# SIMULATION OF ENVIRONMENTAL AND VARIETAL EFFECTS IN RICE USING CERES MODEL


By

NAZIYA

(2012-11-170)


**THESIS**

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**Department of Agricultural Meteorology**

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## DECLARATION

I, **Naziya** (2012-11-170) hereby declare that this thesis entitled **"Simulation of environmental and varietal effects in rice using CERES model"** 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, associateship, fellowship or other similar title, of any other University or Society.

Vellanikkara
27-10-14

Naziya
(2012-11-170)

# CERTIFICATE

Certified that this thesis entitled **"Simulation of environmental and varietal effects in rice using CERES model"** is a bonafide record of research work done independently by **Ms. Naziya (2012-11-170)** 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.

Vellanikkara

27-10-14

**Dr. B. Ajithkumar**
(Chairman, Advisory Committee)
Assistant Professor & Head
Department of Agricultural Meteorology
College of Horticulture
Vellanikkara

## CERTIFICATE

We, the undersigned members of the advisory committee of **Ms. Naziya (2012-11-170)** a candidate for the degree of **Master of Science in Agriculture** with major field in Agricultura Meteorology, agree that this thesis entitled **"Simulation of environmental and varietal effect in rice using CERES model"** may be submitted by **Ms. Naziya** in partial fulfillment of th requirement for the degree.

**Dr. B. Ajithkumar**
(Chairman, Advisory Committee)
Assistant Professor and Head
Department of Agricultural Meteorology
College of Horticulture
Vellanikkara

**Dr. U. Jaikumaran**
(Member, Advisory Committee)
Professor and Head
Agricultural Research Station
Mannuthy

**Smt P. Lincy Davis**
(Member, Advisory Committee)
Assistant Professor
Department of Agricultural Meteorology
College of Horticulture
Vellanikkara

**Dr. C. Laly John**
(Member, Advisory Committee)
Associate Professor
Department of Agricultural Statistics
College of Horticulture
Vellanikkara

**EXTERNAL EXAMINER**
Dr. R. Jagannathan
Professor
Department of Agronomy, TNAU
Coimbatore

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Naziya

## LIST OF CONTENTS

## LIST OF TABLES

## LIST OF TABLES (contd.)

## LIST OF TABLES (contd.)

## LIST OF FIGURES

## LIST OF FIGURES (contd.)

## LIST OF PLATES

## LIST OF APPENDICES

# INTRODUCTION

# 1. INTRODUCTION

Agriculture is always vulnerable to unfavorable weather events and climatic conditions. Despite technological advances such as improved crop varieties and irrigation systems, weather and climate are important factors, which play significant roles in agricultural productivity. Weather variability both within and between seasons is uncontrollable and cause variations in crop yield. The impact of weather and climate on food production is of vital importance. Weather variables affect the crop differently during different stages of development. The extent of influence of weather on crop yield depends not only on the magnitude of weather variables but also on the distribution pattern of weather over the crop season. Thus, there is need to develop statistically sound and objective forecasts of crop yield based on weather variables so that reliable forecasts can be obtained (Laxmi and Kumar 2011). By developing crop weather relationships of rice using relevant meteorological skills, crop manipulation could be made effective for improving its production both in quality and quantity.

Rice is the most important staple food and a mainstay for the rural population all over the world. It occupies prime place among the food crops cultivated around the world. In India rice is cultivated in about 42.86 m ha. Average productivity of rice is 2.13 t $ha^{-1}$ in India which is far below the world's average of 3.7 t $ha^{-1}$ (Jagtap *et al.*, 2012). India has to produce about 130 million tonne of rice by 2025 to feed the ever growing population (Hugar *et al.*, 2009). During the last 45 years there was a steady reduction in area under paddy in Kerala. During 1961, there was around 7.53 lakh hectares of paddy land. But by 2010-11 this was reduced to 2.13 lakh hectare. The rice production also declined to 5.2 lakh metric tonnes from 5.98 lakh metric tonnes in 2009 to 2010 (Kumar and Smitha, 2013).

Area and production of rice can be increased by manipulating the planting date according to weather conditions and incorporating high yielding varieties. Manipulation in planting dates refers to the adjustment with the weather conditions according to the crop need. Optimum date of transplanting for rice crop helps in exhibiting the full yield potential of the particular variety.

Planting time and selection of variety play the deciding role in performance of rice. Hence, choice of correct variety and selection of right time for transplanting under particular agro-climatic condition will lead to success of rice production under changing climatic scenario. Knowledge about the relationships between crop growth stages and weather parameters is very important to maximize the production and productivity of rice by adjusting the crop management practices. For a plant to be successful in a given region, the sequence of its growth phases must fit in the climate to ensure good and adequate production. Agro-climatological knowledge of individual varieties and locations is thus very essential.

The need for information to aid decision-making about suitable management practices for implement in rice production improvement is rapidly increasing. The generation of new data through agronomic research methods is insufficient to meet these needs. Conducting experiments at particular points in time and space is time consuming and expensive due to the requirement of many years of data collection. In recent years, several dynamic crop growth simulation models have been developed as tools to support decision-making for agronomic research, land-use planning and crop production. These models are part of or come under the Decision Support System for Agrotechnology Transfer (DSSAT) (Hoogenboom *et al.*, 2010). Crop simulation models can also be used as a tool for agricultural risk analysis and allow researchers to explore potential cropping location and appropriate farm management strategies. These models, properly validated against experimental data have the potential for tactical and strategic decision making in agriculture.

The CERES-Rice model is one such crop simulation model. The model has wide application in the field of agriculture and therefore, genetic coefficients are an essential component of the model. Crop performance in terms of genetic coefficients used in the model can be used as a tool in choosing varieties. In this background, the present investigation was planned to identify the critical weather elements influencing the growth and development of Jyothi and Kanchana varieties of rice, with the following objectives.

i. Simulation of phenology, growth and yield of Jyothi and Kanchana varieties of rice.
ii. Calibrate their genetic coefficient
iii. To determine the crop weather relationships

# REVIEW OF LITERATURE

## 2. REVIEW OF LITERATURE

In order to sustain the higher production and minimize the degradation of crop production by varied environmental conditions, an understanding of crop growth in relation to varying resource input and agro environments is required for management options. Improved production technology at the farm level is the most crucial starting point for future improvement of productivity of rice by employing and adapting suitable crop growth simulation models.

Crop growth simulation modeling is a new technique that enables to understand the effects of weather and climatic, soil and agronomic management factors on crop growth, development and productivity in varying agroclimatic situations in more quantitative terms. These models take into consideration like the process (physiological, physical and chemical), mechanisms and processes that result in growth and development of the crop. Based on the resource inventory of a location or region, crop growth models are being used for evaluating the production potential varieties and management practices etc. Crop growth models also helpful in identifying the precise reasons for yield gap at farmer's field and forecasting crop yields. These models also help in studying short and long-term consequences of agricultural practices on crop production.

Rice production is influenced by a set of meteorological variables such as rainfall, temperature etc (Ji *et al.*, 2007). The climate extremities, particularly high temperatures affect the plant growth and reduce the rice yield significantly. Rice is staple food for South East Asian countries including India; this region itself is consuming almost 90% of rice production. India is the second largest rice producer in world following by China. Rice *(Oryza sativa* L) is known as miracle crop and responding well due its unique adoptability to diverse agroecological / climatic situation. It is its unique capacity to adopt in any situation. Present day rice is grown from tropics to temperate condition, below sea level in Kerala to above 5000 M in

Nepal and handsomely adopted to problematic soils viz. acidic to saline alkaline. Being one of the most important cereals, everyday rice is sown and harvested in the global village. Available literatures on the influence of weather on growth and development of rice and crop growth simulation models are reviewed in this chapter.

## 2.1. EFFECT OF PLANTING DATES ON GROWTH AND YIELD OF RICE

It is generally observed that rice varieties widely differ in their tillering behaviour depending on the time of transplanting season, agrometeorological conditions of locality and varietal characteristics. But time of transplanting is a critical component for realizing high yield and better quality. Appropriate transplanting or sowing time of the crop is the best way to adjust to the suitable weather conditions for attainment of different phenological phases of the crop.

Chaudhary and Sodhi (1979) studied the effect of weather factors on growth of rice cv. Taichung (native) 1 sown at 14 intervals from 15 May to 30 April and transplanted after 14 to 21 days at Kharagpur. They reported that the growth duration varied with air temperature and increased in proportion to the length of time, which experienced low temperature during vegetative growth and flowering. Temperature accounted for 86% of the variation in the growth.

Roy and Biswas (1980) found out the effect of date of sowing on the yield of boro rice. When rice was sown in the Gangetic plains on 12 November, 26 November, or 10 December, seedling height, plant dry matter (DM) content, number of fertile tillers $plant^{-1}$ and crop duration decreased with delayed sowing and decreasing minimum day and night temperature. Grain yield was reduced by 22% and 30% after delaying sowing from 12 to 26 November and 10 December respectively. Low temperature reduced seedling leaf emergence by up to 30 days.

Reddy and Reddy (1986) reported that transplanting of four Nellore rice cultivars between 5 and 20 September gave higher paddy yields than transplanting in 20

August or 20 October. The duration of the crop decreased with delay in planting, but the production/day was increased. Harvest index increased in the crops transplanted between 5 September and 5 October, while it decreased in crops planted on 20 August and 20 October.

Maity and Mahapatra (1988) reported that crop transplanted on 25 December 1985 and 5 January 1986 produced maximum yield of 3.7 and 2.6 t $ha^{-1}$ compared to 10 December 1985 and 10 January 1986 because of appropriate environmental condition.

Kulkarni *et al.* (1989) reported significant differences for days to 50% flowering, productive tillers/$m^2$, sterility and grain yield between two rice cultivars (Tella Hamsa and Pothana) sown at fortnightly intervals from 15 November to 15 January at Warangal. The number of days to 50 % flowering decreased as sowing was delayed. Spikelet sterility was greater in Pothana than in Tella Hamsa and was higher at early sowings when minimum temperature before flowering was <19.6°C and gradually decreased in later sowing when temperature before flowering were 21 to 22°C.

Reddy and Reddy (1992) from Warangal, Andhra Pradesh reported that the rice cultivar Surekha, planted on 29 August produces more productive tillers per unit area than 30 July and 14 August planting. Early dates received lesser solar radiation due to cloudy weather registering greater mortality of tillers. Om *et al.* (1993) showed from a field experiment conducted at Kaul, Haryana with rice cv. Basmati 370 transplanted on 25 June, 5, 15 or 25 July or 4 August that grain yields of 4.29, 4.09, 3.85, 3.67 and 3.45 t $ha^{-1}$, respectively. The decrease in yield through delaying transplanting was due to reduction in panicles/ hill and grains/panicle.

Lee and Lee (1997) showed the effect of dates of planting on yield potential of rice transplanted on 4 or 25 August or 16 September 1995 and on 7 or 21 August or 5 September 1996. Yield decreased as transplanting was delayed, associated with delayed heading, decreased plant height, yield components and shortened growth duration. Low temperatures and reduced solar radiation decreased both vegetative and reproductive growth and inhibited panicle heading with delayed transplanting, particularly in September.

Begum *et al.* (2000) observed that date of transplanting greatly altered the time of anthesis, maturity and finally, the total duration of both varieties (moulata and matichak) in Bangladesh with 10 dates of sowing, starting with 1 July, 1994 and ending with 28 March, 1995 at 30 days interval with two rice varieties. It was observed by them that in both the varieties, transplanted on 29 September and 29 October field durations prolonged and the longest field duration was of 187 days in both the varieties transplanted on 29 October.

Sherief *et al.* (2000) studied the effect of sowing dates (April 20$^{th}$, May 10$^{th}$, May 25$^{th}$, and June 10$^{th}$) on yield and yield components of rice. They found that early sowing dates (May 10$^{th}$) had marked effect on number of panicles per $m^2$, number of filled grains per panicle, 1000 grain weight, grain and straw yield. As compared with the planting in April 25$^{th}$, however planting in May 25$^{th}$ or June 10$^{th}$ significantly reduced the above mentioned characteristics.

Biswas and Salokhe (2001) from Bangkok reported that, 1000 kernel weight was significantly affected by sowing date. Rice sown on 20$^{th}$ June produced heavier grains while crop sown on 20$^{th}$ July produced minimum grain weight. This indicated that the environmental conditions like temperature, humidity was most favourable for grain development during 20$^{th}$ June as compared to other sowing dates.

Vange and Obi (2006) investigated the effect of planting dates on growth and some agronomic characters by early seeding ( June 15 and June 30) and late seeding ( July 15 and July 30) and indicated that planting date affected the performance of these traits significantly. Grain yield (t/ha) and plot yield (g) were highest on the July 30 at Makurdi, a location in the southern Guinea Savanna zone.

Khakwani *et al.* (2006) reported that most of the yield and yield contributing factors were significantly affected by date of transplanting. Highest paddy yields were obtained in early transplanted rice (May 1) while seedlings transplanted late (July 15) were heavily infested by stem borer thereby reducing yield to larger extent at Agricultural Research Station, Dera during 2003.

Akram *et al.* (2007) find the effect of different planting dates from July 1 to 30 with 10 days interval on six rice varieties ( 98001, PK-5261-1-2-1, 97502, 98409, Basmati- 385 and super Basmati) at AARI, Faisalabad during 2002-2003. Different yield and yield and yield parameters like number of tillers, grains per spike, plant height, 1000 grain weight and sterility were significantly affected. Basmati -385 and super Basmati produced maximum paddy yield when planted on July 11 and July 1 respectively.

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

According to Bashir *et al.* (2010), direct seeded rice sown among 31$^{st}$ May, 10$^{th}$ June, 20$^{th}$ June, 30$^{th}$ June, 10$^{th}$ July and 20$^{th}$ July, the sowing date of 20$^{th}$ June proved to be the best for obtaining maximum grain yield and net return. 20$^{th}$ June sowing also gave maximum number of productive tillers, number of kernels per panicle, 1000 grain weight and benefit cost ratio in Faisalabad during the year 2008. According to Moradpour *et al.*, (2013) more grain yield was produced in May 30$^{th}$ and June 9$^{th}$ planting compared to June 19$^{th}$ planting because of appropriate growth condition and reaching to maximum use of environmental conditions.

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

According to Khalifa *et al.*(2014), maximum tillering, panicle initiation, heading dates, leaf area index, cholorophyll content, 1000 grain weight were increase by increased seed rates upto 143 kg seed/ha. Earlier sowing time (20$^{th}$ April) gave highest value of all studied characters in Sakha 101 variety compared to 1$^{st}$ May and 10$^{th}$ May sowing during the year 2006 and 2007 in Egypt.

## 2.2. EFFECT OF WEATHER PARAMETERS ON THE GROWTH AND YIELD OF RICE

Ghosh *et al.* (1973) studied the effects of weather factors on yield attributes of rice at CRRI, Cuttack using regression technique. They reported that high maximum temperature (29 to 31.5°C) and high total sunshine hours 3 weeks after flowering favoured panicle number and grain weight in the mid season cultivar T-141. They also reported that the absence of rainy days during the ripening phase was not beneficial to grain weight. Bhargava *et al.* (1974) studied the recurrence of rainfall deficiency in relation to rice crop at Raipur. They reported that, rainfall during July, September and the total rainfall during the crop season in the district were highly correlated with yield of paddy.

Van (1974) studied the effects of climate on rice yields in Malaysia during both the off-season and main-season rice crop. The off-season crop yielded better than the main-season crop but no significant differences were detected. He found that the performance of the rice crop was affected by the number of rainy days particularly during the growth phase between floral initiation and ripening.

Huda *et al.* (1975) studied the contribution of climatic variables in predicting rice yield in Pantnagar. They used a second degree polynomial multiple regression equation. They reported that average weekly total rainfall is beneficial during the nursery period and detrimental during vegetative and ripening phases. Above-average maximum daily temperature was beneficial during the first 3 weeks of establishment and slightly detrimental during the next 2 weeks, then had an increasing adverse effect which was greatest at maximum tillering and ear initiation and was still severe during flowering; a decrease of 1°C was beneficial. A 1°C increase in average minimum daily temperature was beneficial during establishment and had a progressively increasing adverse effect throughout flowering and ripening. Grain yields were decreased by increased maximum and minimum relative humidity and increased at low relative humidity.

Robertson (1975) reported that wind was an important factor for rice production. Transpiration rates increased under high wind condition. Dry winds have been known to cause desiccation of rice leaves. Wind can also cause mechanical damage of leaves. Such damage is more severe for upland than for lowland rice crops (Vergara, 1976).

Rao (1978) fitted a regression equation for yield and significant weather parameters to study the effects of weather on productivity of rice in Kenya and found positive effects of mean temperature and a negative effect of radiation on yield. Due to altitude (1159 m) the effect of weather conditions was significantly different from other places around the equator and at near sea level.

Ramdoss and Subramaniam (1980) studied the influence of weather parameters during the 45 days of crop growth on rice yield at Coimbatore. They reported that the maximum temperature and number of sunshine hours had a positive effect on paddy yield and a negative effect on straw yield. Agrawal *et al.* (1983) studied the joint effects of climatic variables on rice yield at different stages of crop growth in Raipur district.

Beneficial effect was observed on yield for above average maximum temperature with rise in humidity during active vegetative phase while detrimental effect was observed in other phases of crop growth. The rise in humidity has small beneficial effect in general throughout the crop season. The effect increased with increase in temperature. Rise in temperature associated with high rainfall had beneficial effect during growth phase of the crop.

Lomas and Herrera (1985) studied weather and rice yield relationships in tropical Costa Rica. They reported that the rice yield were most variable due to low rainfall. They concluded that rainfall during August when rice was in the reproductive stage could be used to assess rice yields.

According to Kim *et al.* (1989), the probability of damage to rice crop due to strong winds was higher during night. Types of damage included white heads, white and discoloured glumes. Rice growth was significantly affected by the north east monsoon with an average monthly wind speed of $4.7 ms^{-1}$. Strong winds caused leaf breakage and delayed crop maturity. Ebata and Ishikawa (1989) reported that wind damage to rice crop at the reproductive phase was triggered by temporary water stress in the panicle spikelet and the injury was accompanied by rain. Viswambaran *et al.* (1989) reported that high wind speed especially during flowering and maturity stages of rice led to poor yield due to high sterility of spikelets.

According to Shi and Shen (1990), relative humidity was the most significant meteorological factor affecting spikelet sterility in rice followed by mean temperature at 3 days after heading. The root-shoot dry weight ratio of plants at 90 percent relative humidity was lower at low temperature but higher at high temperature than in plants grown at 60 percent relative humidity.

Hoa and Singh (1993) developed regression model to forecast rice yield based on weather parameters at Pantnagar. They reported that the effect of maximum temperature, minimum temperature and relative humidity was beneficial at the end of the seedling stage. During the vegetative growth stage, relative humidity and total rainfall were found beneficial, while increase in minimum temperature was found harmful. The forecasting model using weather data upto $13^{th}$ week (the third week of August) was appropriate for forecasting rice yield as it explained 85 % variation in yield.

According to Hirai *et al.* (1993), nitrogen uptake and content of leaves and roots in plants grown at 90 percent RH were higher at 24/20°C and 28/24°C of day/night temperatures, but lower at 32/28 and 36/32°C than those of the plants grown in 60 percent relative humidity. Root dry matter production was more influenced by RH than shoot dry weight. A decrease in the fertility of spikelets at high air temperatures with increased humidity was reported by Matsui *et al.* (1997) who suggested that humidity modified the impact of high temperature on spikelet fertility. Spikelet fertility was reduced with increasing relative humidity.

Godwin *et al.* (1994) documented that night temperatures less than 18°C immediately preceding flowering in rice crops can adversely affect floret fertility and, hence, yield. They have suggested that sterility induced by low temperature is also influenced by floodwater depth and nitrogen (N) rate.

Yong and Yang (1994) studied the effect of solar radiation and air temperature on rice *cv.* Tainung 67 yield in Taiwan at five different levels of water deficit. They found that rice yield increased with increasing total solar radiation and heat sums, decreased with increased water stress but was not significantly affected by total sunshine hours or rainfall.

Rai and Chandrahas (1997) reported that the relative humidity and number of rainy days were beneficial up to early growth phase whereas sunshine and maximum temperature in addition to relative humidity contributed positively towards rice yield up to the vegetative phase. During the reproductive phase, minimum temperature and rainfall had the deleterious effect on the yield of rice. Grain yield was negatively correlated with number of rainy days and humidity during the reproductive stage, but was positively correlated with sunshine hours during the pre and post flowering stages (Reddy and Reddy, 1997).

Kaladevi *et al.* (1999) evaluated the effect of agrometeorological factors (maximum and minimum temperature, relative humidity, solar radiation, wind speed, evaporation and total rainfall) on the yield of *rabi* rice in Tamil Nadu. They reported that increased lower minimum temperatures resulted in higher dry matter production.

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

Lalitha *et al.* (2000) studied the influence of temperature on duration of tillering in lowland rice varieties in Andhra Pradesh. They reported that temperature prevailing during tillering period controlled its duration. Daily mean temperature exceeding 26°C during period of tillering restricted the durations to 5 weeks after planting whereas the temperature in the range 22.9 to 25.8°C increased the duration up to 8 weeks. They concluded that the period taken to attain maximum tillering stage could be predicted by using degree day concept.

Sarangi *et al.* (2001) developed a regression model to forecast transplanted summer rice grain yield using growth and environmental parameters in Orissa. They reported that the grain yield was positively and significantly correlated with growth characters. The grain yield was poorly correlated with temperature sum from flowering to ripening but strongly correlated with sum of bright sunshine hours during entire growth period. They concluded that on the basis of data available till flowering, this regression model could predict the yields of rice grain with 90 to 95%. Sarmah and Handique (2001) utilised multiple regression approach for preharvest forecasting of winter rice productivity for Jorhat district of Assam. They reported that weekly total rainfall, average weekly maximum temperature, average weekly bright sunshine hours, average weekly morning and evening relative humidity exhibited positive effect on rice yield. They also reported that the best time for rice yield forecasting was in the 43$^{rd}$ standard meteorological week, i.e., 4$^{th}$ week of October.

An RH of 85–90% at the heading stage induced almost complete grain sterility in rice at a day/night temperature of 35/30 °C (Abeysiriwardena *et al.*, 2002).

Nigam and Mishra (2003) studied the correlation between weather factors and rice grain yield in the tarai region of Pantnagar. They reported that effect of weather variables vary according to the time of transplanting. Under early transplanting conditions, the number of sunshine hours was significantly correlated with rice yield. Minimum temperature, maximum relative humidity, minimum relative humidity and rainfall were negatively correlated with yield, whereas the number of rainy days, wind velocity and evaporation were positively correlated with yield. Under timely transplanting conditions, the number of sunshine hours and maximum temperature showed a significant correlation with yield. Yield was negatively correlated with minimum temperature, maximum relative humidity, minimum relative humidity and rainfall, but was positively correlated with the number of rainy days, wind velocity and evaporation. Under late transplanting conditions, only the number of sunshine hours was significantly correlated with yield.

High temperature affects almost all the growth stages of rice from emergence to ripening and harvesting. The developmental stage at which the plant is exposed to heat stress determines the severity of the possible damage to the crop (Wahid *et al*, 2007). Low temperature during active vegetative phase may result poor tillering and less productive tillers. Similarly during reproductive phase higher temperature coupled with speedy wind may cause poor setting of seed, consequently leads to pitiable harvest (Singh and Singh 2007).

Weerakoon *et al.* (2008) reported that spikelet fertility was not always inhibited by high humidity. They also observed that with increased RH, pollen shedding on stigma was reduced at high temperature, while no such reduction with increased RH was noted at lower air temperatures. These observations suggest that the shedding of pollen on the stigma and the subsequent spikelet sterility are affected by RH along with temperature.

According to Soleymani and Shahrajabian (2011), rice planted on 25th May had obtained the highest number of fertile tiller, number of grain, thousand grain weight, grain yield and harvest index. This indicated that the environmental conditions like temperature, humidity was not favourable for grain development. There were no significant differences in thousand grain weight, grain yield and harvest index of rice in Mazandaran Province, Iran.

Humidity also plays an important role in rice yield, as higher relative humidity at the flowering stage under increased temperature affects spikelet fertility negatively (Yan *et al.*, 2010). According to Shah *et al.* (2011) booting and flowering are the stages most sensitive to high temperature, which may sometimes lead to complete sterility. Humidity also plays a vital role in increasing the spikelet sterility at increased temperature.

## 2.3. WEATHER INFLUENCE ON THE INCIDENCE OF PEST AND DISEASES

Weather parameters have got profound influence on the incidence of pest and diseases in rice. Some weather conditions are highly congenial for the incidence of pest and diseases whereas some conditions protect the crop. By knowing that, we can modify the weather conditions to suit the requirements of rice crop.

Sheath rot of rice (*Sarocladium oryzae*) was becoming an important disease in rainfed low land rice, especially in delayed plantings. The occurrence was high in 50 days old seedlings. In general, photoperiod sensitive tall varieties were more resistant than photoperiod insensitive ones (Singh *et al.*, 1986).

Maximum percentage of rice blast (*Pyricularia oryza*) occurrence was recorded in the second fortnight of October followed by the first fortnight of November when the maximum and minimum temperature varied between 31.5 and 16.6 $^{m}$ – 18.1$^{0}$C and RH 40-90 per cent (Tripathi *et al.*, 1997).

At low temperature, nymphs of brown plant hopper (*Nilaparvatha lugens*) moulted successfully and emerged as adults within 1-2 days. They also suggested that a temperature of around 10$^{0}$C was critical for the survival and development of nymphs. (Yang and Chu, 1988).

In Tamil Nadu, the activity of the parasitioid Tetrastichus schoenobii attacking rice yellow borer (*Scirpophage incertulas*) was reduced as temperature and wind velocity increased (Chandramohan and Chelliah, 1990). According to the reports of Ramakrishnan and Venugopalan (1991), 50 per cent of the variation in dead heart, due to the attack of rice stem borer infestation was attributed to weather.

The entire vegetative growing stage of rice was suitable for the population growth of rice gall midge. Humidity was the main factor influencing the reproduction of the cecidomycid. An average humidity of more than 78 per cent at the early to middle stages of rice tillering, the rate of reproduction increased by more than seven times from the previous generation to the following generation (Pan *et al.*, 1993).

According to Raju *et al.* (1997), peak occurrence of green leaf hopper (*Nephotettix virescens*) on rice was recorded during September and October in Tamil Nadu. Influence of weather parameters on green leaf hopper population for spring, autumn and winter seasons showed positive correlation with RH and negative correlation with minimum temperature.

## 2.4. CROP SIMULATION MODELS

Crop growth simulation models, properly validated against experimental data have the potential for tactical and strategic decision making in agriculture. Improved production technology at the farm level is the most crucial starting point for the fulsome further growth of Rice which can be triumphed by adopting suitable crop growth simulation models. Crop models are the softwares that simplify the complex relationship between climate and crop performance by using established mathematical or statistical techniques or both.

CERES (Crop Estimation through Resource & Environment Synthesis) model were the result of an attempt made in the user oriented; general simulation models for various crops. These models predict the performance of a particular cultivar, sown at any time in any climate, which would lead to transfer of agro-technology information.

The CERES – Rice model developed by (Ritchie, 1986) estimated the yields for rainfed and irrigated rice crops. The model primarily handled phasic development/ duration of growth stage as influenced by plant genetics, weather and other environmental factors; biomass production and its partitioning, root system dynamics, effect of soil water deficit and N deficiency on photosynthesis partioning in plant system. The effect of other yield limiting factors such as weeds, diseases and insects which are important, however are not simulated.

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

Meyer *et al.* (1994) reported that the yield estimated by the CERES-Rice model was within 10 per cent of the measured value of 9.5t/ha. Similarly Jand *et al.* (1994)

tested CERES-Rice model was under Punjab conditions using three dates of transpiration viz., 13th June, 27th June and 13th July and two varieties (PR106 and PR109). They reported that the prediction made by the model for yield and yield components varied from 8.34 to 10.9 percent of the observed yield. Crop simulation models are effective tools for assessment of growth and yield of crops as well as suggest optimal resource management options (Aggarwal *et al.*, 1994).

Timsina *et al.* (1995) reported that the simulated grain yields of Pant-4 were generally within 1 to 15% of observed yields for many experiments at Pantnagar in North West India. But in some cases, the simulated yields were out by up to 40%, mainly due to the fact that the model didn't accurately predict the phenological events.

Timsina *et al.* (1998) validated CERES-Rice model using two rice cultivars, three N regimes, two soil moisture regimes and two dates of transplanting. Close correspondence between simulated and observed number of days to anthesis and maturity with root mean square error of 4.3 and 2.3 days respectively, across cutivars. Simulated grain yields, however were over or under estimated relative to observed yields. A comparative study of the performance of the yield and the CERES-Rice model was done by Mahmood and Mahmood (1998). The yield and the CERES- Rice model were used to estimate boro rice productivity under normal and abnormal climate scenarios in Bangladesh, boro rice productivity predicted by yield was higher than the production by CERES-Rice.

Saseendran *et al.* (1998) reported average potential yield using CERES-Rice v.3.0, across four transplanting dates of 15.4 t $ha^{-1}$ for cv. Jaya in Kerala, compared with average actual yields of 5.2 t $ha^{-1}$ under rainfed and sub-optimal N management practices. The very large yield gaps in Kerala suggested the need for capturing and storing the surplus rainwater during the rainy season for irrigating crops during the non-rainy periods using CERES-Wheat v.3.0.

Cheyglinated *et al.* (2001) used CERES-Rice model to simulate growth and yield of four rice varieties in Thailand and reported that the model reasonably predicted the phenology and yields of all the varieties. The CERES-Rice model emphasized the effects of management and the influence of soil properties on crop performance.

Pathak *et al.* (2003) studied trends of climatic potential yields and on farm yields of wheat and rice in the Indo-Gangetic Plains using DSSAT model (CERES-Wheat and CERES-Rice). They also carried out sensitivity test of the models for radiation and temperature. Their results showed that solar radiation decrease by 1.7 $MJm^{-2}$ $day^{-1}$ reduced rice and wheat yields from 10.9 to 10.3 and 8.3 to 7.5 Kg $ha^{-1}$, respectively. Increased minimum temperature by 1.7°C decreased yields of rice and wheat from 10.9 to 10.0 and 8.3 to 8.1 Kg $ha^{-1}$, respectively.

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

CERES- Rice predicted grain and biomass yields quite variably across a range of tropical to temperate locations, with generally good predictions under nitrogen and water conditions (predicted values usually 10-15% of observations) but not under stress (N deficit, water deficit and low temperature). CERES- Wheat however generally predicted the grain and biomass yields satisfactorily except at very low yields or in high temperature environments (Timsina and Humphery, 2006).

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

Wikarmpapraharn and Kositsakulchai (2010) evaluated the ORYZA2000 and CERES-Rice models under potential growth conditions in the central plain of Thailand. They concluded that both models are adequate for simulating rice growth and development, particularly ORYZA2000 can be used as an alternative research tool to assist management decision at field level in the central plain of Thailand.

Larijani *et al.* (2011) revealed that the ORYZA2000 model can be applied as supportive research tool for selecting the most appropriate strategies for rice yield improvement across the North Iran.

According to Dass *et al.* (2012), CERES-Rice model was applied to the data recorded in two years (2008 and 2009) with two rice varieties ('Pant Dhan 4' and 'Hybrid 6444') cultivated with system of rice intensification (SRI).The overall gap between predicted and observed yield was 5% for 'Pant Dhan 4' and 11.4 % for 'Hybrid 6444'. Hence the model can be used for predicting maturity and yield of these rice varietiesgrown with SRI method.

According to Lamsal *et al.* (2013), there was sharp decrease in rice yield due to change in temperature, CO2 and solar radiation. Climatic scenario developed by CERES-Rice model in sensitivity analysis resulted yield reduction up to 80%. Among the cultivar, hybrid rice shows more vulnerability with climate change. Decrease in yield were mainly associated with lowering growth duration along with increasing temperature, where as there is very less counter effect of increasing carbon dioxide concentration and solar radiation.

CERES-Rice model was used to simulate growth and yield of NERICA 2 variety in Ibadan, Nigeria for proper planning and efficient irrigation scheduling. The prediction by CERES-Rice model for grain and biomass yields were quite higher but reasonable for planning rice productivity, especially in Nigeria, going by the assumptions used which varied considerably with environmental conditions (Akinbile, 2013).

# MATERIALS AND METHODS

# 3. MATERIALS AND METHODS

The present study, on "Simulation of environmental and varietal effects in rice using CERES model" was carried out at the Department of Agricultural Meteorology, College of Horticulture, Vellanikkara, Thrissur during 2012-14.

## 3.1. DETAILS OF FIELD EXPERIMENT

### 3.1.1. Location

The field experiments were conducted during May 2013 to November 2013 at the Agricultural Research Station, Mannuthy Kerala Agricultural University, Thrissur. The station is located at $10^0$ 32' N latitude and $76^0$ 20' E longitudes at an altitude of 22 m above mean sea level.

### 3.1.2. Soil

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

Table 3.1. Mechanical composition of soil of the experimental field (International pipette method, Piper, 1966)

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

### 3.1.3. Climate

The area experiences a typical warm humid tropical climate. The area is benefited both by southwest and northeast monsoons. The maximum rainfall is received during the month of June and July. The mean maximum and minimum temperatures of the location are 32.0°C and 23.3 °C respectively. The average annual sunshine is 5.3 h $day^{-1}$. The mean annual relative humidity is 70% with forenoon relative humidity of 80% and afternoon relative humidity of 60 %. The average annual wind speed is 2.5 km $h^{-1}$.

The details of the weekly weather parameters during the experiment are presented in the Table 3.2.

### 3.1.4. Season of Experiment

The experiment was conducted from May 2013 to November 2013.

## 3.2. EXPERIMENTAL MATERIALS AND METHODS

### 3.2.1. Variety

Two varieties of rice, Jyothi and Kanchana which are the most popular varieties among the farmers of Kerala were selected for this study. Both are short duration varieties with duration of 110-125 days for Jyothi and 105-110 days for Kanchana.

Jyothi is a short duration variety with wide adaptability and is grown extensively in a wide range of field conditions in Kerala, in all three seasons. The cross between the famous short duration improved local strain viz., PTB 10 and the internationally famous high yielding genotype viz., IR8 led to the evolution of this variety.

Kanchana is a short duration variety evolved from the cross between IR36 and Pavizham. This variety is recommended for cultivation in the whole Kerala state including problem areas such as kole lands of Thrissur and Kuttanad areas of Alappuzha distirct

Table 3.2 Weekly weather parameters during the experimental period in 2013

| Week No. | T max (°C) | T min (°C) | RH 1 (%) | RH II (%) | BSS (hrs) | RF (mm) | RD | EVP (mm) | WS (km $h^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| 22 | 29.4 | 23.5 | 96.4 | 79 | 0.9 | 217.8 | 5.0 | 12.6 | 1.65 |
| 23 | 29.5 | 22.8 | 95.3 | 79 | 1.8 | 160.4 | 6.0 | 19.6 | 1.91 |
| 24 | 28.1 | 23.2 | 96.9 | 87.1 | 0.5 | 330.3 | 7.0 | 18.3 | 1.85 |
| 25 | 27.7 | 23 | 97.6 | 86.1 | 0.7 | 308.4 | 7.0 | 12.7 | 1.3 |
| 26 | 28.7 | 22.9 | 96.1 | 83.3 | 0.9 | 104.5 | 6.0 | 13.2 | 0.92 |
| 27 | 28.7 | 22.8 | 96.7 | 86.7 | 1.1 | 41.3 | 7.0 | 54 | 2.08 |
| 28 | 28.2 | 22.8 | 96.6 | 86.6 | 0.6 | 16.4 | 3.0 | 54 | 1.4 |
| 29 | 27.3 | 22.7 | 97 | 89.6 | 0.2 | 277.4 | 7.0 | 14.7 | 1.32 |
| 30 | 29.1 | 22.3 | 96.4 | 79 | 1 | 191.6 | 6.0 | 24.6 | 2.24 |
| 31 | 28.4 | 22.8 | 95.9 | 81 | 0.9 | 271.4 | 7.0 | 17.3 | 2.84 |
| 32 | 29.5 | 23.5 | 96 | 72.4 | 4.5 | 4.3 | 1.0 | 16.3 | 2.71 |
| 33 | 29.9 | 23.1 | 96.3 | 71.4 | 3.4 | 41.3 | 7.0 | 18.5 | 1.62 |
| 34 | 30.1 | 22.5 | 96.9 | 69.6 | 6.5 | 16.4 | 3.0 | 24.3 | 2 |
| 35 | 32.0 | 23.2 | 93.7 | 68.1 | 6 | 0.4 | 0.0 | 20.7 | 1.4 |
| 36 | 29.5 | 22 | 95.7 | 75.6 | 3.3 | 66.5 | 4.0 | 15 | 1.31 |
| 37 | 29.0 | 22.1 | 96.4 | 79.1 | 2 | 196.9 | 6.0 | 17.9 | 1.9 |
| 38 | 29.7 | 22.8 | 96 | 76.3 | 3.7 | 66.4 | 4.0 | 18 | 2.3 |
| 39 | 30.7 | 21.6 | 93.4 | 69 | 5.1 | 14.8 | 3.0 | 16.8 | 1.22 |
| 40 | 31.0 | 21.5 | 95.9 | 61.6 | 6.3 | 15.2 | 1.0 | 9 | 1.88 |
| 41 | 30.9 | 22.6 | 96 | 69.4 | 7.1 | 69.3 | 4.0 | 21 | 2.14 |
| 42 | 30.6 | 23.1 | 95.6 | 71.6 | 4.2 | 152.6 | 5.0 | 20.4 | 1.74 |
| 43 | 29.8 | 23 | 97 | 77.3 | 3.3 | 104.1 | 4.0 | 14.9 | 1.28 |
| 44 | 32.8 | 24 | 88.9 | 65.1 | 6.4 | 29.8 | 2.0 | 16.8 | 3.31 |

### 3.2.2. Design and Layout

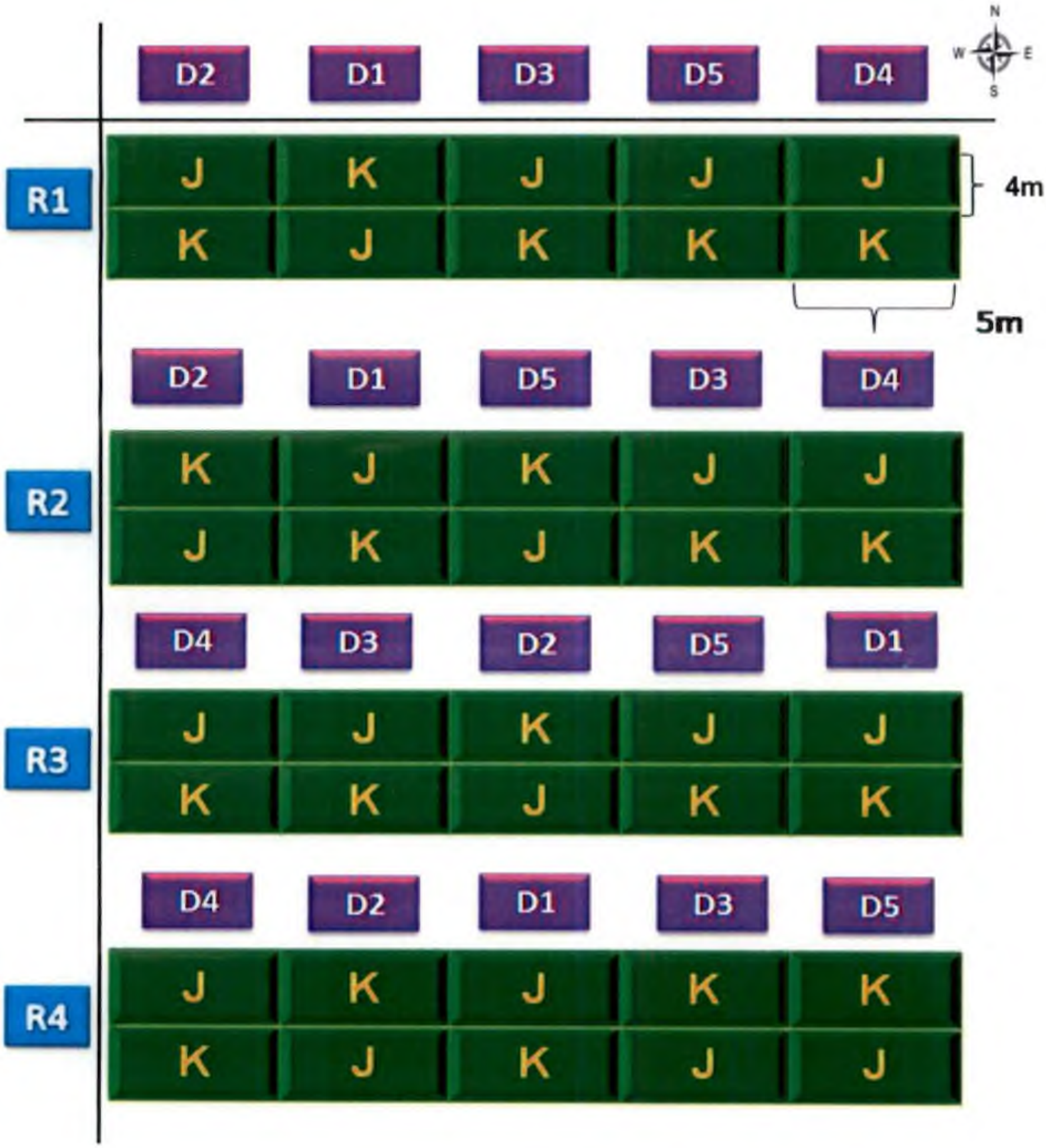
The experiment was laid out in split plot design with five dates of planting at an interval of 15 days from June 5th to August 5th as the main plot treatments and two varieties (Jyothi and Kanchana) as sub plot treatments. There were four replications. The layout is provided in (Fig 3.1). There were 40 plots in the field with a plot size of 5x4 $m^2$ each. The spacing adopted was 15x10cm (Plate 3.1).

### 3.2.3. Treatments

The treatments included five planting times at an interval of 15 days starting from 5th June to August 5th with two varieties, *viz.*, Jyothi and Kanchana. The different treatments are described in the following Table 3.3.

Table. 3. 3. Treatments used in the experiment

| Main plot | Sub plot |
|---|---|
| Planting time | Variety |
| 5th June | Jyothi |
| 5th June | Kanchana |
| 20th June | Jyothi |
| 20th June | Kanchana |
| 5th July | Jyothi |
| 5th July | Kanchana |
| 20th July | Jyothi |
| 20th July | Kanchana |
| 5th August | Jyothi |
| 5th August | Kanchana |




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

J- Jyothi, K- Kanchana

**Fig. 3.1. Layout of the experimental field**


Plate 3.1. General view of experimental plot

## 3.3. CROP MANAGEMENT

### 3.3.1. Nursery Management

Nurseries were raised prior to each date of transplanting. Eighteen days old seedlings were transplanted with 2-3 seedlings per hill. Irrigation and drainage were provided as and when required. Adequate plant protection measures were also taken.

### 3.3.2. Land Preparation and Planting

The package of practices recommended (KAU, 2012) for "Jyothi" and "Kanchana" by Kerala Agricultural University were followed. The experimental area was cleared off. The land was ploughed well and the soil was brought to puddled condition. Plots were prepared as per the layout (Plate 3.2).

### 3.3.3. Application of Manures and Fertilizers

Farm yard manure at the rate of 5000 kg $ha^{-1}$ was incorporated into the field at the time of land preparation. Urea, rajphos and murate of potash were used as fertilizers to supply the required amount of nutrients (70 N: 35 $P_2O_5$: 45 $K_2O$ kg $ha^{-1}$ ). The entire dose of $P_2O_5$, half dose of N and $K_2O$ were applied as basal and the remaining fertilizers were top dressed at 30 days after transplanting.

### 3.3.4. After Cultivation

The plots were hand weeded twice, first at 30 days after transplanting and second at 45 days after transplanting. Pest and diseases were controlled by recommended plant protection measures.

## 3.4. OBSERVATIONS

Observations on growth and yield parameters were recorded on randomly selected plants from a unit area in each replication for each treatment after leaving the border rows. Growth observations were taken at different growth stages i.e., active

Plate 3.2. (a). Land preparation

Plate 3. 2.(b).Transplanting

(c) Harvesting

Plate 3.2. Land preparation and planting

tillering, panicle initiation, booting, heading, flowering, physiological maturity and ripening.

### 3.4.1. Biometric Characters

#### *3.4.1.1. Height of the Plant*

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

#### *3.4.1.2. Biomass*

Biomass production was estimated at 15 days interval from transplanting. Four sample hills were selected randomly and uprooted from the sampling row. Thereafter, samples were first sun dried and then oven dried to a temperature of 80°C to a constant weight. Biomass was recorded in gram per plant.

#### *3.4.1.3. Leaf Area Index*

The leaf area was calculated using leaf area meter from the randomly selected plants at 15 days interval from transplanting to harvest.

Leaf area index = Total leaf area/ Land area

#### *3.4.1.4. Effective Tillers*

Number of effective tillers per plant was counted and recorded randomly from 10 plants.

#### *3.4.1.5. Number of Panicles/ Unit Area*

Number of panicles per plant was counted and recorded randomly from 10 plants.

### *3.4.1.6. Number of Spikelets / Panicle*

Number of spikelets per panicles was recorded from 10 plants.

### *3.4.1.7. Number of Filled Grains / Panicle*

The number of filled grains per panicle from 10 plants was recorded at the time of harvest.

### *3.4.1.8. Thousand Grain Weight*

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

### *3.4.1.9. Grain Yield*

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

### *3.4.1.10. Straw Yield*

The straw from each net plot was dried uniformly, weighed and expressed as kg $ha^{-1}$.

## 3.4.2. Phenological Observations

### *3.4.2.1. Days for Active Tillering*

Number of days taken for active tillering was calculated from transplanting in both the varieties and recorded in days.

### *3.4.2.2. Days for Panicle Initiation*

Number of days taken for panicle initiation was calculated from transplanting in both the varieties and recorded in days.

#### *3.4.2.3. Days for Booting*

Number of days taken for booting after transplanting for each date of planting was determined and expressed in days.

#### *3.4.2.4. Days for Heading*

Days to heading was recorded from each plot in every replication and expressed in days from date of transplanting.

#### *3.4.2.5. Days for 50 Per cent Flowering*

Number of days taken for 50 percent flowering after transplanting for each date of planting was calculated and expressed in days.

#### *3.4.2.6. Days for Ripening*

Number of days taken for ripening was determined from transplanting in both varieties and recorded in days.

#### *3.4.2.7. Days for Physiological Maturity*

Number of days taken for physiological maturity was calculated from transplanting in both varieties and recorded in days.

### 3.4.3. Soil analysis

Soil samples were collected before planting from 5cm, 15cm and 30 cm depth. The samples were dried separately powdered well in a mortar and respective samples were analyzed for pH, EC, available nitrogen, available phosphorous, available potassium and organic carbon content. The results of chemical analysis are presented in Table 3.4.

Table 3.4. Chemical properties of the soil

| Sl .No | Parameter | Sampling depth in cm | | |
|---|---|---|---|---|
| | | 0-5 | 5-15 | 15-30 |
| 1 | pH | 4.9 | 5.0 | 5.3 |
| 2 | Electrical conductivity (ds/m) | 0.08 | 0.12 | 0.10 |
| 3 | Organic carbon (%) | 0.49 | 0.76 | 0.70 |
| 4 | Available Phosphorous (kg/ha) | 122 | 118 | 104 |
| 5 | Available Pottasium (kg/ha) | 234 | 298 | 289 |
| 6 | Available Nitrogen (kg/ha) | 224.5 | 236.8 | 212.0 |

### 3.4.4. Weather Data

The daily data on the different weather parameters were recorded from the Agromet observatory of College of Horticulture, Vellanikkara. The daily data on maximum temperature, minimum temperature, bright sunshine hours, rainfall, number of rainy days, relative humidity, evaporation, wind speed and direction were taken and converted to weekly data and used for the study. The different weather parameters used in the study are described in Table 3.5.

Table 3.5. Weather parameters used in the experiment

| Sl .No. | Weather parameter | Unit |
|---|---|---|
| 1 | Maximum temperature (Tmax) | °C |
| 2 | Minimum temperature (Tmin) | °C |
| 3 | Diurnal temperature range (DTR) | °C |
| 4 | Rainfall (RF) | mm |
| 5 | Rainy days (RD) | days |
| 6 | Relative humidity (RH)<br>Forenoon relative humidity (RH I)<br>Afternoon relative humidity (RH II) | % |
| 7 | Forenoon vapour pressure deficit (VPD I)<br>Afternoon vapour pressure deficit (VPD II) | mm Hg |
| 8 | Bright Sunshine hours (BSS) | h |
| 9 | Wind speed (WS) | km $hr^{-1}$ |
| 10 | Wind direction (WD) | - |
| 11 | Evaporation (EVP) | mm |

3.5. HEAT UNITS

### 3.5.1. Growing Degree Days (GDD)

The growing degree days (GDD) were worked out during the crop period and attempted to relate the same with crop duration as well as grain yield. The GDD were calculated using the following formula. The base or threshold temperature is assumed as 10°C for rice. (Islam and Sikder, 2011).

$$GDD = \sum_{i=1}^{n} \frac{T\max + T\min}{2} - T\text{ base}$$

where $\sum_{i=1}^{n}$ n=Number of days from sowing date till the last date of harvesting

$T\max_i$ = Maximum temperature in °C on $i^{th}$ day

$T\min_i$ = Minimum temperature in °C on $i^{th}$ day

T base = Minimum threshold temperature or base temperature

### 3.5.2. Heliothermal Units (HTU)

The heliothermal units were calculated for different crop growth stages and correlated with the various growth and yield characteristics. The following formula was used for the calculation of heliothermal units and expressed in °C day h.

$$HTU = \sum_{i=0}^{n} GDD \times SSH$$

Where, GDD is growing degree days and SSH is the number of actual bright sunshine hours.

### 3.5.3. Photothermal Units (PTU)

The photothermal units were also worked out to study the effect of maximum possible sunshine hours on the crop. The photothermal units were calculated using the following formula and expressed in °C day h.

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

Where, L is the maximum possible sunshine hours.

3.6. STATISTICAL ANALYSIS

The data recorded from the field experiment was analysed statistically using the standard procedure derived by Fisher (1947) for split plot design. The equations used in the experiment are given below.

SE of difference between two main plot treatment means

$$SE = \sqrt{\frac{2 \times Ea}{rb}}$$

SE of difference between two sub plot treatment means at the same level of main plot treatment

$$SE = \sqrt{\frac{2Eb}{r}}$$

SE of difference between two main plot treatment means at the same or different levels of sub plot treatment

$$SE = \sqrt{\frac{2(b-1)Eb + Ea}{rb}}$$

Where, a is date of planting, b is variety, r is replication, Ea is main plot treatment and Eb is sub plot treatment.

Correlation analysis was carried out to study the influence of weather parameters on biometric and phenological characters on rice crop. Weekly weather variables prior to critical growth stages were worked out and then correlated with important crop growth and yield characters.

Different software packages, Microsoft – excel, SPSS and MSTAT-C were used in the study for various statistical analyses.

### 3.7. CROP GROWTH SIMULATION

The crop simulation models simulate growth, development and yield as a function of the soil-plant-atmosphere dynamics. DSSAT (Decision Support System for Agro Technology Transfer) and its crop simulation models have been used for many applications ranging from on-farm and precision management to regional assessments of the impact of climate variability and climate change. The crop models require daily weather data, soil surface profile information, and detailed crop management as input. Crop genetic information defined in a crop species file provided by DSSAT in a data file and cultivar or variety information should be provided by the user in another data file. For applications, DSSAT combines crop, soil, and weather database with crop models and application programs to simulate multi-year outcomes of crop management strategies.

DSSAT integrates the effects of soil, crop phenotype, weather and management options, and allows users to ask "what if" questions by conducting virtual simulation experiments on a desktop computer in minutes which would consume a significant part of an agronomist's career if conducted as real experiments.

DSSAT v.4.5 consists of many different applications, including data programs, various crop simulation models and analysis programs for Agrotechnology transfer. The following is a very brief description of DSSAT v.4.5 CERES-Rice models.

### 3.7.1. CERES- Rice model

The CERES-Rice (Crop Estimation through Resource and Environment Synthesis) model (Ritchie and Otter, 1985; Ritchie, 1986 and Godwin *et al.*, 1990) was adopted as the basis to simulate the effects of cultivar, planting density, weather, soil water and nitrogen on crop growth, development and yield. CERES- Rice model shared a common input and output data format, which had been developed and embodied in a software package called Decision Support System for Agro-technology Transfer (DSSAT) (Jones, 1993 and Tsuji *et al.*, 1994).

The minimum data set required for the operation and calibration of the CERES – Rice models was provided by Hunt and Boote (1994). The CERES- Rice input and output files include:

#### *3.7.1.1. Input Files*

- Experiment directory file
- Weather directory file
- Soil properties directory file
- Soil profile initial condition file
- Irrigation management file
- Fertilizer management file
- Treatment management file
- Field observed data file

#### *3.7.1.2. Output Files*

- Output file – 1

The output file OUT1.RI contained the experimental and treatments details, crop summary, simulated crop phenology, crop performance and comparison between observed and predicted values

➢ Output file – 2

The output file OUT2.RI contained the detailed crop performance summary with respect to biomass production, its partioning and leaf area indices at a given frequency.

➢ Output file – 3

The output file OUT3.RI contained the simulated information on soil water balance along with actual values of solar radiation, temperature and precipitation.

➢ Output file – 4

The output file OUT4.RI contained the simulated nitrogen balance with respect to vegetative N-uptake, grain N-uptake and layer wise soil nitrogen contents at a given frequency from sowing to harvesting. However, Nitrogen subroutine was remained switched off in this present study.

#### 3.7.2. Running the Crop Model

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

### 3.7.3. Calibration of the CERES Rice Model

Model calibration or parameterization is the adjustment of parameters so that simulated values compare well with observed values. The genetic coefficients that influence the occurrence of developmental stages in the CERES model were derived by manipulating the relevant coefficients to achieve the best possible match between the simulated and observed number of days to the phenological events. This involved determining the values of the phenology coefficients initially and then the values of the coefficients describing growth and grain development. The details regarding genetic coefficient of CERES- Rice model are presented in Table 3.6. Minimum crop performance data set are required viz., dates of emergence, anthesis, beginning of grain filling, maturity duration, grain yield, above ground biomass, grain density and weight for calibrating the genetic coefficient. Genetic coefficients can be determined using the GENCALC software that uses the observations of phenological events from one or several experiments from a range of environments.

### 3.7.4. Hypothesis for the CERES Rice Model

The procedure for determining genetic coefficients involved in running the model using a range of values of each coefficient, until the desired level of agreement between simulated and observed values was reached. Iterations for the coefficients were stopped when the agreement reached ± 10%.

Separate coefficients were developed for Jyothi and Kanchana. Root mean square error (RMSE) and D – stat (index of agreement) was used to evaluate the model performances. The equations for RMSE and D- stat index are given below.

$$\text{RMSE} = \left[\sum_{i=1}^{n} \frac{(Pi-Oi)^2}{n}\right]^{0.5}$$

$$\text{D -stat} = \frac{\sum_{i=1}^{n}(Pi-Oi)^2}{\sum(Pi-Oiavg)+(Oi-Oiavg)^2}$$

Where, RMSE is root mean square error and D is index of agreement, O$i$ is Observed value, P$i$ is Predicted value, O$iavg$ is average of observed value and n is no of observation.

Table 3.6. Genetic Coefficients for the CERES Rice model

| Genetic coefficient | Description |
|---|---|
| P1 | Basic vegetative phase of the plant |
| P2R | Extent to which phasic development leading to panicle initiation is delayed |
| P2O | Time period in (GDD $^{\circ}$ C) from beginning of grain filling |
| P5 | Critical photoperiod or the longest day length (in hours) at which the development occurs at a maximum rate |
| G1 | Potential spikelet number coefficient |
| G2 | Single grain weight (g) under ideal growing conditions |
| G3 | Tillering coefficient |
| G4 | Temperature tolerance coefficient |

# RESULTS

# 4. RESULTS

The results obtained from the study on "Simulation of environmental and varietal effects in rice using CERES model" are presented below.

## 4.1. PHENOLOGICAL PHASES

The study of the time pattern associated with the development of the different phenophases in the plant as affected by the plant environment is called phenology. The development of the phenophase is the most essential component of the study of crop weather models, which can be used to specify the most appropriate rate and time of specific developmental phase for the maximization of crop yield.

In the present investigation, the whole life cycle of the rice crop from the transplanting to physiological maturity was subdivided into seven distinct growth and development periods called phenophases, on the basis of the external morphological characters. These phenophases are:

i. Transplanting to active tillering **(P1)**
ii. Active tillering to panicle initiation **(P2)**
iii. Panicle initiation to booting **(P3)**
iv. Booting to heading **(P4)**
v. Heading to 50% flowering **(P5)**
vi. 50% flowering to ripening **(P6)**
vii. Ripening to physiological maturity **(P7)**

The combination of phenophases P1 – P2 comprised of vegetative period and was denoted as P8, P3 - P5 comprised of reproductive period of crop and was denoted as P9 and P5 – P7 comprised of ripening period was denoted as P10.

The calendar for different phenophase of the rice crop as observed in the present study under five different dates of planting during the *kharif* season are presented in

Fig.4.1.(a and b).The number of days taken by the crop for completion of particular phenophase varied with the date of planting.

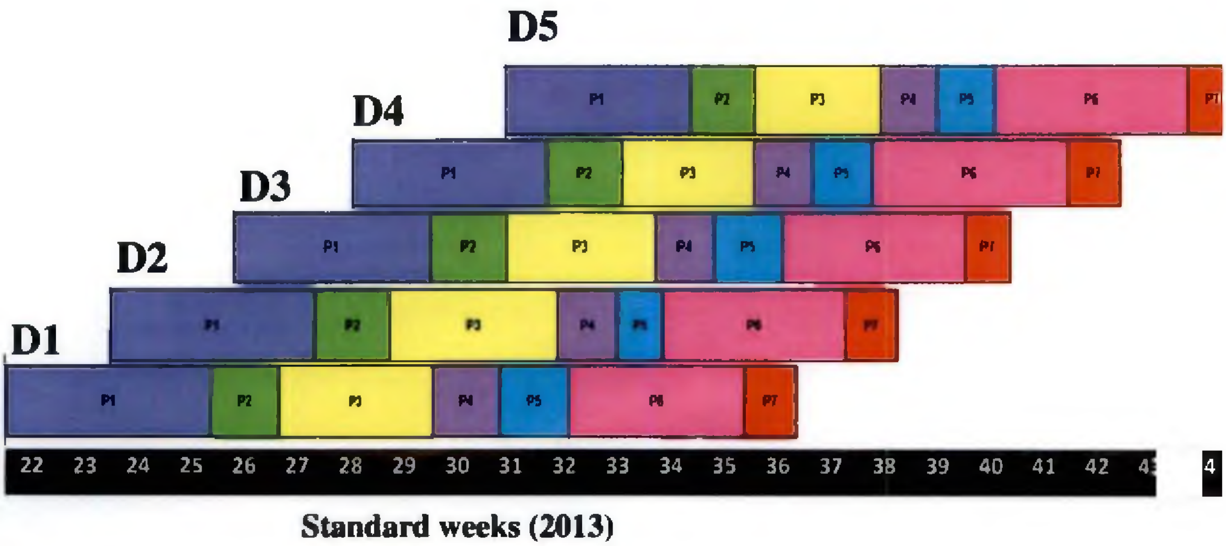



**Fig 4.1(a) Phenological calendar of Jyothi**

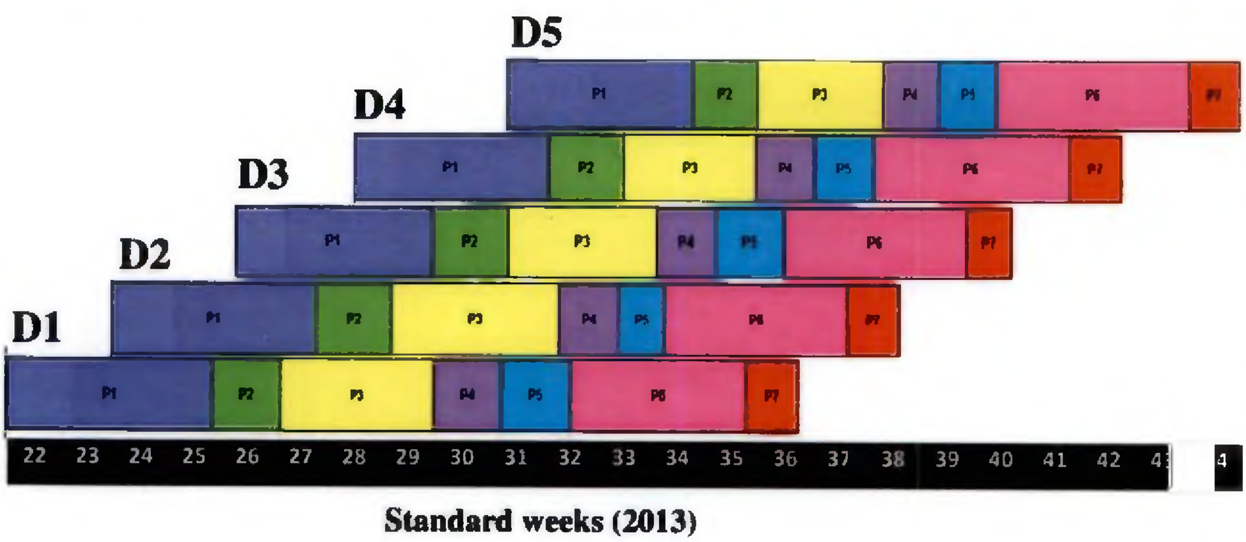



**Fig.4.1(b) Phenological calendar of Kanchana**

**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 ripening
**P7** - Ripening to physiological maturity

The number of days required from transplanting of the crop to the physiological maturity under different planting times ranged from 101-104 days respectively. The maturity duration of the crop was extended during the early planting dates as compared to late planting because of the prevailing favourable weather parameters.

The results presented in Fig.4.1 (a and b), also revealed that the number of days for maturity taken by D1 (104 days) and D2 (104 days) transplanted crops was the highest and gradual reduction was observed in late planted crops of D3 (102 days), D4 (102 days) and D5 (101 days) in both the varieties.

## 4.2. WEATHER PREVAILED DURING CROP GROWTH PERIOD

The weather conditions prevailed during the crop growing season of the year 2013 was studied and is presented graphically (Fig 4.2. to 4.6). The different meteorological elements are averaged over the standard meteorological weeks corresponding to different phenophase of the crop growth. The weather elements discussed here under are the air temperature, relative humidity, vapour pressure deficit, rainfall, rainy days, bright sunshine hours, wind speed and pan evaporation.

### 4.2.1. Air temperature

Weekly average of the maximum (Tmax) and minimum (Tmin) air temperatures of all the planting dates are plotted graphically against the standard meteorological weeks corresponding to different phenophases of the crop growth and development are depicted in Fig.4.2. The maximum temperature showing an increasing trend with delay in planting dates and it ranged from 27.3 to 32.8°C during the crop season. The minimum temperature was fluctuating with respect to different planting dates and ranged from 21.5 to 24.1°C. The mean temperature that prevailed during the crop growing season ranged from 24.9 to 28.3°C and it was showing the same pattern as that of maximum temperature. The diurnal temperature (DTR) range also exhibited the same pattern as that of maximum temperature and it ranged from 4.6 to 9.5°C. The results revealed that the maximum temperature, mean temperature and diurnal temperature

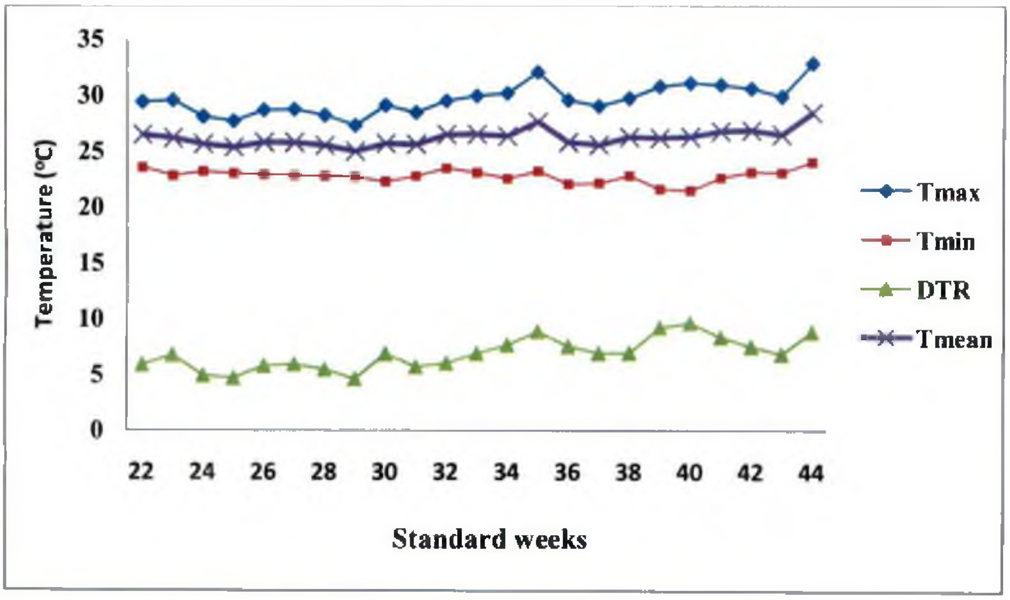



Fig.4.2. Weekly air temperature during the experiment

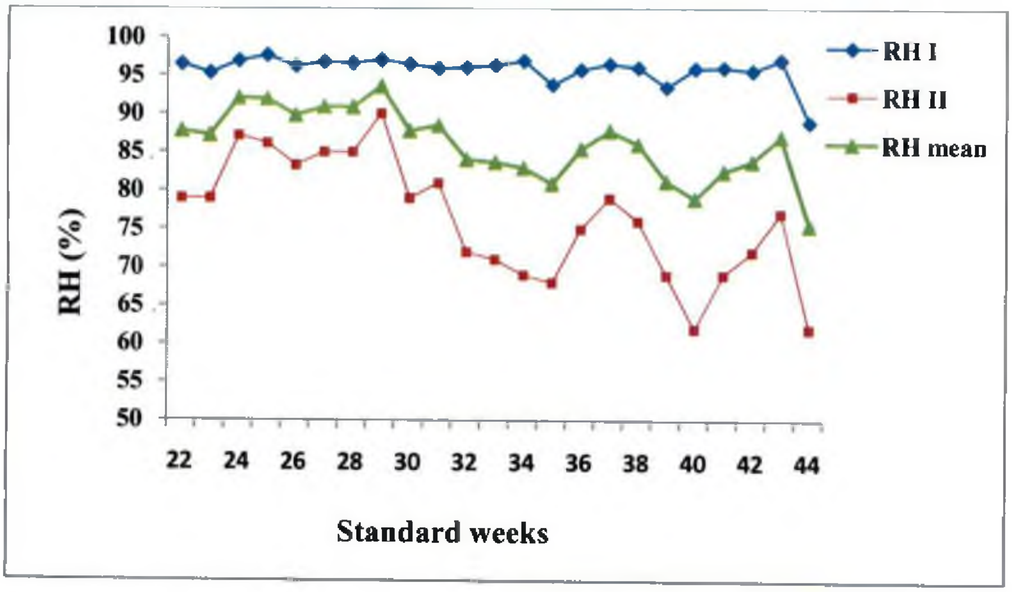



Fig. 4.3. Weekly relative humidity during the experiment

range were found low in the early planting dates while it gradually increased with late planting.

### 4.2.2. Relative humidity (RH)

The forenoon RH (RH I) and afternoon RH (RH II) were determined throughout the growing season of the crop and are plotted against the standard meteorological week for all the five planting dates and are presented in Fig.4.3.

The forenoon time RH was remained from 88.9 to 97.6 % during the season. Similarly afternoon RH was ranged from 54.0% to 90 % in the growing season. The RH mean was found to be ranged from 75.4% to 93.5%. From the Fig. 4.3., it is clear that RH was high during the early planting dates while it gradually decreased during the late planting.

### 4.2.3. Vapour pressure deficit (VPD)

The forenoon VPD (mm Hg) and afternoon VPD (mm Hg) were computed by putting the observations of the dry and wet bulb temperatures. The weekly values of VPD I and VPD II were plotted and presented in Fig. 4.4. The forenoon VPD during different planting dates was ranged from 21.1 mm Hg to 22.6 mm Hg throughout the growing season. The afternoon VPD was ranged from 20.5 mm Hg to 23.4 mm Hg during the crop season. The afternoon VPD exhibited the same pattern as that of forenoon VPD in all the planting dates from transplanting to physiological maturity.

### 4.2.4. Bright sunshine hours (BSS)

The bright sunshine and pan evaporation were analyzed in all the planting dates for different phenophases as well as for different standard meteorological weeks during the crop season. The weekly average of BSS and pan evaporation are presented in Fig.4.5.

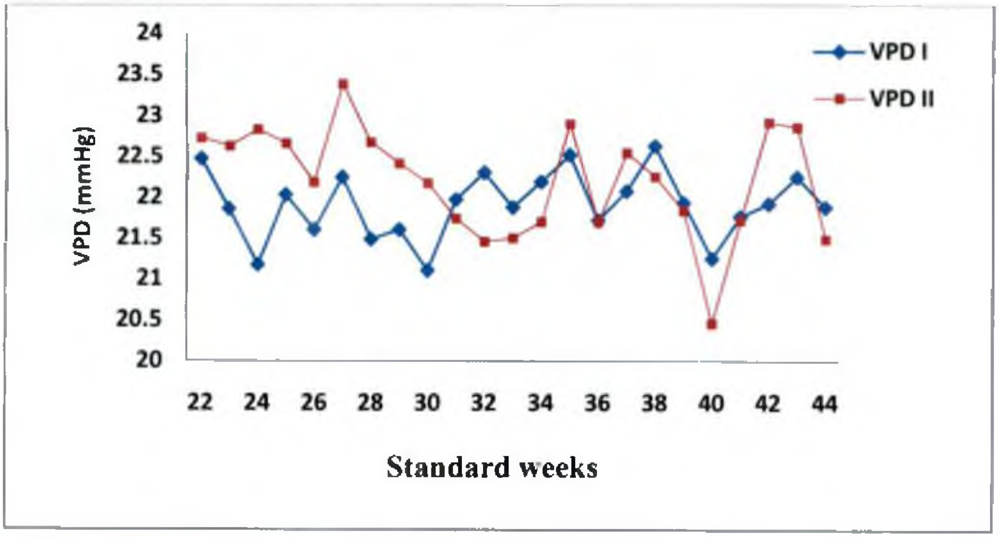



Fig.4.4. Weekly vapour pressure deficit during the experiment

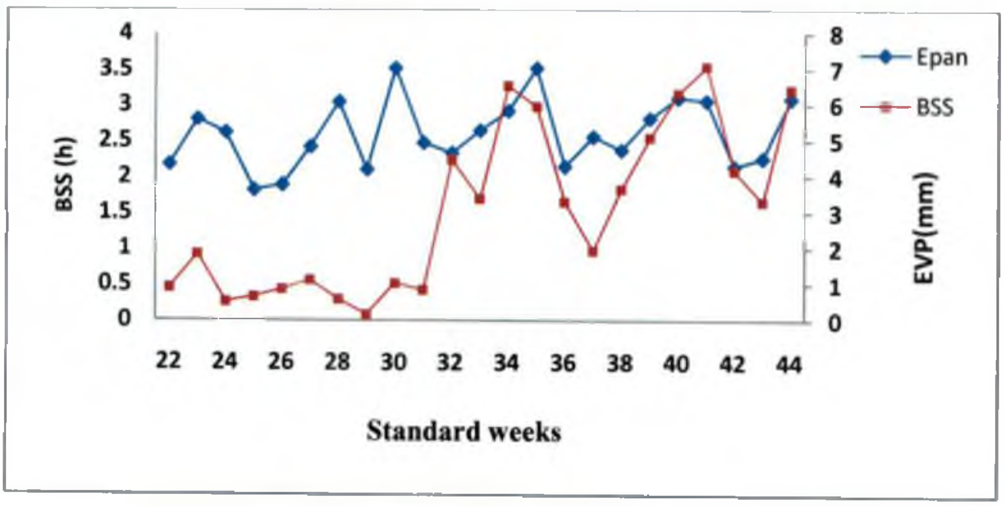



Fig.4.5. Weekly bright sunshine hours and evaporation during the experiment

Bright sunshine hours experienced by the crop during the growing season ranged from 0.2 h to 7.1 h. The BSS was found to be less during the early planting dates while it showed an increasing trend in delayed plantings. BSS was found to be increasing throughout the crop season from transplanting to maturity.

### 4.2.5. Pan Evaporation

Pan evaporation rate ranged from 1.8 mm to 3.5 mm was experienced by the crop during the entire growing season. The pan evaporation rate was increased in the late planting crops during all stages from transplanting to physiological maturity.

### 4.2.6. Rainfall and rainy days

Rainfall and rainy days experienced by the crop throughout the growing season of the crop were determined and are plotted against the standard meteorological week for all the five planting dates and are presented in Fig.4.6.

The total amount of rainfall received by the crop during the entire season was 2650.5mm. Rainfall received by the early planted crop was more compared to crops with delayed planting.

The total number of rainy days experienced by the crop throughout the season was 109. The rainy days was found to be more in crops planted in early dates whereas crop planted with delay in planting dates experienced less rainy days.

### 4.2.7. Wind speed (WS)

The wind speed experienced by the crop during the entire growing periods in different planting dates ranged from 0.9 to 3.3 km $h^{-1}$. The crops transplanted on early dates experienced less wind speed whereas the crops which transplanted with delay in planting dates experienced high wind speed during the entire growth period from transplanting to maturity (Fig.4.7).

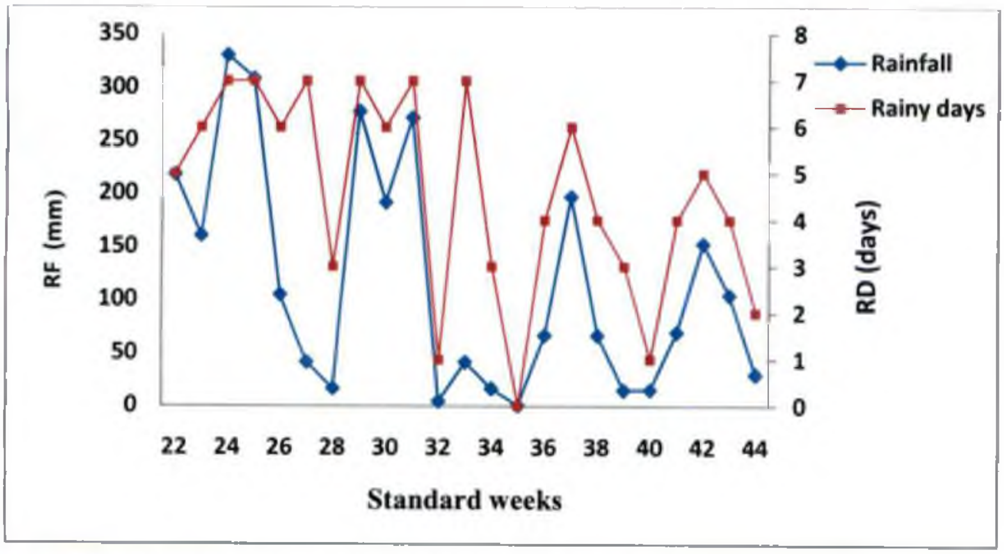



Fig. 4.6. Weekly rainfall and rainy days during the experiment

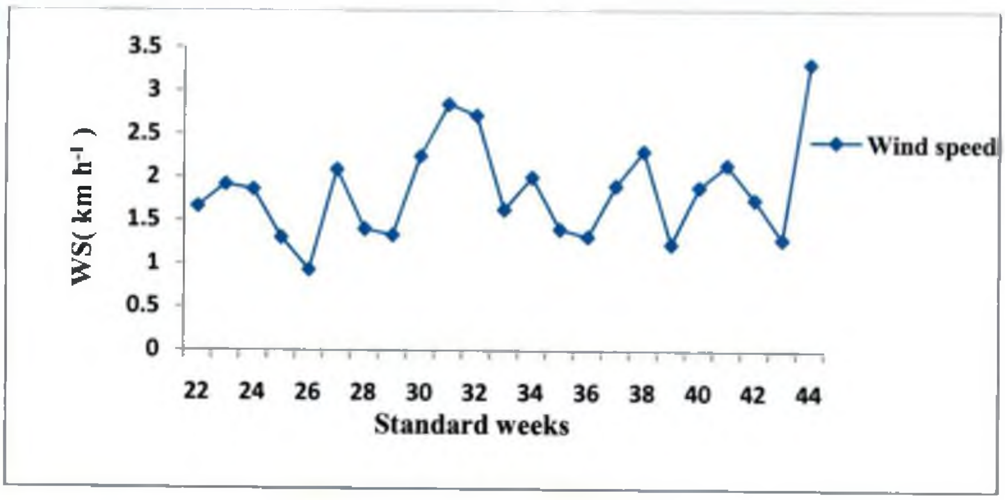



Fig.4.7. Weekly wind speed during the experiment

## 4.3. CHRONOLOGICAL OBSERVATIONS OF CROP GROWTH AND DEVELOPMENT

The seedlings of Jyothi and Kanchana varieties were transplanted on five dates of planting at an interval of 15 days starting from June $5^{th}$ to August $5^{th}$. There were no variations between varieties with respect to number of days taken for different stages of growth. The duration taken for each particular growth stage is presented in Table 4.1.

## 4.4. WEATHER CONDITIONS EXPERIENCED BY THE CROP AT DIFFERENT STAGES

The weather conditions experienced by the crop during the different growth stages with respect to different dates of planting are presented below.

### 4.4.1. Weather during transplanting (TP) to active tillering (AT)

The various weather parameters experienced by the crop during the transplanting (TP) to active tillering (AT) phase are presented in Table 4.2.

#### *4.4.1.1. Temperature (maximum temperature, minimum temperature, mean temperature and diurnal temperature range)*

The maximum temperature experienced by the crops from transplanting to active tillering varies from 28.2 to 29.9°C and the minimum temperature experienced by the crops varies from 22.7 to 23.0°C. August $5^{th}$ planted crop experienced maximum temperature (29.9°C) while minimum temperature (22.7°C) was experienced by crop planted on July $5^{th}$. The mean temperature ranged between 25.4°C in July $5^{th}$ and 26.4°C in August $5^{th}$ plantings. The diurnal temperature range (DTR) varied from 5.4 to 6.9°C. The diurnal temperature range was found to be increasing with delay in planting.

#### *4.4.1.2. Relative humidity (RH I, RH II, RH mean, VPD I and VPD II)*

The forenoon relative humidity (RH I) and afternoon relative humidity (RH II) showed a decreasing trend with delay in planting. The RH ranged from 96 % to 96.7%

Table : 4.1. Number of days taken during each phenophase of crop growth and development

| Variety | Date of transplanting | Number of days | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Active tillering | Panicle initiation | Booting | Heading | 50% flowering | Ripening | Physiological maturity |
| Jyothi | June 5 | 27 | 36 | 56 | 65 | 74 | 97 | 104 |
| Kanchana | June 5 | 27 | 36 | 56 | 65 | 74 | 97 | 104 |
| Jyothi | June 20 | 27 | 37 | 59 | 67 | 73 | 97 | 104 |
| Kanchana | June 20 | 27 | 37 | 59 | 67 | 73 | 97 | 104 |
| Jyothi | July 5 | 26 | 36 | 55 | 63 | 72 | 96 | 102 |
| Kanchana | July 5 | 26 | 36 | 55 | 63 | 72 | 96 | 102 |
| Jyothi | July 20 | 26 | 36 | 53 | 61 | 69 | 95 | 102 |
| Kanchana | July 20 | 26 | 36 | 53 | 61 | 69 | 95 | 102 |
| Jyothi | August 5 | 26 | 35 | 52 | 60 | 68 | 95 | 101 |
| Kanchana | August 5 | 26 | 35 | 52 | 60 | 68 | 95 | 101 |

in forenoon and 70.9% to 84.8% in afternoon. The crop planted on August 5th experienced low RH II (70.9%) while crop planted on June 5th experienced high RH II (84.8%). The RH mean was in the range 83-90%. The forenoon vapour pressure deficit (VPD I) was in the range 21.6-22.1 mm Hg and the afternoon vapour pressure deficit (VPD II) ranged from 21.5 to 22.7 mm Hg. The highest afternoon VPD was experienced by June 20th planted crop (22.7 mm Hg).

#### *4.4.1.3. Rainfall (RF) and rainy days (RD)*

Rainfall during transplanting to active tillering phase under different planting times for the crop ranged from 147.6 mm to 890.4 mm. The total amount of rainfall was observed to be decreasing with delay in planting date. June 5th planted crop received maximum amount of rainfall (890.4mm) while minimum (147.6 mm) amount of rainfall was received by crop planted on August 5th.

Crop under different planting dates experienced 12 – 26 rainy days during transplanting to active tillering phase with the maximum 26 days in June 5th, June 20th and July 5th planted crops while the minimum 12 days was experienced by crop planted on August 5th.

#### *4.4.1.4. Sunshine hours*

The bright sunshine hours (BSS) varied from 0.7 to 4.8h with a maximum of 4.8 h for crop planted on August 5th while the minimum amount of BSS was experienced for crop planted on June 5th.

#### *4.4.1.5. Pan Evaporation*

The evaporation rate was found to be increasing with delay in planting. It ranged from 2.2 to 2.8 mm. The maximum amount of evaporation rate was observed in crop planted on August 5th.

Table 4.2. Weather conditions experienced by the crop from transplanting to active tillering in different dates of planting

| **Weather variable** | **Date of transplanting** | | | | |
|---|---|---|---|---|---|
| | June 5$^{th}$ | June 20$^{th}$ | July 5$^{th}$ | July 20$^{th}$ | August 5$^{th}$ |
| Tmax (°C) | 28.2 | 28.4 | 28.2 | 28.8 | 29.9 |
| Tmin (°C) | 22.9 | 22.9 | 22.7 | 22.8 | 23.0 |
| Tmean (°C) | 25.6 | 25.6 | 25.4 | 25.8 | 26.4 |
| DTR (°C) | 5.4 | 5.4 | 5.5 | 6.0 | 6.9 |
| VPD I (mm Hg) | 21.7 | 21.9 | 21.6 | 21.7 | 22.1 |
| VPD II (mm Hg) | 22.5 | 22.7 | 22.6 | 21.7 | 21.5 |
| RHI (%) | 96.7 | 96.7 | 96.7 | 96.1 | 96 |
| RH II (%) | 84.4 | 84.5 | 84.8 | 79.4 | 70.9 |
| RH mean (%) | 90 | 89.9 | 90 | 87.1 | 83 |
| RF (mm) | 890.4 | 803.9 | 725.5 | 562.4 | 147.6 |
| RD | 26 | 26 | 26 | 19 | 12 |
| BSS (h) | 0.8 | 0.7 | 0.7 | 2.0 | 4.8 |
| EVP (mm) | 2.2 | 2.3 | 2.7 | 2.6 | 2.8 |
| WS( km h$^{-1}$) | 1.5 | 1.5 | 1.7 | 2.3 | 2.0 |

#### *4.4.1.6. Wind speed*

The wind speed was also found to be increasing with delay in planting. It ranged from 1.5 to 2.3 km $h^{-1}$. The crop planted on July $20^{th}$ experienced maximum wind speed of 2.3 km $h^{-1}$.

### 4.4.2. Weather during transplanting (TP) to panicle initiation (PI)

The various weather parameters experienced by the crop during TP to PI are presented in Table 4.3.

#### *4.4.2.1. Temperature (maximum temperature, minimum temperature, mean temperature and diurnal temperature range)*

The average maximum temperature from TP to PI ranged from 28.2 to 30.1°C. August $5^{th}$ planted crop experienced highest maximum temperature (30.1 °C) than all other planting dates. The minimum temperature ranged from 22.7 to 22.9 °C was found to be fluctuating in different planting dates. The mean temperature was found to be more in August $5^{th}$ planted crop (26.5 °C). The DTR was found to be increasing with delay in planting dates. It ranged from 5.4 to 7.2 °C.

#### *4.4.2.2. Relative humidity (RH I, RH II, RH mean, VPD I and VPD II)*

The RH I ranged from 96.7 to 95.6 % was found to be decreasing with delay in planting. The RH II ranged from 72 to 85.1% was also found to be decreasing with delay in planting dates except June $20^{th}$ planting. The crop planted on June $20^{th}$ experienced high amount of RH II (85.1%). The RH mean was also found to be decreasing from 90.2 to 83.5% with delay in planting. The VPD I was in the range of 21.7– 22mm Hg was found to be fluctuating whereas afternoon vapour pressure deficit ranged from 21.7 to 22.7 mm Hg decreasing with delay in planting. The maximum (22.7 mm Hg) VPD II was obtained for June $5^{th}$ planted crop.

Table. 4.3. Weather conditions experienced by the crop from transplanting to panicle initiation in different dates of planting

| Weather variable | Date of transplanting | | | | |
|---|---|---|---|---|---|
| | June 5th | June 20th | July 5th | July 20th | August 5th |
| Tmax (°C) | 28.4 | 28.2 | 28.3 | 29.1 | 30.1 |
| Tmin (°C) | 22.9 | 22.8 | 22.7 | 22.7 | 22.8 |
| Tmean (°C) | 25.6 | 25.5 | 25.5 | 25.9 | 26.5 |
| DTR (°C) | 5.4 | 5.4 | 5.5 | 6.3 | 7.2 |
| VPD I (mm Hg) | 21.8 | 21.7 | 21.7 | 21.8 | 22.0 |
| VPD II (mm Hg) | 22.7 | 22.6 | 22.3 | 21.7 | 21.8 |
| RHI (%) | 96.7 | 96.6 | 96.5 | 96.2 | 95.6 |
| RH II (%) | 84.9 | 85.1 | 83.5 | 77.2 | 72.0 |
| RH mean (%) | 90.2 | 90.1 | 89.7 | 85.8 | 83.5 |
| RF (mm) | 1206.2 | 1144.9 | 995.7 | 607 | 210 |
| RD | 34 | 35 | 32 | 26 | 15 |
| BSS (h) | 0.8 | 0.6 | 1.0 | 2.8 | 4.6 |
| EVP (mm) | 2.3 | 2.4 | 2.6 | 2.6 | 2.7 |
| WS( km $h^{-1}$) | 1.5 | 1.6 | 1.9 | 2.1 | 1.7 |

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

Rainfall experienced by the crops under different planting dates during TP to PI phase was found to be decreasing with delay in planting. The highest amount of rainfall (1206.2 mm) was received by June 5$^{th}$ planted crop and the lowest (210 mm) by August 5$^{th}$ planted crop.

Rainy days experienced by crops under different planting dates ranged from 15 to 35. June 20$^{th}$ planted crop experienced maximum of 35 rainy days whereas August 5$^{th}$ planted crop experienced 15 rainy days which was the least.

*4.4.2.4. Sunshine hours*

The bright sunshine hours (BSS) experienced by crops under different dates of planting ranged from 0.8 to 4.6 h. The crop planted on August 5$^{th}$ experienced more sunshine hours than all other planting dates.

*4.4.2.5. Pan Evporation*

Evaporation rate was found to be increasing with delay in planting dates. It ranged from 2.3 h in June 5$^{th}$ planted crop to 2.7 h in August 5$^{th}$ planted crop.

*4.4.2.6. Wind speed*

Wind speed ranges from 1.5 to 2.1 km h$^{-1}$ were found to be fluctuating with a maximum (2.1 km h$^{-1}$) was experienced by crop planted on July 20$^{th}$ and minimum wind speed (1.5 km h$^{-1}$) was experienced by crop planted on August 5$^{th}$.

**4.4.3. Weather during transplanting to booting**

The various weather parameters experienced by the crop during transplanting to booting are presented in Table 4.4.

Table 4.4. Weather conditions experienced by the crop from transplanting to booting in different times of planting

| **Weather variable** | **Date of transplanting** | | | | |
|---|---|---|---|---|---|
| | June 5th | June 20th | July 5th | July 20th | August 5th |
| Tmax (°C) | 28.3 | 28.5 | 28.8 | 29.6 | 29.9 |
| Tmin (°C) | 22.8 | 22.8 | 22.8 | 22.7 | 22.7 |
| Tmean (°C) | 25.5 | 25.6 | 25.8 | 26.1 | 26.3 |
| DTR (°C) | 5.4 | 5.6 | 6.0 | 6.8 | 7.1 |
| VPD I (mm Hg) | 21.8 | 21.7 | 21.7 | 21.8 | 22.0 |
| VPD II (mm Hg) | 22.6 | 22.3 | 22.0 | 21.9 | 21.9 |
| RHI (%) | 96.7 | 96.4 | 96.5 | 95.9 | 95.8 |
| RH II (%) | 84.9 | 82.4 | 79.0 | 75.4 | 73.5 |
| RH mean (%) | 90.2 | 89.0 | 87.1 | 85.3 | 84.3 |
| RF (mm) | 1780.4 | 1518.6 | 1053.4 | 679.1 | 477.8 |
| RD | 53 | 46 | 42 | 31 | 26 |
| BSS (h) | 0.7 | 1.1 | 2.3 | 3.4 | 4.1 |
| EVP (mm) | 2.5 | 2.4 | 2.6 | 2.7 | 2.6 |
| WS( km $h^{-1}$) | 1.6 | 1.9 | 1.9 | 1.9 | 1.8 |

#### *4.4.3.1. Temperature (maximum temperature, minimum temperature, mean temperature and diurnal temperature range)*

Maximum temperature was (Tmax) found to be increasing with delay in planting dates and was in the range 28.3 – 29.9 °C. Tmax (29.9 °C) was experienced by crop planted on August 5th. Minimum temperature was 22.8 °C for crops planted on June 5th, June 20th and July 5th whereas it was 22.7 °C for crops planted on July 20th and August 5th. The mean temperature was found to be increasing with each delay in planting. DTR also exhibited the same pattern as that of maximum temperature. It ranged from 5.4 to 7.1 °C with a maximum of 7.1 °C in August 5th planted crop.

#### *4.4.3.2. Relative humidity (RH I, RH II, RH mean, VPD I and VPD II)*

Forenoon RH was found to be decreasing with delay in planting dates. A maximum of 96.7% forenoon RH was experienced for crop planted on June 5th while the minimum 95.8% was experienced by crop planted on August 5th. The afternoon RH was also found to be decreasing. The RH mean varies from 90.2 % to 84.3% was also found to be decreasing with delayed planting dates. The forenoon VPD was found to be fluctuating with a maximum of 22 mm Hg for August 5th planting whereas the afternoon VPD was found to be decreasing with delay in planting dates.

#### *4.4.3.3. Rainfall (RF) and rainy days (RD)*

Rainfall received by crop planted on June 5th was 1780.4 mm, which was decreased by each delay in planting dates. The crop planted on August 5th received the lowest rainfall of about 477.8 mm.

Rainy days experienced by the crops differ from 26 -35 days. August 5th planted crop experienced only 26 rainy days during the period from transplanting to booting.

#### *4.4.3.4. Sunshine hours*

Bright sunshine hours were found to be increasing from 0.7 to 4.1 h. August 5th planted crop experienced the maximum amount of sunshine hours than all other planting dates.

#### *4.4.3.5. Pan Evaporation*

Evaporation rate was found to be fluctuating and varies between 2.4 to 2.7 mm. July 20th planted crop experienced 2.7 mm of evaporation rate and 2.4 mm evaporation rate was experienced for crop planted on June 5th.

#### *4.4.3.6. Wind speed*

Wind speed ranges from 1.6 to 1.9 km $h^{-1}$ were experienced by crops planted on different dates. June 20th, July 5th and July 20th planted crops experienced same wind speed (1.9 km $h^{-1}$) and June 5th crop experienced 1.6 km $h^{-1}$ of wind speed.

### 4.4.4. Weather during transplanting to heading

The various weather parameters experienced by the crop during transplanting to heading period are presented in the Table 4.5.

#### *4.4.4.1. Temperature (maximum temperature, minimum temperature, mean temperature and diurnal temperature range)*

Maximum temperature was found to be increasing during transplanting to heading stage with delay in planting dates. Tmax of 30°C was experienced by crop planted on August 5th and June 5th planted crop received Tmax of 28.3 °C. Minimum temperature was found to be fluctuating which ranged from 22.5 to 22.8 °C. The mean temperature and DTR exhibited the same pattern as that of maximum temperature. DTR was maximum in August 5th planted crop (7.4 °C).

Table 4.5. Weather conditions experienced by the crop from transplanting to heading in different times of planting

| **Weather variable** | **Date of transplanting** | | | | |
|---|---|---|---|---|---|
| | June 5th | June 20th | July 5th | July 20th | August 5th |
| Tmax (°C) | 28.3 | 28.7 | 29.2 | 29.6 | 30.0 |
| Tmin (°C) | 22.7 | 22.8 | 22.8 | 22.6 | 22.5 |
| Tmean (°C) | 26 | 26 | 26.1 | 26.2 | 26.3 |
| DTR (°C) | 5.6 | 5.9 | 6.4 | 6.9 | 7.4 |
| VPD I (mm Hg) | 22 | 22 | 22 | 21.9 | 22.1 |
| VPD II (mm Hg) | 26 | 26 | 26.1 | 26.2 | 26.3 |
| RHI (%) | 96.6 | 96.4 | 96.1 | 95.9 | 95.5 |
| RH II (%) | 84.1 | 80.6 | 77.7 | 75.4 | 73.0 |
| RH mean (%) | 89.7 | 87.9 | 86.6 | 85.4 | 82.9 |
| RF (mm) | 2051.8 | 1567.2 | 1053.8 | 838.4 | 492.6 |
| RD | 60 | 54 | 42 | 36 | 29 |
| BSS (h) | 0.7 | 1.7 | 2.7 | 3.3 | 4.2 |
| EVP (mm) | 2.5 | 2.5 | 2.7 | 2.7 | 2.6 |
| WS( km $h^{-1}$) | 1.7 | 1.9 | 1.9 | 1.9 | 1.8 |

#### *4.4.4.2. Relative humidity (RH I, RH II, RH mean, VPD I and VPD II)*

The forenoon and afternoon RH were progressively decreasing with delay in planting dates and it ranged between 96.6 % to 95.5 % in forenoon and 84.1% to 73% in afternoon. The RH mean was also found to be decreasing and it ranged from 82.9% to 89.7%. The forenoon VPD was 22 mm Hg for June 5th, June 20th, and July 5th planted crops whereas 21.9 mm Hg VPD was experienced by crop planted on July 20th. Crop planted on August 5th experienced 22.1 mm Hg VPD during forenoon. The afternoon VPD was found to be increasing with delay in planting date.

#### *4.4.4.3. Rainfall (RF) and rainy days (RD)*

The amount of rainfall received by crop planted on June 5th was highest (2051.8mm) when compared to crops planted on other dates. The lowest (492.6 mm) was received by crop planted on August 5th.

The number of rainy days varies from 29-60. Crop planted on June 5th recorded 60 rainy days and 29 rainy days was recorded for crop planted on August 5th.

#### *4.4.4.4. Sunshine hours*

Bright sunshine hours varies from 0.7 to 4.2 h with a minimum of 0.7 was experienced for crop planted on June 5th and crop planted on August 5th experienced maximum 4.2 h of sunshine hours.

#### *4.4.4.5. Pan Evaporation*

The evaporation rate varies from 2.5 to 2.7 mm. Crop planted on June 5th and June 20th recorded 2.5 mm of evaporation rate and 2.7 mm evaporation rate was recorded from crop planted on July 5th and July 20th .

#### *4.4.4.6. Wind speed*

Wind speed varies from 1.7 to 1.9 km $h^{-1}$ was experienced for the crop during different planting dates. Wind speed of 1.9 km $h^{-1}$ was experienced for crop planted on June 20th, July 5th and July 20th. The lowest wind speed (1.7 km $h^{-1}$ ) was recorded from June 5th planted crop.

### 4.4.5. Weather during transplanting to 50% flowering

The various weather parameters experienced by the crop during transplanting to 50% flowering phase are presented in Table 4.6.

#### *4.4.5.1. Temperature (maximum temperature, minimum temperature, mean temperature and diurnal temperature range)*

Maximum air temperature was found to be increasing from 28.4°C to 30.1°C with delay in planting whereas the minimum temperature was found to be decreasing from 22.8 to 22.4°C. The mean temperature (26°C) was experienced by crop planted on June 5th, June 20th and July 5th. The diurnal temperature range exhibited the same pattern as that of maximum temperature and it ranged from 5.5°C to 7.6°C.

#### *4.4.5.2. Relative humidity (RH I, RH II, RH mean, VPD I and VPD II)*

The forenoon and afternoon RH were progressively decreasing with delay in planting dates and it ranged from 96.5% to 95.6% in forenoon. The afternoon RH varies from 82.9% to 71.7% in afternoon. The RH mean ranged from 82.9% to 83.7% was also found to be decreasing. The forenoon VPD of 22mm Hg was experienced by crop planted on June 5th, June 20th, July 20th and August 5th except crop planted on July 5th which experienced 21.9 mm Hg VPD at forenoon. The afternoon VPD varies from 21.8 to 22.1 mm Hg.

Table 4.6. Weather conditions experienced by the crop from transplanting to 50% flowering in different times of planting

| Weather variable | Date of transplanting | | | | |
|---|---|---|---|---|---|
| | June 5th | June 20th | July 5th | July 20th | August 5th |
| Tmax (°C) | 28.4 | 28.8 | 29.3 | 29.5 | 30.1 |
| Tmin (°C) | 22.8 | 22.8 | 22.7 | 22.6 | 22.4 |
| Tmean (°C) | 26 | 26 | 26 | 26.1 | 26.3 |
| DTR (°C) | 5.6 | 6 | 6.5 | 6.8 | 7.6 |
| VPD I (mm Hg) | 22 | 22 | 21.9 | 22 | 22.0 |
| VPD II (mm Hg) | 22 | 22 | 22.1 | 22 | 21.8 |
| RHI (%) | 96.5 | 96.4 | 96.1 | 95.9 | 95.6 |
| RH II (%) | 82.9 | 79.5 | 77.3 | 76.0 | 71.7 |
| RH mean (%) | 89.2 | 87.4 | 86.5 | 85.5 | 83.3 |
| RF (mm) | 2056.1 | 1576.3 | 1121.2 | 942.7 | 510.7 |
| RD | 61 | 56 | 46 | 41 | 31 |
| BSS (h) | 1.1 | 2.5 | 2.8 | 3.1 | 4.4 |
| EVP (mm) | 2.4 | 2.5 | 2.7 | 2.6 | 2.7 |
| WS( km $h^{-1}$) | 1.8 | 1.8 | 1.8 | 2.0 | 1.8 |

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

Rainfall received by June 5th planted crop was highest (2056.1 mm) while the lowest (510.7 mm) was recorded in August 5th planted crop.

Rainy days varies from 31 to 61 days for crops planted on different dates. June 5th planted crop experienced 61 rainy days and 31 rainy days was experienced for crop planted on August 5th.

*4.4.5.4. Sunshine hours*

Bright sunshine hours were found to be increasing from 1.1 to 4.4 h. The maximum possible BSS was experienced by crop planted on August 5th.

*4.4.5.5. Pan evaporation*

Evaporation rate was found to be fluctuating. It varies from 2.4 to 2.7 mm. June 5th planted crop experienced 2.4 mm evaporation rate whereas 2.7 mm was experienced for August 5th planted crop.

*4.4.5.6. Wind speed*

Wind speed experienced for crops planted on different dates was found to be same for crop planted on June 5th, June 20th, July 5th, and August 5th. July 20th planted crop experienced maximum wind speed (2.0 km $h^{-1}$ ).

**4.4.6. Weather during transplanting to ripening**

The various weather parameters experienced by the crop during transplanting to ripening phase are presented in Table 4.7.

*4.4.6.1. Temperature (maximum temperature, minimum temperature, mean temperature and diurnal temperature range)*

Maximum temperature experienced for the crop was found to be increasing from

29.0 to 30.3°C with delay in planting dates whereas the minimum temperature was found to be decreasing from 22.8 to 22.6°C. The mean temperature was increasing from 25.9 to 26.5°C. DTR pattern exhibited by the crop also found to be same as that of maximum temperature and it varies from 6.1 to 7.7 °C.

#### *4.4.6.2. Relative humidity (RH I, RH II, RH mean, VPD I and VPD II)*

The forenoon and afternoon RH were progressively decreasing with delay in planting dates and it ranged from 96.2 % to 95.5% in forenoon and 79.6% to 71.1% in afternoon. The RH mean was also found to be decreasing with delayed planting. The forenoon VPD (21.9 mm Hg) was same for crop planted on June 5th, June 20th, and July 20th whereas it was 22mm Hg for July 5th and August 5th planted crop. The afternoon VPD was found to be decreasing from 22.3 mm Hg to 21.9 mm Hg with delay in planting dates.

#### *4.4.6.3. Rainfall (RF) and rainy days (RD)*

Highest rainfall was recorded from June 5th planted crop (2169 mm) while lowest rainfall was recorded from August 5th planted crop (863.6 mm).

Rainy days recorded from crop planted on June 5th was 73 and 45 days was recorded from August 5th planted crop.

#### *4.4.6.4. Sunshine hours*

Bright sunshine hours were found to be increasing from 2.1 to 4.6 for the period during transplanting to ripening. Crop planted on August 5th received maximum possible BSS (4.6 h).

#### *4.4.6.5. Pan Evaporation*

Evaporation rate varies from 2.5 to 2.7 mm. June 5th and June 20th planted crop experienced 2.5 mm evaporation rates while July 5th and July 20th planted crop received

Table. 4.7. Weather conditions experienced by the crop from transplanting to ripening in different times of planting

| Weather variable | Date of transplanting | | | | |
|---|---|---|---|---|---|
| | June 5th | June 20th | July 5th | July 20th | August 5th |
| Tmax (°C) | 29.0 | 29.1 | 29.4 | 29.9 | 30.3 |
| Tmin (°C) | 22.8 | 22.7 | 22.5 | 22.5 | 22.6 |
| Tmean (°C) | 25.9 | 25.9 | 26 | 26.2 | 26.5 |
| DTR (°C) | 6.1 | 6.3 | 6.9 | 7.4 | 7.7 |
| VPD I (mm Hg) | 21.9 | 21.9 | 22 | 21.9 | 22 |
| VPD II (mm Hg) | 22.3 | 22.2 | 22.1 | 21.9 | 22 |
| RHI (%) | 96.2 | 96.1 | 95.9 | 95.7 | 95.5 |
| RH II (%) | 79.6 | 78.7 | 76.2 | 73.5 | 71.7 |
| RH mean (%) | 87.6 | 87.0 | 85.8 | 84.2 | 83.3 |
| RF (mm) | 2169 | 1885 | 1410 | 1097 | 863.6 |
| RD | 73 | 68 | 60 | 51 | 45 |
| BSS (h) | 2.1 | 2.3 | 3.1 | 4.0 | 4.6 |
| EVP (mm) | 2.5 | 2.5 | 2.7 | 2.7 | 2.6 |
| WS( km $h^{-1}$) | 1.7 | 1.8 | 1.8 | 1.9 | 1.8 |

2.7 mm evaporation. Evaporation rate of 2.6 mm was experienced by crop planted on August 5th.

#### *4.4.6.6. Wind speed*

Wind speed ranges from 1.7 to 1.9 km $h^{-1}$. Crop planted on July 20th experienced maximum wind speed of 1.9 km $h^{-1}$.

### 4.4.7. Weather during transplanting to physiological maturity

The various weather parameters experienced by the crop during transplanting to maturity phase are presented in Table 4.8.

#### *4.4.7.1. Temperature (maximum temperature, minimum temperature, mean temperature and diurnal temperature range)*

Maximum temperature from transplanting to maturity was found to be increasing with delay in planting dates. It varies from 29.0 to 30.4°C. The minimum temperature during this period was found to be decreasing and it varies from 22.8 to 22.5°C. The mean temperature varies from 25.9 to 26.6°C was found to be increasing with delay in planting. DTR exhibited the same pattern as that of maximum temperature and it varies from 6.2°C to 7.7°C. Maximum DTR (7.7°C) was found in August 5th planted crop.

#### *4.4.7.2. Relative humidity (RH I, RH II, RH mean, VPD I and VPD II)*

Forenoon and afternoon RH were progressively decreasing with each delay in planting dates. It ranged from 96.2% to 94.3% in forenoon and 79.4% to 70.8% in afternoon. The mean RH ranges from 82.9% to 87.4 % was also found to be decreasing. The forenoon VPD experienced by the crop was same (21.9 mm Hg) for all plantings whereas the afternoon VPD was found to be decreasing from 22.3 to 21.8 mm Hg for each delay in planting dates.

Table 4.8.Weather conditions experienced by the crop from transplanting to physiological maturity in different times of planting

| Weather variable | Date of transplanting | | | | |
|---|---|---|---|---|---|
| | June 5th | June 20th | July 5th | July 20th | August 5th |
| Tmax (° C) | 29.0 | 29.1 | 29.5 | 29.9 | 30.4 |
| Tmin (°C) | 22.8 | 22.7 | 22.5 | 22.5 | 22.7 |
| Tmean (°C) | 25.9 | 25.9 | 26.0 | 26.2 | 26.6 |
| DTR (°C) | 6.2 | 6.4 | 7.0 | 7.4 | 7.7 |
| VPD I (mm Hg) | 21.9 | 21.9 | 21.9 | 21.9 | 21.9 |
| VPD II (mm Hg) | 22.3 | 22.2 | 22.0 | 21.9 | 21.8 |
| RHI (%) | 96.2 | 96.2 | 95.9 | 95.7 | 94.3 |
| RH II (%) | 79.4 | 78.4 | 75.7 | 73.4 | 70.8 |
| RH mean (%) | 87.4 | 79.5 | 85.5 | 84.3 | 82.9 |
| RF (mm) | 2182 | 1907 | 1422 | 1217.4 | 864 |
| RD | 75 | 70 | 62 | 55 | 45 |
| BSS (h) | 2.2 | 2.5 | 3.3 | 3.9 | 4.8 |
| EVP (mm) | 2.5 | 2.5 | 2.7 | 2.6 | 2.7 |
| WS( km $h^{-1}$) | 1.7 | 1.8 | 1.8 | 1.9 | 2.0 |

#### *4.4.7.3. Rainfall and Rainy days*

Crops under different planting dates experienced rainfall during TP to physiological maturity was highest in June 5$^{th}$ planted crop (2182 mm) whereas the lowest (863.6 mm) for august 5$^{th}$ planted crop.

Rainy days was more in June 5$^{th}$ planted crop (75 days) and August 5$^{th}$ planted crop experienced 45 rainy days during this period.

#### *4.4.7.4. Sunshine hours*

BSS was found to be increasing for crops under different planting dates from transplanting to ripening. It varies from 2.5 to 4.8 h. Crop planted on August 5$^{th}$ experienced maximum BSS during this period.

#### *4.4.7.5. Pan Evaporation*

Evaporation rate also found to be increasing during this period as the planting days advances and it varies from 2.5 to 2.7 mm.

#### *4.4.7.6. Wind speed*

Wind speed recorded for crops under different planting dates was found to be 1.7 to 2.0 km $h^{-1}$. Minimum wind speed was recorded for crop planted on June 5$^{th}$ (1.7 km $h^{-1}$) and August 5$^{th}$ planted crop recorded maximum (2.0 km $h^{-1}$) during the period from transplanting to maturity.

## 4.5. PLANT CHARACTERS

### 4.5.1. Weekly plant height

Analysis of variance was performed for weekly plant height upto ripening stage and the results are presented in Appendix II- page iii. Date of planting had a significant influence on plant height for both the varieties.

The analysis between dates of planting for plant height at different weeks after transplanting was provided in Table 4.9. The comparison was made for Jyothi and Kanchana varieties separately. Generally, plant height was higher in June $5^{th}$ and June $20^{th}$ plantings for both the varieties in all the weeks. At $6^{th}$ and $7^{th}$ weeks, Kanchana did not show any significant difference in plant height for all the dates of transplanting. In the first week, $5^{th}$ June planting had highest (34 cm) and $5^{th}$ August planting had lowest (24 cm) for Jyothi. For Kanchana, June $5^{th}$ and June $20^{th}$ plantings were similar in height (29 and 28.2 cm) while height was lowest for $5^{th}$ August planting.

A comparison between varieties for the plant heights at different weeks after transplanting is presented in Table 4.10. In all the weeks height was significantly higher for Jyothi variety than Kanchana during the season.

**4.5.2. Leaf area index at fortnightly intervals**

Analysis of variance was performed for leaf area index at fortnightly intervals till harvest. Dates of planting showed significant influence on leaf area index in both the varieties are presented in Appendix II- page- iii.

LAI observed at fortnightly intervals till harvesting are presented in Table 4.11. It was showing an increasing trend from transplanting to 75 days after transplanting and there after it started showing a decreasing trend for both the varieties. The crop planted on June $5^{th}$ recorded the highest LAI (5.6) for both the varieties, 75 days after planting.

For Jyothi variety, June $5^{th}$ planting recorded the maximum LAI (1.9) during harvest and was significantly different from all other planting dates. The minimum leaf area index (1.6) at the time of harvest was recorded for August $5^{th}$ planting. In case of Kanchana, during harvest, maximum LAI (1.8) was recorded for June $5^{th}$ planting and was significantly different from all other planting dates. August $5^{th}$ planting recorded the minimum LAI (1.5) at the time of harvest.

Table .4.9. Effect of dates of transplanting on plant height (cm) at weekly intervals

| Dates of planting | Week 1 | | Week 2 | | Week 3 | | Week 4 | | Week 5 | | Week 6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | J | K | J | K | J | K | J | K | J | K | J | K |
| 5$^{th}$ June | 34$^{a}$ | 29$^{a}$ | 44.5$^{a}$ | 42.1$^{a}$ | 65.5$^{a}$ | 53.3$^{a}$ | 77.4$^{a}$ | 66.9$^{a}$ | 87$^{a}$ | 78.6$^{a}$ | 96.5$^{a}$ | 84.6$^{a}$ |
| 20$^{th}$ June | 31.8$^{b}$ | 28.2$^{a}$ | 44.6$^{a}$ | 38.3$^{b}$ | 62.3$^{b}$ | 52.3$^{ab}$ | 75.1$^{ab}$ | 66.4$^{ab}$ | 85.6$^{a}$ | 76.8$^{ab}$ | 89.9$^{b}$ | 85$^{a}$ |
| 5$^{th}$ July | 28$^{c}$ | 25.6$^{b}$ | 44.5$^{a}$ | 37.1$^{b}$ | 61.9$^{bc}$ | 50.8$^{ab}$ | 74.3$^{b}$ | 63.7$^{bc}$ | 82.2$^{b}$ | 75.2$^{b}$ | 88.2$^{b}$ | 83.9$^{a}$ |
| 20$^{th}$ July | 27.8$^{c}$ | 24.7$^{b}$ | 42.2$^{ab}$ | 36.8$^{b}$ | 61.4$^{bc}$ | 49.6$^{bc}$ | 73.7$^{b}$ | 61.7$^{cd}$ | 80.6$^{bc}$ | 74.3$^{b}$ | 86.4$^{c}$ | 83.1$^{a}$ |
| 5$^{th}$ August | 24$^{d}$ | 21.6$^{c}$ | 40.7$^{b}$ | 36.3$^{b}$ | 59.4$^{c}$ | 46.9$^{c}$ | 73.6$^{b}$ | 59.4$^{d}$ | 79.6$^{c}$ | 71.5$^{c}$ | 85.3$^{c}$ | 77.9$^{b}$ |
| CD | 1.9 | | 3.4 | | 2.7 | | 3.0 | | 2.5 | | 3.0 | |

| Dates of planting | Week 7 | | Week 8 | | Week 9 | | Week 10 | | Week 11 | | Week 12 | | Week 13 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | J | K | J | K | J | K | J | K | J | K | J | K | J | K |
| 5$^{th}$ June | 99.6$^{a}$ | 90.5$^{a}$ | 102.7$^{a}$ | 100.4$^{a}$ | 110.2$^{a}$ | 108.2$^{a}$ | 115.6$^{a}$ | 112.2$^{a}$ | 118.1$^{a}$ | 115.6$^{a}$ | 121.3$^{a}$ | 118.9$^{a}$ | 123.3$^{a}$ | 121.6$^{a}$ |
| 20$^{th}$ June | 97.1$^{ab}$ | 90.1$^{a}$ | 102.1$^{a}$ | 98.4$^{a}$ | 108.7$^{ab}$ | 106.2$^{a}$ | 114.0$^{ab}$ | 111.3$^{a}$ | 117.1$^{ab}$ | 114.0$^{ab}$ | 120.1$^{ab}$ | 118.7$^{ab}$ | 122.3$^{ab}$ | 121.2$^{a}$ |
| 5$^{th}$ July | 95$^{bc}$ | 89.8$^{a}$ | 101.0$^{a}$ | 94.2$^{b}$ | 107.9$^{ab}$ | 105.7$^{ab}$ | 113.1$^{abc}$ | 110.4$^{a}$ | 116.4$^{ab}$ | 113.9$^{ab}$ | 120.2$^{ab}$ | 118.6$^{ab}$ | 122.0$^{b}$ | 120.7$^{ab}$ |
| 20$^{th}$ July | 92.3$^{cd}$ | 88.9$^{a}$ | 100.9$^{a}$ | 93.5$^{b}$ | 106.6$^{b}$ | 103.4$^{b}$ | 111.4$^{bc}$ | 107.3$^{b}$ | 115.8$^{bc}$ | 113.0$^{b}$ | 119.0$^{b}$ | 116.9$^{b}$ | 121.7$^{b}$ | 120.0$^{b}$ |
| 5$^{th}$ August | 91.1$^{d}$ | 88.4$^{a}$ | 94.6$^{b}$ | 93.0$^{b}$ | 106.5$^{b}$ | 99.1$^{c}$ | 111.0$^{c}$ | 106.0$^{b}$ | 113.9$^{c}$ | 112.1$^{b}$ | 118.5$^{b}$ | 116.9$^{b}$ | 120.4$^{c}$ | 119.7$^{b}$ |
| CD | 2.8 | | 3.1 | | 2.7 | | 2.9 | | 2.2 | | 1.9 | | 1.1 | |

Means bearing the same superscript do not differ significantly

J- Jyothi, K – Kanchana

Table 4.10. Comparison between varieties and plant height (cm) at weekly intervals

| Variety | Plant height (cm) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Week 1 | Week 2 | Week 3 | Week 4 | Week 5 | Week 6 | Week 7 | Week 8 | Week 9 | Week 10 | Week 11 | Week 12 | Week 13 |
| Jyothi | $29.9^a$ | $43.3^a$ | $62.1^a$ | $74.8^a$ | $83^a$ | $89.2^a$ | $95^a$ | $100.3^a$ | $107.9^a$ | $113^a$ | $116.3^a$ | $119.8^a$ | $121.9^a$ |
| Kanchana | $25.8^b$ | $38.1^b$ | $50.5^b$ | $63.6^b$ | $75.2^b$ | $82.9^b$ | $89.5^b$ | $95.9^b$ | $104.5^b$ | $109.4^b$ | $113.7^b$ | $118.4^b$ | $120.6^b$ |
| CD | 0.3 | 0.6 | 0.5 | 0.8 | 0.6 | 0.7 | 0.7 | 0.7 | 0.6 | 0.6 | 0.5 | 0.3 | 0.2 |

Means bearing same superscripts do not differ significantly

Table. 4.11. Effect of dates of transplanting on Leaf area index at fortnightly intervals

| Dates of planting | 15DAP | | 30DAP | | 45DAP | | 60DAP | | 75DAP | | 90DAP | | At harvest | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | J | K | J | K | J | K | J | K | J | K | J | K | J | K |
| 5th June | 1.0a | 0.9a | 2.7b | 3.1 a | 4.2 a | 4.4a | 5.3a | 4.8 ab | 5.6 a | 5.6 a | 3.2a | 3.1a | 1.9a | 1.8a |
| 20th June | 0.8bc | 0.9 a | 2.9 a | 2.8 b | 3.5 b | 3.6b | 4.6 b | 4.9 a | 5.1 b | 5.1b | 2.9b | 2.9b | 1.8b | 1.7b |
| 5th July | 1.0a | 1.0 a | 2.6 b | 2.7 b | 3.6 b | 3.2c | 4.5b | 4.3b | 5.0 b | 5.1 b | 2.7c | 2.7c | 1.8b | 1.7b |
| 20th July | 0.9b | 1.0 a | 2.2 c | 2.2 c | 2.9 c | 3.1c | 4.5 b | 4.6 ab | 5.0 b | 4.9 bc | 2.7c | 2.6c | 1.7c | 1.6c |
| 5th August | 0.7c | 0.8 a | 2.2 c | 2.3 c | 3.1 c | 3.0c | 3.3 c | 3.7 c | 4.9b | 4.6c | 2.5d | 2.4d | 1.6d | 1.5d |
| CD | 0.1 | | 0.2 | | 0.2 | | 0.5 | | 0.3 | | 0.1 | | 0.06 | |

Table. 4.12. Comparison between leaf area index and varieties at fortnightly intervals

| Variety | 15DAP | 30 DAP | 45 DAP | 60 DAP | 75 DAP | 90 DAP | harvest |
|---|---|---|---|---|---|---|---|
| Jyothi | 0.9a | 2.5a | 3.4b | 4.4b | 5.1a | 2.8a | 1.8a |
| Kanchana | 0.9a | 2.6b | 3.5a | 4.5a | 5.0b | 2.7b | 1.7b |
| CD | 0.02 | 0.05 | 0.06 | 0.13 | 0.2 | 0.1 | 0.04 |

DAP – Days after transplanting

Means bearing same superscripts do not differ significantly

Comparison between the two varieties for leaf area index is shown in Table 4.12. Leaf area index was found to be superior for Kanchana during the initial stages of growth but during the later stages (from 75 days after transplanting), Jyothi was found to be superior.

### 4.5.3. Dry matter accumulation at fortnightly intervals

Analysis of variance was performed and the results for plant dry matter accumulation are presented in Appendix-II- page iii. High significant influence of dates of planting on plant dry matter accumulation was observed in both the varieties.

Dry matter accumulation during the various time intervals for the different planting dates for both varities are given in Table 4.13. Plant dry matter accumulation was found to be decreasing with delay in planting dates. Dry matter accumulation was observed to be highest at 75 days after planting for both the varieties. Jyothi recorded a dry matter accumulation of 15086.6 kg $ha^{-1}$ on June $5^{th}$ planting which was on par with June $20^{th}$ planting while the lowest dry matter production of 12789 kg $ha^{-1}$ was obtained from August $5^{th}$ planting and it was inferior from all other plantings. Kanchana recorded the highest dry matter accumulation of 17148.6 kg $ha^{-1}$ in June $5^{th}$ planting and was significantly higher than all other planting dates while the lowest dry matter accumulation of 13136.6kg $ha^{-1}$ was recorded on August $5^{th}$ planting.

#### 4.5.3.1. Dry matter accumulation at the time of harvest

Dry matter accumulation at the time of harvest is given in Table 4.14. It was found to be significant with respect to different planting dates in Jyothi while non significant result was observed in Kanchana. In Jyothi, dry matter accumulation obtained from June $5^{th}$ planting was on par with June $20^{th}$ and July $5^{th}$ plantings. Dry matter accumulation obtained from August $5^{th}$ planting was significantly low from June $5^{th}$, June $20^{th}$ and July $5^{th}$ plantings, while on par with July $20^{th}$ planting. Dry matter accumulation recorded from Kanchana was found to be non significant with respect to different planting dates.

Table 4.13. Effect of dates of planting on dry matter acumulation (kg ha$^{-1}$) at fortnightly intervals

| Dates of planting | 15 DAP | | 30 DAP | | 45 DAP | |
|---|---|---|---|---|---|---|
| | Jyothi | Kanchana | Jyothi | Kanchana | Jyothi | Kanchana |
| 5$^{th}$ June | 624.5$^{a}$ | 485$^{a}$ | 3700.8$^{a}$ | 3669.5$^{a}$ | 9318.7$^{a}$ | 8924.1$^{a}$ |
| 20$^{th}$ June | 497.5$^{b}$ | 450$^{ab}$ | 3594.1$^{a}$ | 3477.5$^{a}$ | 9060.8$^{a}$ | $8065.8_{ab}$ |
| 5$^{th}$ July | 449.5$^{bc}$ | 300$^{c}$ | 3570$^{a}$ | 3353.7$^{a}$ | 7664.1$^{b}$ | 7298.7$^{bc}$ |
| 20$^{th}$ July | 396.6$^{cd}$ | 296.2$^{c}$ | 3063.7$^{ab}$ | 3116.2$^{a}$ | 7023.7$^{b}$ | 7262.9$^{bc}$ |
| 5$^{th}$ August | 316.6$^{d}$ | 379.5$^{bc}$ | 2451.2$^{b}$ | 2443.3$^{b}$ | 6902$^{b}$ | 6737.9$^{c}$ |
| CD | 97.6 | | 666.1 | | 919.4 | |

| Dates of planting | 60 DAP | | 75 DAP | | 90 DAP | |
|---|---|---|---|---|---|---|
| | Jyothi | Kanchana | Jyothi | Kanchana | Jyothi | Kanchana |
| 5$^{th}$ June | 13526$^{a}$ | 12770.4$^{a}$ | 15086.6$^{a}$ | 17148.6$^{a}$ | 14882.9$^{a}$ | 14148.3$^{a}$ |
| 20$^{th}$ June | 13046.2$^{a}$ | 12488.3$^{ab}$ | 14817.9$^{ab}$ | 15663.7$^{b}$ | 14293.7$^{ab}$ | 13238.3$^{b}$ |
| 5$^{th}$ July | 12982$^{a}$ | 12386.6$^{ab}$ | 14306.6$^{b}$ | 14830.4$^{c}$ | 13895.1$^{bc}$ | 13071.2$^{bc}$ |
| 20$^{th}$ July | 11087.5$^{b}$ | 11207.3$^{bc}$ | 14289.1$^{b}$ | 14619.5$^{c}$ | 13220$^{c}$ | 12939.1$^{c}$ |
| 5$^{th}$ August | 11003.3$^{b}$ | 10945.4$^{c}$ | 12789$^{c}$ | 13136.6$^{d}$ | 11591$^{d}$ | 12054.1$^{d}$ |
| CD | 1290.3 | | 666.4 | | 731.9 | |

DAP- Days after transplanting

Means bearing same superscripts do not differ significantly

Table 4.14. Effect of dates of planting on total dry matter accumulation (kg $ha^{-1}$) at the time of harvest

| Dates of planting | Dry matter production (kg $ha^{-1}$) | |
|---|---|---|
| | Jyothi | Kanchana |
| 5th June | 13063.1[a] | 12051[a] |
| 20th June | 12745[ab] | 12023.7[a] |
| 5th July | 12067[ab] | 12001.2[a] |
| 20th July | 11882.9[bc] | 11641.6[a] |
| 5th August | 10761[c] | 11043.1[a] |
| CD | 1220.2 | |

Table.4.15. Comparison between varieties and dry matter accumulation (kg$ha^{-1}$)

| Variety | 15DAP | 30 DAP | 45 DAP | 60 DAP | 75 DAP | 90 DAP | Harvest |
|---|---|---|---|---|---|---|---|
| Jyothi | 457[a] | 3276[a] | 7993.9[a] | 12329.6[a] | 15079.8[a] | 13576.9[a] | 12104[a] |
| Kanchana | 382.1[b] | 3212.0[b] | 7657.9[b] | 11959.6[b] | 14257.8[b] | 13090.2[b] | 11752.1[b] |
| CD | 21.1 | 111.2 | 260.4 | 338.1 | 250.5 | 163.6 | 270.8 |

Means bearing same superscripts do not differ significantly

With respect to varieties, Jyothi recorded the highest dry matter accumulation throughout the season compared to Kanchana .Comparisons between mean dry matter accumulations for both the varieties are given in Table 4.15.

### 4.5.4. Number of effective tillers per $m^{-2}$

Analysis of variance was done for number of effective tillers per $m^{-2}$ for both the varieties with respect to different planting dates and the results are presented in Appendix II- page iv.

Effective tillers per $m^{-2}$ for the two varieties in the different planting dates are depicted in Table 4.16. For Jyothi variety, no significant difference was observed for June $5^{th}$ to July $20^{th}$ plantings. August $5^{th}$ planting was significantly different from the other plantings and had lowest value (328.3) for the character. Kanchana planted on $5^{th}$ June was found to be superior (453.9) and it was significantly different from all other plantings.

With respect to varieties, number of effective tillers per $m^{-2}$ was highest in Kanchana compared to Jyothi during the season. (Table 4.17)

### 4.5.5. Number of spikelets per panicle

Number of spikelets per panicle was influenced by different planting dates on both the varieties. Analysis of variance was done for number of spikelets per panicle for both the varieties with respect to different planting dates and the results are presented in Appendix II- page iii.

Number of spikelets per panicle obtained from June $5^{th}$ planting was on par with July $20^{th}$ planting and it was significantly superior from all other plantings in Jyothi. In case of Kanchana, number of spikelets per panicle obtained from June $20^{th}$ planting (98.2) was significantly superior from July $20^{th}$ and August $5^{th}$ planting and it was on par with June $5^{th}$ and July $5^{th}$ planting (Table 4.16).

Table 4.16. Effect of dates of planting on yield and yield attributes

| Date of planting | Yield (kg ha$^{-1}$) | | Panicles per unit area | | 1000 grain weight | | Spikelets per panicle | | Straw yield (kg ha$^{-1}$) | | Effective tillers per m$^{-2}$ | | Filled grains per panicle | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | J | K | J | K | J | K | J | K | J | K | J | K | J | K |
| 5th June | $6712.5^{a}$ | $5797.5^{b}$ | $408.7^{a}$ | $453.9^{a}$ | $27.4^{a}$ | $25.3^{b}$ | $119.9^{a}$ | $89.9^{ab}$ | $6520^{a}$ | $5747.5^{ab}$ | $408.7^{a}$ | $453.9^{a}$ | $101.9^{a}$ | $73.4^{a}$ |
| 20th June | $5622.5^{c}$ | $6355^{a}$ | $405.3^{a}$ | $410^{b}$ | $25.8^{c}$ | $27.0^{a}$ | $102.0^{c}$ | $98.2^{a}$ | $6330^{a}$ | $6650^{a}$ | $405.3^{a}$ | $410^{b}$ | $82.5^{bc}$ | $82.1^{a}$ |
| 5th July | $6405^{b}$ | $6132.5^{a}$ | $402^{a}$ | $405.2^{b}$ | $26.4^{bc}$ | $26.5^{a}$ | $106.5^{bc}$ | $94.7^{ab}$ | $6100^{a}$ | $5355^{ab}$ | $402^{a}$ | $405.2^{b}$ | $88.4^{bc}$ | $75.6^{a}$ |
| 20th July | $6520^{ab}$ | $4427.5^{c}$ | $396.9^{a}$ | $393.6^{b}$ | $26.5^{b}$ | $25.2^{b}$ | $118.1^{ab}$ | $85.7^{b}$ | $6000^{a}$ | $5417.5^{ab}$ | $396.9^{a}$ | $393.6^{b}$ | $94.5^{ab}$ | $70.7^{a}$ |
| 5th August | $4835^{d}$ | $4370^{c}$ | $328.3^{b}$ | $373.5^{b}$ | $24.5^{d}$ | $25.1^{b}$ | $97.4^{c}$ | $84.2^{b}$ | $5342.5^{a}$ | $4427.5^{b}$ | $328.3^{b}$ | $373.5^{b}$ | $78.7^{c}$ | $68.5^{a}$ |
| CD | 285.7 | | 36.7 | | 0.6 | | 11.9 | | 1427.8 | | 36.7 | | 13.0 | |

Means bearing same superscripts do not differ significantly

Table.4.17. Comparison between varieties and yield attributes

| Variety | Yield (kg $ha^{-1}$) | Panicles per unit area | 1000 grain weight | Spikelets per panicle | Straw yield (kg $ha^{-1}$) | Effective tillers per $m^{-2}$ | Filled grains per panicle |
|---|---|---|---|---|---|---|---|
| Jyothi | 6019$^{a}$ | 388.2$^{b}$ | 26.1$^{a}$ | 108.8$^{a}$ | 6058.5$^{a}$ | 388.2$^{b}$ | 89.2$^{a}$ |
| Kanchana | 5416.5$^{b}$ | 407.2$^{a}$ | 25.8$^{b}$ | 90.5$^{b}$ | 5519.5$^{b}$ | 407.2$^{a}$ | 74.0$^{b}$ |
| CD | 67.0 | 9.4 | 0.02 | 2.7 | 372.6 | 9.4 | 3.3 |

Means bearing same superscripts do not differ significantly

Table.4.18. Comparison between varieties with respect to planting dates

| Date of planting | Yield (kg $ha^{-1}$) | | Filled grains per panicle | | 1000 grain weight (g) | | Number of panicles per unit area | |
|---|---|---|---|---|---|---|---|---|
| | Jyothi | Kanchana | Jyothi | Kanchana | Jyothi | Kanchana | Jyothi | Kanchana |
| 5$^{th}$ June | 6712.5$^{a}$ | 5797.5$^{b}$ | 101.9$^{a}$ | 73.4$^{b}$ | 27.4$^{a}$ | 25.3$^{b}$ | 408.7$^{b}$ | 453.9$^{a}$ |
| 20$^{th}$ June | 5622.5$^{b}$ | 6355$^{a}$ | 82.5$^{a}$ | 82.1$^{a}$ | 25.8$^{b}$ | 27.0$^{a}$ | 405.3$^{a}$ | 410$^{a}$ |
| 5$^{th}$ July | 6405$^{a}$ | 6132.5$^{b}$ | 88.4$^{a}$ | 75.6$^{a}$ | 26.4$^{a}$ | 26.5$^{b}$ | 402$^{a}$ | 405.2$^{a}$ |
| 20$^{th}$ July | 6520$^{a}$ | 4427.5$^{b}$ | 94.5$^{a}$ | 70.7$^{a}$ | 26.5$^{a}$ | 25.2$^{b}$ | 396.9$^{a}$ | 393.6$^{a}$ |
| 5$^{th}$ August | 4835$^{a}$ | 4370$^{b}$ | 78.7$^{a}$ | 68.5$^{a}$ | 24.5$^{a}$ | 25.1$^{a}$ | 328.3$^{b}$ | 373.5$^{a}$ |
| CD | 319.4 | | 15.8 | | 0.8 | | 44.8 | |

With respect to varieties, number of spikelets per panicle obtained from Jyothi was significantly superior to Kanchana during the season (Table 4.17).

### 4.5.6. Thousand grain weight

1000 grain weight was affected significantly by different dates of planting on both the varieties. The result obtained after analysis of variance are presented in Appendix II- page iii.

Maximum grain weight (27.4g) was recorded from June 5$^{th}$ planting and it was significantly superior from all other plantings while minimum grain weight (24.5g) was recorded from August 5$^{th}$ planting in Jyothi. In case of Kanchana 1000 grain weight recorded from June 20$^{th}$ planting (27.0g) was on par with July 5$^{th}$ planting and it was significantly superior from all other planting dates (Table 4.16).

Comparisons between varieties at the same date of planting were done and are presented in Table 4.18. Jyothi variety had significantly high value for 1000 grain weight than Kanchana for June 5$^{th}$ and July 20$^{th}$ planting while Kanchana showed significant high value than Jyothi for June 20$^{th}$ planting. On July 5$^{th}$ and August 5$^{th}$ planting the two varieties were on par for this character.

With respect to varieties, 1000 grain weight was found to be highest in Jyothi compared to Kanchana during the season (Table 4. 17).

### 4.5.7. Number of panicles per unit area

Analysis of variance was done for number of panicles per unit area for both the varieties with respect to different planting dates and the results are presented in Appendix II- page iv.

Number of panicles per unit area for the two varieties in the different planting dates is depicted in Table 4.16. For Jyothi variety, no significant difference was observed for June 5$^{th}$ to July 20$^{th}$ plantings. August 5$^{th}$ planting was significantly different from the other plantings and had lowest value for the character (328.3). Kanchana planted on 5th June was found to be superior (453.9) and it was significantly different from all other plantings.

Comparisons between varieties at the same date of planting were done and are presented in Table 4.18. Kanchana had significantly high value for number of panicles per unit area than Jyothi for June 5th and August 5th plantings. On all other dates of planting, the two varieties were on par for this character.

With respect to varieties, number of panicles per unit area was highest in Kanchana (407.2) compared to Jyothi (388.2) during the season. (Table 4.17)

### 4.5.8. Number of filled grains per panicle

Number of filled grains per panicle was influenced by different planting dates on both the varieties and the result obtained after the analysis of variance are presented in Appendix II- page iv.

Number of filled grains per panicle observed in both the varieties with respect to different planting dates is given in Table 4.16. For Jyothi, number of filled grains per panicle obtained in June 5th planting was on par with July 20th planting while it was significantly superior from other plantings. The number of filled grains obtained in Kanchana was found to be non significant with respect to different planting dates.

Comparisons between varieties at the same date of planting were done and are presented in Table 4.18. Jyothi variety had significantly high value for filled grains per panicle than Kanchana for June 5th and July 20th plantings. On all other planting, the two varieties were on par for this character.

With respect to varieties, Jyothi (89.2) is found to be superior to Kanchana (74.0) for number of filled grains per panicle (Table 4.17).

### 4.5.9. Straw yield

There was no much significant difference in straw yield obtained for both the varieties with respect to different planting dates. Analysis of variance was done and the results are presented in Appendix II- page iv. The straw yield obtained for Jyothi was non significant with respect to different planting dates. In case of Kanchana, straw yield obtained from June 20$^{th}$ planting was on par with June 5$^{th}$, July 5$^{th}$ and July 20$^{th}$ planting while it was significantly superior from August 5$^{th}$ planting (Table 4.16).

With respect to varieties, highest straw yield was obtained from Jyothi (6058.5 kg ha$^{-1}$) compared to Kanchana (5519.5 kg ha$^{-1}$) during the season. Comparisons between mean straw yields for both the varieties are presented in Table 4.17.

### 4.5.10. Grain yield

The date of planting showed significant influence on grain yield in both the varieties. The result of analysis of variance for grain yield in both the varieties at different planting dates is presented in Appendix II- page iv.

The grain yield obtained for both the varieties on different planting dates is given in Table 4.16. Grain yield in Jyothi, obtained from June 5$^{th}$ planting (6712.5 kgha$^{-1}$) was on par with July 20$^{th}$ planting and was significantly higher than June 20$^{th}$, July 5$^{th}$ and August 5$^{th}$ plantings. The lowest yield (4835 kgha$^{-1}$) was recorded in August 5$^{th}$ planting. In case of Kanchana, June 20$^{th}$ planting (6355 kgha$^{-1}$) was on par with July 5$^{th}$ (6132 kgha$^{-1}$) planting and it was significantly higher than June 5$^{th}$, July 20$^{th}$, and August 5$^{th}$ plantings

Comparison between varieties at the same date of planting was done and is presented in Table 4.18. Jyothi had significantly high yield than Kanchana for June 5$^{th}$, July 20$^{th}$ and August 5$^{th}$ plantings while yield of Kanchana was higher during June 20$^{th}$ planting. On July 5$^{th}$ planting the two varieties was on par for this character.

During the season (Table 4.17), high grain yield was obtained from Jyothi (6019 kgha$^{-1}$) compared to Kanchana (5416 kgha$^{-1}$).

## 4.6. HEAT UNIT REQUIREMENT OF RICE

The various agro-meteorological indices like growing degree days (GDD), heliothermal units (HTU) and photothermal units (PTU) were calculated for different growth stages of rice for both Jyothi and Kanchana for different growth stages from P1 to P7 are presented below. GDD, HTU and PTU were same for both the varieties as the duration of phenological phases was same.

### 4.6.1. Growing degree days (GDD)

The details regarding the GDD requirement of rice crop for both the varieties for different phenophases are given in Table 4.19. The GDD was found to be same for both the varieties, as the duration of phenological phases are same.

Date of planting plays a major role in the accumulation of GDD from transplanting to physiological maturity of crop. The accumulated GDD varied from 402.5°C days to 428.7°C in phenophase P1, 141.8°C days to 163.9°C days in P2, 283.7°C days to 306.4°C days in P3, 126.8°C days to 181.1°C days in P4, 109.9°C days to 145.9°C days in P5, 356.6°C days to 444.6°C days in P6 and 48.4°C days to 111.1°C days in P7 during different planting dates.

The total accumulated GDD was maximum during August 5$^{th}$ (1675.8°C days) planting whereas the minimum amount of GDD accumulated was during June 20$^{th}$ planting (1587.3°C days).

### 4.6.2. Heliothermal units (HTU)

The details regarding the HTU requirement of rice for both the varieties in the present study are given in the Table 4.20.

Table.4.19. Accumulated GDD during different growth stages of rice

| Crop phases | Planting dates | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | June 5th | | June 20th | | July 5th | | July 20th | | August 5th | |
| | J | K | J | K | J | K | J | K | J | K |
| P1 | 423.15 | 423.15 | 422.85 | 422.85 | 402.50 | 402.50 | 411.95 | 411.95 | 428.70 | 428.70 |
| P2 | 141.80 | 141.80 | 152.15 | 152.15 | 156.90 | 156.90 | 163.95 | 163.95 | 149.75 | 149.75 |
| P3 | 306.45 | 306.45 | 302.30 | 302.30 | 314.15 | 314.15 | 283.70 | 283.70 | 268.55 | 268.55 |
| P4 | 141.95 | 141.95 | 181.15 | 181.15 | 139.80 | 139.80 | 126.80 | 126.80 | 129.80 | 129.80 |
| P5 | 129.80 | 129.80 | 117.35 | 117.35 | 144.65 | 144.65 | 109.90 | 109.90 | 145.95 | 145.95 |
| P6 | 434.85 | 434.85 | 356.65 | 356.65 | 400.95 | 400.95 | 444.60 | 444.60 | 441.95 | 441.95 |
| P7 | 78.75 | 78.75 | 54.90 | 54.90 | 48.45 | 48.45 | 99.50 | 99.50 | 111.10 | 111.10 |
| Total | 1656.75 | 1656.75 | 1587.35 | 1587.35 | 1607.40 | 1607.40 | 1640.40 | 1640.40 | 1675.80 | 1675.80 |

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 ripening
P7- Ripening to physiological maturity
J- Jyothi and K- Kanchana

Table.4.20. Accumulated HTU during different growth phases of rice

| Crop phases | June 5th | | June 20th | | July 5th | | July 20th | | August 5th | |
|---|---|---|---|---|---|---|---|---|---|---|
| | J | K | J | K | J | K | J | K | J | K |
| P1 | 395.2 | 395.2 | 342.1 | 342.1 | 316.8 | 316.8 | 888.4 | 888.4 | 2101.2 | 2101.2 |
| P2 | 117.6 | 117.6 | 36.3 | 36.3 | 169.2 | 169.2 | 804 | 804 | 660.5 | 660.5 |
| P3 | 123.7 | 123.7 | 725.3 | 725.3 | 1600 | 1600 | 1431.8 | 1431.8 | 804.4 | 804.4 |
| P4 | 183.5 | 183.5 | 848.5 | 848.5 | 873.1 | 873.1 | 356.5 | 356.5 | 728.1 | 728.1 |
| P5 | 526.7 | 526.7 | 793.1 | 793.1 | 597.7 | 597.7 | 206.8 | 206.8 | 837.3 | 837.3 |
| P6 | 2224.5 | 2224.5 | 1244.9 | 1244.9 | 1670.6 | 1670.6 | 2635.6 | 2635.6 | 2367.2 | 2367.2 |
| P7 | 264.275 | 264.275 | 426.73 | 426.73 | 691.52 | 691.52 | 340.96 | 340.96 | 975.365 | 975.365 |
| Total | 3835.74 | 3835.74 | 4417.26 | 4417.26 | 5919.21 | 5919.21 | 6664.36 | 6664.36 | 84874.35 | 84874.35 |

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 ripening
P7- Ripening to physiological maturity
J- Jyothi and K- Kanchana

The accumulated HTU varies from 316.8°C day h to 2101°C day h in P1, 36.3°C day h to 804°C day h in P2, 123.7°C day h to 1600°C day h in P3, 183.5°C day h to 873.1°C day h in P4, 206.8°C day h to 837.3°C day h in P5, 1244.9°C day h to 2635.6°C day h in P6 and 264.2°C day h to 975.3°C day h in phenophase P7 during different planting dates.

The maximum amount of HTU was accumulated during August 5$^{th}$ planting (8474.3°C day h) and the minimum amount of HTU was accumulated during June 5$^{th}$ planting (3835.7°C day h).

### 4.6.3. Photothermal units (PTU)

The details regarding the PTU requirement of rice for both the varieties in the present study are given in Table 4.21.

PTU was calculated for different growth phases from transplanting to physiological maturity. Accumulated PTU varied from 5071.5 °C day h to 5372.4 °C day h in P1, 1786.6 °C day h to 2032.9°C day h in P2, 3249.4°C day h to 3928.7°C day h in P3, 1534.2°C day h to 2246.2°C day h in P4, 1329.7°C day h to 1750.2°C day h in P5, 4336.3°C day h to 5392.1 °C day h in P6 and 976.5°C day h to 1337.5°C day h in phenophase P7 during different planting dates..

The maximum amount of PTU was accumulated during June 5$^{th}$ (2077.2 °C day h) and the minimum amount of PTU was accumulated during July 20$^{th}$ planting (1999.1 °C days h).

### 4.7. CROP WEATHER RELATIONSHIPS

Simple linear correlation between weather elements and important growth and yield characters of rice were worked out and are given below. Correlation between weather parameters and duration were similar for both Jyothi and Kanchana as the duration for each phenophase were found to be same.

Table.4.21. Accumulated PTU during different growth phases of rice

| Crop Phases | June 5th | | June 20th | | July 5th | | July 20th | | August 5th | |
|---|---|---|---|---|---|---|---|---|---|---|
| | J | K | J | K | J | K | J | K | J | K |
| P1 | 5372.41 | 5372.41 | 5345.13 | 5345.13 | 5071.5 | 5071.5 | 5145.59 | 5145.59 | 5315.88 | 5315.88 |
| P2 | 1786.68 | 1786.68 | 1917.09 | 1917.09 | 1964.93 | 1964.93 | 2032.98 | 2032.98 | 1822.535 | 1822.535 |
| P3 | 3861.27 | 3861.27 | 3770.67 | 3770.67 | 3928.72 | 3928.72 | 3478.73 | 3478.73 | 3249.455 | 3249.455 |
| P4 | 1773.32 | 1773.32 | 2246.26 | 2246.26 | 1729.63 | 1729.63 | 1534.28 | 1534.28 | 1570.58 | 1570.58 |
| P5 | 1609.52 | 1609.52 | 1455.14 | 1455.14 | 1750.265 | 1750.265 | 1329.79 | 1329.79 | 1726.83 | 1726.83 |
| P6 | 5392.14 | 5392.14 | 4336.36 | 4336.36 | 4831.92 | 4831.92 | 5295.09 | 5295.09 | 5207.54 | 5207.54 |
| P7 | 976.5 | 976.5 | 1194.27 | 1194.27 | 1337.53 | 1337.53 | 1174.1 | 1174.1 | 1292.24 | 1292.24 |
| Total | 20771.84 | 20771.84 | 20264.9 | 20264.9 | 20614.5 | 20614.5 | 19990.6 | 19990.6 | 20185.1 | 20185.1 |

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 ripening
P7- Ripening to physiological maturity
J- Jyothi and K- Kanchana

### 4.7.1. Influence of weather parameters on crop duration

The results of the correlation analysis between weather parameters and duration of each phenophase of crop are presented in the Table 4.22.

#### 4.7.1.1. Transplanting to active tillering ($P_1$)

RH (Forenoon and afternoon), vapour pressure deficit (afternoon) and rainy days showed significant positive correlation with days taken from transplanting to active tillering. The influence of rainfall on the days taken to active tillering was observed to be positive.

Maximum temperature, DTR, BSS, wind speed and evaporation showed significant negative correlation with days taken from transplanting to active tillering. The influence of minimum temperature and forenoon VPD also observed to be negative.

#### 4.7.1.2. Active tillering to panicle initiation (P2)

After noon VDP had a significant negative correlation while wind speed had a significant positive correlation with the days taken from active tillering to panicle initiation. The influence of forenoon RH, rainy days, bright sunshine hours and evaporation were observed to be positive.

#### 4.7.1.3. Panicle initiation to booting (P3)

Minimum temperature and wind speed exhibited significant negative positive correlation while DTR and afternoon VPD were observed to be positive correlation with days taken from panicle initiation to booting

#### 4.7.1.4. Booting to heading (P4)

Maximum temperature DTR, afternoon VPD, bright sunshine hours and evaporation showed significant negative correlation where as afternoon RH, rainfall, Table.4.22.Correlation between weather parameters at crop phenophases and the duration of Jyothi and Kanchana

| Crop stages | Tmax | Tmin | DTR | RH I | RH II | VPD I | VPD II | RF | RD | BSS | WS | EVP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1 | -0.786** | -0.092 | -0.836** | 0.653** | 0.800** | -0.323 | 0.874** | 0.442 | 0.701** | -0.589** | -0.838** | -0.508* |
| P2 | -0.356 | -0.056 | -0.322 | 0.053 | -0.232 | -0.118 | -0.688** | -0.11 | 0.218 | 0.085 | 0.729** | 0.26 |
| P3 | -0.398 | 0.611** | -0.751** | 0.416 | -0.131 | -0.146 | -0.833** | -0.065 | -0.326 | -0.164 | 0.471* | 0.243 |
| P4 | -0.789** | 0.313 | -0.485* | 0.273 | 0.845** | -0.051 | -0.517* | 0.841** | 0.634** | -0.814** | 0.865** | -0.484* |
| P5 | 0.408 | -0.618** | 0.603** | -0.723** | -0.538* | -0.972** | -0.702** | -0.36 | -0.39 | 0.223 | -0.337 | 0.132 |
| P6 | 0.739** | 0.496* | 0.616** | -0.196 | -0.844** | -0.4 | -0.640** | -0.496* | -0.583** | 0.901** | -0.087 | 0.946** |
| P7 | 0.467* | -0.098 | 0.603** | -0.723** | -0.538* | -0.972** | -0.702** | -0.36 | -0.39 | 0.223 | -0.337 | 0.132 |

**- Significant at 1% level　　*- Significant at 5% 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 ripening
P7- Ripening to physiological maturity

rainy days and wind speed exhibited significant positive correlation during booting to heading.

### 4.7.1.5. Heading to 50% flowering (P5)

Minimum temperature, afternoon RH, forenoon and afternoon VPD exhibited significant negative correlation where as DTR exhibited significant positive correlation with days taken from heading to flowering.

### 4.7.1.6. 50% flowering to ripening (P6)

Maximum temperature, minimum temperature, DTR, BSS and evaporation exhibited significant positive influence on the duration while afternoon RH, VPD, rainfall and rainy days showed significant positive correlation with number of days taken from flowering to ripening.

### 4.7.1.7. Ripening to physiological maturity (P7)

Maximum temperature and DTR exhibited positive influence on the duration from ripening to maturity. RH (forenoon and afternoon) and VPD (forenoon and afternoon) showed significant negative correlation with duration from ripening to maturity.

## 4.7.2. Correlation between weather and yield of Jyothi

The results of the correlation analysis between weather parameters during each phenophases and the grain yield of Jyothi are presented in Table 4.23.

### 4.7.2.1. Transplanting to active tillering ($P_1$)

DTR, forenoon VPD, BSS and evaporation showed significant negative correlation with grain yield while afternoon RH exhibited significant positive correlation with grain yield during phenophase P1.

Table.4.23.Correlation between yield and weather parameters at different phenophases of Jyothi

| Crop stages | Tmax | Tmin | DTR | RH I | RH II | VPD I | VPD II | RF | RD | BSS | WS | EVP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1 | -0.433 | -0.018 | -0.475* | 0.265 | 0.493* | -0.491* | 0.094 | 0.3 | -0.108 | -0.712** | 0 | -0.860** |
| P2 | -0.325 | 0.862** | -0.473* | 0.376 | 0.083 | -0.029 | -0.409 | 0.341 | 0.538* | -0.125 | 0.523* | -0.015 |
| P3 | -0.258 | -0.599** | 0.189 | -0.007 | 0.219 | -0.892** | -0.533* | 0.388 | 0.403 | -0.13 | -0.599** | 0.572** |
| P4 | -0.523* | 0.703** | -0.598** | 0.391 | 0.573** | 0.492* | 0.241 | 0.614** | 0.207 | -0.544* | 0.636** | -0.004 |
| P5 | -0.880** | 0.511* | -0.855** | -0.114 | 0.737** | 0.469* | 0.577** | 0.352 | 0.256 | -0.682** | 0.362 | -0.799** |
| P6 | -0.203 | -0.343 | -0.067 | 0.037 | 0.016 | 0.305 | 0.121 | -0.01 | -0.032 | -0.187 | -0.433 | 0.044 |
| P7 | -0.667** | -0.776** | 0.15 | 0.792** | 0.546* | 0.523* | 0.635** | 0.431 | 0.587** | -0.588** | -0.781** | -0.720** |
| P8 | -0.895** | -0.447* | -0.890** | 0.357 | 0.918** | -0.772** | 0.896** | 0.881** | 0.854** | -0.909** | -0.597** | -0.678** |
| P9 | -0.306 | 0.832** | -0.587** | 0.125 | 0.142 | -0.311 | -0.597** | 0.197 | 0.512* | -0.147 | 0.637** | 0.450* |
| P10 | -0.965** | -0.448* | -0.525* | 0.189 | 0.877** | 0.879** | 0.544* | -0.142 | -0.157 | -0.914** | -0.603** | -0.517* |

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 ripening
P7- Ripening to physiological maturity
P8- Vegetative period
P9- Reproductive period
P10- Ripening period

#### 4.7.2.2. Active tillering to panicle initiation (P2)

Minimum temperature, rainy days and wind speed exhibited significant positive correlation while DTR exhibited significant negative correlation with grain yield during phenophase P2.

#### 4.7.2.3. Panicle initiation to booting (P3)

Significant positive correlation was found between grain yield and evaporation during panicle initiation to booting period while minimum temperature, wind speed, forenoon and afternoon VPD minimum temperature, wind speed exhibited significant negative correlation with grain yield.

#### 4.7.2.4. Booting to heading (P4)

Minimum temperature, afternoon RH, forenoon VPD, rainfall and wind speed had a significant positive correlation while maximum temperature, DTR and BSS showed significant negative correlation with grain yield during phenophase P4.

#### 4.7.2.5. Heading to 50% flowering (P5)

Maximum temperature, DTR, BSS and evaporation exhibited significant negative correlation with grain yield while minimum temperature, afternoon relative humidity, forenoon and afternoon VPD exhibited significant positive influence on grain yield.

#### 4.7.2.6. 50% flowering to ripening (P6)

RH ( forenoon and afternoon) ,VPD (forenoon and afternoon) and evaporation showed positive correlation with grain yield while all other parameters exhibited negative correlation with grain yield during phenophase P6.

#### 4.7.2.7. Ripening to physiological maturity (P7)

Maximum temperature, minimum temperature, BSS, wind speed and evaporation exhibited significant negative correlation with grain yield while RH (forenoon and afternoon), VPD (forenoon and afternoon) and rainy days exhibited significant positive correlation with grain yield during phenophase P7.

#### 4.7.2.8. Vegetative period (P8)

Significant positive correlation was found between grain yield and afternoon relative humidity, afternoon VPD, rainfall and rainy days while maximum temperature, minimum temperature, DTR, forenoon VPD, BSS, wind speed and evaporation had significant negative correlation with grain yield during vegetative period.

#### 4.7.2.9. Reproductive period (P9)

Significant positive correlation was observed between grain yield and minimum temperature, rainy days, wind speed and evaporation while DTR and afternoon VPD exhibited significant negative correlation with grain yield during reproductive period.

#### 4.7.2.10. Ripening period (P10)

Afternoon relative humidity and VPD (forenoon and afternoon) exhibited significant positive correlation while maximum temperature, minimum temperature, DTR, BSS, wind speed and evaporation showed significant negative correlation with grain yield during ripening period.

### 4.7.3. Correlation between weather and yield of Kanchana

The results of the correlation analysis between weather parameters during each phenophases and the grain yield of Kanchana are presented in Table 4.24.

Table.4.24. Correlation between yield and weather parameters at different phenophases of Kanchana

| Crop stages | Tmax | Tmin | DTR | RH I | RH II | VPD I | VPD II | RF | RD | BSS | WS | EVP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1 | -0.935** | -0.767** | -0.720** | 0.718** | 0.920** | -0.862** | 0.877** | 0.964** | 0.720** | -0.767** | -0.351 | -0.427 |
| P2 | -0.967** | -0.874** | -0.938** | 0.930** | 0.762** | -0.921** | -0.112 | 0.873** | 0.737** | -0.874** | 0.829** | 0.034 |
| P3 | -0.197 | 0.048 | -0.447* | 0.663** | -0.323 | -0.185 | -0.820** | -0.129 | -0.287 | 0.048 | 0.416 | 0.465* |
| P4 | -0.046 | 0.179 | -0.26 | 0.249 | 0.028 | 0.501* | 0.036 | -0.086 | -0.071 | 0.179 | 0.369 | 0.278 |
| P5 | -0.016 | 0.349 | -0.284 | 0.513* | -0.163 | 0.143 | -0.207 | -0.514* | -0.490* | 0.349 | -0.452* | 0.208 |
| P6 | -0.739** | -0.852** | -0.439 | 0.23 | 0.558* | 0.134 | 0.308 | 0.243 | 0.527* | -0.852** | -0.134 | -0.674** |
| P7 | -0.623** | -0.237 | 0.176 | 0.618** | 0.550* | 0.558* | 0.153 | -0.281 | 0.187 | -0.237 | -.606** | -0.381 |
| P8 | -0.616** | -0.611** | -0.628** | 0.934** | 0.573** | 0.216 | 0.329 | 0.616** | 0.649** | -0.590** | 0.21 | -0.21 |
| P9 | -0.323 | 0.675** | -0.536* | 0.902** | 0.477* | -0.01 | 0.526* | 0.312 | 0.248 | -0.392 | -0.03 | -0.117 |
| P10 | -0.372 | -0.667** | 0.335 | 0.918** | -0.047 | 0.383 | -0.378 | -0.739** | -0.437 | -0.099 | -0.747** | 0.035 |

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 ripening
P7- Ripening to physiological maturity
P8- Vegetative period
P9- Reproductive period
P10- Ripening period

#### 4.7.3.1. Transplanting to active tillering ($P_1$)

Relative humidity (forenoon and afternoon), afternoon vapour pressure deficit, rainfall and rainy days showed significant positive correlation with grain yield while maximum temperature, minimum temperature, DTR, forenoon VPD and BSS showed significant negative correlation with grain yield during phenophase P1.

#### 4.7.3.2. Active tillering to panicle initiation (P2)

Relative humidity (forenoon and afternoon), rainfall wind speed and rainy days exhibited significant positive correlation with grain yield while maximum temperature, minimum temperature, DTR, forenoon VPD and BSS showed significant negative correlation with grain yield.

#### 4.7.3.3. Panicle initiation to booting (P3)

Forenoon relative humidity and evaporation exhibited significant positive correlation with grain yield while DTR and afternoon VPD exhibited showed significant negative correlation with grain yield during phenophase P3.

#### 4.7.3.4. Booting to heading (P4)

Significant positive correlation was observed between grain yield and forenoon VPD during booting to heading period.

#### 4.7.3.5. Heading to 50% flowering (P5)

Rainfall, rainy days and wind speed showed significant negative correlation with grain yield while forenoon RH showed significant positive correlation with grain yield during phenophase P5.

### .7.3.6. 50% flowering to ripening (P6)

Rainy days and afternoon RH exhibited significant positive correlation with grain yield while maximum temperature, minimum temperature, BSS and evaporation had significant negative correlation with grain yield.

### 4.7.3.7. Ripening to physiological maturity (P7)

Relative humidity (forenoon and afternoon) and forenoon VPD showed significant positive correlation with grain yield while maximum temperature and wind speed exhibited significant negative correlation with grain yield during phenophase P7.

### 4.7.3.8. Vegetative period

Relative humidity (forenoon and afternoon), rainfall and rainy days exhibited significant positive correlation while maximum temperature, minimum temperature, DTR and BSS showed significant negative correlation with grain yield during vegetative period.

### 4.7.3.9. Reproductive period

Minimum temperature, relative humidity (forenoon and afternoon), and afternoon VPD exhibited significant positive correlation while DTR exhibited significant negative correlation with grain yield during reproductive period.

### 4.7.3.10. Ripening period

Forenoon relative humidity exhibited significant positive correlation with grain yield while minimum temperature, rainfall and wind speed showed significant negative correlation with grain yield during ripening period.

#### 4.7.4. Correlation between weather parameters on the yield characters of rice

Correlation between weather and yield attributes like number of filled grains per panicle, number of spikelets per panicle, number of panicles per unit area and1000 gain weight, were done and presented below.

##### 4.7.4.1. Correlation between weather and number of filled grains per panicle of Jyothi

Significant negative correlation was found between filled grains and DTR during phenophase P2. Significant positive correlation was exhibited by DTR with filled grains during phenophase P4. Correlation between weather and number of filled grains per panicle of Jyothi are presented in Table 4.25.

##### 4.7.4.2. Correlation between weather and number of spikelets per panicle of Jyothi

Wind speed had a significant positive correlation with spikelets during P1. Significant negative correlation was obtained between spikelets and DTR during active tillering to panicle initiation period (P2). Maximum temperature and wind speed exhibited significant positive correlation while forenoon VPD exhibited significant negative correlation with spikelet during phenophase P3. Maximum temperature, afternoon VPD, DTR and evaporation exhibited significant positive correlation while rainy days, afternoon RH and wind speed had a significant negative correlation with spikelets during phenophase P4. Significant negative correlation was found between minimum temperature and spikelets during phenophase P5. VPD (forenoon and afternoon) showed significant negative correlation during phenophase P6.

Forenoon VPD and evaporation had significant positive correlation with spikelets during vegetative period (P8). Maximum temperature and BSS had a significant positive correlation while rainfall and rainy days had a significant negative correlation during reproductive period (P9). Minimum temperature exhibited significant negative correlation while DTR exhibited significant positive correlation with spikelets

Table.4.25. Correlation between weather and filled grains at different phenophases of Jyothi

| Jyothi | Stages | Tmax | Tmin | Rf | RD | RH I | RH II | VPD I | VPD II | DTR | BSS | EVP | WS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Filled grains | P1 | 0.015 | -0.222 | 0.153 | -0.213 | -0.104 | 0.002 | -0.259 | -0.142 | 0.12 | -0.092 | -0.111 | 0.281 |
| | P2 | 0.01 | 0.10 | -0.038 | 0.229 | -0.102 | -0.013 | -0.207 | -0.048 | -0.444* | -0.011 | 0.131 | -0.348 |
| | P3 | 0.245 | -0.258 | -0.081 | -0.172 | 0.035 | 0.171 | -0.205 | -0.115 | 0.034 | 0.382 | 0.196 | 0.26 |
| | P4 | 0.187 | 0.234 | -0.078 | -0.108 | -0.337 | -0.224 | -0.14 | 0.442 | 0.445* | 0.157 | 0.107 | 0.385 |
| | P5 | -0.238 | -0.184 | 0.197 | 0.175 | -0.294 | 0.194 | -0.124 | 0.106 | -0.056 | -0.281 | -0.293 | -0.144 |
| | P6 | 0.059 | -0.281 | -0.266 | -0.081 | 0.02 | -0.319 | -0.307 | -0.364 | 0.208 | 0.112 | 0.306 | -0.172 |
| | P7 | 0.27 | -0.026 | -0.115 | -0.145 | -0.078 | -0.253 | -0.376 | -0.248 | 0.376 | 0.27 | 0.197 | 0.125 |
| | P8 | -0.116 | -0.437 | 0.052 | 0.063 | 0.285 | 0.063 | -0.209 | -0.07 | -0.09 | -0.076 | 0.259 | 0.291 |
| | P9 | 0.232 | 0.135 | -0.247 | -0.278 | 0.326 | -0.173 | 0.254 | 0.113 | 0.127 | 0.208 | 0.297 | -0.32 |
| | P10 | -0.086 | -0.319 | -0.033 | 0.333 | 0.324 | -0.115 | -0.09 | -0.299 | 0.325 | 0.025 | 0.627 | 0.834 |

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 ripening
P7- Ripening to physiological maturity
P8- Vegetative period
P9- Reproductive period
P10- Ripening period

during ripening period (P10). The details of Correlation between weather and number of spikelets per panicle of Jyothi are presented in 4.26.

### 4.7.4.3. Correlation between weather and number of panicles per unit area of Jyothi

Evaporation and wind speed had a significant negative correlation with panicles during P1. Maximum temperature, afternoon VPD and evaporation had a significant negative correlation while rainfall exhibited significant positive correlation with panicles during phenophase P3. Afternoon relative humidity and wind speed showed significant positive correlation while DTR exhibited significant negative correlation with panicles during P4. Significant positive correlation was observed between panicles and minimum temperature during heading to flowering period (P5).

Rainy days had significant positive correlation during vegetative period (P8) with panicles. Rainfall and afternoon RH exhibited significant positive correlation while maximum temperature, forenoon VPD, DTR and BSS showed significant negative correlation during reproductive period (P9). Rainfall exhibited significant negative correlation during ripening period (P10) with panicles. Correlation between weather and number of panicles per unit area of Jyothi are presented in Table 4.27.

### 4.7.4.4. Correlation between weather and 1000 grain weight of Jyothi

Maximum temperature, minimum temperature, sunshine hours, evaporation and wind speed has significant negative correlation while RD, RH I, RH II, VPD I and VPD II had a significant positive correlation during phenophase P1. Maximum temperature and BSS has significant negative correlation and minimum temperature, rainy days and RH I had a significant positive correlation during phenophase P2. Minimum temperature, RD, DTR and VPD II had significant negative correlation while evaporation had a significant positive correlation during P3. Maximum temperature, BSS and evaporation had a significant negative correlation whereas minimum temperature, rainfall, RD and VPD I had significant positive correlation during P4.

Table.4.26. Correlation between weather and spikelets at different phenophases of Jyothi

| Jyothi | Stages | Tmax | Tmin | Rf | RD | RH I | RH II | VPD I | VPD II | DTR | BSS | EVP | WS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spikelets | P1 | 0.17 | -0.198 | 0.084 | -0.116 | -0.11 | -0.206 | -0.077 | -0.247 | 0.282 | 0.12 | 0.275 | 0.476* |
| | P2 | 0.112 | -0.285 | -0.255 | 0.154 | -0.323 | -0.207 | -0.348 | -0.023 | -0.457* | 0.16 | 0.255 | -0.306 |
| | P3 | 0.529* | 0.018 | -0.42 | -0.037 | -0.291 | 0.112 | -0.471* | 0.223 | 0.304 | 0.435 | -0.145 | 0.517* |
| | P4 | 0.492* | 0.015 | -0.43 | -0.527* | -0.346 | -0.476* | 0.336 | 0.507* | 0.467* | 0.439 | 0.496* | -0.454* |
| | P5 | 0.036 | -0.453* | 0.211 | 0.246 | -0.196 | 0.018 | -0.218 | 0.02 | 0.269 | -0.101 | -0.02 | -0.406 |
| | P6 | 0.015 | -0.215 | -0.166 | 0.092 | 0.216 | -0.329 | -0.530* | -0.515* | 0.125 | 0.126 | 0.332 | 0.153 |
| | P7 | 0.27 | -0.026 | -0.115 | -0.145 | -0.078 | -0.253 | -0.376 | -0.248 | 0.376 | 0.27 | 0.197 | 0.125 |
| | P8 | -0.116 | -0.437 | 0.052 | 0.037 | 0.257 | -0.413 | 0.607** | 0.157 | -0.058 | -0.042 | 0.513* | 0.336 |
| | P9 | 0.500* | 0.177 | -0.503* | -0.447* | 0.285 | 0.001 | -0.143 | -0.251 | 0.321 | 0.465* | -0.41 | 0.199 |
| | P10 | -0.107 | -0.532* | 0.204 | 0.133 | 0.281 | -0.071 | -0.108 | -0.173 | 0.519* | -0.055 | -0.138 | -0.425 |

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 ripening
P7- Ripening to physiological maturity
P8- Vegetative period
P9- Reproductive period
P10- Ripening period

Table.4.27. Correlation between weather and panicles at different phenophases of Jyothi

| Jyothi | stages | Tmax | Tmin | Rf | RD | RH I | RH II | VPD I | VPD II | DTR | BSS | EVP | WS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Panicles | P1 | -0.313 | -0.073 | 0.152 | 0.066 | 0.108 | 0.377 | -0.235 | 0.344 | -0.316 | -0.276 | -0.457* | -0.469* |
| | P2 | -0.257 | 0.415 | 0.431 | 0.394 | 0.388 | 0.408 | -0.173 | 0.249 | -0.322 | -0.365 | 0.064 | 0.063 |
| | P3 | -0.516* | -0.146 | 0.461* | 0.37 | 0.148 | 0.394 | -0.332 | -0.463* | -0.337 | 0.427 | -0.464* | 0.049 |
| | P4 | -0.444 | 0.252 | 0.438 | 0.364 | 0.227 | 0.462* | -0.012 | -0.302 | -0.461* | -0.415 | -0.264 | 0.511* |
| | P5 | -0.159 | 0.465* | -0.257 | -0.316 | 0.059 | 0.02 | 0.112 | -0.064 | -0.356 | 0.023 | -0.119 | 0.311 |
| | P6 | -0.031 | -0.073 | -0.024 | -0.151 | -0.289 | 0.218 | 0.419 | 0.395 | 0.001 | -0.164 | -0.273 | -0.384 |
| | P7 | -0.336 | -0.263 | -0.023 | 0.097 | 0.225 | 0.251 | 0.377 | 0.199 | -0.089 | -0.213 | -0.225 | -0.251 |
| | P8 | -0.267 | 0.05 | 0.378 | 0.470* | 0.237 | 0.335 | -0.163 | 0.41 | -0.314 | -0.311 | -0.134 | -0.334 |
| | P9 | -0.527* | 0.242 | 0.513* | 0.333 | 0.226 | 0.515* | -0.474* | 0.057 | -0.517* | -0.516* | -0.388 | 0.343 |
| | P10 | -0.176 | 0.052 | -0.484* | -0.283 | 0.22 | 0.108 | 0.321 | -0.002 | -0.276 | -0.085 | 0.278 | -0.273 |

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 ripening
P7- Ripening to physiological maturity
P8- Vegetative period
P9- Reproductive period
P10- Ripening period

Maximum temperature, sunshine hours, evaporation and wind speed has significant negative correlation while minimum temperature, VPD I, VPD II and DTR has significant positive correlation during P5. Bss had a significant positive correlation during phenophase P6. Maximum temperature, minimum temperature, BSS, evaporation and WS had significant negative correlation while RD, RH I, RH II, VPD I and VPD II had significant positive correlation during Phenophase P7. Correlation between weather and 1000 grain weight of Jyothi is given in Table 4.28.

### 4.7.4.5. Correlation between weather and number of filled grains per panicle of Kanchana

Maximum temperature, DTR, BSS and evaporation exhibited significant negative correlation while afternoon RH had a significant positive correlation with filled grains during phenophase P1. Significant positive correlation was observed between filled grains and DTR during panicle initiation to booting period (P3). Significant positive correlation was observed between filled grains and afternoon VPD during booting to heading period (P4). Evaporation exhibited significant positive correlation with filled grains during phenophase P6.

Rainfall, rainy days, afternoon RH, afternoon VPD exhibited significant positive correlation while DTR and BSS had a significant negative correlation during vegetative period (P8). Maximum temperature, forenoon VPD, DTR and BSS had a significant negative correlation while rainfall, rainy days and RH (forenoon and afternoon) exhibited significant positive correlation during reproductive period (P9). Significant negative correlation was observed between rainfall and filled grains during ripening period. The correlation analyses between weather and number of filled grains per panicle of Kanchana are presented in Table 4.29.

Table .4.28. Correlation between 1000 grain weight and weather parameters during different phenophases of Jyothi

| Crop stages | Tmax | Tmin | RF | RD | RH I | RH II | VPD I | VPD II | DTR | SH | EVP | WS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1 | $-0.793^{**}$ | $-0.812^{**}$ | 0.424 | $0.643^{**}$ | $0.859^{**}$ | $0.677^{**}$ | $0.677^{**}$ | $0.702^{**}$ | 0.036 | $-0.678^{**}$ | $-0.798^{**}$ | $-0.860^{**}$ |
| P2 | $-0.476^{*}$ | $0.885^{**}$ | $0.491^{*}$ | $0.576^{**}$ | $0.698^{**}$ | $0.526^{*}$ | 0.266 | -0.142 | -0.282 | $-0.618^{**}$ | -0.299 | 0.110 |
| P3 | -0.385 | $-0.476^{*}$ | 0.417 | $-0.502^{*}$ | 0.370 | 0.026 | 0.258 | $-0.912^{**}$ | $-0.681^{**}$ | -0.002 | $0.593^{**}$ | -0.224 |
| P4 | $-0.617^{**}$ | $0.765^{**}$ | $0.655^{**}$ | $0.752^{**}$ | 0.324 | $0.519^{*}$ | $0.651^{**}$ | 0.426 | 0.097 | $-0.714^{**}$ | $-0.581^{**}$ | -0.102 |
| P5 | $-0.832^{**}$ | $0.667^{**}$ | 0.222 | 0.366 | 0.133 | 0.054 | $0.673^{**}$ | $0.548^{*}$ | $0.530^{*}$ | $-0.908^{**}$ | $-0.561^{*}$ | $-0.698^{**}$ |
| P6 | -0.332 | -0.376 | 0.114 | -0.412 | 0.065 | 0.059 | 0.206 | -0.156 | -0.351 | $0.444^{*}$ | 0.298 | -0.200 |
| P7 | $-0.793^{**}$ | $-0.812^{**}$ | 0.424 | $0.643^{**}$ | $0.859^{**}$ | $.677^{**}$ | $0.677^{**}$ | $0.702^{**}$ | 0.036 | $-0.678^{**}$ | $-0.798^{**}$ | $-0.860^{**}$ |

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 ripening
P7- Ripening to physiological maturity

Table.4.29. Correlation between weather and filled grains at different phenophases of Kanchana

| Kanchana | Stages | Tmax | Tmin | RF | RD | RH I | RH II | VPD I | VPD II | DTR | BSS | EVP | WS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Filled grains | P1 | -0.449* | -0.075 | 0.266 | 0.059 | 0.232 | 0.516* | -0.388 | 0.34 | -0.467* | -0.519* | -0.687** | -0.374 |
| | P2 | 0.309 | 0.159 | -0.287 | -0.245 | -0.286 | -0.404 | 0.306 | -0.323 | 0.258 | 0.388 | -0.247 | -0.066 |
| | P3 | 0.185 | -0.434 | 0.068 | 0.207 | -0.133 | 0.028 | -0.168 | 0.231 | 0.451* | 0.063 | 0.126 | -0.375 |
| | P4 | 0.187 | 0.234 | -0.078 | -0.337 | -0.224 | -0.14 | 0.442 | 0.445* | 0.157 | 0.107 | 0.385 | -0.108 |
| | P5 | -0.308 | -0.217 | 0.382 | 0.341 | -0.408 | 0.32 | -0.053 | 0.249 | -0.085 | -0.437 | -0.414 | 0.141 |
| | P6 | 0.281 | 0.071 | -0.271 | -0.259 | -0.259 | -0.071 | -0.196 | -0.331 | 0.292 | 0.36 | 0.461* | -0.145 |
| | P7 | 0.14 | -0.045 | 0.147 | 0.014 | 0.002 | -0.173 | -0.221 | 0.013 | 0.235 | 0.051 | 0.01 | 0.021 |
| | P8 | -0.414 | -0.037 | 0.565** | 0.502* | 0.443 | 0.500* | -0.287 | 0.575** | -0.479* | -0.469* | -0.401 | -0.495 |
| | P9 | -0.734** | 0.384 | 0.713** | 0.624* | 0.446* | 0.741** | -0.641** | 0.151 | -0.739** | -0.732** | 0.393 | -0.142 |
| | P10 | -0.258 | 0.121 | -0.756** | -0.368 | 0.435 | 0.096 | 0.435 | -0.116 | -0.303 | -0.086 | -0.418 | 0.416 |

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 ripening
P7- Ripening to physiological maturity
P8- Vegetative period
P9- Reproductive period
P10- Ripening period

### 4.7.4.6. Correlation between weather and number of spikelets per panicle of Kanchana

Maximum temperature, DTR and wind speed showed significant positive correlation while afternoon RH and afternoon VPD showed significant negative correlation with spikelets during phenophase P1. DTR and BSS exhibited significant positive correlation while rainfall, rainy days, RH (forenoon and afternoon) and afternoon VPD exhibited significant negative correlation with spikelets during phenophase P2. Maximum temperature and evaporation had a significant positive correlation while afternoon relative humidity showed significant negative correlation during P3. Maximum temperature, afternoon VPD and DTR exhibited significant positive correlation while rainy days, afternoon RH and wind speed exhibited significant negative correlation with spikelets during P4. Rainfall and rainy days exhibited significant positive correlation while minimum temperature had a significant negative correlation with spikelets during phenophase P5. Evaporation had a significant positive correlation while afternoon RH and VPD (forenoon and afternoon) showed significant negative correlation with spikelets during phenophase P6.

Minimum temperature and forenoon VPD showed significant negative correlation while forenoon RH and wind speed had a significant positive correlation during vegetative period (P8). Forenoon RH had a significant positive correlation with spikelets during reproductive period. Minimum temperature and afternoon VPD had a significant negative correlation while forenoon RH and DTR had a significant positive correlation with spikelets during ripening period (P10). The correlation analyses between weather and number of spikelets per panicle of Kanchana are presented in Table 4.30.

Table.4.30. Correlation between weather and spikelets at different phenophases of Kanchana

| Kanchana | Stages | Tmax | Tmin | RF | RD | RH I | RH II | VPD I | VPD II | DTR | BSS | EVP | WS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spikelets | P1 | 0.475* | 0.073 | -0.239 | -0.39 | -0.328 | -0.506* | 0.196 | -0.590** | 0.496* | 0.314 | 0.352 | 0.661** |
| | P2 | 0.439 | -0.262 | -0.573** | -0.546* | -0.534* | -0.659** | 0.332 | -0.506* | 0.462* | 0.596** | -0.31 | -0.071 |
| | P3 | 0.529* | 0.018 | -0.42 | -0.291 | 0.112 | -0.471* | 0.223 | 0.304 | 0.435 | -0.145 | 0.517* | -0.037 |
| | P4 | 0.474* | -0.212 | -0.354 | -0.503* | -0.386 | -0.448* | 0.222 | 0.560* | 0.517* | 0.337 | 0.416 | -0.547* |
| | P5 | -0.079 | -0.604** | 0.489* | 0.510* | -0.391 | 0.196 | -0.193 | 0.205 | 0.276 | -0.337 | -0.203 | -0.221 |
| | P6 | 0.243 | 0.056 | -0.233 | -0.071 | 0.188 | -0.540* | -0.572** | -0.645** | 0.125 | 0.416 | 0.606** | 0.197 |
| | P7 | 0.14 | -0.045 | 0.147 | 0.014 | 0.002 | -0.173 | -0.221 | 0.013 | 0.235 | 0.051 | 0.01 | 0.021 |
| | P8 | -0.315 | -0.719** | 0.211 | 0.258 | 0.637** | 0.217 | -0.484* | -0.061 | -0.279 | -0.248 | 0.272 | 0.504* |
| | P9 | 0.256 | 0.374 | -0.269 | -0.307 | 0.657** | -0.12 | 0.421 | 0.349 | 0.047 | 0.195 | 0.245 | -0.428 |
| | P10 | -0.2 | -0.654** | -0.207 | -0.78 | 0.667** | -0.164 | -0.007 | -0.447* | 0.574** | 0.211 | -0.209 | -0.327 |

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 ripening
P7- Ripening to physiological maturity
P8- Vegetative period
P9- Reproductive period
P10- Ripening period

#### 4.7.4.7. Correlation between weather and number of panicles per unit area of Kanchana

Positive significant correlation was observed between panicles and afternoon RH while maximum temperature, DTR, BSS and evaporation had a significant negative correlation during phenophase P1. Minimum temperature, rainfall, rainy days and forenoon RH showed significant positive correlation while DTR exhibited significant negative correlation with panicles during P2. Rainfall, BSS and wind speed showed significant positive correlation while maximum temperature and VPD (forenoon and afternoon) showed significant negative correlation with panicles during P3. Minimum temperature, rainfall, afternoon RH and wind speed showed significant positive correlation while maximum temperature, DTR and BSS had a significant negative correlation during P4. Minimum temperature showed significant positive influence while maximum temperature and DTR had a significant negative correlation with panicles during P5. Forenoon VPD exhibited significant positive correlation during phenophase P6. Maximum temperature, minimum temperature, evaporation and wind speed showed significant negative correlation while forenoon RH and forenoon VPD exhibited significant positive correlation with panicles during phenophase P7.

Maximum temperature, DTR and BSS showed significant negative correlation while rainfall, rainy days, RH (forenoon and afternoon) and afternoon VPD had a significant positive correlation during vegetative period (P8). Maximum temperature, DTR and BSS had a significant negative correlation while minimum temperature, rainfall, rainy days and RH (forenoon and afternoon) showed significant positive correlation during reproductive period (P9). Rainfall and wind speed had a significant negative correlation while forenoon RH showed significant positive correlation during ripening period (P10). The correlation analyses between weather and number of panicles per unit area of Kanchana are presented in Table 4.31.

Table.4.31. Correlation between weather and panicles at different phenophases of Kanchana

| Kanchana | Stages | Tmax | Tmin | RF | RD | RH I | RH II | VPD I | VPD II | DTR | BSS | EVP | WS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Panicles | P1 | -0.449* | -0.075 | 0.266 | 0.059 | 0.232 | 0.516* | -0.388 | 0.34 | -0.467* | -0.519* | -0.687** | -0.374 |
| | P2 | -0.366 | 0.646** | 0.493* | 0.546* | 0.477* | 0.38 | -0.177 | 0.042 | -0.469* | -0.366 | 0.073 | 0.282 |
| | P3 | -0.502* | -0.304 | 0.485* | 0.408 | 0.12 | 0.369 | -0.599** | -0.591** | -0.218 | 0.541* | -0.402 | 0.485* |
| | P4 | -0.547* | 0.489* | 0.563** | 0.369 | 0.355 | 0.575** | 0.179 | -0.153 | -0.599** | -0.516* | -0.209 | 0.650** |
| | P5 | -0.453* | 0.580** | -0.081 | -0.158 | 0.049 | 0.291 | 0.291 | 0.172 | -0.612** | -0.22 | -0.374 | 0.358 |
| | P6 | -0.149 | -0.211 | 0.017 | -0.084 | -0.178 | 0.219 | 0.455* | 0.377 | -0.069 | -0.247 | -0.238 | -0.439 |
| | P7 | -0.547* | -0.517* | 0.151 | 0.322 | 0.503* | 0.44 | 0.524* | 0.415 | -0.03 | -0.414 | -0.474* | -0.521* |
| | P8 | -0.478* | -0.199 | 0.560* | 0.540* | 0.543* | 0.513* | -0.424 | 0.477* | -0.518* | -0.502* | -0.418 | -0.207 |
| | P9 | -0.541* | 0.479* | 0.523* | 0.485* | 0.506* | 0.582** | -0.377 | 0.215 | -0.627** | -0.552* | -0.147 | 0.285 |
| | P10 | -0.319 | -0.231 | -0.649** | -0.408 | 0.513* | 0.113 | 0.437 | -0.101 | -0.113 | -0.15 | 0.0194 | -0.526* |

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 ripening
P7- Ripening to physiological maturity
P8- Vegetative period
P9- Reproductive period
P10- Ripening period

#### 4.7.4.7. Correlation between weather and 1000 grain weight of Kanchana

Maximum temperature had significant negative correlation while RH II and VP I had significant positive correlation during P1. Maximum temperature, VPD II, BSS and evaporation had significant ngative correlation while RH I, RH II, VPD I and wind speed had significant negative correlation during P2. Maximum temperature, DTR and BSS had significant negative correlations while minimum had significant positive correlation in phenophase P3. DTR and BSS had a significant negative correlation, while RD and RH II had significant positive correlation during phenophase P4. Rainfall and RH I had significant negative correlation, while minimum temperature, RH II and evaporation had significant positive correlation during phenophase P5. Maximum temperature, VPD II, DTR and wind speed had significant negative correlation while rainfall, RH I, VPD I and BSS had a significant positive correlation during P6. Maximum temperature had significant negative correlation while RH II and VPD I had significant positive correlation during phenophase P7. The results of correlation analyses between weather and 1000 grain weight of Kanchana are presented in Table 4.32.

## 4.8. INFLUENCE OF HEAT UNITS ON THE YIELD OF CROP

The correlation of heat units with the grain yield of Kanchana and Jyothi at different phenophases was determined by using the accumulated growing degree days (GDD), heliothermal units (HTU) and photothermal units (PTU). The results are presented in Table 4.33.

### 4.8.1. Influence of heat units on yield at different growth stages of Jyothi

Accumulated GDD exhibited significant negative correlation with grain yield during phenophase P1 (TP to AT) while significant positive correlations with grain yield during phenophase P3 (panicle initiation to booting). Accumulated HTU exhibited significant negative correlation with grain yield during phenophase P1, P4 (booting to heading), P5 (heading to flowering) and P7 (ripening to maturity). Accumulated PTU

Table 4.32. Correlation between 1000 grain wt and weather parameters during different phenophases of Kanchana

| Crop stages | Tmax | Tmin | RF | RD | RH I | RH II | VPD I | VPD II | DTR | SH | EVP | WS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1 | -0.556* | -0.211 | -0.034 | 0.260 | 0.331 | 0.576** | 0.654** | 0.289 | -0.434 | -0.385 | -0.351 | -0.375 |
| P2 | -0.684** | 0.086 | 0.649** | 0.310 | 0.688** | 0.661** | 0.770** | -0.526* | 0.457* | -0.657** | -0.748** | 0.506* |
| P3 | -0.472* | 0.543* | 0.056 | 0.404 | -0.201 | 0.179 | 0.079 | -0.088 | -0.640** | -0.768** | 0.091 | -0.315 |
| P4 | -0.346 | 0.326 | 0.122 | 0.461* | 0.432 | 0.530* | 0.276 | -0.205 | -0.534* | -0.457* | -0.092 | -0.337 |
| P5 | 0.182 | 0.640** | -0.528* | -0.058 | -0.493* | 0.727** | -0.251 | 0.343 | -0.177 | -0.228 | 0.501* | 0.418 |
| P6 | -0.603** | -0.218 | 0.537* | 0.113 | 0.469* | 0.158 | 0.801** | -0.842** | -0.737** | 0.537* | 0.701** | -0.594** |
| P7 | -0.556* | -0.211 | -0.034 | 0.260 | 0.331 | 0.576** | 0.654** | 0.289 | -0.434 | -0.385 | -0.351 | -0.375 |

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 ripening
P7- Ripening to physiological maturity

exhibited significant positive correlation during phenophase P3 while significant negative correlation was observed in grain yield during phenophase P7.

Table . 4. 33. Influence of heat units on yield of crop

| Variety | Heat units | Crop phenophases | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | P1 | P2 | P3 | P4 | P5 | P6 | P7 |
| Jyothi | GDD | -0.575** | 0.116 | 0.626** | -0.128 | -0.339 | 0.111 | -0.341 |
| | HTU | -0.712** | -0.223 | 0.087 | -0.537* | -0.720** | 0.107 | -0.725** |
| | PTU | -0.34 | 0.285 | 0.636** | -0.084 | -0.266 | 0.256 | -0.481* |
| Kanchana | GDD | -0.243 | -0.307 | 0.895** | 0.753** | 0.028 | -0.799** | -0.942** |
| | HTU | -0.816** | -0.960** | -0.169 | 0.316 | 0.302 | -0.868** | -0.323 |
| | PTU | 0.083 | -0.08 | 0.895** | 0.788** | 0.159 | -0.663** | -0.118 |

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

**4.8.1. Influence of heat units on yield at different growth stages of Kanchana**

Accumulated GDD exhibited significant positive correlation with phenophase P3 (panicle initiation to booting) and P4 (booting to heading) while significant negative correlation with phenophases P6 (flowering to ripening) and P7 (ripening to physiological maturity) with grain yield. Accumulated HTU showed significant negative correlation with grain yield during phenophases P1 (transplanting to active tillering), P2 (active tillering to panicle initiation) and P6 (flowering to ripening). Accumulated PTU had significant positive correlation with grain yield during phenophases P3 (panicle initiation to booting) and P4 (booting to heading) while significant negative correlation during phenophase P6 ((flowering to ripening).

### 4.8.1. Influence of heat units on yield at different growth stages of Kanchana

Accumulated GDD exhibited significant positive correlation with phenophase P3 (panicle initiation to booting) and P4 (booting to heading) while significant negative correlation with phenophases P6 (flowering to ripening) and P7 (ripening to physiological maturity) with grain yield. Accumulated HTU showed significant negative correlation with grain yield during phenophases P1 (transplanting to active tillering), P2 (active tillering to panicle initiation) and P6 (flowering to ripening). Accumulated PTU had significant positive correlation with grain yield during phenophases P3 (panicle initiation to booting) and P4 (booting to heading) while significant negative correlation during phenophase P6 ((flowering to ripening).

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

The correlation of heat units with the duration of different crop growth stages were determined using the accumulated growing degree days (GDD), heliothermal units (HTU) and photothermal units (PTU) for the corresponding growth stages. (Table 4.34)

Table.4.34. Influence of heat units on the duration of different growth stages

| Crop stages | GDD | HTU | PTU |
|---|---|---|---|
| P1 | 0.449* | -0.529* | 0.744** |
| P2 | 0.790** | -0.082 | 0.905** |
| P3 | 0.691** | -0.432 | 0.708** |
| P4 | -0.05 | -0.746** | 0.005 |
| P5 | 0.986** | 0.432 | 0.962** |
| P6 | 0.841** | 0.857** | 0.722** |
| P7 | 0.045 | 0.488* | 0.07 |

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

The different heat units exhibited significant positive correlation with crop growth stages. Accumulated GDD exhibited significant positive correlation with all the duration of crop growth except booting to heading (P4) and ripening to maturity (P7). Accumulated HTU exhibited significant positive correlation with duration from flowering to ripening (P6) and ripening to maturity (P7) while it showed significant negative correlation with the duration from transplanting to active tillering (P1) and booting to heading (P4). Accumulated PTU exhibited significant positive correlation with the duration of all growth stages except booting to heading (P4) and ripening to maturity (P7).

## 4.9. MODEL FOR THE PREDICTION OF GRAIN YIELD

Multiple linear regression equations were fitted for predicting the grain yield using mean weather variables experienced by the crop during the different phenophases. Some of the prediction equation developed is given in Table 4.35. The models could predict the yield satisfactory with an adjusted $R^2$ between yield and weather variables.

## 4.10. INCIDENCE OF PESTS AND DISEASES

During the course of investigation, incidence of various pests and diseases were comparatively less (Table 4.36).The incidence of pests was more in delayed planting crops compared to early plantings. The different pests noticed in the field during the crop season are Leaf folder (*Cnaphalocrocis medinalis*), Stem borer (*Scirphophaga incertulas*), Rice bug (*Leptocorisa acuta*) and Rice case worm (*Nymphula depunctalis*). Incidences of diseases were very less compared to pests and the two important diseases noticed in the field were sheath rot (*Sarocladium oryzae*) and sheath blight (*Rhizoctonia solani*).

Table.4.35. Yield prediction model for Jyothi and Kanchana

| Jyothi | | |
|---|---|---|
| Crop phases | Model | Adjusted $R^2$ |
| TP-AT | Yield= 7.258$^{**}$ – 0.058$^{**}$ RD – 0.319$^{**}$ BSS | 0.93 |
| AT-PI | Yield = -79.299$^{**}$ + 3.729$^{**}$ Tmin + 0.97$^{**}$ WS – 0.148$^{**}$ RD | 0.94 |
| PI-B | Yield = -53.717$^{**}$ + 0.284$^{**}$ VPD II + 3.247$^{**}$ EVP + 2.269$^{**}$ Tmin– 3.328$^{**}$ WS | 0.97 |
| H-F | Yield = 94.805$^{**}$- 2.613$^{**}$ Tmax + 0.861$^{**}$ BSS – 1.482$^{**}$ VPD I+ 0.834$^{**}$ VPD II | 0.97 |
| R-M | Yield = -1.079$^{**}$ - 0.543$^{**}$ VPD I+ 1.664$^{**}$ VPD II– 0.578$^{**}$ RD – 0.689$^{**}$ Tmin | 0.97 |
| Vegetative | Yield = 666.296$^{**}$ + 1.5$^{**}$ Tmax+ 30.273$^{**}$ Tmin-6.088$^{**}$ EVP+ 0.181$^{**}$ RD | 0.93 |
| Reproductive | Yield = 26.915$^{**}$ + 1.547$^{**}$ Tmin – 0.745$^{**}$ BSS + 0.142$^{**}$ VPDII - 0.154$^{**}$ RD | 0.93 |
| Kanchana | | |
| TP-AT | Yield = 3.999$^{**}$ + 0.007$^{**}$ RF + 0.315$^{**}$ VPD II – 0.212$^{**}$ Tmax | 0.98 |
| TP-F | Yield = 45.178$^{**}$ – 0.454$^{**}$ Tmax – 1.248$^{**}$ VPD I+ 0.269$^{**}$ WS | 0.97 |
| F-R | Yield = 29.7555$^{**}$ – 0.94$^{**}$ Tmin – 0.11$^{**}$ RD – 0.672$^{**}$ EVP – 0.187BSS$^{**}$ | 0.97 |
| R-M | Yield = 1212.092$^{**}$- 27.972$^{**}$Tmax – 17. 016$^{**}$ VPD I+ 8.511$^{**}$ WS | 0.95 |
| Vegetative | Yield = - 41.124$^{**}$ – 4.49$^{**}$ Tmax + 8.189$^{**}$ Tmin + 0.004$^{**}$ RF – 0.482$^{**}$ RD | 0.98 |
| Reproductive | Yield = 1.609$^{**}$ + 1.847$^{**}$ Tmin – 1.714$^{**}$ VPD II+ 0.012$^{**}$ RD | 0.95 |

TP-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-R- 50% flowering to ripening
R-M- Ripening to physiological maturity

Table 4.36. Pests and diseases observed in different dates of planting

| Date of planting | Pests | | | | Diseases | |
|---|---|---|---|---|---|---|
| | Leaf folder | Rice bug | Stem borer | Case worm | Sheath rot | Sheath blight |
| June 5th | ✓ | ✓ | ✓ | | ✓ | ✓ |
| June 20th | ✓ | ✓ | ✓ | | ✓ | ✓ |
| July 5th | ✓ | ✓ | ✓ | | ✓ | ✓ |
| July 20th | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| August 5th | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

## 4.11. CERES- RICE SIMULATION RESULTS

### 4.11.1. Calibration of genetic coefficient

Calibration was done with the independent data sets of two rice varieties viz. Jyothi and Kanchana for different genetic coefficient which characterize the rice performance. Accuracy in simulation of yield, phenology and growth requires the accurate genetic coefficient. These coefficients were adjusted until there was a close match between the observed and simulated dates of panicle initiation, anthesis, physiological maturity and grain yield (Table 4.37).

Table.4.37.Calibrated genetic coefficient for rice varieties, Jyothi and Kanchana

| Variety | P1 | P2R | P5 | P20 | G1 | G2 | G3 | G4 |
|---|---|---|---|---|---|---|---|---|
| Jyothi | 556.8 | 29.7 | 423.0 | 10.4 | 49.8 | 0.0235 | 1 | 1 |
| Kanchana | 465.0 | 149.1 | 404.9 | 12.1 | 49 | 0.0230 | 1 | 1 |

### 4.11.2. Simulated v/s Observed Grain yield

Measured grain yield of rice varied from 6712.5 kg $ha^{-1}$ (D1) to 4835 (D5) kg $ha^{-1}$ in variety Jyothi for different planting dates while in Kanchana the grain yield varied from 6355 kg $ha^{-1}$ (D2) to 4370 (D5) kg $ha^{-1}$ .

The model underestimated the grain yield in D1 and D4 while it was overestimated in D2, D3, and D5 planting in Jyothi. In case of Kanchana, the model underestimated the grain yield in D1 and D3 planting while it was overestimated in D2, D4 and D5. Error percent of CERES-Rice simulated grain yields from those corresponding observed ones during the crop season was presented in Table 4.38.

Table.4.38. Observed and predicted grain yield ($kgha^{-1}$) of rice with their percent error

| Planting dates | Jyothi | | | Kanchana | | |
|---|---|---|---|---|---|---|
| | Observed | Simulated | Error % | Observed | Simulated | Error % |
| D1 | 6712 | 5362 | -20 | 5797 | 5498 | -5.1 |
| D2 | 5622 | 5816 | 3.4 | 6355 | 5896 | -7.2 |
| D3 | 6088 | 6405 | -4.9 | 6132 | 6088 | -0.7 |
| D4 | 6520 | 6292 | -3.4 | 4427 | 6271 | 41.6 |
| D5 | 4835 | 6332 | 30.9 | 4370 | 6308 | 44.3 |
| Average | 6018.8 | 5978 | -0.6 | 5416.2 | 6012.2 | 11 |

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

### 4.11.3. Simulated v/s Observed Phenological development

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

#### 4.11.3.1. Days to panicle initiation

The results showed that, the observed duration of panicle initiation varied from 37 days to 34 days with respect to different planting dates for both the varieties. Days to panicle initiation as simulated by model were found to be overestimated in all the plantings but the error percentage is ± 10. Observed day and simulated day for anthesis was found same in D4 planting in Jyothi (Table 4.39).

In Kanchana, the simulated value for days taken to panicle initiation varies from 39 days to 33 days. Simulated values are over estimated in D1, D2 and D3 while it was underestimated in D5. The model error percentage is less than ± 10. A comparison between the model simulated and the field observed duration with their error percent are presented in Table 4.39.

Table.4.39. Observed and predicted panicle initiation days for rice with their percent error

| Planting dates | Jyothi | | | Kanchana | | |
|---|---|---|---|---|---|---|
| | Observed | Simulated | Error % | Observed | Simulated | Error % |
| D1 | 36 | 38 | 5.5 | 36 | 39 | 8.3 |
| D2 | 37 | 38 | 2.7 | 37 | 39 | 5.4 |
| D3 | 36 | 38 | 5.5 | 36 | 38 | 5.5 |
| D4 | 36 | 36 | 0 | 36 | 36 | 0 |
| D5 | 34 | 35 | -2.8 | 34 | 33 | -5.7 |
| Average | 36.8 | 36 | 2.2 | 36 | 37 | 2.7 |

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

#### 4.11.3.2. Days to anthesis

As effort was made to predict the days to anthesis and maturity for different treatments (date of planting and variety) and the results of predictions were evaluated with respect to the observed duration in days. The observed duration of days to anthesis varied between 74 days in first planting (D1) to 68 days in fifth planting (D5) for both the varieties and that simulated by CERES-Rice model for Jyothi varied from 73 (D1) days to 68 (D5) days while in Kanchana it varies from 74 (D1) days to 67 days (D5). The values of error percent in the model simulated days to anthesis and their correspondingly observed values for both the varieties are presented in Table 4.40.

Table.4.40. Observed and predicted anthesis days for rice with their percent error

| Planting dates | Jyothi | | | Kanchana | | |
|---|---|---|---|---|---|---|
| | Observed | Simulated | Error % | Observed | Simulated | Error % |
| D1 | 74 | 73 | -1.3 | 74 | 74 | 0 |
| D2 | 73 | 72 | -1.3 | 73 | 73 | 0 |
| D3 | 72 | 72 | 0 | 72 | 72 | 0 |
| D4 | 69 | 70 | 1.4 | 69 | 70 | 1.4 |
| D5 | 68 | 68 | 0 | 68 | 67 | -1.4 |
| Average | 71 | 71.2 | -0.3 | 71.2 | 71.2 | 0 |

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

### 4.11.3.3. Days to maturity

As far as the prediction of the days to physiological maturity was concerned, it can be seen from the Table 4.41 that, the predictions for all the five transplanting dates were with an error of one to two days. The observed duration of maturity varied from 104 days to 101 days with respect to different planting dates while the model predicted maturity ranges from 105 days to 99 days. The model overestimated the days in D1 and D3 while, in D5 it underestimated the maturity days.

Table 4.41. Observed and predicted maturity days for rice with their percent error

| Planting dates | Jyothi | | | Kanchana | | |
|---|---|---|---|---|---|---|
| | Observed | Simulated | Error % | Observed | Simulated | Error % |
| D1 | 104 | 105 | 0.9 | 104 | 105 | 0.9 |
| D2 | 104 | 104 | 0 | 104 | 104 | 0 |
| D3 | 102 | 104 | 1.9 | 102 | 103 | 0.9 |
| D4 | 102 | 102 | 0 | 102 | 101 | -0.9 |
| D5 | 101 | 99 | -1.9 | 101 | 97 | -3.9 |
| Average | 102.8 | 102.6 | 0.2 | 102.6 | 102 | -0.5 |

#### 4.11.3.4. Model Performance

The RMSE between the simulated and observed values with their D stat index for yield and phenological phases is given in Table 4.42.

Table 4.42. RMSE and D- index for Jyothi and Kanchana

| Variety | Panicle initiation day | | Anthesis day | | Maturity day | | Yield kg $ha^{-1}$ | |
|---|---|---|---|---|---|---|---|---|
| | RMSE | D-index | RMSE | D-index | RMSE | D-index | RMSE | D-index |
| Jyothi | 1.29 | 0.5 | 0.82 | 0.9 | 1.15 | 0.82 | 251.7 | 0.8 |
| Kanchana | 2.38 | 0.3 | 0 | 1 | 0.7 | 0.8 | 330.4 | 0.7 |

RMSE- Root Mean Square Error

# DISCUSSION

# 5. DISCUSSION

The present investigation was taken up with a view to simulate the phenology, growth and yield of Jyothi and Kanchana varieties of rice, calibrate their genetic coefficient and to determine the crop weather relationship. The results of the experiments details are discussed below.

## 5.1. EFFECT OF WEATHER ON GROWTH AND DEVELOPMENT OF RICE

### 5.1.1. Plant height

The results indicated that the plant height at weekly intervals after transplanting was influenced by dates of planting. It showed a gradual decreasing trend from first planting (June 5$^{th}$) to last planting (August 5$^{th}$) in both the varieties. Minimum height of 120.4 cm was recorded in Jyothi for August 5$^{th}$ planting. Reduction in plant height with respect to delay in planting date was also reported by Singh *et al.,* (2012). The influence of temperature may be the reason for the reduction in plant height with delay in plantings. During the study period there was increase in maximum temperature and DTR which may be the reason for the reduction in the plant height. Maximum temperature beyond 30°C reduces the plant height during vegetative and reproductive period in both the varieties. This is in agreement with findings of Chang *et al.,* (2009). The correlation studies also showed that the high minimum temperature during the early stages of the crop favours the plant height in both the varieties (Table 5.1.)

Table 5.1. Correlation coefficients between weather parameters and plant height

| Variety | Tmax (° C) | Tmin (° C) | RH I (%) | RH II (%) | RF (mm) |
|---|---|---|---|---|---|
| Jyothi | -0.652 | 0.757** | 0.417 | 0.626** | 0.605** |
| Kanchana | -0.478 | 0.444* | 0.172 | 0.42 | 0.439 |

Relative humidity favoured the plant height during early plantings which was in agreement with the studies conducted by Hirai *et al.,* (2000). Bright sunshine hours had

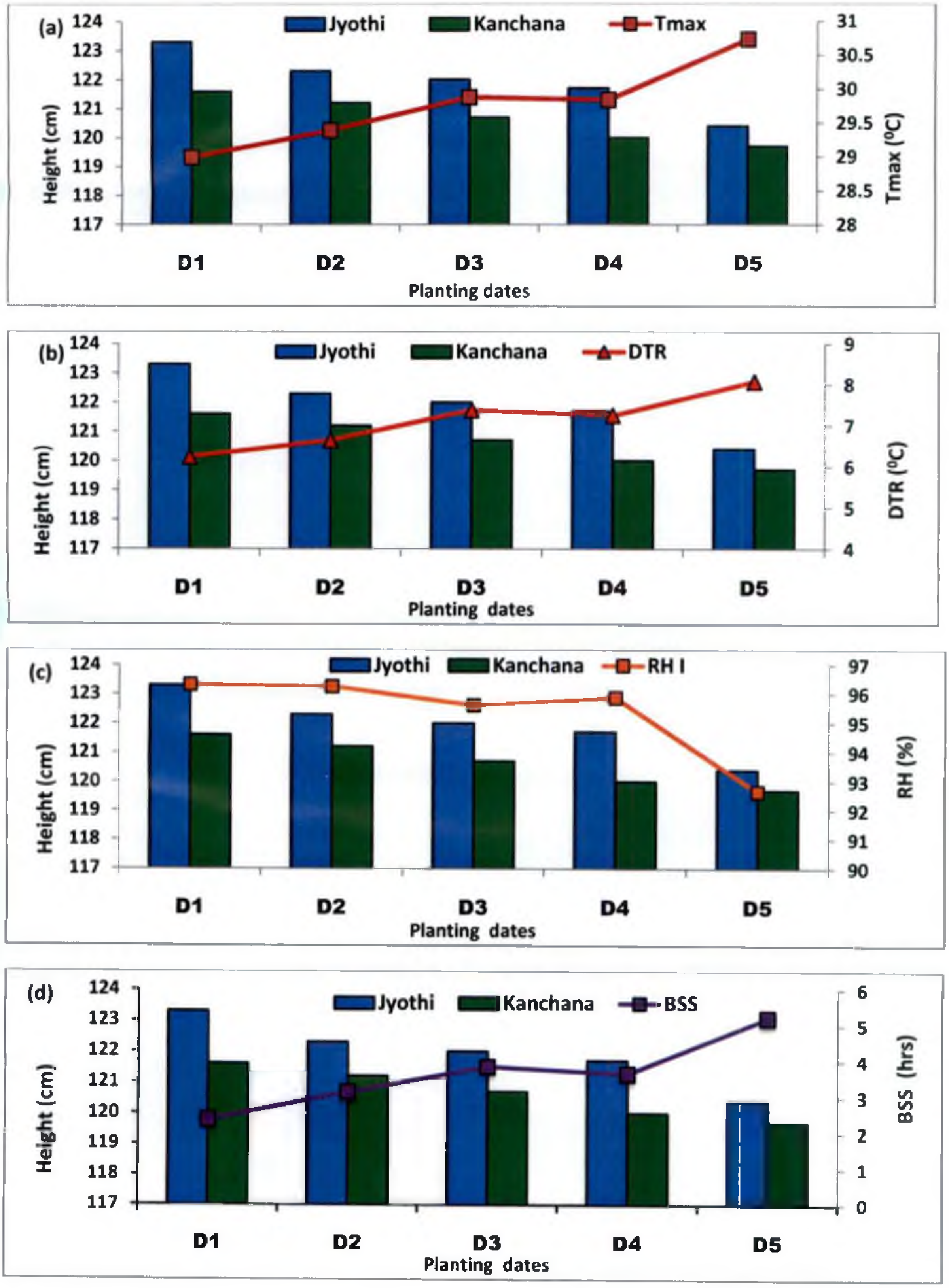



**Fig.5.1. Influence of weather parameters on height with respect to different planting date**

a negative influence on the plant height. BSS beyond 3.0 hours may also decrease the plant height during vegetative and reproductive period (Fig 5.1).

### 5.1.2. Leaf area index (LAI)

The highest leaf area index was recorded at 75 days after planting in both the varieties. LAI was influenced by different planting dates and it showed decreasing trend with delay in planting dates. Leaf area index increases and reached maximum at 75 days after planting in both the varieties and there after leaf area declined in all the planting dates (Fig 5.2 (A) and Fig.5.2 (B). This is in concurrence with the findings of Ahmad *et al.,* (2009).

The high LAI for the earlier planted crop may be due to high relative humidity, low sunshine hours and diurnal temperature range during beginning of grain filling stage. These are in agreement with findings of Sunil (2000).

Table 5.2. Correlation coefficients between weather parameters and Leaf area Index

| Variety | Tmax (°C) | Tmin (°C) | RH I (%) | RH II (%) | RF (mm) |
|---|---|---|---|---|---|
| Jyothi | -0.642 | 0.545* | 0.502* | 0.669** | 0.620** |
| Kanchana | -0.664 | 0.531* | 0.435 | 0.653** | 0.628** |

Rainfall and rainy days had positively influenced the LAI on both the varieties during June 5$^{th}$ planting (Table 5.2). Reduction in LAI during late planting was attributed to increase in maximum temperature during flowering period. Evaporation and BSS also showed a negative impact on LAI. BSS beyond 3.0 hours had a negative impact on LAI in late planted crops.

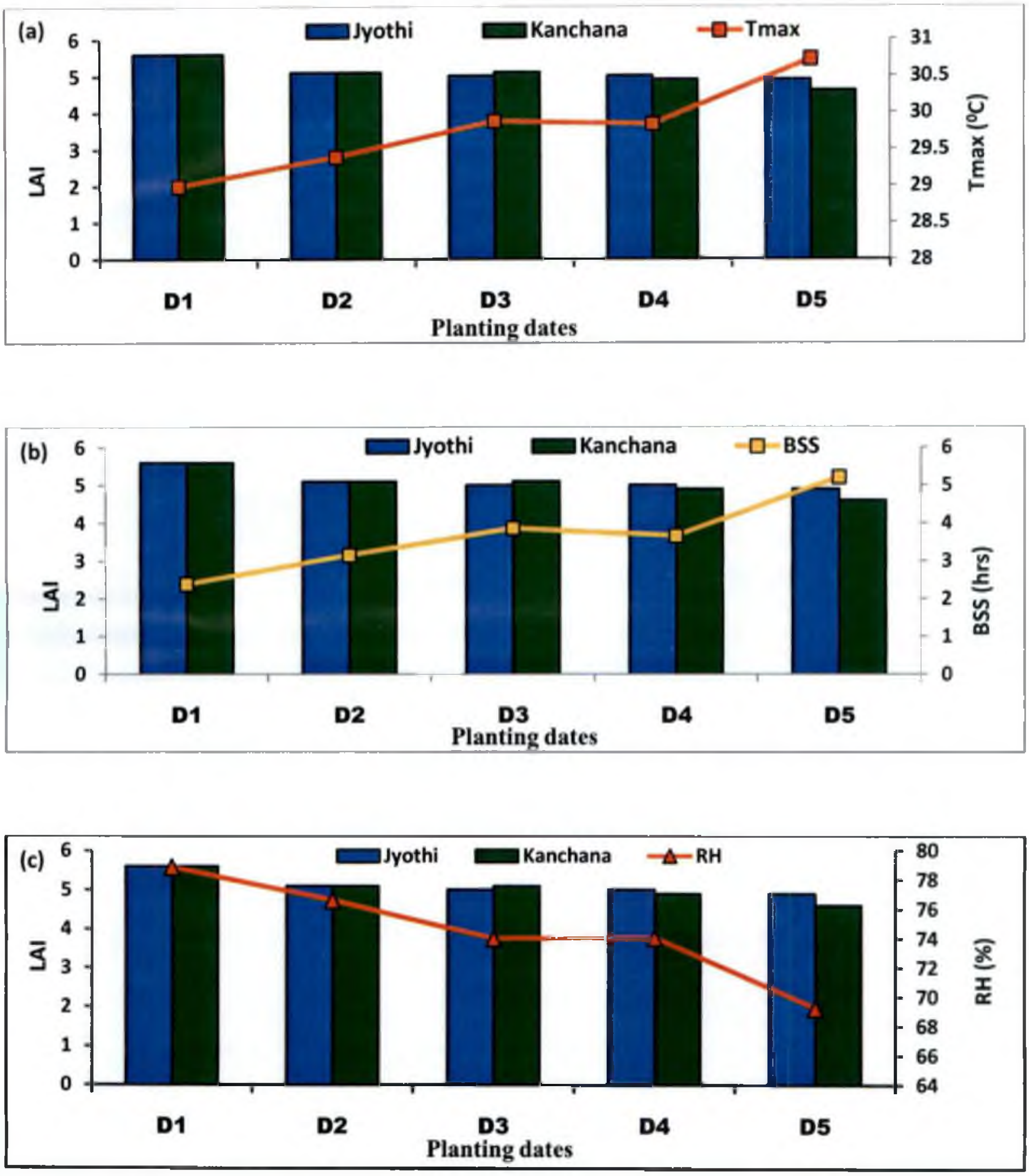
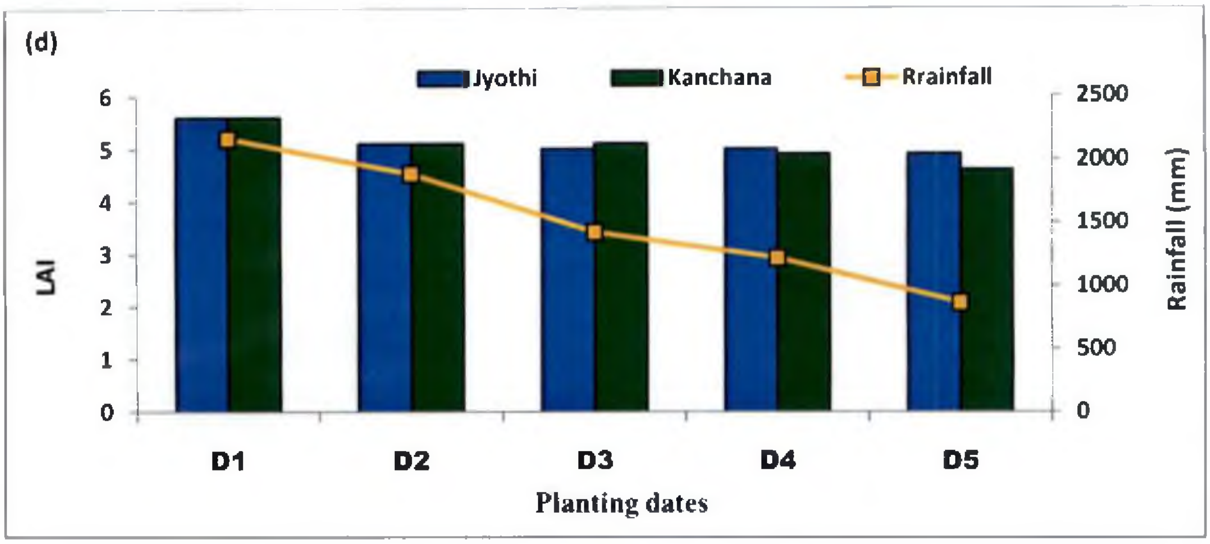



**Fig.5.2.A. Influence of weather parameters on LAI with respect to different planting dates**



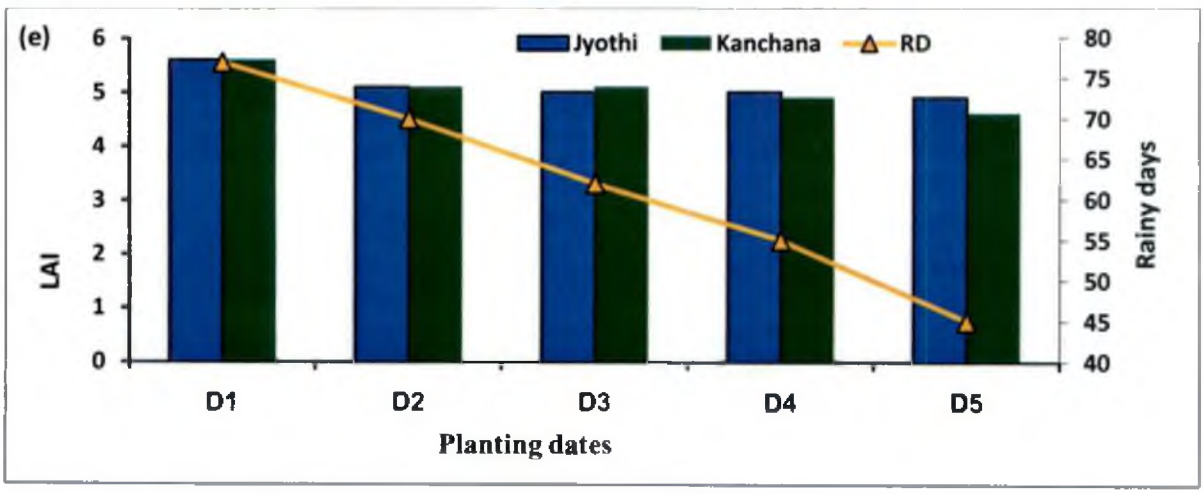




**Fig.5.2.B. Influence of weather parameters on LAI with respect to different planting dates**

### 5.1.3. Dry matter production

Delay in planting dates significantly reduced the dry matter accumulation in both the varieties. Early planting crop availed more time to complete its life cycle because of appropriate environmental conditions and hence influence the dry matter production. The maximum temperature negatively influenced the dry matter production on delayed plantings while relative humidity (Table 5.3) and minimum temperature during the early planting periods favoured the high biomass in both the varieties (Fig.5.3). This was supported by studies of Hirai *et al.*, (1992) and Singh *et al.*, (2012). Diurnal temperature also showed negative influence on plant dry matter production with delay in plantings as also reported by Peng *et al.*, (2004) and Nagarajan *et al.*, (2010).

Table 5.3. Correlation coefficients between weather parameters and Dry matter accumulation

| Variety | Tmax (° C) | Tmin (° C) | RH I (%) | RH II (%) | RF (mm) |
|---|---|---|---|---|---|
| Jyothi | -0.451 | 0.730** | 0.683** | 0.492* | 0.404 |
| Kanchana | -0.218 | 0.679** | -0.049 | 0.117 | 0.163 |

### 5.1.4. Number of effective tillers per $m^{-2}$

Among yield components, effective tillers are very important because the final yield is mainly a function of the number of panicles bearing tillers per unit area. This increase of effective tillers per $m^{-2}$ at June $5^{th}$ planting in both the varieties was attributed to favourable environmental conditions which enabled the plant to improve its growth and development as compared to other planting dates. Increase in temperature may reduce the number of effective tillers in late planted crops (Fig.5.4). This is in conformity with findings of Shah *et al.*, (2005).

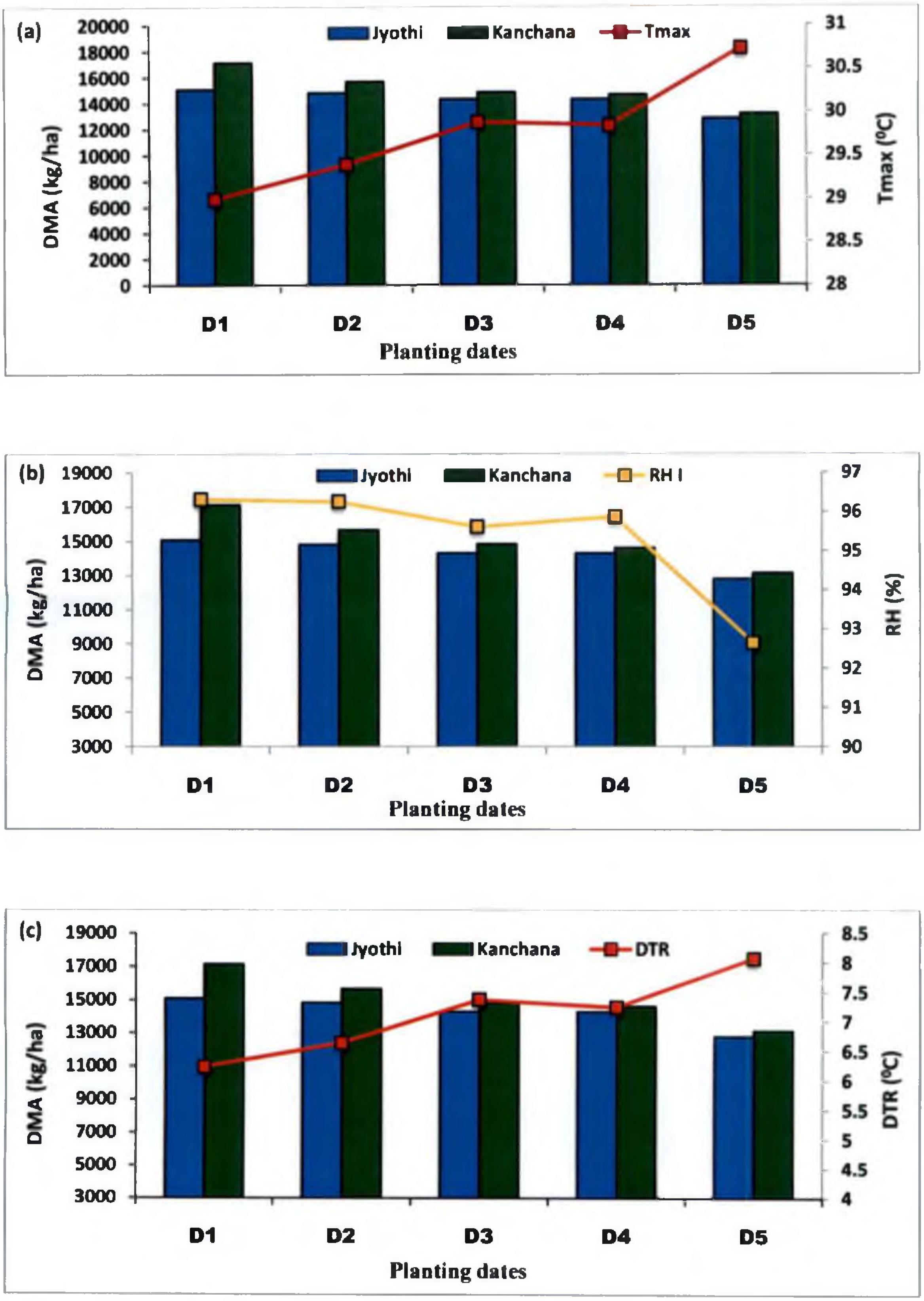



**Fig.5.3. Influence of weather parameters on DMA with respect to different planting dates**

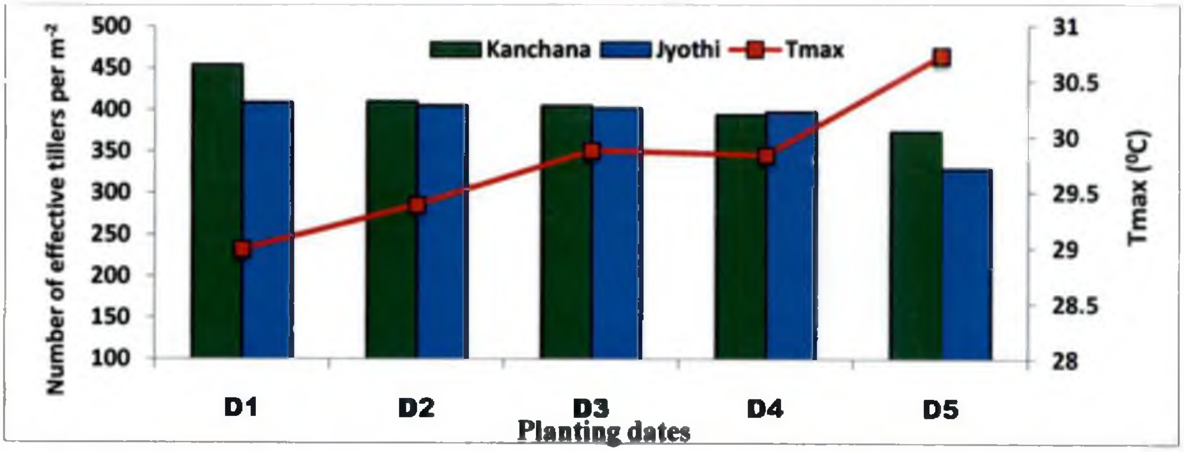



Fig.5.4. Influence of maximum temperature on effective tillers with respect to different planting dates

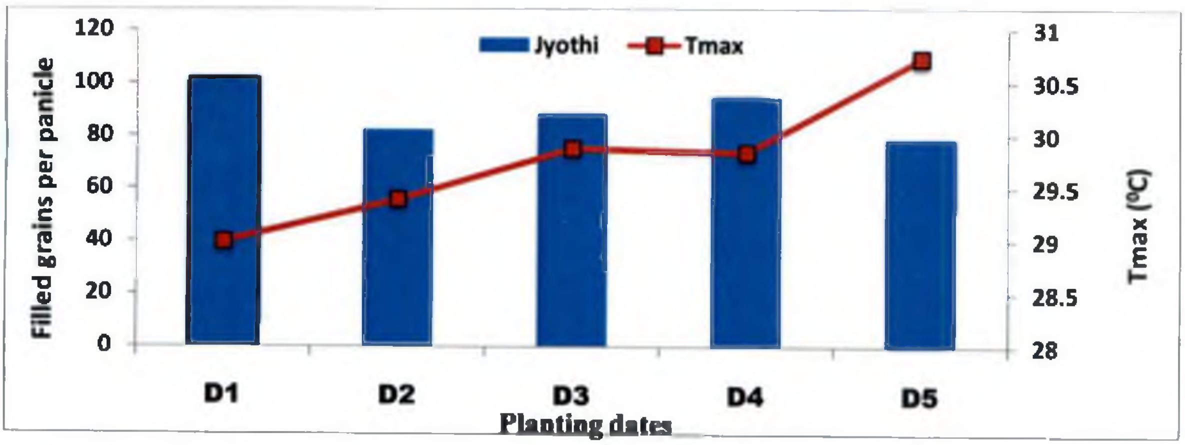



Fig.5.5. Influence of maximum temperature on filled grains with respect to different planting dates

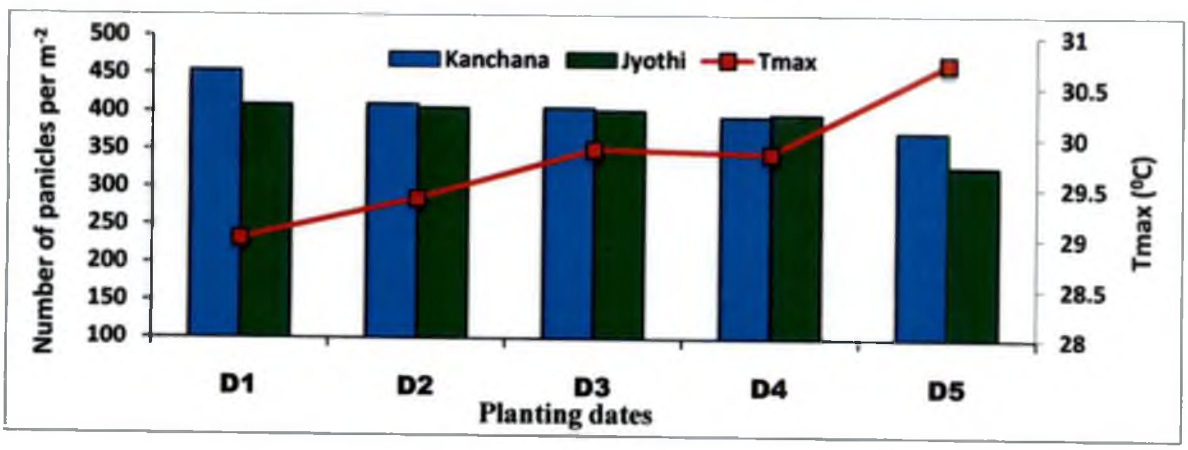



Fig.5.6. Influence of maximum temperature on panicles with respect to different planting dates

### 5.1.5. Number of filled grains per panicle

There was a significant difference between varieties in terms of number of filled grains per panicle. The highest number of filled grains per panicle was achieved for Jyothi. This arises from the genetic difference and different cultivar responses to environmental conditions. Planting date significantly influenced the number of filled grains per panicle in Jyothi (Fig.5.5).

Higher temperature during the grain filling and maturity stages decreased the number of filled grains per panicles in Jyothi on August $5^{th}$ planting. The results were in line with findings of Shahram *et al.,* (2012). High temperature during the ripening stage can decrease the carbohydrate supply from vegetative organs to the developing grains resulting in poor grain filling was also reported by Shimono and Ishii, (2012).

### 5.1.6. Number of panicles per unit area

It is evident from the data that number of panicles per unit area was affected significantly by different planting dates. The total number of panicles gradually showing a decreasing trend as the planting was delayed (Fig.5.6). The number of panicles decreased with rising temperature. These results are in line with Shah *et al.,* (2005) and Akbar *et al.,* (2010).

### 5.1.7. Number of spikelets per panicle

Number of spikelets per panicle was significantly affected by different planting dates. The reduction of spikelets in June $20^{th}$, July $5^{th}$ and August $5^{th}$, planting was might be due to high temperature and high relative humidity during the heading and flowering stages which adversely affected the formation of number of spikelets in Jyothi (Fig.5.7). These results are in agreement with findings of Yan *et al.,* (2010).

Number of spikelets observed in Kanchana was less significant with respect to different planting dates. The number of spikelets was less in Kanchana compared to

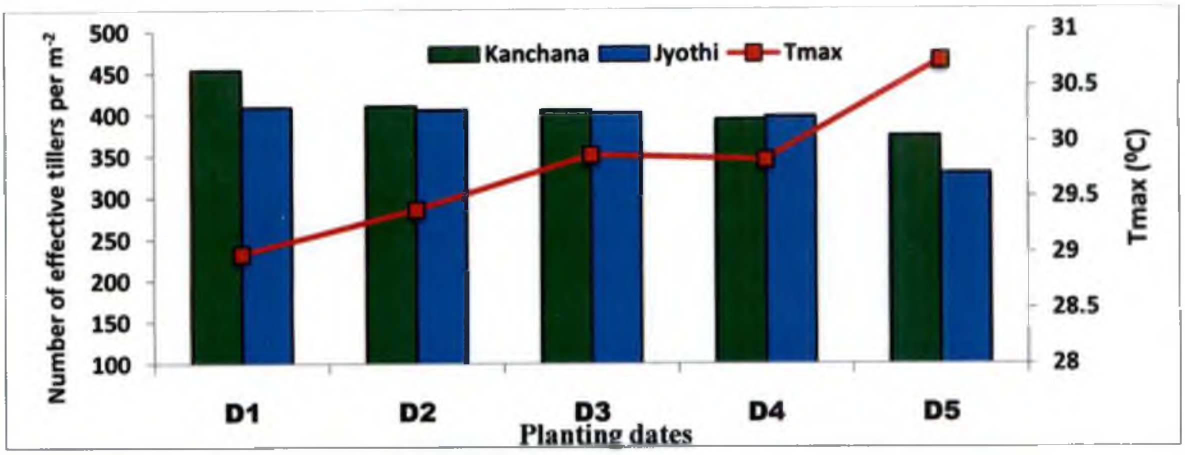



**Fig.5.4. Influence of maximum temperature on effective tillers with respect to different planting dates**

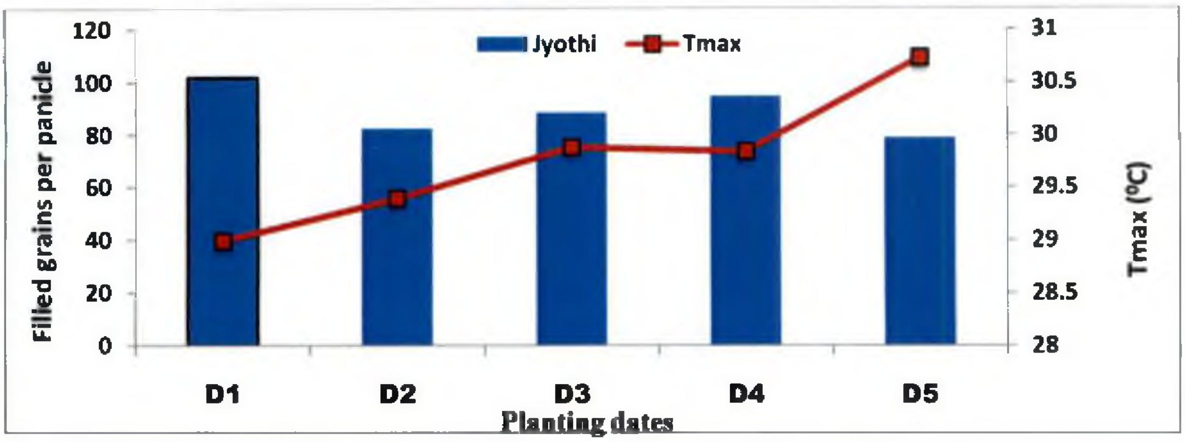



**Fig.5.5. Influence of maximum temperature on filled grains with respect to different planting dates**

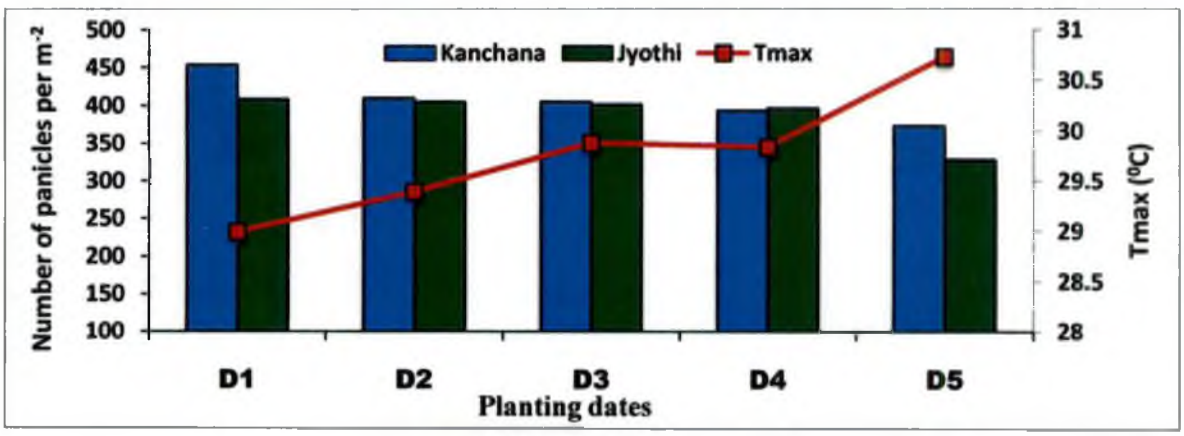



**Fig.5.6. Influence of maximum temperature on panicles with respect to different planting dates**

Jyothi. Significant difference in number of spikelets per panicle was noticed in Jyothi and Kanchana, was due to varietal characteristics.

### 5.1.8. 1000 grain weight

Variations in 1000 grain weight were very less with respect to different planting dates in both the varieties. It ranged from 24.5g to 27.4g in Jyothi. Maximum grain weight was recorded in June 5$^{th}$ planting while the minimum was recorded in August 5$^{th}$ planting. Highest grain weight in early plantings may be due to low temperature during grain filling period. Similar results were also reported by Chowdhury (1978). Lowest grain weight was recorded in August 5$^{th}$ planting was attributed to high temperature (Fig.5.8). Wakamatsu *et al.*, (2007) also reported the same in grain weight.

In Kanchana, the maximum grain weight was recorded from June 20$^{th}$ (27.0g) and July 5$^{th}$ (26.5g) plantings. Low temperature during ripening period favoured the maximum grain weight in Kanchana during this planting. These are in agreement with findings of Ahmad *et al.,* (2008).

### 5.1.9. Straw yield

The straw yield obtained from Jyothi was found to be non significant with respect to different planting dates while in Kanchana, small variations are found in straw yield planted at different dates. Crops taken during early dates received high relative humidity with low temperature during the entire growth period favoured more straw yield (Fig.5.9). August 5$^{th}$ planted crop experienced low relative humidity with high temperature reduced the straw yield compared to June 20$^{th}$ planting. This is in conformity with findings of Sreelatha (1989).

### 5.1.10. Grain yield

Planting date significantly affected grain yield in both the varieties. There was a significant difference among varieties in terms of grain yield. The highest grain yield was obtained in Jyothi for June 5$^{th}$ and July 20$^{th}$ planting. Number of panicles per unit

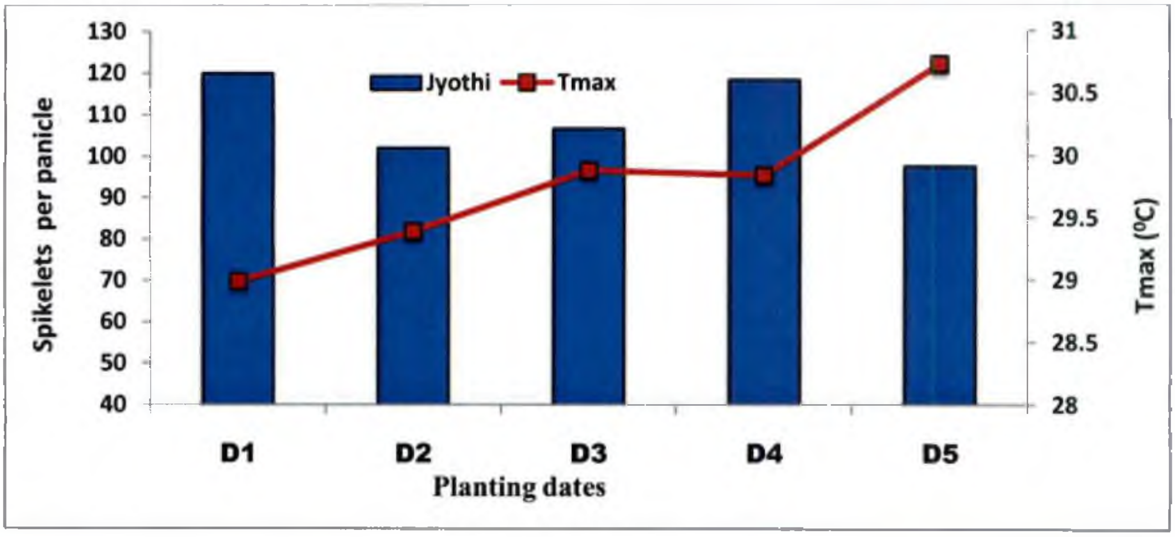



**Fig.5.7. Influence of maximum temperature on spikelets with respect to different planting dates**

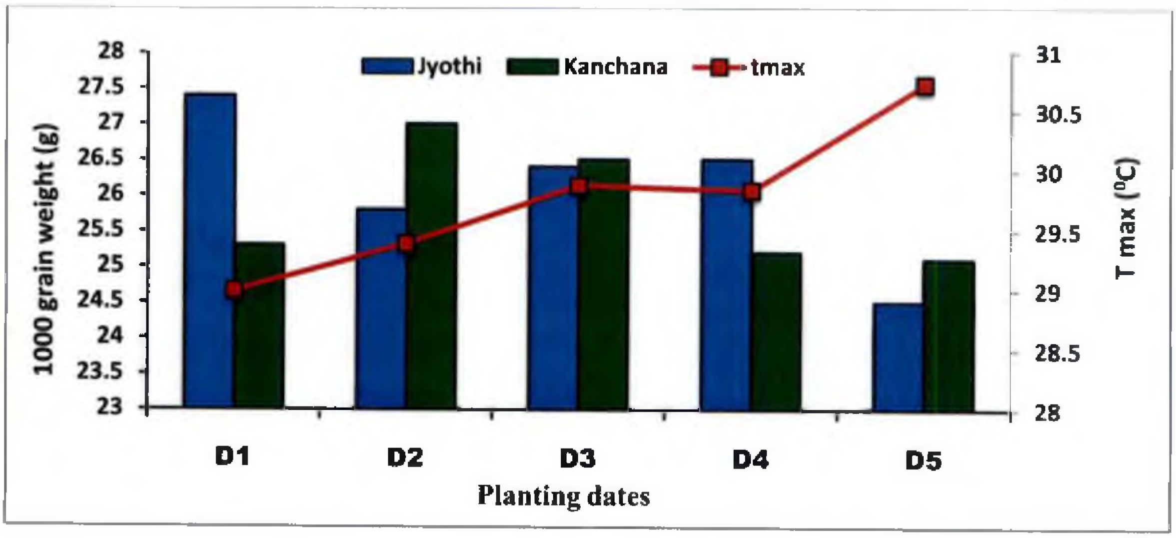



**Fig.5.8. Influence of maximum temperature on grain weight with respect to different planting dates**

area, filled grains per panicle and 1000 grain weight contributed the high yield in June $5^{th}$ and July $20^{th}$ planted crops. The reduction in grain yield on June $20^{th}$ planting was due to increased relative humidity with increased temperature at the heading stage which might have induced grain sterility and thus reduced the yield (Fig.5.10). Grain yield decreased in August $5^{th}$ planting was due to high temperature prevailed throughout the growing period. These results are in agreement with findings of Abeysiriwardena *et al.,* (2002).

In Kanchana, less grain yield recorded in July $20^{th}$ planting may be due to high wind speed and more rainfall during ripening to maturity period which caused lodging. Reduction in grain yield in August $5^{th}$ planting was due to high temperature and less rainfall during the growth period, which was also reported by Wahid *et al.*, (2007). High yield was obtained in July $20^{th}$, and July $5^{th}$ planted crops were contributed by increased 1000 grain weight during this period with favourable weather conditions.

## 5.2. EFFECT OF WEATHER ON THE DURATION OF PHENOLOGICAL STAGES

The duration taken for each growth stages was found to be same for both the varieties with respect to different planting dates. Similar results in which different varieties have same pheophases were observed in the study conducted by Sajitha , (2002).

Early planted crops took more days to attain maturity compared to late planted crops. Results revealed that days taken to complete life cycle was reduced with delay in planting dates. It might be due to the fact that the weather conditions prevails during each dates were not the same for all the planting dates even though the season was same.

From the correlation analysis, it was identified that maximum temperature and bright sunshine hours during transplanting to active tillering and booting to heading reduced the phenophases in early planting crops while relative humidity, rainfall and rainy days during this period influenced the number of days taken for the phenophases.

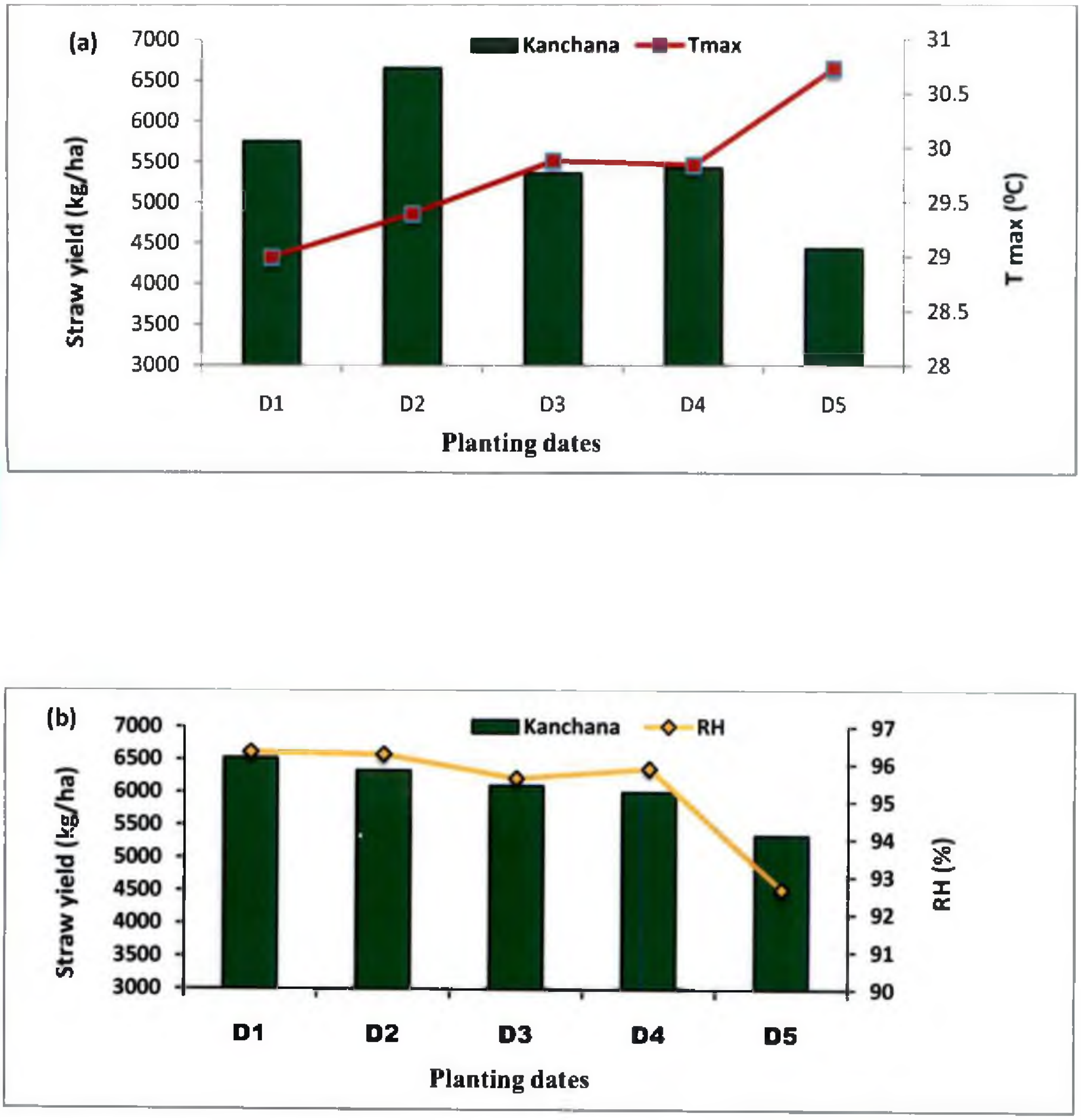



**Fig.5.9. Influence of maximum temperature on straw yield with respect to different planting dates**

Relative humidity during heading to flowering period had a negative influence on phenophase. Maximum temperature and bright sunshine hours during flowering to ripening and ripening to physiological maturity increases the phenophases in late planted crops compared to early plantings. Low relative humidity, rainfall and rainy days during this period increase the phenophase in late planted crops.

Days to physiological maturity and 50% flowering were significantly shorter with late transplanting than with early transplanting. This view was supported by work of Nagarajan *et al.*, (2010). The various phenological stages like active tillering, panicle initiation, ripening and physiological maturity taken for the crops with delayed planting was found to be shorter than early planting. This reduction in phenological phases during late planting was attributed to the increase in temperature (Fig.5.11 and 5.12). Similar results were reported by Rani and Maragatham (2013).

Environmental conditions like less maximum temperature and high relative humidity was most favourable for early planted crops to attain its full maturity. Similar findings were also reported by Soleymani and Shahrajabian (2011). Delay in planting dates experienced high temperature throughout the growing season which reduced the growth duration. This was in agreement with studies of Darko *et al.*, (2013).

The heat units like growing degree days (GDD) and photothermal units (PTU) exhibited significant positive influence on crop duration from P1 to P7 except P4 while PTU exhibited positive influence on duration taken for P5, P6 and P7. Increase in GDD and HTU decreased the number of days taken for transplanting to maturity in delayed plantings (Fig.5.13 and 5.14). Similar findings were reported by Praveen *et al.*, (2013) and Sandhu *et al.*, (2013).

The optimum range of weather variables for Jyothi and Kanchana was identified and presented in Table 5.4 and Table 5.5.

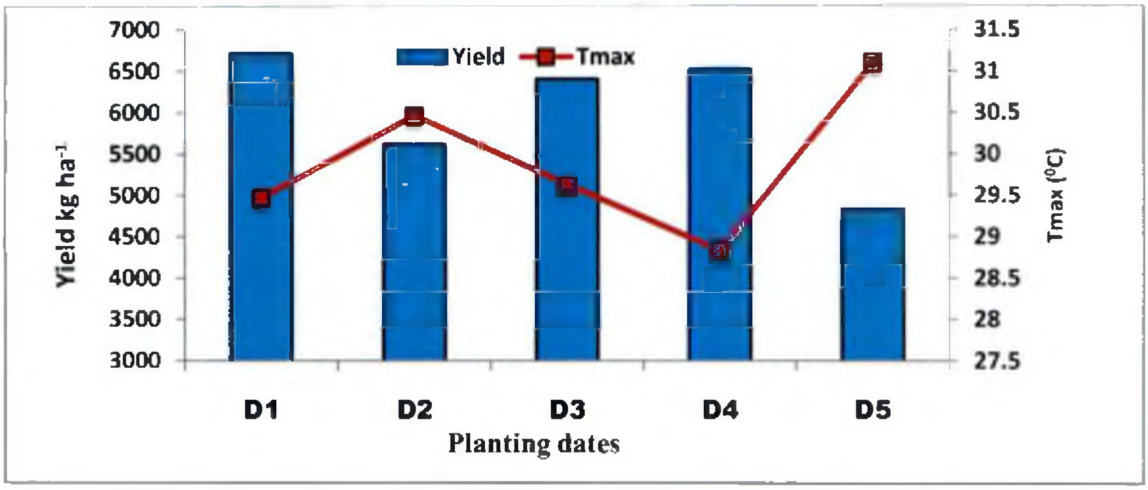



Fig.5.10.Influence of maximum temperature on yield with respect to different planting dates

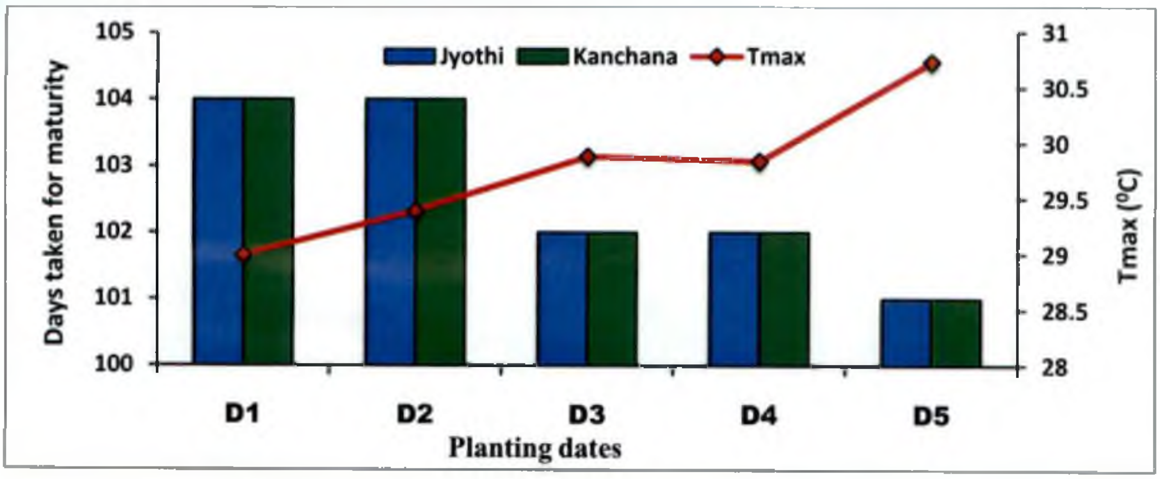



Fig.5.11. Influence of maximum temperature on days taken for maturity

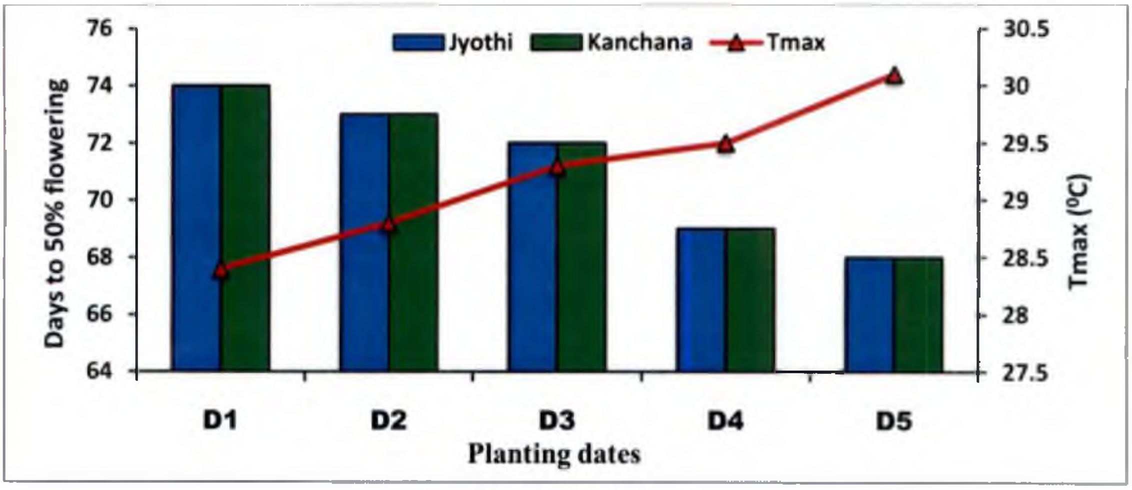



Fig.5.12. Influence of maximum temperature on days taken for flowering

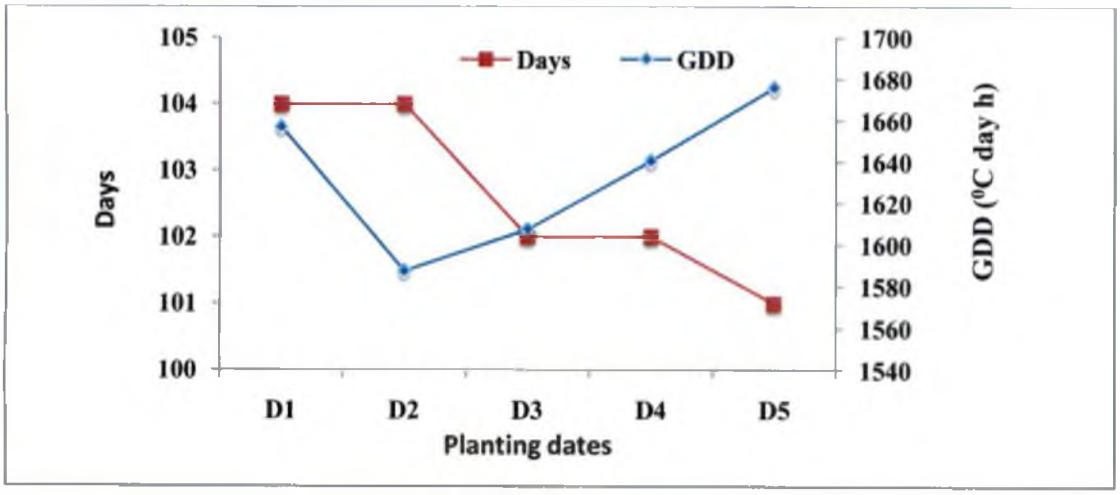



Fig. 5.13. Influence of GDD on days to physiological maturity

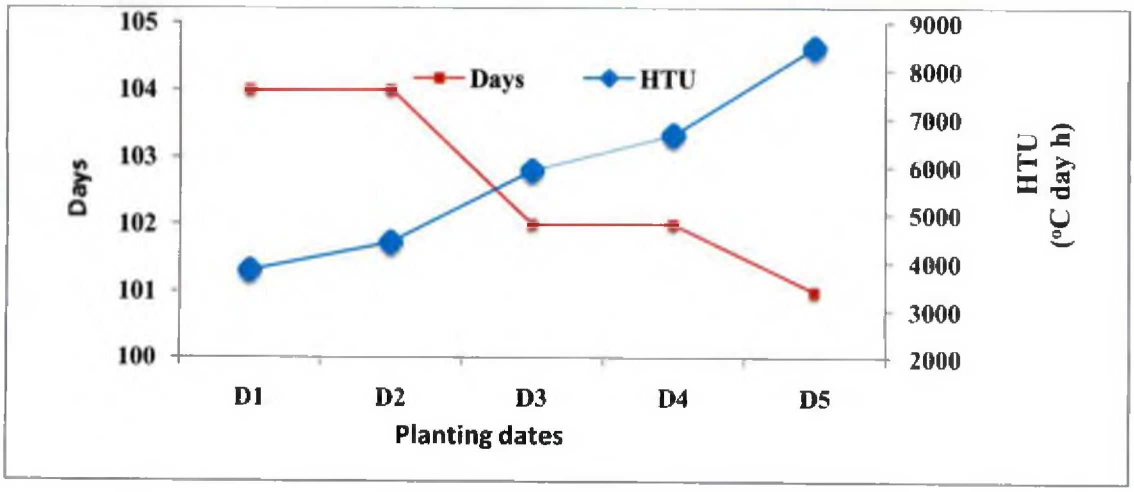



Fig. 5.14. Influence of HTU on days to physiological maturity

Table. 5.4. Optimum range of weather variables for Jyothi

| Jyothi | Tmax (°C) | Tmin (°C) | VPI (mm Hg) | VPII (mm Hg) | RHI (%) | RHII (%) | RF (mm) | BSS (h) |
|---|---|---|---|---|---|---|---|---|
| P1 | 27-30 | 21.5-23.5 | 21-22 | 22-23 | 96-98 | 75-95 | 20 | 2 |
| P2 | 28-30 | 21.5- 23.5 | 21.6 – 23.6 | 21-24.6 | 96-98 | 85-90 | 20-40 | 1 |
| P3 | 27-29 | 22.5-23 | 21-22.5 | 22-23 | 96-98 | 85-95 | 15-50 | 1 |
| P4 | 27-30 | 21.8-23 | 22.5-23 | 22.5-22.8 | 95-97 | 75-88 | 30 | 1 |
| P5 | 29-30 | 22-23.7 | 21-22.8 | 21.5-22.5 | 96-98 | 65-77 | - | 5 |
| P6 | 29-32 | 22-23 | 21-22.7 | 20.5-22.5 | 93-98 | 65-88 | 7.5 | 8 |
| P7 | 29-30 | 21.2-23 | 21-22.7 | 21.6-22.1 | 96-98 | 70-90 | 1 | 6.5 |

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 ripening
P7- Ripening to physiological maturity

During transplanting to active tillering (P1) the optimum temperature for Jyothi was identified as 27 – 30 °C. Tmax more than 30°C had a harmful effect on crop. Optimum minimum temperature was 21.5 – 23.5 °C .More than 23.5 had a negative effect on crop. The optimum VPI and VPII ranges from 21-22 mm Hg and 22-23 mm Hg respectively. VPI less than 22 and VPII more than 22 had a negative influence on crop. RHI and RHII range from 96-98% and 75% -95 %. RH I less than 96% and RH II less than 75 % was harmful for crop. Rainfall less than 20mm adversely affects the crop. BSS less than 2 hours was harmful for crop during this period.

During active tillering to panicle initiation (P2) the optimum temperature for Jyothi was identified as 28-30 °C. Tmax more than 30 °C had a negative impact on crop.Optimum minimum temperature was 21.5 – 23.5 °C .More than 23.5 °C had a negative effect on crop. The optimum VPI and VPII ranges from 21.6 – 23.6mm Hg and 21-24.6mm Hg respectively. VPI less than 21.6 and VPII more than 21 had a negative influence on crop. RHI and RHII range from 96-98% and 85% -90 %. RH I less than 96% and RH II less than 85 % was harmful for crop. Rainfall less than 20mm adversely affects the crop. BSS less than 1 hour was harmful for crop during this period.

During panicle initiation to booting (P3) the optimum temperature for Jyothi was identified as 27-29 °C. Tmax more than 29 °C had a negative impact on crop. Optimum minimum temperature was 22.5-23 °C , More than 23 °C had a negative effect on crop. The optimum VPI and VPII ranges from 21-22.5 mm Hg and 22-23 mm Hg respectively. VPI less than 22.5 and VPII less than 22 had a negative influence on crop. RHI and RHII range from 96-98 %and 85% -95 %. RH I less than 96% and RH II less than 85 % was harmful for crop. Rainfall less than 15mm adversely affects the crop. BSS more than 1 hour was harmful for crop during this period.

During booting to heading (P4) the optimum temperature for Jyothi was identified as 27- 30 °C. Tmax more than30 °C had a negative impact on crop. Optimum minimum temperature was 22-23.7°C, less than 22 °C had a negative effect on crop. The optimum VPI and VPII ranges from 22.5-23 mm Hg and 22.5-22.8 mm Hg respectively .VPI less than 22.5 and VPII less than 22.5 had a negative influence on crop. RHI and RHII range from 95-97%and 75-88%. RH I less than 95% and RH II less than 75 % was harmful for crop. Rainfall less than 30 mm adversely affects the crop. BSS more than 1 hour was harmful for crop during this period.

During heading to flowering (P5) the optimum temperature for Jyothi was identified as 29- 30 °C. Tmax more than30 °C had a negative impact on crop. Optimum minimum temperature was 21.8-23 °C , More than 23 °C had a negative effect on crop. The optimum VPI and VPII ranges from 21-22.8mm Hg and 21.5-22.5mm Hg respectively. VPI less than 21 and VPII less than 21.5 had a negative influence on crop. RHI and RHII range from 96-98 %and 65-77 %. RH I less than 96% and RH II less than 65 % was harmful for crop. BSS more than 5 hour was harmful for crop during this period.

During flowering to ripening (P6) the optimum temperature for Jyothi was identified as 29- 32 °C. Tmax more than 32 °C had a negative impact on crop. Optimum minimum temperature was 22-23 °C, more than 23 °C had a negative effect on crop. The optimum VPI and VPII ranges from 21-22.7 mm Hg and 20.5-22.5mm Hg respectively. VPI more than 22.7 and VPII more than 22.5 had a negative influence on crop. RHI and RHII range from 93 – 98 %and 65-88%. RH I less than 93% and RH II less than 65 % was harmful for crop. Rainfall more than 8 mm adversely affects the crop. BSS more than 7.5 hour was harmful for crop during this period.

During ripening to maturity (P7) the optimum temperature for Jyothi was identified as 29- 30 °C. Tmax more than 30 °C had a negative impact on crop. Optimum minimum temperature was 21.2-23 °C, more than 23 °C had a negative effect on crop. The optimum VPI and VPII ranges from 21-22.7 mm Hg and 21.6-22.1 mm Hg respectively. VPI less than 21.6 and VPII less than 21.6 had a negative influence on crop. RHI and RHII range from 96 – 98 %and 70 – 90 %. RH I less than 96 % and RH II less than 70 % was harmful for crop. Rainfall more than 1 mm influences the crop. BSS more than 6.5 hour was harmful for crop during this period.

Table.5.5. Optimum range of weather variables for Kanchana

| Kanchana | Tmax (°C) | Tmin (°C) | VPI (mm Hg) | VPII (mm Hg) | RHI (%) | RHII (%) | RF (mm) | BSS (h) |
|---|---|---|---|---|---|---|---|---|
| P1 | 27-29.5 | 22-23.5 | 21-22 | 22-23 | 95-98 | 75-95 | 20 | 2 |
| P2 | 27-29 | 22.5- 23 | 21-22 | 22-22.8 | 96-98 | 80-95 | 16-50 | 1 |
| P3 | 27-30 | 21.5-23.5 | 21-22.8 | 20.5-23 | 96-97 | 68-85 | 30 | 5 |
| P4 | 29-30 | 22-23 | 21.5-22.7 | 21-22.5 | 65-70 | 96-98 | 8 | 5 |
| P5 | 30-31.2 | 22-24 | 22-23 | 20-22.5 | 95-98 | 60-73 | - | 6 |
| P6 | 29-32 | 21.5-22.8 | 21.3-22.5 | 20.7-22.7 | 93-98 | 65-90 | 37.5 | 6.5 |
| P7 | 30-30.5 | 22-23 | 22-23.5 | 20.4-23.6 | 95-97 | 75-80 | - | 5 |

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 ripening
P7- Ripening to physiological maturity

During transplanting to active tillering (P1) the optimum temperature for Kanchana was identified as 27-29.5°C. Tmax more than 29.5 °C had a negative effect on crop. Optimum minimum temperature was 22-23.5°C .More than 23.5 had a negative effect on crop. Optimum DTR was found to be 4.2- 7. 2 °C. The optimum VPI and VPII ranges from 21-22 mm Hg and 22-23 mm Hg respectively. VPI more than 22 and VPII less than 22 had a negative influence on crop. RHI and RHII range from 95-98% and 75% -95 %. RH I less than 95% and RH II less than 75 % was harmful for crop. Rainfall less than 20mm adversely affects the crop. BSS less than 2 hours was harmful for crop during this period.

During active tillering to panicle initiation (P2) the optimum temperature for Kanchana was identified as 27-29°C. Tmax more than 29 °C had a negative impact on crop. Optimum minimum temperature was 22.5- 23 °C .More than 23 °C had a negative effect on crop. The optimum VPI and VPII ranges from 21-22 mm Hg and 22-22.8mm Hg respectively. VPI more than 22 and VPII less than 22.8 had a negative influence on crop. RHI and RHII range from 96-98% and 80% -95 %. RH I less than 96% and RH II less than 80 % was harmful for crop. Rainfall less than 16 mm adversely affects the crop. BSS more than 1 hour was harmful for crop during this period.

During panicle initiation to booting (P3) the optimum temperature for Kanchana was identified as 27-30°C. Tmax more than 30 °C had a negative impact on crop. Optimum minimum temperature was 21.5-23.5 °C , More than 23.5 °C had a negative effect on crop. The optimum VPI and VPII ranges from 21-22.8 mm Hg and 20.5-23 mm Hg respectively. VPI more than 22.8 and VPII more than 23 had a negative influence on crop. RHI and RHII range from 96-97 %and 68% -85 %. RH I less than 96% and RH II less than 68 % was harmful for crop. BSS more than 5 hour was harmful for crop during this period.

During booting to heading (P4) the optimum temperature for Kanchana was identified as 29-30°C. Tmax more than30 °C had a negative impact on crop. Optimum minimum temperature was 22-23 °C, less than 22 °C had a negative effect on crop. The optimum VPI and VPII ranges from 21-22.5 mm Hg and 21-22.5 mm Hg respectively. VPI less than 21.5 and VPII more than 22.8 had a negative influence on crop. RHI and RHII range from 96 -98 %and 65-70 %. RH I less than 96% and RH II less than 65 %

was harmful for crop. Rainfall less than 8 mm adversely affects the crop. BSS more than 5 hour was harmful for crop during this period.

During heading to flowering (P5) the optimum temperature for Kanchana was identified as 30-31.2°C. Tmax more than 31.2 °C had a negative impact on crop. Optimum minimum temperature was 22-24 °C , More than 24 °C had a negative effect on crop. The optimum VPI and VPII ranges from 22-23 mm Hg and 20-22.5mm Hg respectively. VPI less than 22 and VPII less than 20 had a negative influence on crop. RHI and RHII range from 95-98 %and 60-73%. RH I less than 95% and RH II less than 60 % was harmful for crop. BSS more than 5 hour was harmful for crop during this period.

During flowering to ripening (P6) the optimum temperature for Kanchana was identified as 29-32 °C. Tmax more than 32 °C had a negative impact on crop. Optimum minimum temperature was 21.5-22.8 °C, more than 22.8 °C had a negative effect on crop. The optimum VPI and VPII ranges from 21.3-22.5mm Hg and 20.7-22.7 mm Hg respectively. VPI less than 21.3 and VPII more than 22.7 had a negative influence on crop. RHI and RHII range from 93 – 98 %and 65-90%. RH I less than 93% and RH II less than 65 % was harmful for crop. Rainfall more than 37.5 mm adversely affects the crop. BSS more than 6.5 hour was harmful for crop during this period.

During ripening to maturity (P7) the optimum temperature for Kanchana was identified as 30-30.5°C. Tmax more than 30.5 °C had a harmful impact on crop. Optimum minimum temperature was 22-23°C, more than 23 °C had a negative effect on crop. The optimum VPI and VPII ranges from 22-23.5mm Hg and 20.4-23.6 mm Hg respectively. VPI less than 22 and VPII less than 20.4 had a negative influence on crop. RHI and RHII range from 95 – 97 %and 75 – 80 %. RH I less than 95 % and RH II less than 75 % was harmful for crop. BSS more than 5 hour was harmful for crop during this period.

## 5.3. PREDICTION MODEL FOR GRAIN YIELD

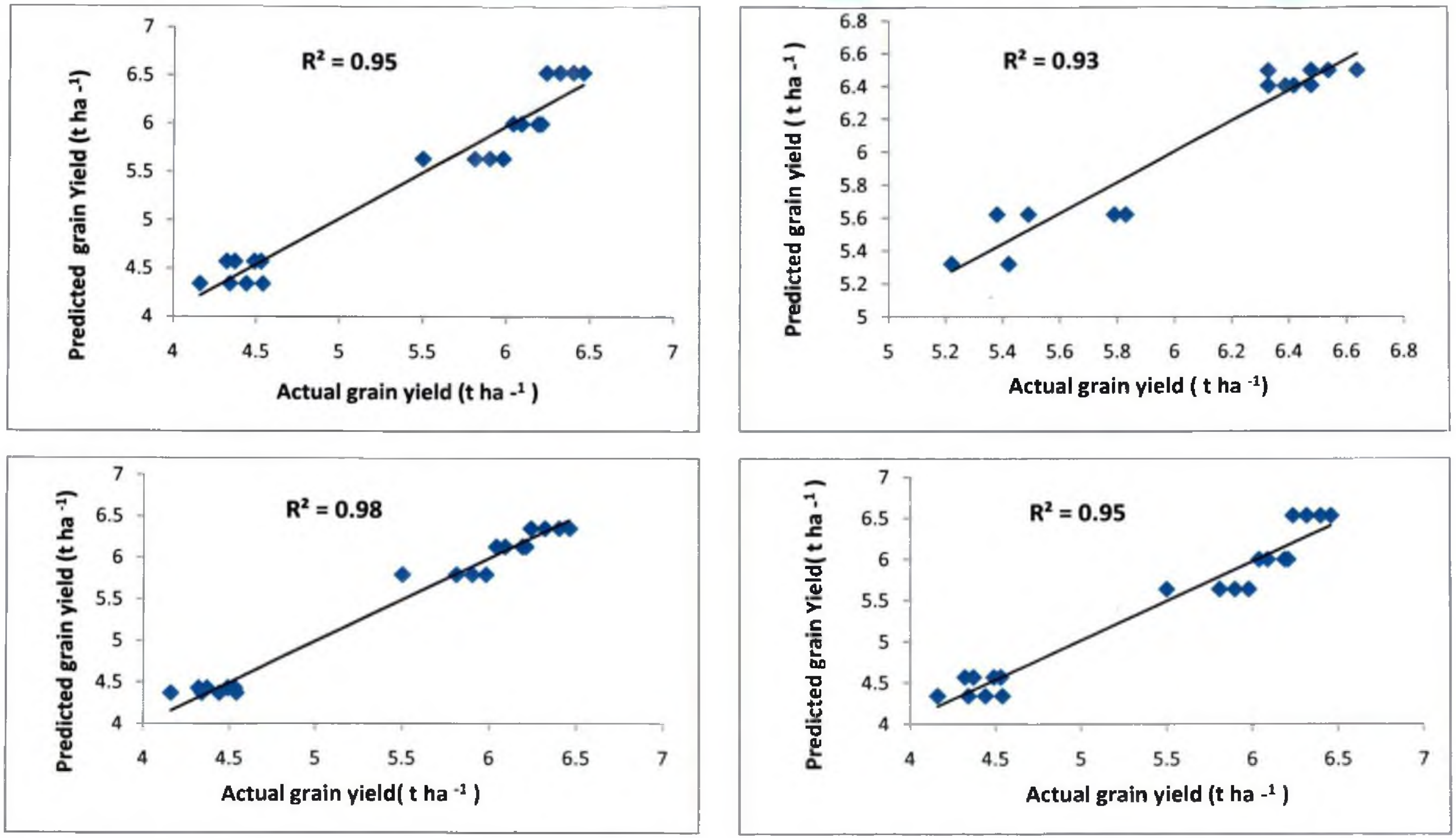
Predictions of rice yield at different stages of growth, based on weather variables is gaining more important for the forecasting of rice production and help to make decision in agricultural planning. Hence, multiple linear regression equations were fitted based on different weather variables using enter and stepwise regression method and the best fitting equation was selected based on adjusted $R^2$ value.

The regression model could predict the yield of Jyothi and Kanchana with a precision of more than 95% during vegetative and reproductive phases of crop and can be used in crop planning Fig. 5.14. Prediction models for estimation of crop yield in relation with weather parameters for rice crop were also developed by Sivapragasam and Prabakaran (2014).

## 5.3. CERES-RICE SIMULATION

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

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




(a)Jyothi (b) Kanchana

Fig. 5.14. Actual and predicted grain yield of Jyothi and Kanchana

### 5.3.1. Grain yield

Predicted grain yield was well agreed with observed yield in case of Jyothi with an RMSE (root mean square error) of 251.7 kg $ha^{-1}$ and D-index of 0.84, indicating good performance of the model (Fig.5.15). Similar findings were also reported by Lamsal *et al.*, (2013) who observed that, predicted grain yield was well agreed with observed yield (RMSE = 747.4 kg $ha^{-1}$, D-stat index= 0.79). The root mean square value (RMSE) and index of agreement (D) for yield are given in Table 5.6.

In Kanchna, also the predicted yield was in agreement with observed yield with an RMSE of 330.42 kg $ha^{-1}$ and D – stat index of 0.7, indicating good performance of the model (Fig.5.16). Similar results were also reported by Timsina *et al.*, (2005) who reported that, predicted grain yields agreed well with observed yields with RMSE=815 kg $ha^{-1}$, D-stat=0.94.

Table. 5.6. RMSE and D- stat index of yield for Jyothi and Kanchana

| Variety | RMSE | D – stat index |
|---|---|---|
| Jyothi | 251.7 kg $ha^{-1}$ | 0.84 |
| Kanchana | 330.42 kg $ha^{-1}$ | 0.7 |

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

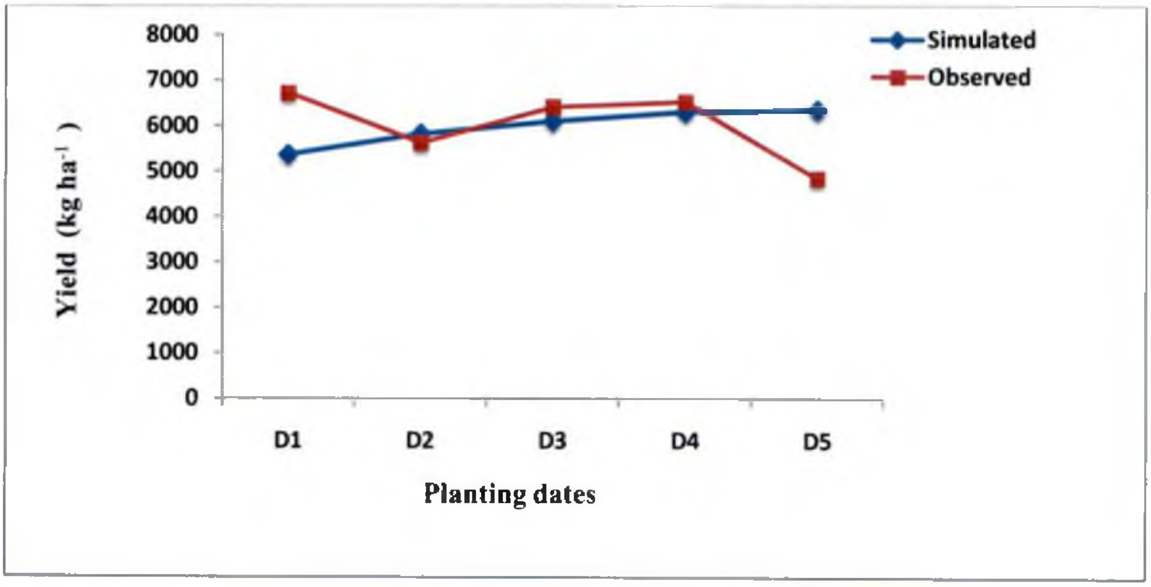



Fig. 5.15.Comparision of observed and simulated yield in Jyothi

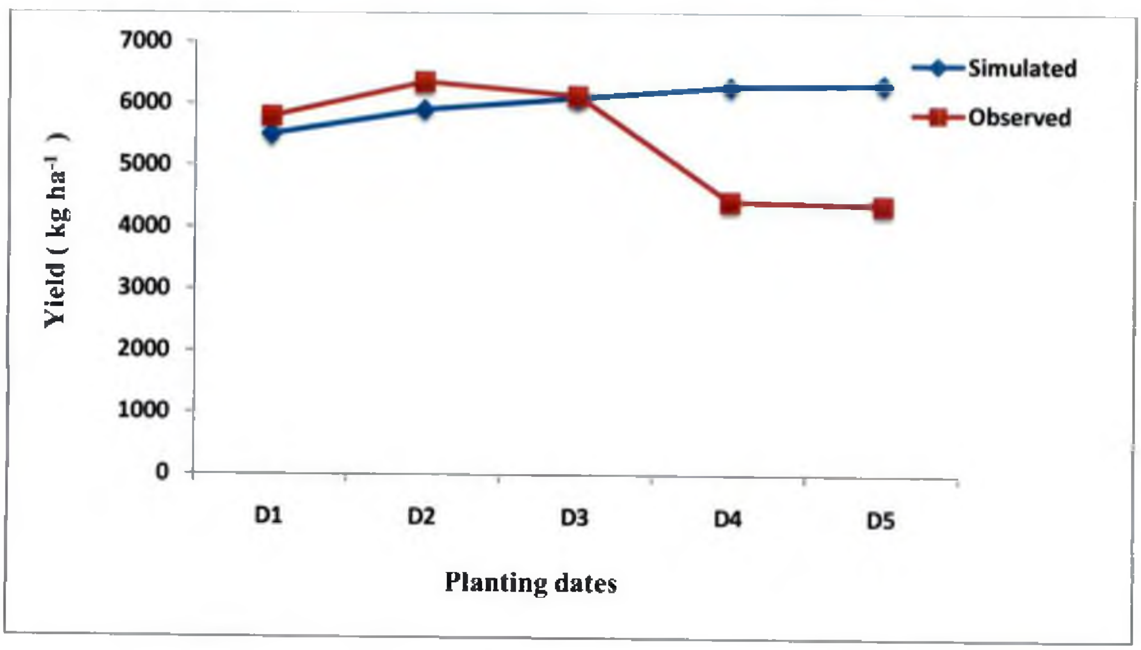



Fig. 5. 16. Comparison of observed and simulated yield in Kanchana

### 5.3.2. Simulation of phenology

There was reasonably a good agreement between observed and simulated phenology for both Jyothi and Kanchana. The root mean square value (RMSE) and index of agreement (D) for simulation of phenology are presented in Table 5.7.

Table 5.7. RMSE and D- stat index for Jyothi and Kanchana for the days to attain different phenophase

| Variety | Panicle initiation day | | Anthesis day | | Maturity day | |
|---|---|---|---|---|---|---|
| | RMSE | D- stat index | RMSE | D- stat index | RMSE | D- stat index |
| Jyothi | 1.29 | 0.5 | 0.82 | 0.9 | 1.15 | 0.82 |
| Kanchana | 2.38 | 0.3 | 0 | 1 | 0.7 | 0.8 |

#### 5.3.2.1. Panicle initiation day

The results showed that, conformity between observed and simulated panicle initiation day for Jyothi and Kanchana was not very satisfactory with an RMSE of 1.29 and D-index of 0.5 for Jyothi (Fig.5.17) and an RMSE of 2.38, D- index of 0.3 for Kanchana (Fig.5.18). But the error percentage was comparatively less in case of days taken for panicle initiation.

#### 5.3.2.2. Anthesis day

Predicted anthesis day was well agreed with simulated day in both the varieties. In Jyothi, the observed and simulated anthesis day showed a good agreement with an RMSE of 0.82, D- index of 0.9 while in Kanchana it showed an RMSE of 0 with D-

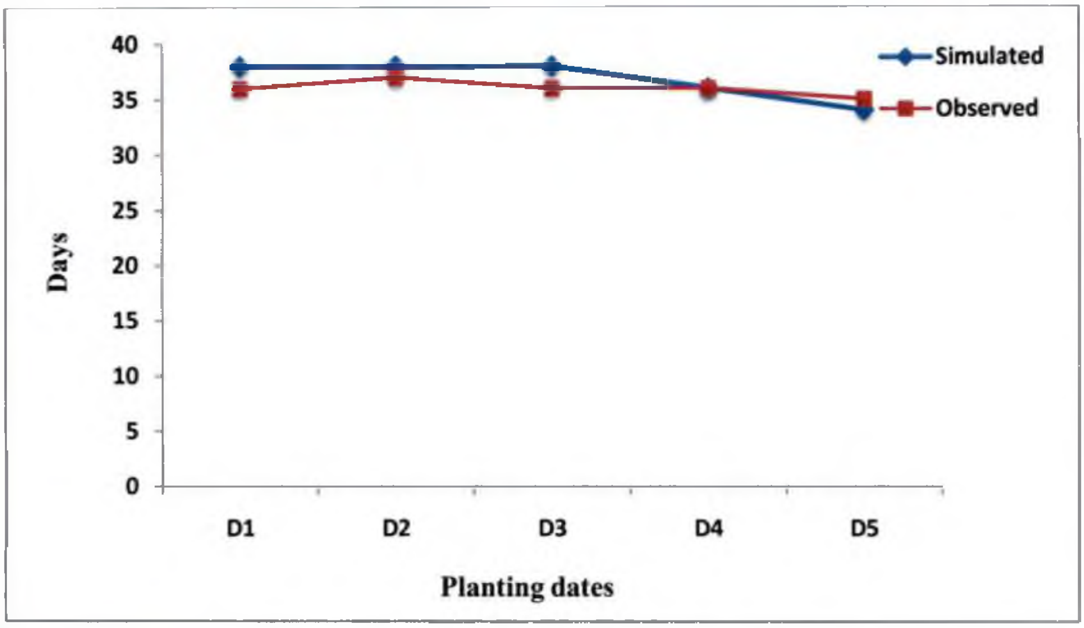



**Fig. 5. 17. Observed and Simulated panicle initiation day in Jyothi**

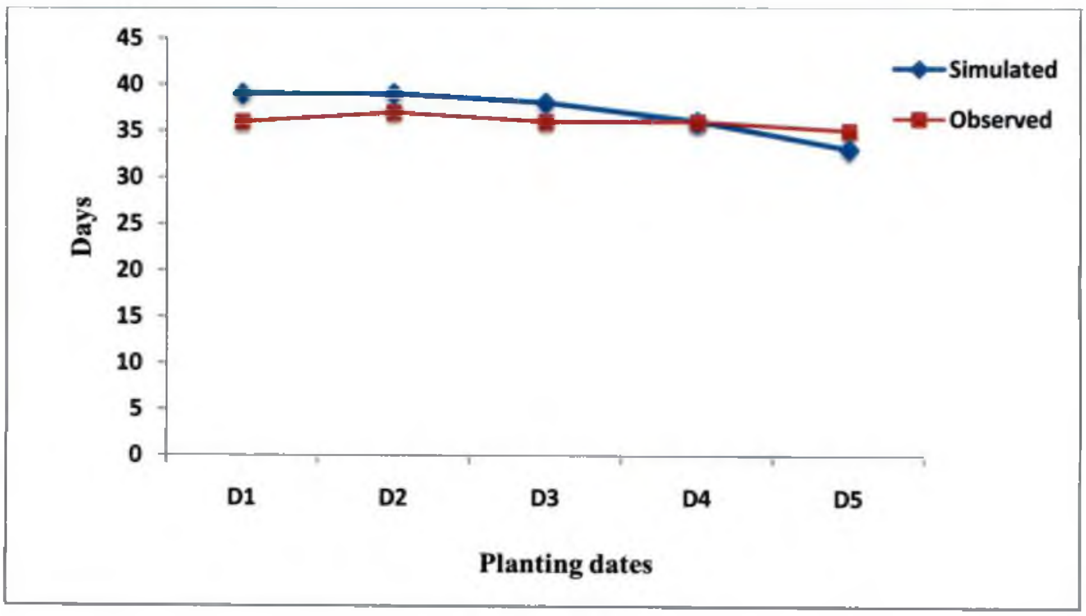



**Fig.5.18. Observed and simulated panicle initiation day in Kanchana**

index of 1. The model accurately predicted the anthesis day for both the varieties. (Fig.5.19 and Fig. 5.20). This was in agreement with studies of Timsina *et al.*, (1998) who also predicted the anthesis day for two varieties (Kanchan and Sowghat with an RMSE of 2.0 and D- index 0.90).

### 5.3.2.4. Physiological maturity day

Close agreement was observed between actual and simulated physiological maturity day (Fig.5.21 and Fig.5.22). In Jyothi, an RMSE of 1.15 with a D- index of 0.7 was obtained while in Kanchana, it showed an RMSE of 0.82 with a D- index of 0.8. Similar findings were studied by Alociljha and Ritchie (1991), reported good agreement between observed and predicted number of days to anthesis and maturity, with normalised RMSE of 4% and 3%, and D-index of 0.65 and 0.87, respectively for three upland rice cultivars in the Philippines.

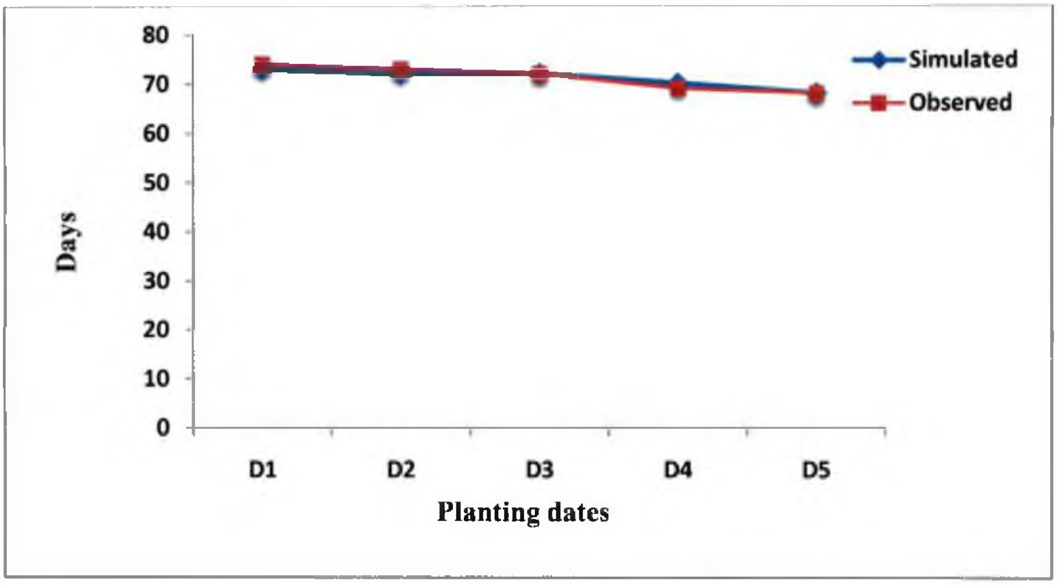



**Fig. 5.19. Observed and simulated anthesis day in Jyothi**

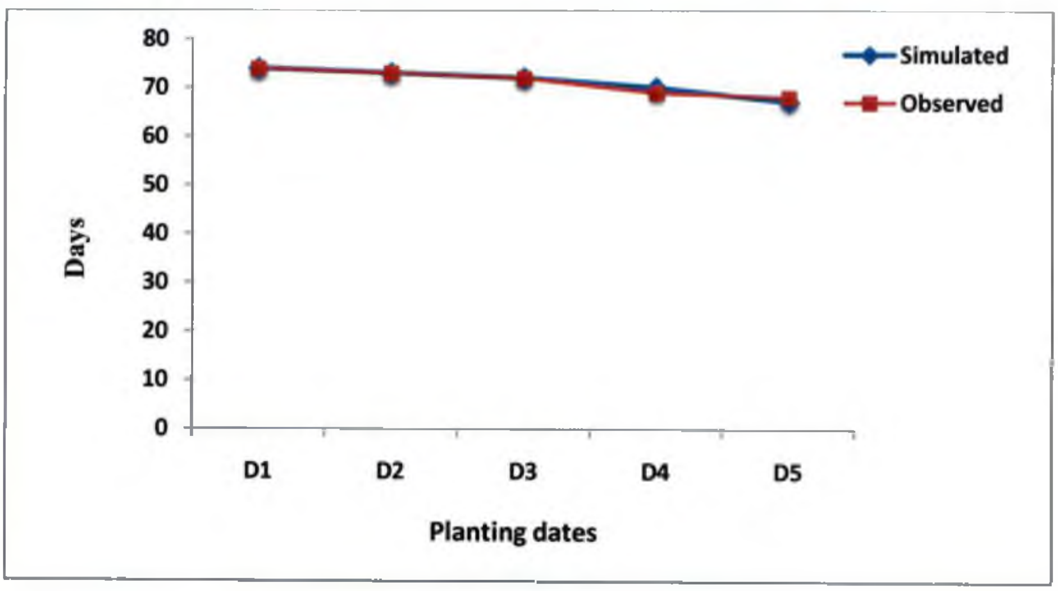



**Fig. 5.20. Observed and simulated anthesis day in Kanchana**

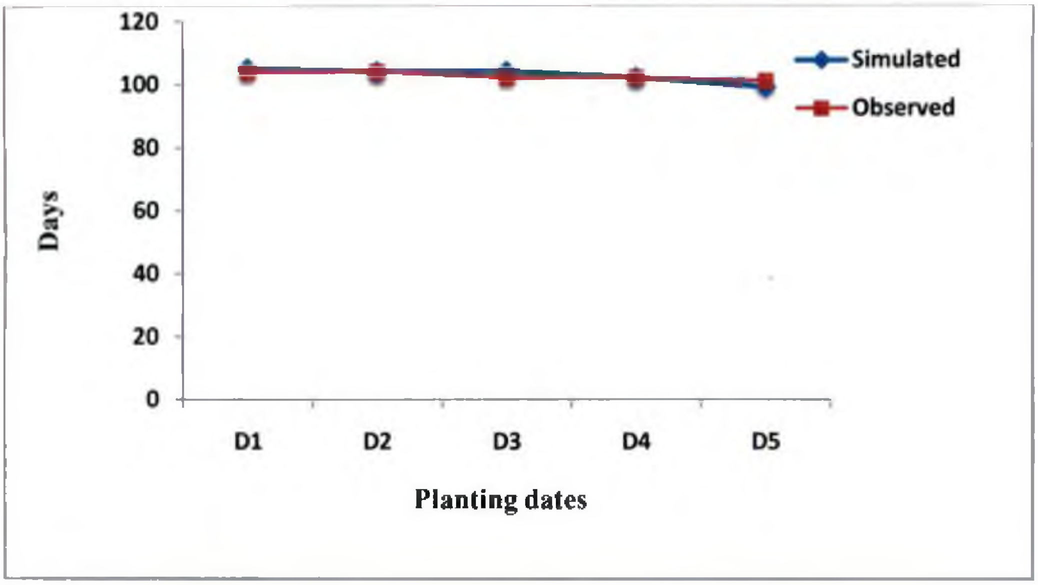



Fig. 5.21.Observed and simulated maturity day in Jyothi

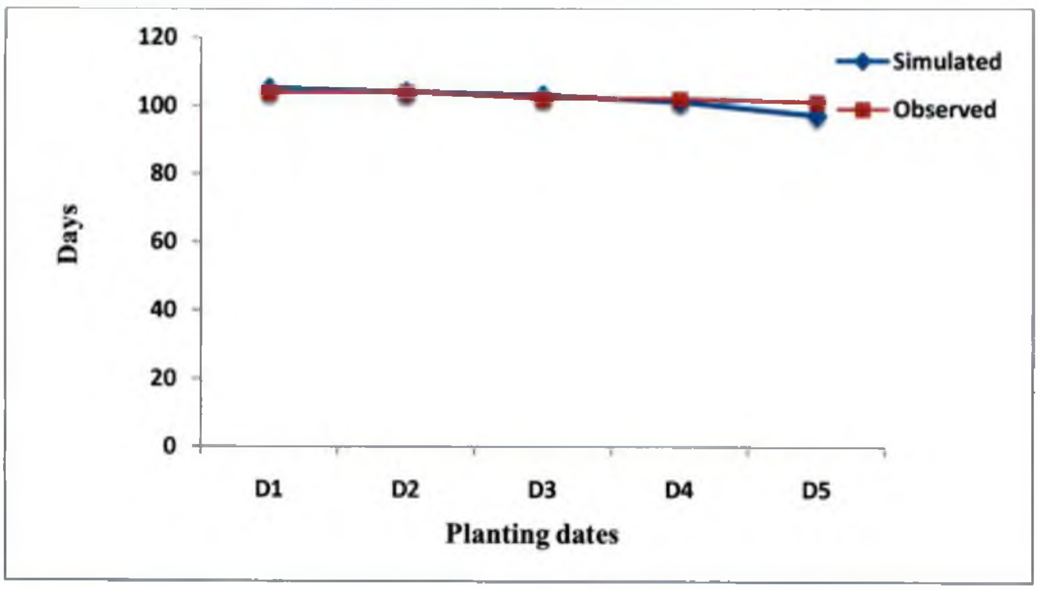



Fig. 5.22. Observed and simulated maturity day in Kanchana

# SUMMARY

# 6. SUMMARY

The experiment on "Simulation of environmental and varietal effects in rice using CERES model" was carried out at Department of Agricultural Meteorology, College of Horticulture, Vellanikkara, Thrissur during 2012-13. The experiment was conducted to simulate the phenology, growth and yield of Jyothi and Kanchana varieties of rice. Calibrate their genetic coefficient and to determine the crop weather relationship. The salient findings of the study are summarized as follows.

The height of the plants for both the varieties at different weeks after transplanting was observed to be highly variable among the different planting dates with respect to prevailing weather conditions. Height was significantly superior in Jyothi compared to Kanchana during the season.

Increase in maximum temperature and DTR reduced the plant height in both the varieties. Maximum temperature beyond 30°C reduces the plant height during vegetative and reproductive period in both the varieties. Relative humidity favoured the plant height during early plantings while bright sunshine hours had a negative influence on the plant height. BSS beyond 3.0 hours may also decrease the plant height during vegetative and reproductive period.

The highest leaf area index was recorded at 75 days after planting in both the varieties. High relative humidity, low sunshine hours and diurnal temperature range during beginning of grain filling stage favoured the LAI. Rainfall and rainy days had positively influenced the LAI on both the varieties. Reduction in LAI during late planting was attributed to increase in maximum temperature during flowering period. Evaporation and BSS showed a negative impact on LAI. BSS beyond 3.0 hours had a negative impact on LAI in late planted crops.

The maximum temperature negatively influenced the dry matter production on delayed plantings while relative humidity during the early planting periods favoured the high biomass in both the varieties. Diurnal temperature also showed negative influence on plant dry matter production with delay in plantings.

Effective tillers per $m^{-2}$ at June 5th planting in both the varieties were attributed to favourable environmental conditions. Increase in temperature (more than 30 °C) may reduce the number of effective tillers in late planted crops.

Number of filled grains per panicle was recorded highest in Jyothi compared to Kanchana during the season. Higher temperature (more than 30 °C) during the grain filling and maturity stages decreased the number of filled grains per panicles in Jyothi on August 5th planting.

Number of panicles per unit area was affected significantly by different planting dates. The total number of panicles gradually showing a decreasing trend as the planting was delayed. Reduction in number of panicles per unit area was attributed to high temperature (more than 30°C).

The reduction of spikelets in June 20th, July 5th and August 5th, planting might be due to high temperature (>30 °C ) and high relative humidity (>95%) during the heading and flowering stages which adversely affected the formation of number of spikelets in Jyothi.

Variations in 1000 grain weight were very less with respect to different planting dates in both the varieties. Highest grain weight recorded in both the varieties may be due to low temperature during grain filling period. Lowest grain weight was recorded in August 5th planting was attributed to high temperature (>30 °C).

Crops taken during early dates received high relative humidity (>95%) with low temperature (<29 °C) during the entire growth period favoured more straw yield. Late planted crop experienced low relative humidity with high temperature reduced the straw yield.

The highest grain yield was obtained in Jyothi for June 5$^{th}$ and July 20$^{th}$ planting. The reduction in grain yield on June 20$^{th}$ planting was due to increased relative humidity (>95%) with increased temperature (>30 $^{o}$C) at the heading stage. In Kanchana, lowest grain yield was recorded in July 20$^{th}$ and August 5$^{th}$ planting was due to high temperature and less rainfall during the growth period.

With respect to varieties, Jyothi is found to be superior in grain yield, straw yield, number of filled grains, number of spikelets, 1000 grain weight, leaf area index, dry matter accumulation and height during the season. Number of effective tillers, was found to be more in Kanchana.

The duration taken for each growth stages was found to be same for both the varieties with respect to different planting dates. Environmental conditions like low temperature and high relative humidity was most favourable for early planted crops to attain its full maturity. Increase in heat units like GDD and HTU decreased the number of days taken for transplanting to maturity in delayed plantings.

Regression model with $R^2$ value of 0.93 was developed for the prediction of yield using the weather parameters experienced by the crop during different stages of crop growth and the equation developed for both the varieties are given below.

a) For Jyothi

- Yield = 666.296 **+ 1.5** Tmax+ 8.189** Tmin + 0.004** RF- 0.482** RD
- Yield = 26.915** + 1.547** Tmin – 6.745** BSS + 0.142** VPD II - 0.154** RD

b) For Kanchana

- Yield = - 41.124** – 4.49 **Tmax + 8.189** Tmin + 0.004** RF – 0.482** RD
- Yield = 1.609** + 1.847** Tmin – 1.714** VPD II + 0.012** RD

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

| Variety | P1 | P2R | P5 | P20 | G1 | G2 | G3 | G4 |
|---|---|---|---|---|---|---|---|---|
| Jyothi | 556.8 | 29.7 | 423.0 | 10.4 | 49.8 | 0.0235 | 1 | 1 |
| Kanchana | 465.0 | 149.1 | 404.9 | 12.1 | 49 | 0.0230 | 1 | 1 |

Predicted grain yield was well agreed with observed yield in case of Jyothi with an RMSE (root mean square error) of 251.7 kg $ha^{-1}$ and D-index of 0.84, indicating good performance of the model. In Kanchna, also the predicted yield was closed agreement with observed yield with an RMSE of 330.42 kg $ha^{-1}$ and D – index of 0.7.

Observed and simulated panicle initiation day for Jyothi and Kanchana was not very satisfactory with an RMSE of 1.29 and D-index of 0.5 for Jyothi and an RMSE of 2.38, D- index of 0.3 for Kanchana.

The model accurately predicted the anthesis day for both the varieties. In Jyothi, the observed and simulated anthesis day showed a good agreement with an RMSE of 0.82 with D- index of 0.9 while in Kanchana it showed an RMSE of 0 with D- index of 1.

Close agreement was observed between actual and simulated physiological maturity day. In Jyothi, an RMSE of 1.15 with a D- index of 0.7 was obtained while in Kanchana, it showed an RMSE of 0.82 with a D- index of 0.8.

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# 7. REFERENCES


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# APPENDICES

## Appendix I

### Abbreviations and units used

**Weather parameters**

Tmax : Maximum temperature

Tmin : Minimum temperature

Tmean : Mean temperature

DTR: Diurnal temperature range

RH I : Forenoon relative humidity

RH II: Afternoon relative humidity

VPD I : Forenoon vapour pressure deficit

VPD II : Afternoon vapour pressure deficit

RF : Rainfall

RD : Rainy days

WS : Wind speed

EVP : Evaporation

BSS : Bright sunshine hours

**Phenophases**

TP – AT: Transplanting – active tillering

AT – PI : Active tillering – panicle initiation

PI – B : Panicle initiation – booting

B – H : Booting – heading

H – F : Heading – flowering

F – R: Floweing - ripening

R – M : Ripening - maturity

**Heat units**

GDD : Growing degree days

HTU : Heliothermal units

PTU : Photothermal units

**Units**

g : gram

kg : Kilogram

Km $hr^{-1}$ : Kilometre per hour

$^{o}$C : degree Celsius

Kg ha : kilogram per hectare

t : tonnes

% : per cent

## APPENDIX II

### ANOVA of different plant growth characters of 2013 experiment

Plant height at different weeks after transplanting

| Source of variation | DF | Mean sum of squares | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 Week | 2 Week | 3 Week | 4 Week | 5 Week | 6 Week | 7 Week | 8 Week |
| Date of planting | 4 | 98.194* | 19.291** | 31.955* | 36.632 | 43.217* | 87.875 | 24.193 | 50.932* |
| Error | 12 | 3.356 | 8.460 | 6.511 | 5.090 | 2.172 | 3.899 | 3.383 | 4.280 |
| Variety | 1 | 100.521* | 268.998* | 1325.952* | 1252.161 | 597.916 | 456.638 | 300.743 | 188.790* |
| Date X variety | 4 | 1.556* | 15.022 | 11.749 | 12.083 | 26.257 | 28.396 | 27.493 | 35.375 |
| Error | 15 | 1.494 | 4.799 | 3.240 | 5.601 | 4.756 | 6.236 | 5.109 | 6.238 |

Plant height at different weeks after transplanting

| Source of variation | DF | Mean sum of squares | | | | |
|---|---|---|---|---|---|---|
| | | 9 Week | 10 Week | 11 Week | 12 Week | 13 Week |
| Date of planting | 4 | 36.112** | 50.518 | 26.761 | 12.139** | 6.442** |
| Error | 12 | 5.089 | 6.296 | 3.311 | 3.100 | 0.689 |
| Variety | 1 | 118.922 | 90.721 | 37.191 | 20.164* | 16.770* |
| Date X variety | 4 | 22.564* | 15.128 | 8.112 | 2.655* | 0.711* |
| Error | 15 | 3.816 | 4.303 | 2.726 | 1.543 | 0.708 |

DF – Degrees of freedom  - ** Significant at 1% level  - * Significant at 5% level  DAT- Days after transplanting

**APPENDIX II (contd.)**

Leaf area index at 15 DAT, 30 DAT, 45 DAT, 60 DAT, 75 DAT, 90 DAT and at the time of harvest

| Source of variation | DF | Mean sum of squares | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 15 DAT | 30 DAT | 45 DAT | 60 DAT | 75 DAT | 90 DAT | At harvest |
| Date of planting | 4 | 0.078 | 0.761** | 2.236 | 3.095* | 0.993** | 0.551* | 0.094* |
| Error | 12 | 0.009 | 0.038 | 0.034 | 0.203 | 0.104 | 0.004 | 0.004 |
| Variety | 1 | 0.020 | 0.072* | 0.001 | 0.030 | 0.016 | 0.056 | 0.125* |
| Date X variety | 4 | 0.004 | 0.079* | 0.086** | 0.110* | 0.012* | 0.003* | 0.001 |
| Error | 15 | 0.005 | 0.035 | 0.046 | 0.175 | 0.031 | 0.019 | 0.002 |

Dry matter production at 15 DAT, 30 DAT, 45 DAT, 60 DAT, 75 DAT, 90 DAT and at the time of harvest

| Source of variation | DF | Mean sum of squares | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 15 DAT | 30 DAT | 45 DAT | 60 DAT | 75 DAT | 90 DAT | At harvest |
| Date of planting | 4 | 73480.381 | 1951033.415 | 7415924.451 | 5731022.777* | 8977242.712** | 6940018.664** | 3287245.528* |
| Error | 12 | 7355.290 | 506620.029 | 122586.900 | 601262.910 | 625821.920 | 383756.143 | 1086434.363 |
| Variety | 1 | 56000.278* | 40853.421 | 1128960.000 | 1364944.931* | 6755679.296** | 2368362.542* | 1237708.670 |
| Date X variety | 4 | 8948.366 | 42360.886 | 620839.199 | 2655919.320 | 2855122.353 | 1686061.248 | 635098.737* |
| Error | 15 | 4490.786 | 123755.119 | 678209.774 | 1143429.775 | 627830.890 | 267700.474 | 733784.090 |

DF – Degrees of freedom - ** Significant at 1% level - * Significant at 5% level DAT- Days after transplanting

**APPENDIX II (contd.)**

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

| Source of variation | DF | Mean sum of squares | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Grain yield | Straw yield | 1000 grain weight | Number of filled grains per panicle | Number of spikelets per panicle | Effective tillers $m^{-2}$ | Panicles per unit area |
| Date of planting | 4 | 3937996.250* | 1301927.500 | 4.784** | 197.735* | 450.387* | 6910.253* | 6910.253** |
| Error | 12 | 50609.583 | 758464.167 | 0.207 | 73.527 | 87.312 | 569.542 | 569.542 |
| Variety | 1 | 3630062.500** | 2905210.000 | 0.156* | 2290.682* | 3325.152* | 3646.188* | 3646.188* |
| Date X variety | 4 | 2113893.750* | 2062510.000 | 3.171* | 257.463** | 79.943* | 1174.435* | 1174.435* |
| Error | 15 | 44934.167 | 1388336.667 | 0.287 | 110.428 | 77.540 | 884.707 | 884.707 |

DF – Degrees of freedom - ** Significant at 1% level - * Significant at 5% level DAT- Days after transplanting

# SIMULATION OF ENVIRONMENTAL AND VARIETAL EFFECTS IN RICE USING CERES MODEL

By

NAZIYA

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## ABSTRACT OF THE THESIS

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Department of Agricultural Meteorology

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

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# ABSTRACT

## ABSTRACT

The present investigation on "Simulation of environmental and varietal effects in rice using CERES model" were carried out in Department of Agricultural Meteorology, College of Horticulture, Vellanikkara during 2012-13 to determine the crop weather relationship, to calibrate the genetic coefficient and simulation of phenology, growth and yield of Jyothi and Kanchana varieties of rice. The experiment was laid out in split plot design with four replications at Agricultural Research Station, Mannuthy during the *Kharif* season of 2013. Five dates of planting was assigned as a main plot treatment *viz.*, 5$^{th}$ June, 20$^{th}$ June, 5$^{th}$ July, 20$^{th}$ July and 5$^{th}$ August with two varieties (Jyothi and Kanchana) as sub plot treatment.

The different growth and yield characters like plant height, leaf area index, dry matter accumulation,1000 grain weight, grain yield, straw yield, number of panicles, spikelets, filled grains and duration of different growth phases were recorded along with monitoring the incidence of various pest and diseases. The daily weather parameters like maximum and minimum temperatures, forenoon and afternoon relative humidity, forenoon and afternoon vapour pressure deficits, bright sunshine hours, evaporation, wind speed, rainfall and rainy days were determined.

The minimum temperature, afternoon and forenoon relative humidity, rainfall, rainy days, bright sunshine hours and evaporation were found to be higher in early planting dates compared to late plantings. Plant height, leaf area index, dry matter accumulation, yield and yield attributes were highly variable among the different planting dates. Yield and yield attributes were influenced by various weather parameters experienced by the crop during different dates of planting. Days taken to complete maturity were reduced with each successive delay in planting dates in both the varieties. Genotypic variations are found between the varieties but days taken for each phenophases were found to be similar. June 5$^{th}$ and July 20$^{th}$ planting recorded the highest yield in Jyothi whereas June 20$^{th}$ and July 5$^{th}$ planting gave highest yield in Kanchana. Jyothi was found to be superior to Kanchana during the crop season.

To determine the critical weather elements affecting the crop growth, correlation analysis was done and it was observed that crop duration would decrease with increase in temperature and bright sunshine hours whereas, the forenoon and afternoon relative humidity, rainfall and rainy days showed a positive influence on crop duration. Multiple linear regression models were fitted, to predict the grain yield based on weather variables.

The crop genetic coefficients that influence the occurrence of developmental stages in the CERES-rice models were derived, to achieve the best possible agreement between the simulated and observed values. Calibration was done with the independent data sets of two rice varieties *viz*. Jyothi and Kanchana for different genetic coefficients, which characterize the performance of the crop.

The performance of the CERES-rice simulation model was tested and evaluated using the calibrated genetic coefficients for both the varieties with their respective planting dates. The results of simulation studies in respect of phenophases and yield of rice were compared with the observed values from the field experiment. Root Mean Square Error (RMSE) and D- stat (index of agreement) were used to evaluate the model performance and found that predicted yield of both rice varieties Jyothi and Kanchana under different planting dates were reasonably close to the observed values.