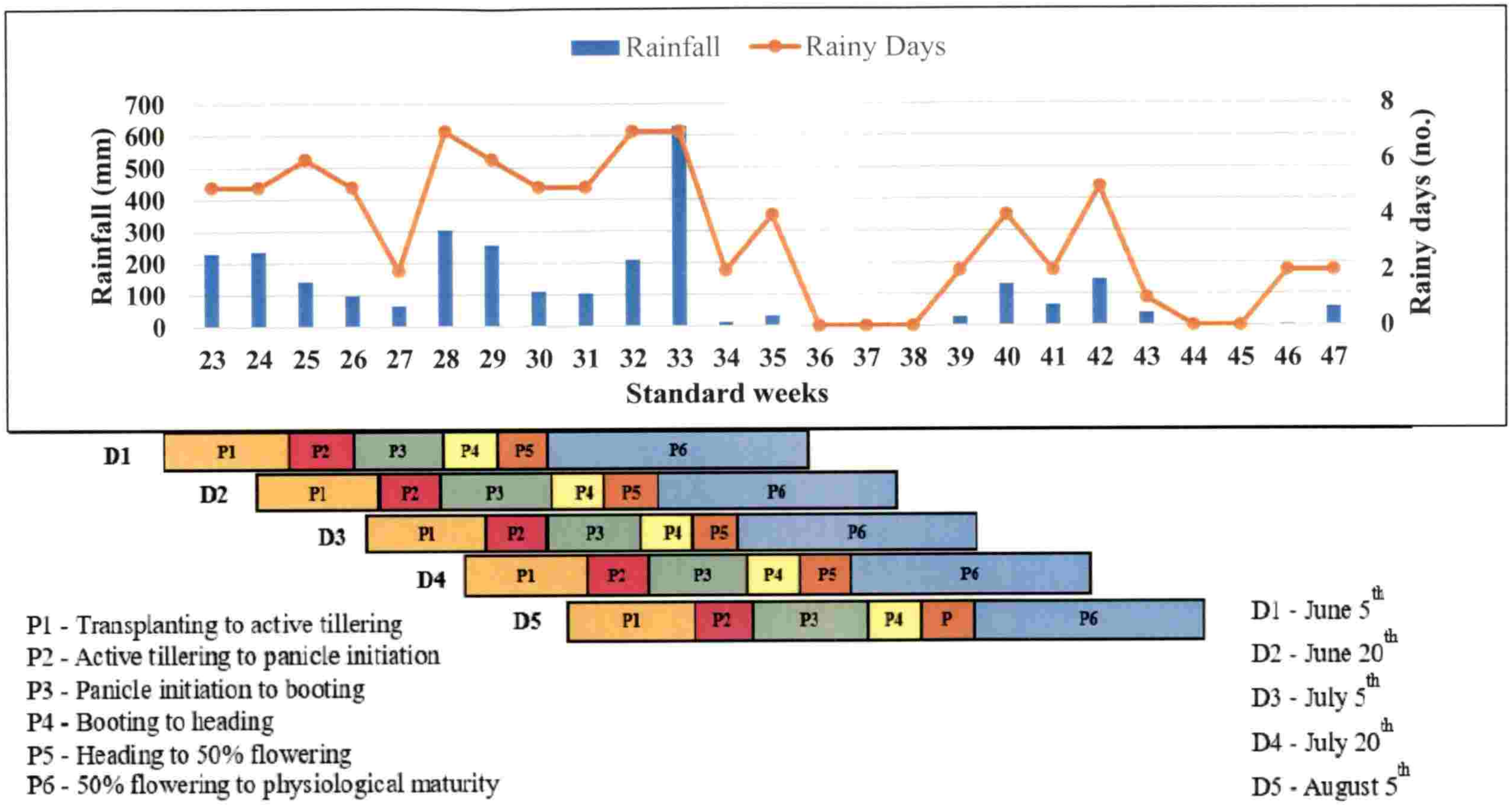



**Fig. 5.2 (a) Rainfall (mm) and rainy days during different phenophases of Jyothi**

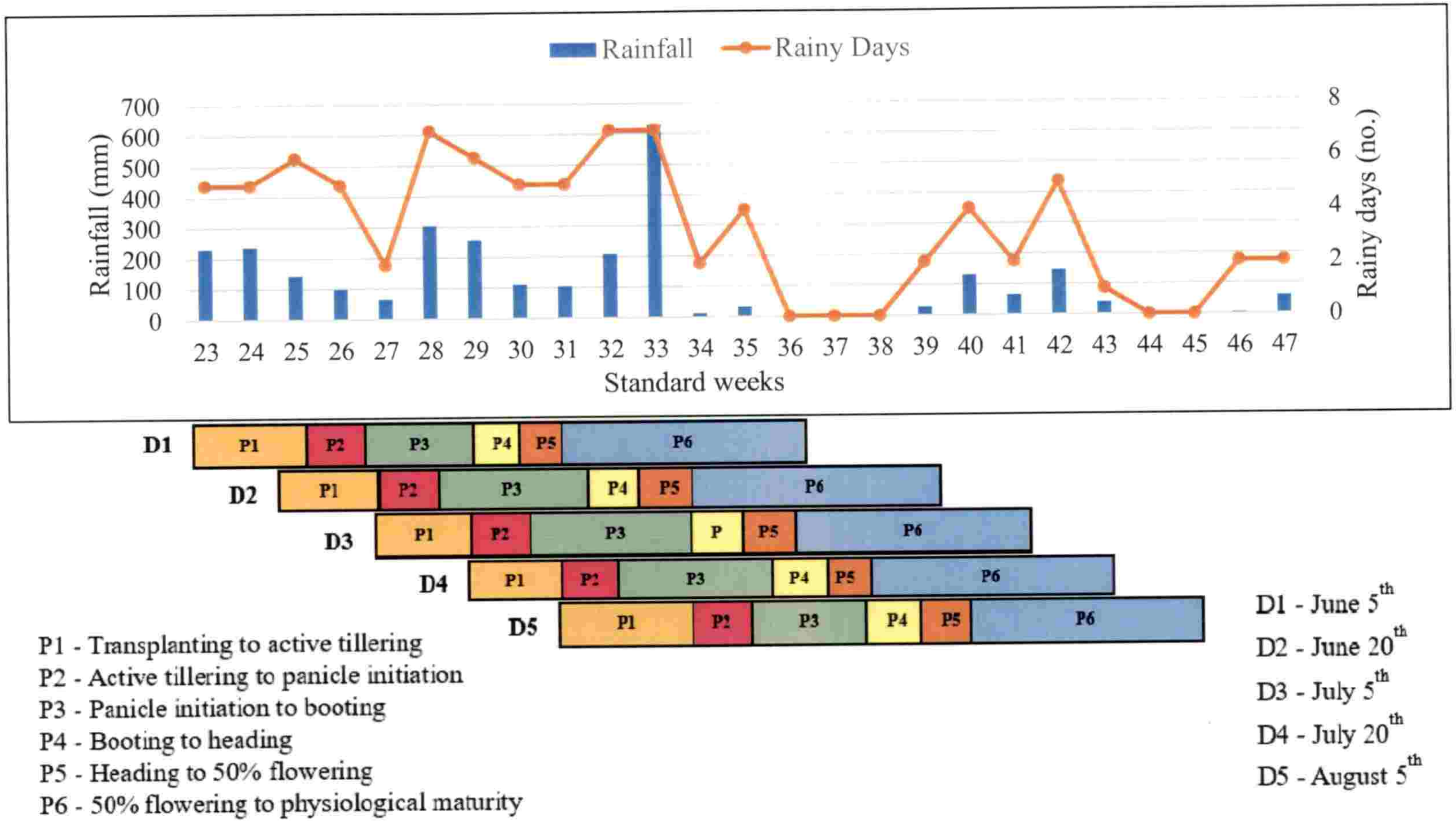



**Fig. 5.2 (b) Rainfall (mm) and rainy days during different phenophases of Jaya**

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## 5.2. EFFECT OF WEATHER PARAMETERS ON GROWTH AND DEVELOPMENT OF RICE VARIETIES

### 5.2.1. Plant height

At weekly intervals plant height showed variation among different planting dates. While comparing two varieties, significant difference was observed between them for all weeks except for first week. Similar result was observed by Vysakh in 2015. Jyothi exhibited higher plant height compared to Jaya variety. The performance of two varieties was different for different planting dates. In Jyothi, maximum height was observed for July 5$^{th}$ planting whereas in Jaya, June 5$^{th}$ planting showed more plant height compared to all other plantings.

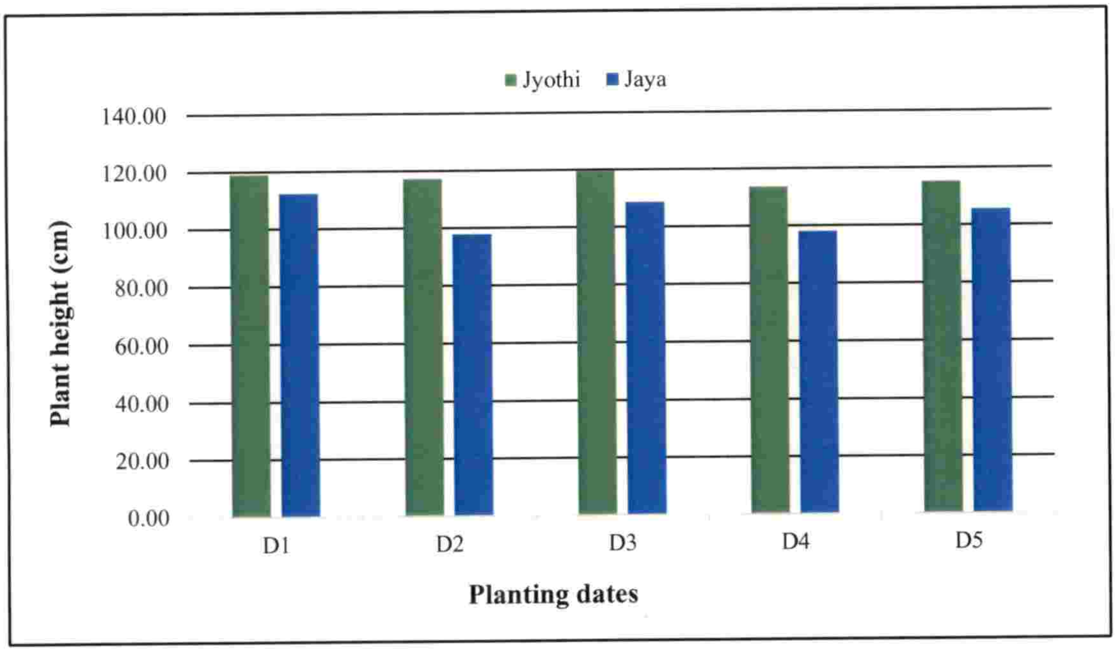


Fig.5.3. Difference in weekly plant height with respect to varieties

### 5.2.2. Dry matter accumulation

In both the varieties, Jyothi and Jaya, dry matter accumulation was reduced with the delay in planting date. 15 days after planting, June 5th planting exhibited lower dry matter accumulation. Because it experienced with a water stress situation during the initial stage. Later on the dry matter accumulation showed an increasing trend after the receipt of enough rainfall. Maximum dry matter accumulation was observed during 75 days after planting. June 5th planting showed higher dry matter production compared to all other planting dates for both the varieties. For all the planting dates, Jaya exhibited higher dry matter accumulation compared to Jyothi during 75 days after planting. In Jaya as well as in Jyothi, a negative influence was observed by the maximum temperature (Singh *et al.*, 2012; Roy and Biswas, 1980) and diurnal temperature range (Peng *et al.*, 2004) with dry matter accumulation (Fig. 5.4). Relative humidity and rainfall showed a positive effect on the dry matter production in both the varieties (Singh *et al.*, 2012; Roy and Biswas, 1980; Hirai *et al.*, 1993).

### 5.2.3. Number of tillers per $m^2$

Significant difference was observed between dates of planting in the case of number of tillers per unit area. More number of tillers were observed for July 20th and August 5th planting. Number of tillers were higher at the time of higher temperature conditions. This was in agreement with the reports by Mahbubul *et al.* in 1985.

### 5.2.4. Number of panicles per $m^2$

Number of panicles per unit area showed significant difference with dates of planting. It was noticed that negative influence of relative humidity affected the panicle number in unit area. The same result was observed by Krishnakumar in 1986.

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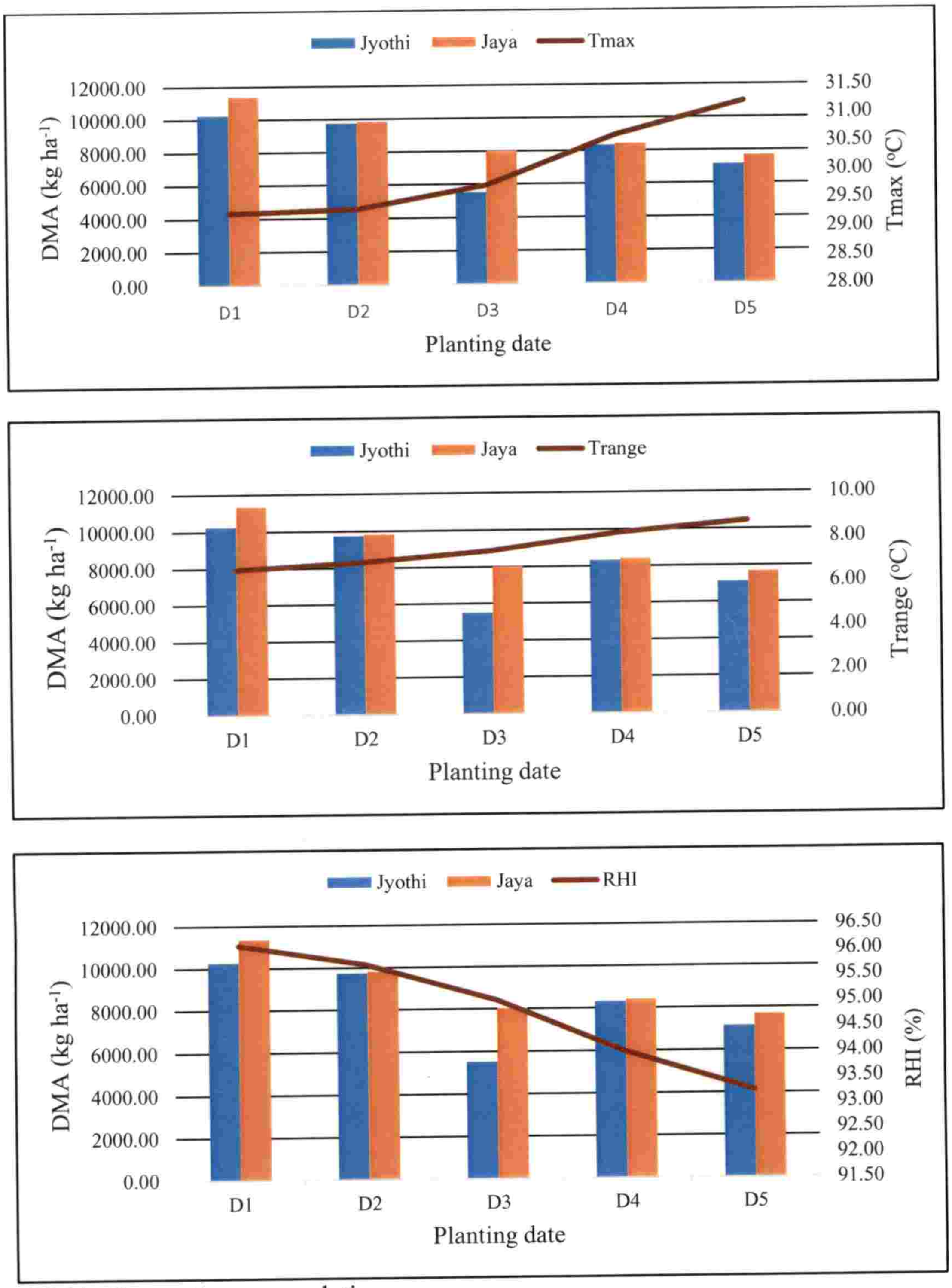


DMA- Dry matter accumulation

Fig.5.4. Effect of weather parameters on DMA with respect to planting dates

### 5.2.5. Number of spikelets per panicle

Number of spikelets per panicle showed a decreasing trend as the planting was delayed. It was observed that the late planting had lesser spikelet number. This result showed similarities with the results of Akbar *et al.* (2010) and Faghani *et al.* (2011).

### 5.2.6. Number of filled grains per panicle

It was observed that early planting showed an increased number of filled grains per panicles whereas late plantings showed lesser number of filled grains per panicle. This results was in agreement with the findings of Akbar *et al.* (2010) and Faghani *et al.* (2011).

### 5.2.7. Thousand grain weight

A decreasing trend was observed in the case of thousand grain weight with delayed planting date. Early planting showed higher grain weight while lower weight was observed in the case of late planting. These results was in conformity with the findings of Akbar *et al.* (2010), Faghani *et al.* (2011), Singh *et al.* (2012) and Khalifa *et al*. (2014).

### 5.2.8. Straw yield

Significant difference was observed among different planting dates for Jyothi and Jaya. Straw yield obtained during June 5th planting was higher than the late plantings since June 5th planting received high relative humidity with low temperature during the crop period. The straw yield for June 20th planting was lesser than June 5th planting, because June 20th planting experienced low relative humidity and high temperature compared to the former (Sreelatha, 1989 and Sherif *et al.*, 2000).

### 5.2.9. Grain yield

Grain yield showed significant difference with different dates of planting in Jyothi as well as in Jaya.

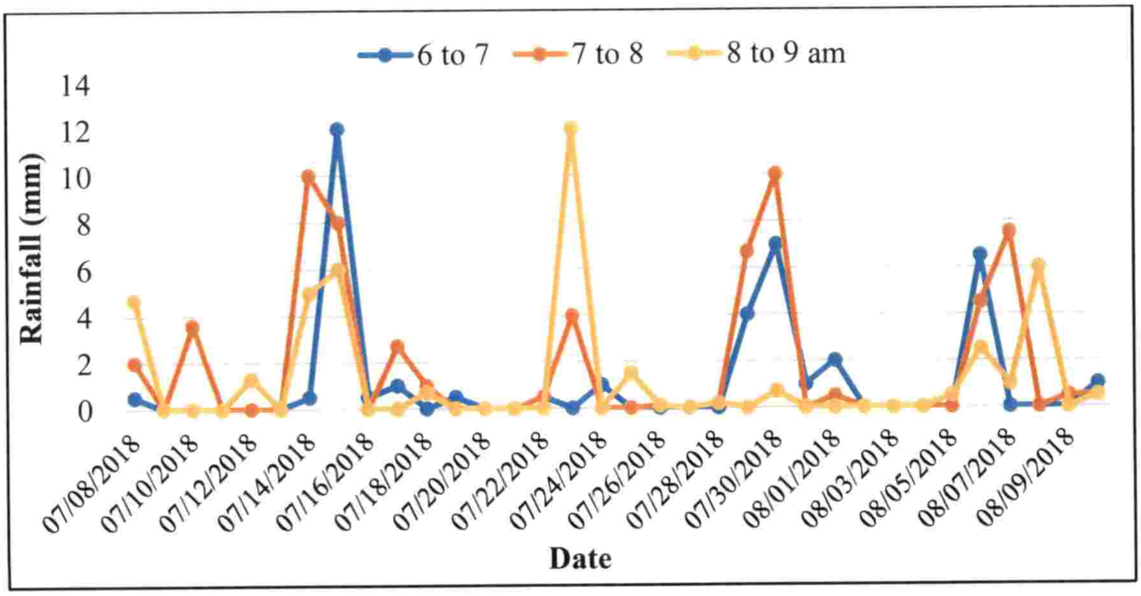


Fig.5.5 Effect of morning rainfall during heading stage of Jyothi and Jaya in June 5th planting

In Jyothi, higher grain yield was obtained during June 20th planting while in Jaya, higher yield recorded during June 5th planting. Because, Jyothi received high morning rainfall continuously for three days during the flowering stage (Fig.5.5) which reduced grain yield. In Fig. 5.3, the heading stage of Jyothi coincided with 12th July, thereafter it received continuous morning rainfall during anthesis time whereas the heading of Jaya occurred during 24th July after which the effect of morning rainfall was less. This was in conformity with the findings of Vijayakumar (1996), i. e, the increased morning rainfall will reduce the pollination of the flowers and more unfertilized ovaries will lead to the production of chaffy grains thereby decreasing the yield. As the planting date was delayed the grain yield showed a decreasing trend because the increased sterile spikelet and decreased 1000 grains weight for later plantings (Faghani *et al.*, 2011). High wind speed during the maturity stages of last plantings also reduced the grain yield (Sreenivasan, 1985). Similar results were found by Mahmood *et al.* (1995), Akram *et al.* (2007) and Ali *et al.* (2015). The grain yield of August 5th planting was higher for both the varieties compared to July 20th planting since August 5th planting

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received some more rainfall during its critical stages compared to July 20th planting as mentioned earlier in the Fig. 5.2 (a) and Fig. 5.2 (b) in Jyothi and Jaya respectively.

After analyzing the relation between yield and weather parameters (Table 5.17) of five planting dates, it was observed that grain yield was affected by varying ranges of weather parameters in Jyothi and Jaya. During transplanting to active tillering, 28.0 to 29.0°C of maximum temperature, 22.0 to 23.0°C of minimum temperature, 80 to 82% afternoon relative humidity and 1.5 to 2 hrs bright sunshine hours favoured the yield in Jyothi whereas in Jaya, maximum temperature of 29.0 to 30.0°C, minimum temperature of 23.0 to 24.0°C, 84 to 86% afternoon relative humidity and 1 to 1.5 hrs bright sunshine hours were observed as good in yield production. Maximum temperature of 29.0 to 31.0°C, minimum temperature of 22.0 to 23.0°C and forenoon relative humidity of 94 to 96% were highly influenced in better production in both the varieties during active tillering to panicle initiation whereas during panicle initiation to booting stage, the optimum range of parameters such as 29.0 to 30.0°C maximum temperature, 22.0 to 23.0°C minimum temperature, 96 to 97 % of forenoon relative humidity, 500 to 800 mm rainfall and 1 to 3 hrs bright sunshine hours were positively affected the yield. In booting to heading also 29 to 30°C maximum temperature, 22.0 to 23.0°C minimum temperature and a forenoon relative humidity of 95-97 % influenced the higher grain production. During heading to 50% flowering, a maximum temperature around 28.0 to 30.0°C, 80 to 100 mm rainfall and 0 to 2 hrs bright sunshine hours favoured the yield production. Forenoon relative humidity of 93 to 96 %, 29.0 to 30.0°C maximum temperature and 600 to 900 mm rainfall positively influencedthe grain yield. These results were in agreement with the findings of Yoshida in 1981.

## 5.3. RELATIONSHIP BETWEEN DURATION OF PHENOLOGICAL STAGES AND WEATHER

The duration of Jyothi and Jaya are different since Jyothi is a short duration variety and Jaya is a medium duration variety. Duration of phenophases of differentplanting dates also showed variation because of the prevailed weather conditions in

Table 5.17. The optimum conditions of weather parameters for higher yield in Jyothi and Jaya

| Weather parameters | T-AT | | AT-PI | | PI-B | |
|---|---|---|---|---|---|---|
| | Jyothi | Jaya | Jyothi | Jaya | Jyothi | Jaya |
| Tmax (°C) | 28.0-29.0 | 29.0-30.0 | 29.0-31.0 | 29.0-30.0 | 29.0-29.5 | 29.5-30.5 |
| Tmin ( °C) | 22.0-23.0 | 23.0-24.0 | 22.0-23.0 | 22.0-23.0 | 22.2-22.3 | 22.0-23.0 |
| RH I (%) | 95-96 | 96-97 | 94-95 | 95-96 | 96-97 | 96-97 |
| RH II (%) | 80-82 | 84-86 | 74-76 | 82-84 | 80-90 | 80-90 |
| Rainfall (mm) | 100-200 | 400-500 | 200-250 | 150-200 | 500-600 | 600-800 |
| BSS (hrs) | 1.5-2.0 | 1-1.5 | 3.5-4.5 | 2-3 | 0-1 | 2-3 |

| Weather parameters | B-H | | H-F | | F-M | |
|---|---|---|---|---|---|---|
| | Jyothi | Jaya | Jyothi | Jaya | Jyothi | Jaya |
| Tmax (°C) | 29.5-30 | 29.0-30.0 | 28.0-29.0 | 28.0-30.0 | 29.0-30.0 | 29.0-30.0 |
| Tmin ( °C) | 22.5-23.0 | 22.6-22.8 | 22.0-22.3 | 22.0-22.8 | 22.2-22.3 | 22.4-22.5 |
| RH I (%) | 96-97 | 95-96 | 96-98 | 95-96 | 93-94 | 95-96 |
| RH II (%) | 70-80 | 75-80 | 80-90 | 70-80 | 60-70 | 70-80 |
| Rainfall (mm) | 150-200 | 50-100 | 80-100 | 80-90 | 600-700 | 800-900 |
| BSS (hrs) | 1-2 | 0-1 | 0-1 | 0-2 | 5-6 | 2-3 |

T-AT - Transplanting to active tillering
AT-PI - Active tillering to panicle initiation
PI-B - Panicle initiation to booting

B-H - Booting to heading
H-F - Heading to 50% flowering
F-M - 50% flowering to physiological maturity

each variety. To attain the physiological maturity, number of days taken showed a decreasing trend towards the last plantings for both the varieties. The weather conditions prevailed during each planting was different compared to previous years. These all may affected the duration of phenophases for Jyothi and Jaya.

Higher duration was observed during June 20$^{th}$ planting for Jyothi and Jaya since it was affected by heavy rainfall situations (Fig. 5.2 (a&b)). The reason behind the decreased physiological maturity was due to the temperature increase with the delay in transplanting (fig. 5.1(a&b)). The reduced duration of phenological stages was also due to the rise in temperature during that particular stages.

From the correlation analysis it was clear that, maximum temperature, minimum temperature, forenoon vapour pressure deficit and evaporation during transplanting to active tillering and panicle initiation to booting, wind speed, bright sunshine hours and evaporation during active tillering to panicle initiation, maximum temperature during booting to heading, maximum temperature, bright sunshine hours and evaporation during heading to 50% flowering, and afternoon vapour pressure deficit during 50% flowering to physiological maturity reduced the duration of phenophases in Jyothi whereas, forenoon relative humidity, afternoon relative humidity, rainfall and rainy days during transplanting to active tillering and heading to 50% flowering, minimum temperature, forenoon relative humidity, afternoon relative humidity, forenoon vapour pressure deficit, afternoon vapour pressure deficit and rainfall during active tillering to panicle initiation, forenoon relative humidity, wind speed, rainfall and rainy days during panicle initiation to booting, and forenoon relative humidity, afternoon relative humidity, afternoon vapour pressure deficit, wind speed and rainy days during booting to heading lead to the increase in phenophase duration in Jyothi.

In Jaya, maximum temperature, minimum temperature, forenoon vapour pressure deficit, bright sunshine hours, rainy days and evaporation during transplanting to active tillering, afternoon relative humidity and afternoon vapour pressure deficit during active tillering to panicle initiation, maximum temperature, bright sunshine hours and evaporation during panicle initiation to booting and booting to heading, minimum temperature, forenoon vapour pressure deficit and afternoon vapour pressure deficit during heading to 50% flowering, and maximum temperature, minimum temperature, wind speed and evaporation during 50% flowering to physiological maturity caused the reduction in phenophase duration while, forenoon relative humidity, afternoon relative humidity and rainfall during transplanting to active tillering, maximum temperature, wind speed, bright sunshine hours, rainy days and evaporation during active tillering to panicle initiation, forenoon relative humidity, afternoon relative humidity, afternoon vapour pressure deficit, rainfall and rainy days during panicle initiation to booting, forenoon relative humidity, afternoon relative humidity, forenoon vapour pressure deficit, rainfall and rainy days during booting to heading, wind speed and rainfall during heading to 50% flowering, and forenoon relative humidity, afternoon relative humidity, forenoon vapour pressure deficit and rainy days during 50% flowering to physiological maturity lead to an increase in duration of phenophases.

## 5.4. GROWTH INDICES

### 5.4.1. Leaf area index (LAI)

In Jyothi as well as in Jaya, highest leaf area index was observed during 75 days after transplanting (Fig. 5.6 (a&b)). An increasing trend of leaf area index was observed from 15 days after transplanting to 75 days after transplanting while later it showed a decreasing trend in Jyothi and Jaya. This result shows similarity with the findings of Medhi *et al.* (2016). The leaf area index of Jyothi for June 5$^{th}$ and June 20$^{th}$ planting during 75 days after planting showed a lower value compared to other plantings as it was affected by heavy rain during this period while Jaya not affected by rainfall during

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this period since it is a medium duration variety. Among two varieties, Jyothi exhibited higher leaf area index compared to Jaya.

### 5.4.2. Leaf area duration (LAD)

In leaf area duration also the maximum value was recorded during 60-75 days after transplanting. Like leaf area index, it also showed an increasing trend towards 60-75 days after transplanting after that, it showed a decreased value at maturity (Fig. 5.7(a&b)). This may be because of the increased temperature that reduced the leaf area duration at the maturity stage. These results are in conformity with the results of Devendra *et al.* (1983), and Sadeghi and Bohrani (2001).

### 5.4.3. Crop growth rate (CGR)

In general, crop growth rate of both Jyothi and Jaya was found to be more during 45-60 days after planting. This result was in agreement with the findings of Taleshi *et al.* (2013). The crop growth rate of July 5$^{th}$ planting was lower due to heavy rainfall in Jyothi whereas this was affected in the early growth stages of July 20$^{th}$ and August 5$^{th}$ plantings of Jaya. The decrease in crop growth rate during the maturity period (Fig. 5.8 (a&b)) was due to the low amount of light absorption by the plant. The increase in growth rate at intermittent stages was because of the absorption of more light (Mani and Noori, 2015).

### 5.4.4. Net assimilation rate (NAR)

Higher value of net assimilation rate was observed at the early growth stages (Fig. 5.9 (a&b)) because of less shadow and increased light penetration compared to other stages. In both Jyothi and Jaya, net assimilation rate was more during 15-30 days after planting and it decreased towards the maturity stage with negative values at 75-90 days after planting. This negative assimilation rate forms because of the increased dry matter accumulation towards the maturity stage. Similar trend was observed in the study conducted by Esfahani *et al.* (2006).

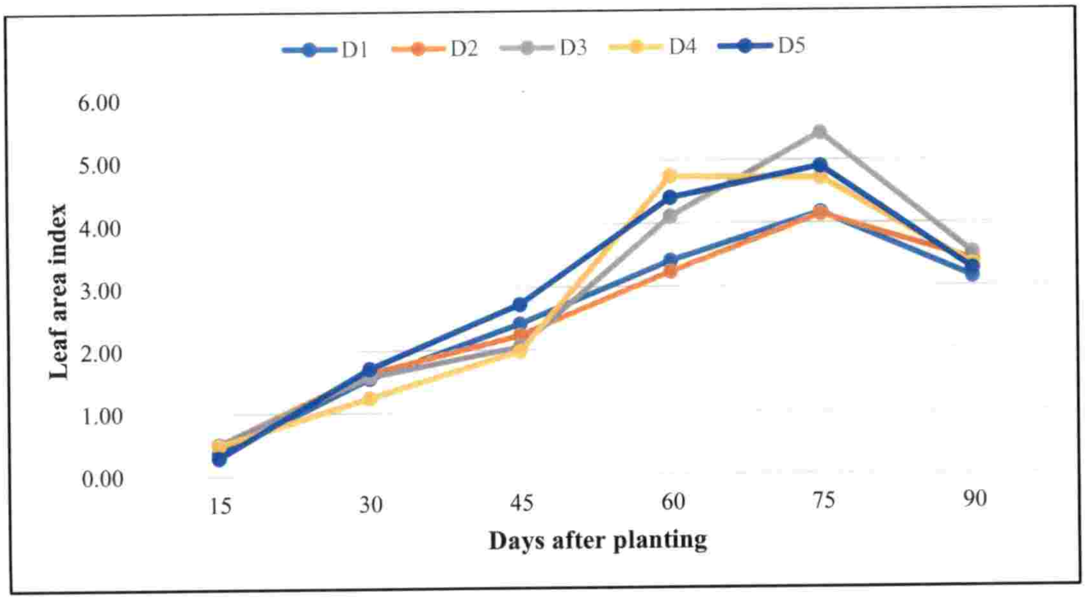


Fig. 5.6. (a) Trend of leaf area index of Jyothi in different planting dates

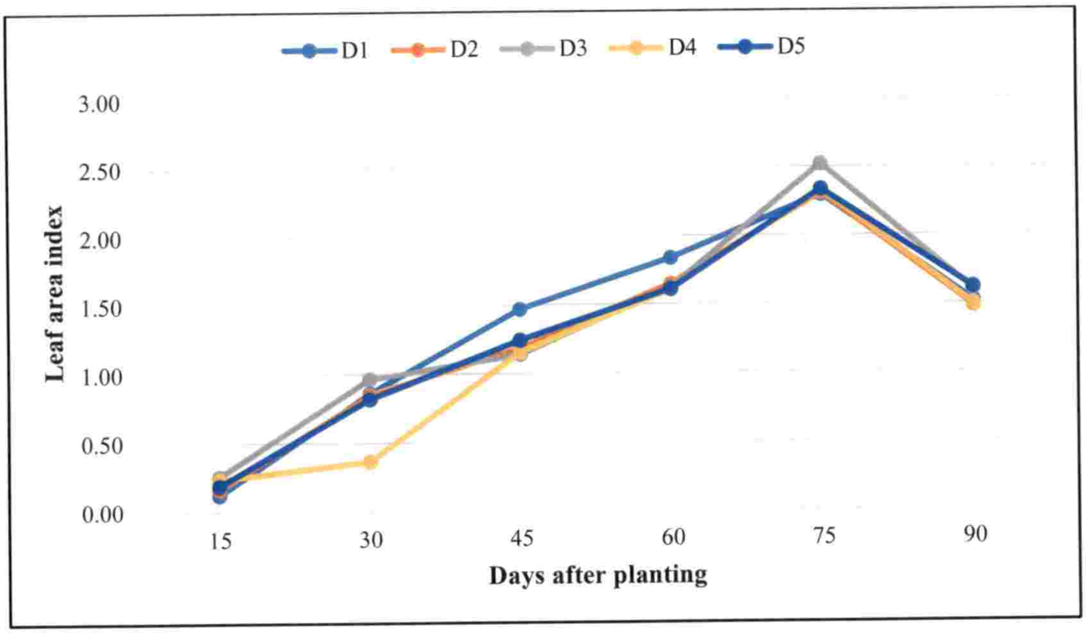


Fig. 5.6. (b) Trend of leaf area index of Jaya in different planting dates

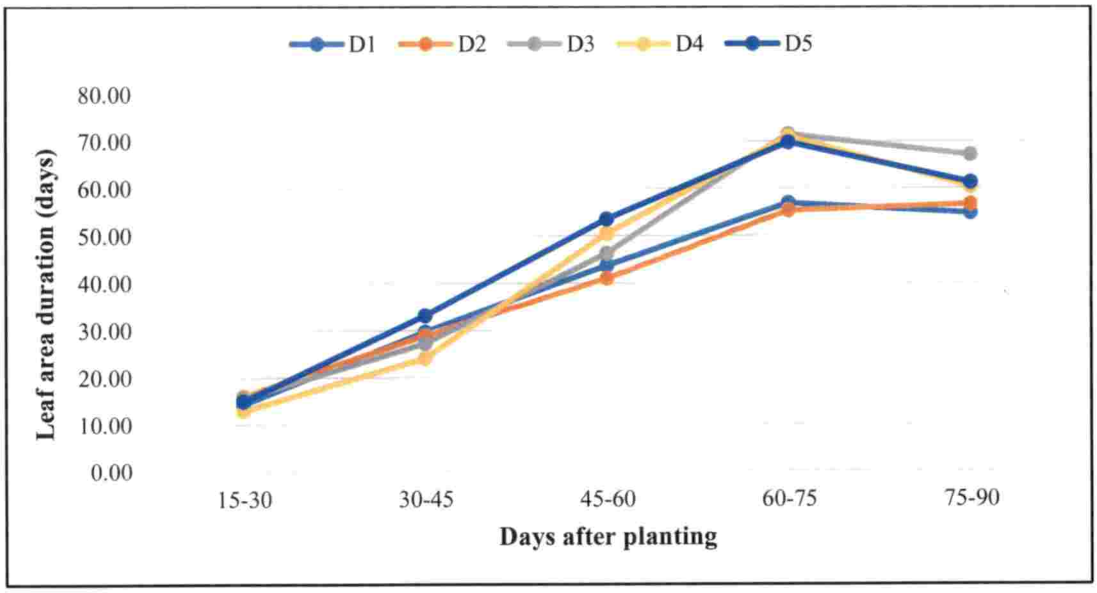


Fig. 5.7. (a) Trend of leaf area duration of Jyothi in different planting dates

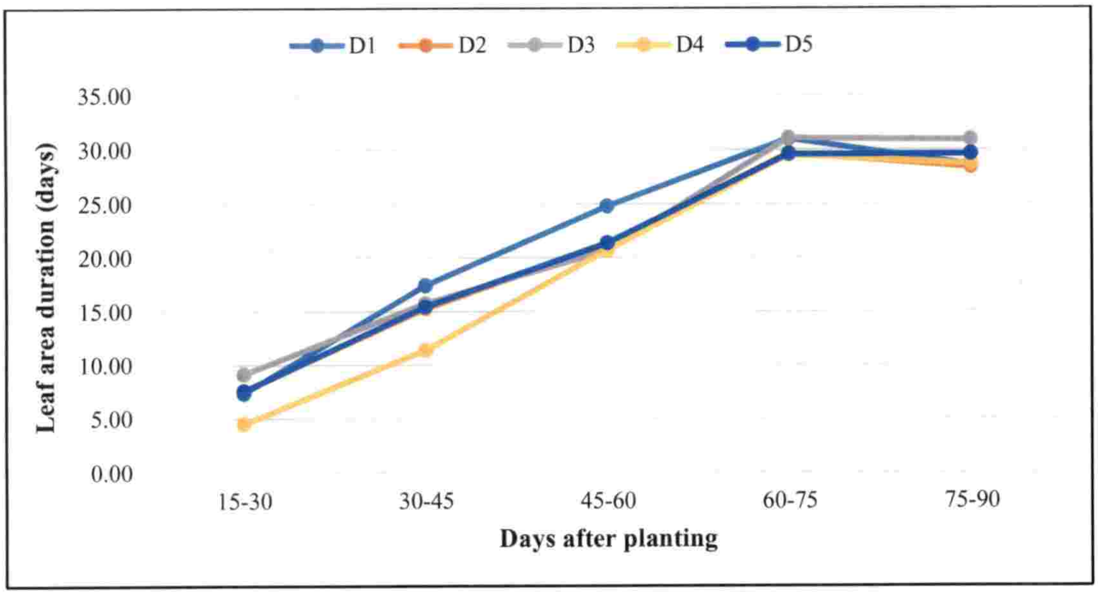


Fig. 5.7. (b) Trend of leaf area duration of Jaya in different planting dates

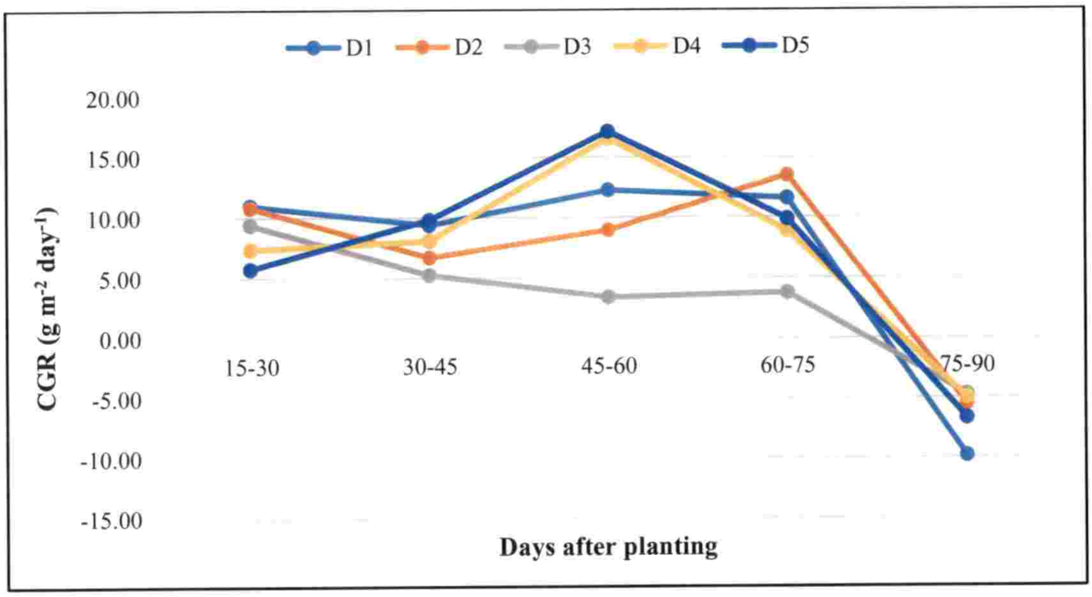


Fig. 5.8. (a) Trend of crop growth rate of Jyothi in different planting dates

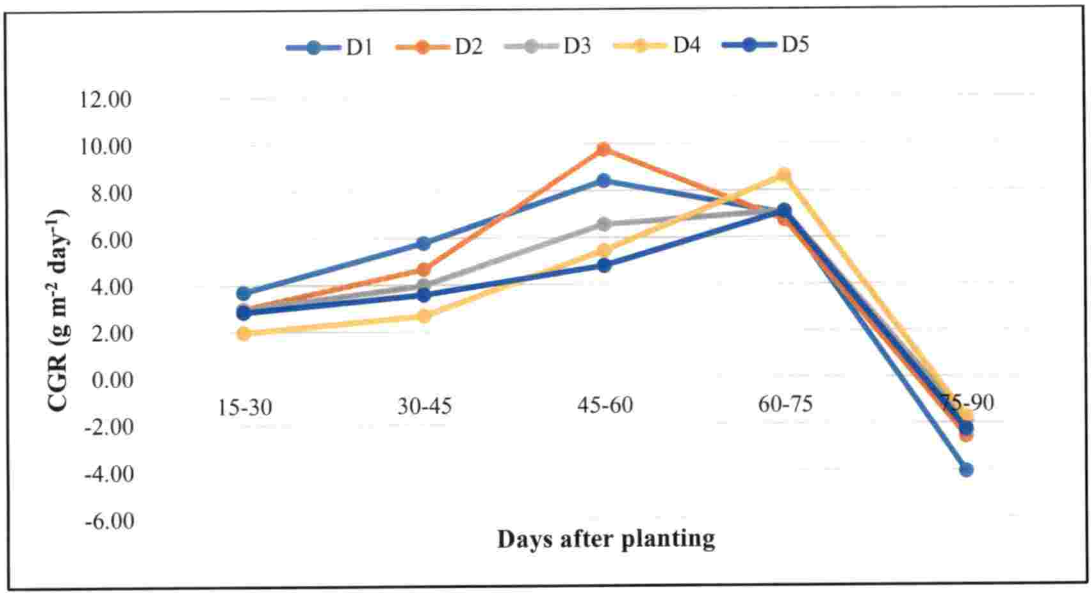


Fig. 5.8. (b) Trend of crop growth rate of Jaya in different planting dates

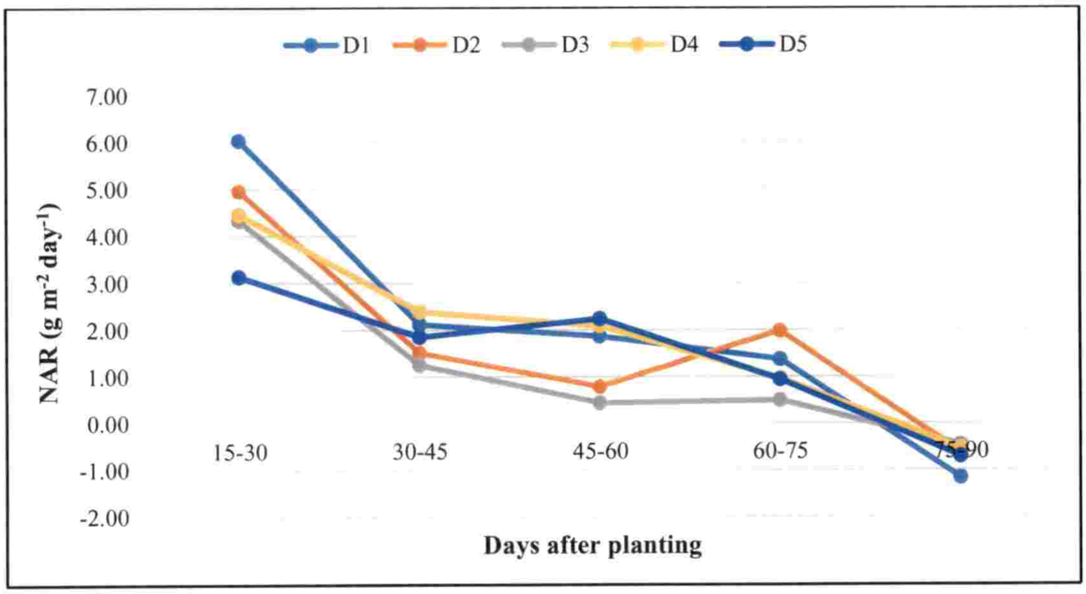


Fig. 5.9. (a) Trend net assimilation rate of Jyothi in different planting dates

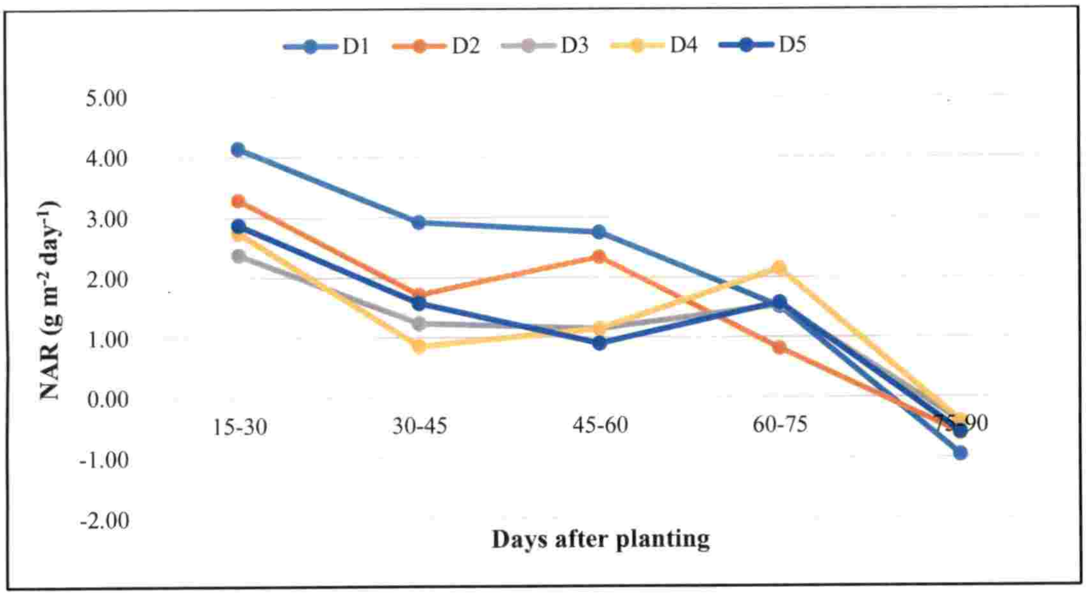


Fig. 5.9. (b) Trend net assimilation rate of Jaya in different planting dates

## 5.5. CROP WEATHER MODELS

Validation of different statistical models developed from Department of Agricultural Meteorology, were carried out for Jyothi using the weather data collected at the time of field experiment. The models used were mainly based on weekly weather variables, fortnightly weather variables, crop stage wise weather variables and composite weather variables. Models based on weekly weather variables used eight week weather variables for better prediction of yield whereas models based on fortnightly weather variables performed well using five fortnightly weather variables. Weather variables during booting to heading stage was selected for the models that are using crop stage wise data for Jyothi and seven weeks data were used in those which uses composite weather variables. Yield prediction model was fitted for Jyothi and Jaya by performing principal component analysis and best model with different components was selected for forecasting the yield in both.

### 5.5.1. Validation of statistical models for forecasting yield in Jyothi

Statistical models were validated using the experimental data collected during 2018. The observed yield and predicted yield obtained from the models were compared by plotting the graphs (Fig.5.10).

Statistical models based on weekly weather variables and that with fortnightly weather variables showed a large difference between observed yield and the predicted yield. Therefore, these are not good in forecasting the yield in Jyothi. The model which uses crop stage wise weather variables performed well in yield prediction compared to the former models. This model needs forenoon vapour pressure deficit ($X_5$) and rainfall ($X_7$) of booting to heading stage of that particular planting and will give forecasted yield before flowering (Ravindran, 2018). The model which used composite weather variables performed better in predicting the yield than all other models. This model uses weighted and un-weighted indices of afternoon relative humidity having good agreement with the observed yield. Among the four statistical models, the yield prediction model using composite weather variables can be used as a good model for Jyothi.

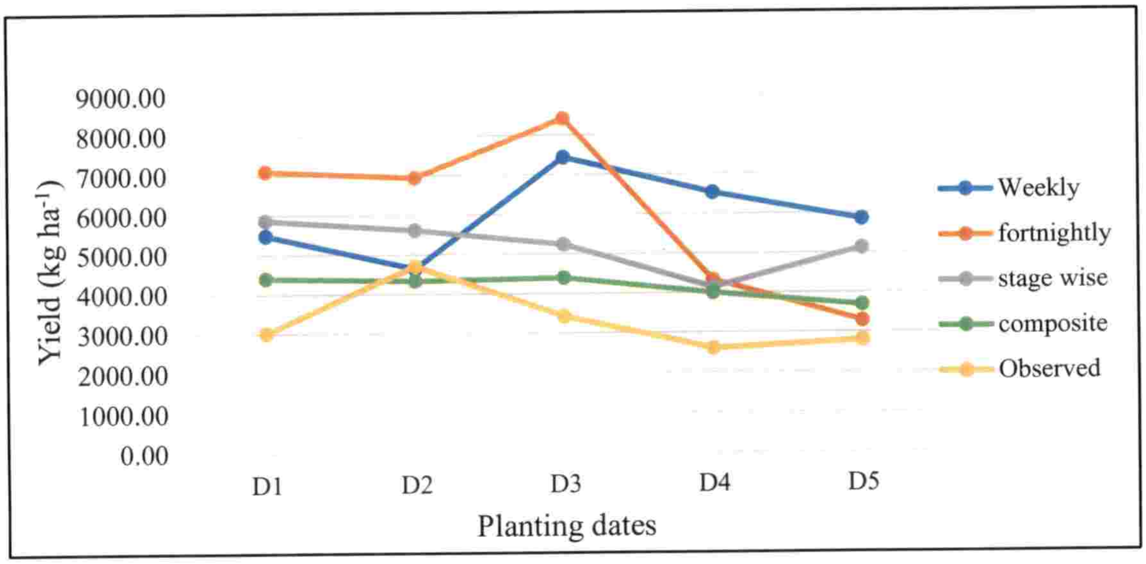


Fig.5.10. Comparison of observed yield and predicted yield using statistical models in Jyothi

### 5.5.2. Crop weather models using Principal Component Analysis in Jyothi and Jaya

Principal component analysis were carried out for Jyothi and Jaya using the experiment data during 2018. Three components for Jyothi and two components for Jaya were obtained to fit the regression equation. Comparison was made between the observed yield and the yield obtained from the regression models. The estimated yields of the developed models were in good agreement with the observed yield for Jyothi and Jaya, and are given in the Fig.5.11 and Fig.5.12 respectively.

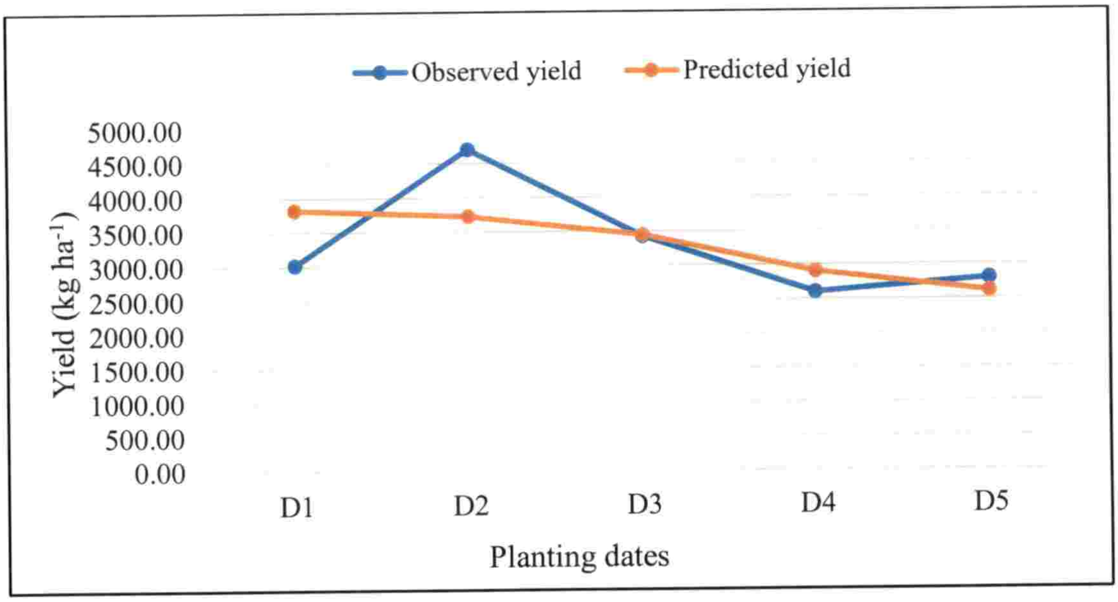


Fig.5.11. Comparison of observed yield and estimated yield using PCA analysis in Jyothi

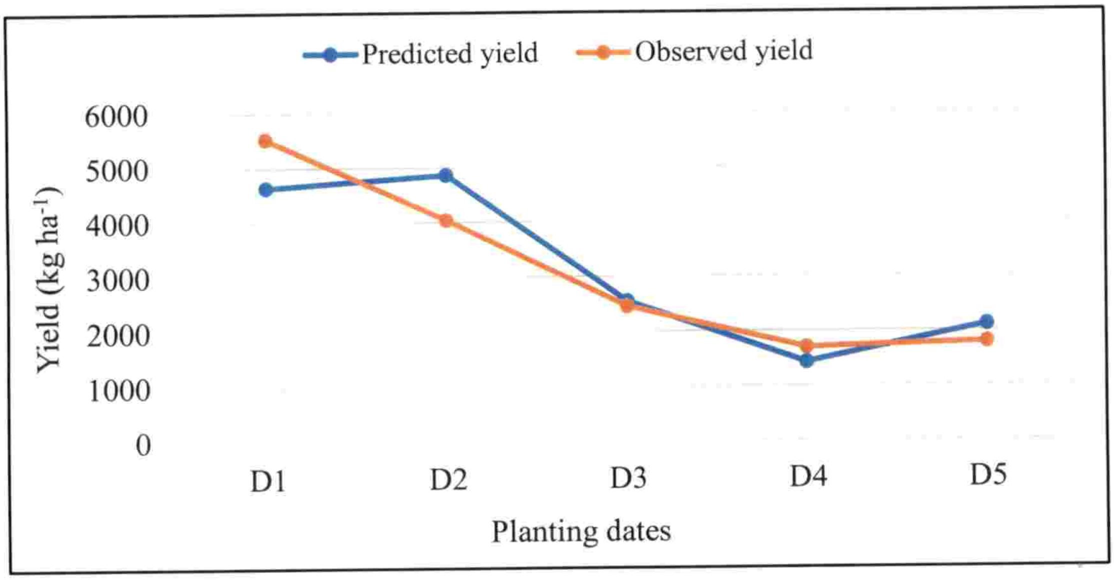


Fig.5.12 Comparison of observed and estimated yield using PCA analysis in Jaya

### 5.5.3. CERES-Rice simulation model

CERES-Rice model was validated for Jyothi and Jaya for the experimental year 2018 after preparing weather file, soil file, crop management file and experiment file. The already calibrated genetic coefficients lead to low accuracy for the estimation and the fine tuning of the model was required (Akinbile, 2013).

The simulated yield and observed yield were analyzed. The number of days taken for anthesis, panicle initiation and physiological maturity were also simulated and were in good agreement with the observed duration (Fig.5.13 (a&b)) with good values of RMSE and d-stat for Jyothi as well as for Jaya.

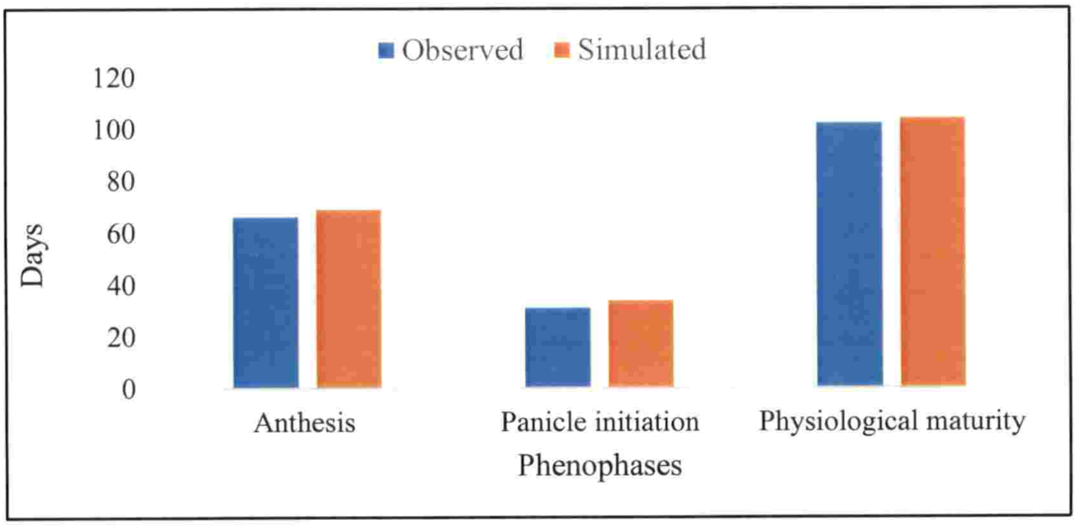


Fig. 5.13 (a) Comparison of observed and simulated duration of phenophases in Jyothi

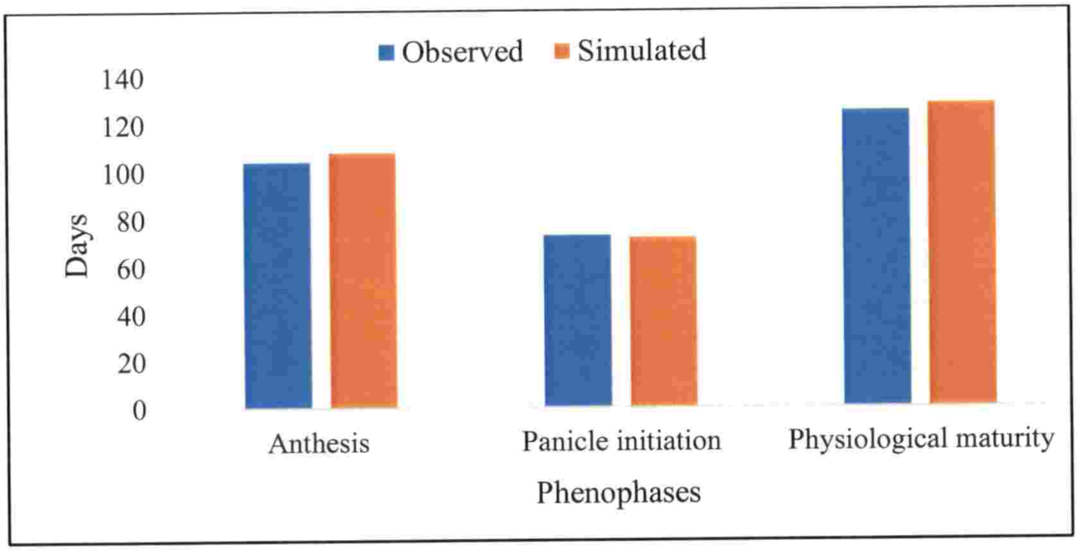


Fig. 5.13 (b) Comparison of observed and simulated duration of phenophases in Jaya

# Summary

# 6. SUMMARY

The research on "Crop weather relationship of rice varieties under different growing environments" was conducted at Department of Agricultural Meteorology, College of Horticulture, Vellanikkara during 2018. The crop weather relationships were studied and the validation of different statistical models and CERES-Rice model were carried out with the collected data through the experiment.

Different observations like weather, biometric, phenological and physiological observations were noted during different plantings. The growth indices like leaf area index, leaf area duration, crop growth rate and net assimilation rate were calculated using biometric observations like leaf area and dry matter taken at fortnightly intervals. Regression equations were fitted for Jyothi and Jaya using Principal Component Analysis. The summarized results of this experiment are given below:

- Significant difference was observed for plant height between the varieties for all weeks except for first week. Jyothi exhibited higher plant height compared to Jaya.
- Dry matter accumulation was higher during 75 days after planting and it showed a decreasing trend as the planting date was delayed. Early plantings showed higher dry matter accumulation than late plantings.
- Increase in temperature, decrease in relative humidity and decrease in rainfall affected yield and duration of crops with delayed planting.
- Higher yield in Jaya was observed for June $5^{th}$ planting whereas in Jyothi, the yield was higher for June $20^{th}$ planting since continuous morning rainfall affected the yield of Jyothi in June $5^{th}$ planting.
- Higher temperature increased the number of tillers per $m^2$. Relative humidity showed a negative influence on the panicle number in unit area.
- Number of spikelets per panicle, filled grains per panicle and thousand grain weight were higher during the early plantings while it showed a decreasing trend towards the later plantings.

- High relative humidity and low temperature favoured the straw yield in early plantings.
- To attain physiological maturity, more number of days was taken for June 20th planting and was lesser for August 5th planting in both the varieties.
- Leaf area index were increasing towards the maturity and was higher for 75 days after planting. Same trend was observed in the case of leaf area duration.
- Heavy rainfall and lower absorption of light reduced the crop growth rate and net assimilation rate. Net assimilation rate was higher during 15-30 days after planting and was decreasing towards the maturity period.
- The validation of different statistical models were carried out using the experiment data of 2018 year and comparison was made between the observed yield and the yield obtained from the models.
- Out of different statistical models, the model which uses composite weather variables was selected as the best one in predicting the yield of Jyothi.
- Regression equations were fitted for Jyothi and Jaya by adopting Principal Component Analysis.
- The yield prediction model of Jyothi obtained using Principal Component Analysis with three components as follows:

$$\textbf{Yield} = 3307.20 + 170.15X_1 + 121.74X_2 + 20.05X_3$$

- The form of yield prediction model of Jaya is given below with two components.

$$\textbf{Yield} = 3099.45 + 470.41X_1 + 34.34X_2$$

- DSSAT CERES-Rice model was run for Jyothi and Jaya with calibrated genetic coefficients after preparing weather file, soil file, crop management file and experiment files (A file and T file).

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# Appendices

(i)

# 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 : Rainydays

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**

J – Jyothi

Ja - Jaya

**Units**

g : gram

kg : kilogram

km $hr^{-1}$: kilometre per hour

$^{0}C$ : degree Celsius

kg $ha^{-1}$ : kilogram per hectare

% : per cent

**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 2017 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 |
| Date of planting | 4 | 33.237** | 37.805* | 79.788* | 121.932** | 89.049 $^{NS}$ | 415.361** | 346.607** | 216.943** |
| Error(a) | 12 | 5.766 | 10.221 | 16.6 | 21.796 | 35.629 | 40.107 | 26.515 | 32.914 |
| Variety | 1 | 6.577 $^{NS}$ | 61.951** | 293.331** | 420.034** | 1404.699** | 2070.721** | 3112.049** | 3474.123** |
| DOP x Variety | 4 | 9.855* | 12.795* | 22.381* | 21.424 $^{NS}$ | 100.321** | 45.211 $^{NS}$ | 33.211 $^{NS}$ | 47.582* |
| Error(b) | 15 | 2.66 | 2.878 | 5.863 | 17.902 | 12.866 | 17.814 | 13.982 | 11.95 |

| Source of variation | DF | Mean sum of squares | | | | |
|---|---|---|---|---|---|---|
| | | Week 9 | Week 10 | Week 11 | Week 12 | Week 13 |
| Date of planting | 4 | 210.021* | 252.388** | 206.069** | 218.084** | 140.98** |
| Error(a) | 12 | 42.185 | 38.126 | 27.236 | 19.572 | 12.892 |
| Variety | 1 | 3246.844** | 3853.369** | 3651.539** | 2792.909** | 1564.751** |
| DOP x Variety | 4 | 46.893* | 36.993* | 38.17* | 47.429* | 50.223** |
| Error(b) | 15 | 12.155 | 9.196 | 11.069 | 11.317 | 6.984 |

DF – degrees of freedom -** 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 |
| Date of planting | 4 | 143705.67* | 837673.66 NS | 1917235.81 NS | 16217001.70** | 22231509.30* | 13477388.20* |
| Error(a) | 12 | 22908.17 | 336002.48 | 1141188.12 | 1485387.82 | 4251565.35 | 3677809.51 |
| Variety | 1 | 299490.71* | 7625917.60** | 14583702.17** | 866330.92 NS | 7625131.68 NS | 12814353.20* |
| DOP x Variety | 4 | 63782.17 NS | 420625.35 NS | 698119.84 NS | 10036928.68** | 2028920.76 NS | 2296339.68 NS |
| Error(b) | 15 | 37452.66 | 441012.43 | 887437.22 | 959351.08 | 3467472.62 | 2284930.25 |

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 |
| Date of planting | 4 | 9028300** | 10786.036* | 24826.344** | 5468.087** | 56.316** | 4438716.25** |
| Error(a) | 12 | 162011.1 | 3135.333 | 3512.642 | 995.015 | 2.616 | 722829.583 |
| Variety | 1 | 431600.6 NS | 204919.225** | 12888.1* | 1331.716 NS | 36.29** | 3277562.5* |
| DOP x Variety | 4 | 4637785** | 9147.685 NS | 19556.038** | 1400.658 NS | 19.301** | 3307931.25** |
| Error(b) | 15 | 161105.7 | 5835.249 | 2465.823 | 1396.217 | 2.445 | 526604.167 |

DF – degrees of freedom    -** 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 |
| Date of planting | 4 | 0.037** | 0.317** | 0.301** | 0.692* | 0.768** | 0.056 NS |
| Error(a) | 12 | 0.003 | 0.054 | 0.042 | 0.179 | 0.098 | 0.052 |
| Variety | 1 | 0.571** | 5.914** | 10.878** | 53.731** | 53.315** | 32.166** |
| DOP x Variety | 4 | 0.015 NS | 0.028 NS | 0.134* | 1.013** | 0.419 NS | 0.045 NS |
| Error(b) | 15 | 0.006 | 0.034 | 0.043 | 0.146 | 0.137 | 0.057 |

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 |
| Date of planting | 4 | 15.855* | 51.923** | 44.672 NS | 129.185** | 65.495** |
| Error(a) | 12 | 3.232 | 6.042 | 16.562 | 22.799 | 7.542 |
| Variety | 1 | 571.687** | 1843.892** | 6350.4** | 12033.267** | 9459.315** |
| DOP x Variety | 4 | 1.526 NS | 12.306 NS | 68.799** | 134.456** | 29.07 NS |
| Error(b) | 15 | 2.479 | 6.105 | 10.206 | 17.485 | 14.81 |

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

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**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 |
| Date of planting | 4 | $14.476^{NS}$ | $16.18^{NS}$ | 69.271** | $22.916^{NS}$ | $17.78^{NS}$ |
| Error(a) | 12 | 4.94 | 11.92 | 10.654 | 62.794 | 5.527 |
| Variety | 1 | 358.142** | 184.341** | 340.181** | $58.057^{NS}$ | 146.039** |
| DOP x Variety | 4 | $7.632^{NS}$ | $8.658^{NS}$ | 108.44* | $57.761^{NS}$ | $3.207^{NS}$ |
| Error(b) | 15 | 5.898 | 12.724 | 21.98 | 67.07 | 9.152 |

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 |
| Date of planting | 4 | $5.278^{NS}$ | $1.766^{NS}$ | 2.64** | $0.507^{NS}$ | 0.502** |
| Error(a) | 12 | 2.217 | 1.483 | 0.479 | 0.635 | 0.05 |
| Variety | 1 | 22.261* | $0.259^{NS}$ | $1.329^{NS}$ | $1.823^{NS}$ | $0.125^{NS}$ |
| DOP x Variety | 4 | $0.986^{NS}$ | $1.505^{NS}$ | 4.785** | $2.083^{NS}$ | $0.012^{NS}$ |
| Error(b) | 15 | 3.383 | 0.723 | 0.623 | 0.748 | 0.179 |

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

# CROP WEATHER RELATIONSHIP OF RICE VARIETIES UNDER DIFFERENT GROWING ENVIRONMENTS

By

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**2017-11-094**

## ABSTRACT OF THE THESIS

**Submitted in partial fulfillment of the requirement for the degree of**

## *MASTER OF SCIENCE IN AGRICULTURE*

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**2019**

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**ABSTRACT**

In India, rice production is an important part of the national economy. India is the second largest producer in the world with approximately 43 million hectares planted area, accounting for 22% of the total rice production in this world. World's leading rice exporter is India, marketing about 12.5 million metric tonnes in 2018-19. Rice is grown in rainfed areas with heavy annual rainfall. Therefore it is fundamentally considered as a *kharif* crop. But its production mainly depends up on weather prevailing in that area. Weather has a profound influence on growth, development and yields of crop; on the incidence of pests and diseases; on water needs; and on fertilizer requirements.

The present experiment was aimed to study the crop weather relationship of rice varieties under different growing environments and to validate different crop weather models for rice varieties including statistical models and crop simulation model (DSSAT CERES-Rice model). Two varieties of rice, Jyothi and Jaya were raised at Agricultural Research Station, Mannuthy by adopting split plot design. Five planting dates such as June $5^{th}$, June $20^{th}$, July $5^{th}$, July $20^{th}$ and August $5^{th}$ were used as main plot treatments and the two varieties were used as sub plot 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 spikelets per panicle, number of filled grains per panicle, thousand grain weight, straw yield and grain yield were observed. Duration of different phenophases and physiological observations such as leaf area index, net assimilation rate, leaf area duration and crop growth rate were also calculated. Pests and diseases were noticed during different growing conditions.

Considerable variation among weather variables were 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 exhibited a decreasing trend with delayed planting in both the varieties. Number of spikelets per panicle, number of filled grains per panicle, thousand grain weight and straw yield were found to

be decreasing as the planting date was delayed. Highest grain yield (4698 kg ha$^{-1}$) was observed in Jyothi during June 20$^{th}$ planting whereas, June 5$^{th}$ planting showed maximum grain yield (5527 kg ha$^{-1}$) in Jaya. Because, continuous morning rainfall during flowering stage of Jyothi reduced its yield in June 5$^{th}$ planting (3021.25 kg ha$^{-1}$). Maximum duration was observed during June 20$^{th}$ planting in Jyothi (129 days) and Jaya (139 days). Total duration was less for August 5$^{th}$ plantings in both the varieties (121 and 129 days for Jyothi and Jaya respectively).

Leaf area index and leaf area duration were more during 75 days after planting for both the varieties and leaf area duration showed a maximum value during 60-75 days after planting for both the varieties. In general, crop growth rate of both Jyothi and Jaya was found to be more during 45-60 days after planting while net assimilation rate was more in the early growth stages.

Validation of statistical models for Jyothi such as models based on weekly weather variables, fortnightly weather variables, crop stage-wise weather variables and that based on composite weather variables, were carried out in which model which uses composite weather variables was selected as the best one in yield prediction of Jyothi after comparing the estimated yield and observed yield. Crop weather model using statistical methods was also developed for Jyothi and Jaya with the aid of principal component analysis. Two principal components were identified for Jaya and three for Jyothi. The regression analysis was carried out using SPSS software. This formed a better tool in predicting the yield of Jyothi and Jaya. DSSAT CERES-Rice model was also run for Jyothi as well as for Jaya after creating weather file, soil file, crop management file and experimental file for the year 2018.