PHASIC DEVELOPMENT MODEL USING THERMAL INDICES FOR RICE (*Oryza sativa* L.) IN THE CENTRAL ZONE OF KERALA

By

ASWANY. K. S.

(2014-11-174)

THESIS

Submitted in partial fulfilment of the requirement for the degree of

Master of Science in Agriculture

Faculty of Agriculture
Kerala Agricultural University

DEPARTMENT OF AGRICULTURAL METEOROLOGY
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR -680 656
KERALA, INDIA
2016

DECLARATION

I, **Aswany, K. S** (2014-11-174) hereby declare that this thesis entitled **"Phasic development model using thermal indices for rice (*Oryza sativa* L.) in the central zone of Kerala"** 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

Date: 30-12-2016

Aswany, K. S

(2014-11-174)

CERTIFICATE

Certified that this thesis entitled **"Phasic development model using thermal indices for rice (*Oryza sativa* L.) in the central zone of Kerala"** is a bonafide record of research work done independently by **Ms. Aswany, K. S. (2014-11-174)** 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.

30/12/16

Vellanikkara

Date : 30.12.2016

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. Aswany, K.S (2014-11-174)**, a candidate for the degree of **Master of Science in Agriculture**with major field in Agricultural Meteorology, agree that this thesis entitled **"Phasic development model using thermal indices for rice (*Oryza sativa* L.) in the central zone of Kerala"** may be submitted by**Ms.Aswany, K. S**in partial fulfilment of the requirement for the degree.

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

Dr. K.M. Sunil
(Member, Advisory Committee)
Assistant Professor
KVK, Palakkad

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

Dr.T. Girija
Professor and Head
Department of Plant Physiology
College of Horticulture

Dr. A. Latha
(Member, Advisory Committee)
Professor & Head
Agricultural Research Station
Mannuthy

EXTERNAL EXAMINER
Dr. S. Sridhara
Principal Nodal Officer of GKMS
Professor of Agronomy
College of Agriculture
Shimoga

ACKNOWLEDGEMENT

Gratitude takes three forms "a feeling from the heart, an expression in words and a giving in return". I sincerely thank all those who directly or indirectly made this research possible.

I feel immense pleasure to express my gratefulness towards each and every member of my advisory committee and I consider myself fortunate to have enjoyed the privilege of being guided by them during my research program. First of all, I wish to place on record my deep sense of gratitude and respect to Dr. B. Ajithkumar, Chairman of my advisory committee and Assistant Professor and Head of the Department of Agricultural Meteorology, for his inspiring and precious suggestions, untiring interest and constructive criticisms throughout the course of my study period.

It is with immense pleasure I avail this opportunity to express my deep sense of whole hearted gratitude to Dr. K. M. Sunil, Member of my advisory committee and Assistant Professor, Academy of Climate Change Education and Research for his constant support, valuable suggestions and critical scrutiny of the manuscript.

I feel great pleasure to express my indebtedness to Dr. A. Latha, Member of my advisory committee and Professor and Head of the Agricultural Research Station, for the valuable advices, ever-willing help and encouragement during my field study and for the relevant suggestions during the preparation of the manuscript.

I consider it as my privilege to express my deep-felt gratitude to Dr. C. Laly John, Member of my advisory committee and Associate Professor of the Department of Agricultural Statistics, for helping me in the statistical analysis. I am extremely thankful to her for the unforgettable care, well-timed support, constructive suggestions and critical evaluation of the manuscript which greatly improved the thesis.

I am deeply obliged to Dr. T. Girija, Member of my advisory committee and Professor and Head of the Department of Plant Physiology, for her invaluable help, guidance and critical assessment throughout the period of work. I thank her for all the help and cooperation she has extended to me.

I am obliged to Mr. Biju Kuruvila, Farm officer of the Agricultural Research station, for the sustained interest, constant support and timely help extended throughout the course of investigation.

My heartfelt thanks to Dr. Dijee Bastian, UG Academic Officer and Dr. Nirmala Devi, PG Academic Officer, for all sorts of helps rendered throughout the course of study.

I acknowledge the relevant suggestions that I received from the teachers of the College of Horticulture during the thesis defense seminar.

I take this opportunity to thank Ms. Sreekala, Mr. Sreejith, Ms. Anu, Mrs. Deena Biju, Mrs. Mini, Mrs. Sajitha, Mrs. Suchithra, and Mr. Simon and of my Department for the unconditional help and co-operation provided by them in these two years.

With immense pleasure, I thank my seniors, Mr. Arjun, Mr. G. Subramanyanm who had contributed in some way or other towards the completion of this work.

I wholeheartedly thank my friends, Ms. Smitha. K, Ms. Sushna. K, Ms. Seenu Joseph, Ms. Aiswarya, Ms. Shafeeqa and all other batch-mates for their love, co-operation and help.

I extend my loving gratitude to my juniors, Mr. Venkata Satish Jasti and Ms. Aswathy for the constant support and indispensable help provided by them.

I take this opportunity to thank Mr. Gangadharan, and Mr. Paulose of my Department for their immense help for the completion of my research work.

I sincerely acknowledge the help and support of Mr. Biju Kuruvila, Mr. Johnkutty, Mrs. Savithry, Mrs Rosy and all other staffs of the Agricultural Research Station for all sorts of helps rendered by them.

Lastly, I will fail in my duty, if I don't record my heartfelt gratitude to my beloved parents for being the pillars of strength for me. I am forever beholden to my parents and sister for their boundless affection, support, prayers, blessings and personal sacrifices for me.

I owe my thanks to Dr. A. T. Francis, Librarian, College of Horticulture and with all regards, I acknowledge the whole-hearted co-operation and gracious help rendered by each and every member of the College of Horticulture during the period of study. I sincerely thank the facilities rendered by the College Library, Computer Club and Central Library. I express my special thanks to Mr. Aravind of Students' computer centre for his valuable support and affection to me. I am obliged to Kerala Agricultural University for granting me the Junior Research Fellowship.

Once again, I thank all those, who extended help and support during the course of study and a word of apology to those, I have not mention in person.

Above all, I gratefully bow my head before the Almighty, for the blessings showered upon me in completing the thesis successfully.

Aswany, K. S.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (Contd)

LIST OF TABLES (Contd)

LIST OF TABLES (Contd)

LIST OF TABLES (Contd)

LIST OF FIGURES

LIST OF FIGURES ((Contd)

LIST OF FIGURES ((Contd)

LIST OF PLATES

Introduction

1. INTRODUCTION

Agriculture is considered as the backbone of Indian economy. In India, agriculture contributes about sixteen per cent of total GDP and ten percent of total exports. Agriculture is the principal means of livelihood for over 58 per cent of the rural households. India is the leading rice producer in the world and stand at 2^{nd} position in the world. Rice is the staple food of the country. India produces rice in a large quantity and its production crossed the mark of 100 million tonnes. In India rice is grown in more than 20 states with an area of over 400 lakh hectares. Rice is fundamentally a *Kharif* crop in India, mainly grown as rainfed crop which receive heavy annual rainfall. Growth and development of rice crop demands temperature of around 25°C and above and rainfall of more than 100 cm. Rice cultivation in Kerala has showed a steady decline since the 1980s. Rice is the single most food crop of Kerala with an area of 2.64 lakh hectares. The productivity of rice increased year by year while area under rice cultivation decreased significantly. Over a period of four decades the productivity of rice crop increased from 1.3t ha^{-1} to 2.3 t ha^{-1}.

Weather plays an important role in shaping the success of agricultural production. Most of the field crops depend on weather to provide life sustain energy. The weather elements like solar radiation, temperature, precipitation, humidity and wind affects the physiology and production of agricultural crops. Weather influencing the growth and yield of rice and the changes in weather can be exploited by resorting to optimum time of sowing or planting.

Weather parameters like sunshine hours, rainfall and temperature are important natural resources which increases the rice productivity. The optimum utilization of these resources can also vary among different rice cultivars. To study the extent and comparative utilization of these resources, some weather based agro indices have been developed. The commonly used weather based agro indices are growing degree days (GDD), photothermal units (PTU) and heliothermal units (HTU). Growing degree day is the most commonly used temperature index used for estimating plant development (Qadir *et al.* 2006). GDD is also used to assess the suitability of a particular crop to a particular region, estimation of crop growth stages and heat stress.

Climate plays a major role in the selection of crops to a particular environment while the prevailing weather conditions in that environment decide the suitability of crops. Rice is a crop whose growth and yield depends on the weather condition. The phenological stages such as reproductive and ripening stages are considered as the most sensitive to weather parameters. The variations in weather variables such as low or high temperature and low solar radiation affect the spikelet fertility in rice crops. High temperature in the lower elevation of the tropics and lower temperature in the temperate regions adversely affects the crop. This critical temperature differs according to variety, duration of critical temperature, diurnal changes and physiological changes of plants (Sridevi and Chellamuthu, 2015).

Identification of physiological indices is useful for the analysis of growth and yield of rice. Some of the physiological indices that are considered in rice studies include Crop Growth Rate (CGR), Relative Growth Rate (RGR), Net Assimilation Rate (NAR) and Leaf Area Duration (LAD) respectively.

A crop model is a simplified representation of a crop. Crop models are tools of systems research which help in solving problems related to crop production. Crop models can be used to understand the impacts of climate change such as elevated carbon dioxide, changes in temperature and rainfall on crop development, growth and yield. In agricultural meteorology, the crop models are used to solve the problems of crop yield variations (Rauff and Bello, 2015). The popular models which are frequently used for agro-meteorological studies are the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) and Decision Support System for Agrotechnology Transfer (DSSAT) models (O'Toole *et al.*1987).

Agricultural system models have untapped potential to help agricultural research and technology transfer in 21st century (Ahuja *et al.*, 2002). The Decision

Support System for Agro Technology Transfer (DSSAT) has been used for the last 15 years by researchers worldwide. This package includes models of 16 different crops with software that facilitates the evaluation and application of the crop models for different purposes. The Crop Estimation through Resource and Environment Synthesis (CERES-Rice) model was used to simulate the seasonal yield with long term weather data and forecast rice yield based on the relationship between weather variables and crop yield. CERES-Rice model is physiologically based model which simulates daily canopy photosynthesis, respiration, growth, biomass partitioning and crop development as a function of daily weather conditions, soil properties, management practices and cultivar characteristics (Jones *et al.* 2003). CERES-Rice model has been commonly used to identifying the relationship between rice and its growing environment. Crop performance in terms of genetic coefficients used in the model can be used as a tool in choosing varieties and extend the utility of field experimentation. In this background, the present investigation was made to understand the critical weather elements influencing the growth and development of Jyothi and Kanchana varieties of rice, with the following objectives.

i. Estimate the different growth phases of rice using thermal indices *viz.* GDD, HTU, PTU
ii. Validate the CERES-Rice model for the varieties Jyothi and Kanchana
iii. Determine the crop weather relationship

Review of literature

2. REVIEW OF LITERATURE

Crop growth models for rice play an important role to understand its yield responses to various environmental conditions. The model uses a minimum of readily available weather, soil and genetic inputs to assess the crop weather relationships. Rice growth simulation models can be used for providing a systematic and quantitative tool for the prediction of growth, development and productivity of rice under changing environmental conditions. The combined effects of genotype, environment and management influence the growth and yield of rice (*Oryza sativa* L.). Rice simulation models like ORYZA2000 and CERES-Rice have been used to explore the adaptation options to climate change and weather- related stresses like drought, heat and the output of these models were more sensitive to accurate modelling of crop development. The possible correlation between temperature and phenology prediction has received little attention, although there are indications that such correlation exists, in particular in the study conducted by Oort *et al.*, (2011).

Rice (*Oryza sativa* L.) is vulnerable to unfavourable weather and climatic conditions. Weather parameters like temperature, rainfall *etc.* plays an important role in rice production (Ji *et al.*, 2007).

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 the growth and development of rice and crop growth simulation models are reviewed in this chapter.

2.1 EFFECT OF THERMAL INDICES ON PHENOLOGY AND YIELD OF RICE

Islam and Sikder (2011) studied the changes in phenology and growing degree days of five rice varieties *viz.* Rajshahi swarna, Silkumul, Kataribhog, Lal pajam and Sanla under organic and inorganic conditions. The experiment was conducted during *aman* season of 2008 at Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur. They reported that the variety Rajshahi swarna took more number of days for attaining different phenological phases, medium number of days in Silkumul, Kataribhog and Lal pajam. The rice variety

Sanla requires comparatively less days to attain different phenological stages. They also reported that the growing degree days (GDD) and heat use efficiency (HUE) was found to be higher in inorganic condition than organic condition.

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

Sikder (2009) studied the effect of accumulated heat units on phenology of wheat cultivars under different sowing conditions such as November 30th as normal date of sowing and December 30th as late sowing heat stress conditions. For this experiment they selected four heat tolerant wheat cultivars such as Gourab, Sourav, Kanchan and Shatabdi and two heat sensitive cultivars such as Sonara and Kalyansona. The results showed that normal sowing condition require more heat units than late sowing conditions during all the phenophases and also the normal sowing periods, all the cultivars showed higher heat use efficiency. They concluded that the heat tolerant cultivars such as Gourav, Sourav, Kanchan and Shatabdi exhibited good performance in phenology, GDD, HTU and heat use efficiency than heat tolerant cultivar.

Shamim *et al.* (2013) studied the effect of agrometeorological indices on grain yield in 12 coarse grain rice genotypes *viz.* Poornima, Ananda, Saket 4, Pant Dhan 10, Pant Dhan 12, PR 115, IR 74, PR 111, PR 116, Sarju 52, Naveen and Narendra 359. The experiment was conducted during *Kharif* season of 2008-2010 at Meerut (U.P). They reported that, Narendra 359 require more growing degree days for panicle initiation (1273.6°Cd), 50% flowering (1474.5°Cd) and physiological maturity (2069.8°Cd) while Poornima require lower growing degree days

(864.1°Cd, 1008.8°Cd and 1546.8°Cd respectively). They also noticed significant variations in heliothermal units, photothermal units and phenothermal index among 12 genotypes. The heat use efficiency and radiation use efficiency was significantly high in Pant Dhan 10 on total biomass basis.

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

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

Mote *et al.* (2015) observed the thermal requirements for attainment of phenophases of rice cultivars under variable weather conditions at college farm of Navsari Agricultural University, Gujarat during *Kharif* season of the year 2012. Three dates of planting *viz.* 12^{th} July, 27^{th} July and 11^{th} August was selected to study the requirement of total GDD for three rice cultivars (Jaya, Gurjari and GNR-2). They reported that the first dates of planting recorded highest grain yield due to more GDD during early plantings. They concluded that the total GDD were decreased with delay in transplanting.

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

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

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

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

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

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

Roy and Biswas (1980) reported that the effect of date of sowing on the yield of boro rice cultivar. Early transplanted rice cultivars gave highest value of seedling height, plant dry matter content, number of tillers per plant and crop duration decreased with delayed sowing and decreasing night temperature. Low temperature reduced seedling leaf emergence by up to 30 days. Ramdoss and Subramanian (1980) studied the effect of weather parameters during the last 45 days of crop growth on rice yield at Coimbatore. They reported that rice yield were positively affected by maximum temperature and number of sunshine hours and negatively affects straw yield.

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

Lomas and Herrera (1985) studied the relationship between rice yield and weather in tropical Costa Rica. They reported that low rainfall affect variations in rice yield. They concluded that the low rainfall during reproductive stages used for the assessment of rice yields.

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

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

According to Kulkarni *et al.* (1989) the two rice varieties Tella Hamsa and Pothana showed significant differences for days to 50% flowering, productive tillers m^{-2}, sterility and grain yield when sown at fortnightly intervals from 15th November to 15th January in Warangal. Delayed sowing reduces the number of days to 50% flowering in both the rice varieties. The early planted rice variety Pothana showed greater spikelet sterility than Tella Hamsa. They concluded that the spikelet sterility was due to the minimum temperature before flowering was $< 19.6^{\circ}C$ and gradually decreased in later stages when the temperature before flowering were 21 to 22°C.

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

Reddy and Reddy (1992) reported that the early transplanted rice variety Surekha produces more productive tillers per unit area than later planted rice cultivar. Early transplanted rice variety received less amount of solar radiation which leads to mortality of rice.

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

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

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

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

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

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

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

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

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

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

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

Khalifa (2009) conducted a field experiment at the experimental farm of Rice Research and Training Centre (RRTC), Egypt in 2008. Six dates of planting with four hybrid rice were selected for the study. The dates of planting were 10th April, 20th April, 1st May, 10th May, 20th May and 1st June. The result showed that the early planting date was best for the growth and development of rice. The crops sown on

April 20th gave highest value of number of tillers, plant height, root length at panicle initiation and heading stages. Number of filled grains per panicles was also influenced by different sowing dates. April 10th sowing recorded highest number of grains per panicle and June 1st recorded the lowest value. They also find out the April 20th sowing gave highest value of 1000 grain weight, number of panicles and grain yield. They concluded that the late planting reduces the plant properties and there by reduces the grain yield.

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

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

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

Khalifa *et al.* (2014) studied the effect of sowing dates and seed rates on growth and yield of rice varieties under two field experiments in Egypt in 2006 and 2007. Twenty five days old seedlings were transplanted in April 20^{th}, May 1^{st} and May 10^{th}. The result showed that the maximum tillering, panicle initiation heading dates, leaf area index, chlorophyll contents, 1000 grain weight, panicle length, number of panicles per hill and grain yield were maximum in early sown varieties. They concluded that the variety Sakha 101 gave the highest value of all studied characters than the other varieties like Sakha 103 and Sakha 104.

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

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

2.3 EFFECT OF WEATHER PARAMETERS ON 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 the panicle number and grain weight of mid season rice cultivar T-141 favoured by high maximum temperature (29 to 31.5°C) and high total sunshine hours 3 weeks after flowering.

Van (1974) studied the effects of climate on rice yields in off-season and main season in Malaysia. The off season crops yielded better than the main season crop but no significant differences were noticed. He reported that the number of rainy days during floral initiation and ripening stages affects the growth of rice crop.

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

According to Vishwambharan *et al.* (1989) poor yield of rice due to high sterility of spikelets was caused by high wind speed especially during flowering and maturity stages. Hirai *et al.*, (1993) studied the effect of relative humidity on dry matter production and nitrogen absorption at various temperature levels. The rice plants were grown for 4 days under 60 and 90% relative humidity at 12h day and 12h night temperatures of 24/20, 28/24, 32/28 and 36/32 °C. The plants grown under 90% relative humidity with 24/20 and 28/24°C increases the dry matter in leaves and roots than that of plants grown under 60% relative humidity. They concluded that the dry matter accumulation was affected by humidity and temperature.

Kaladevi *et al.*, (1999) conducted a study during 1997-98 in Tamil Nadu to understand the effect of agrometeorological parameters such as maximum and minimum temperature, relative humidity, solar radiation, wind speed, evaporation and total rainfall on the yield of *Rabi* rice under three transplanting dates (15^{th}

October, 1st November and 15th November). They reported that higher dry matter production is contributed by lower minimum temperature.

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

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

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

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

Peng *et al.* (2004) reported that the yield of dry season rice crops in the Philippine decreased by 15% for each 1° C increase in the growing season mean temperature. Goswami *et al.* (2006) studied the effect of weather parameters on phenology, growth and yield of rice and wheat. They reported that the relationship of two or more weather parameters and grain yield of crops can be used to predict the actual harvesting of crops.

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

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

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

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

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

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

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

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

Yang Jie *et al.* (2014) studied the effect of changes in temperatures, diurnal temperature range and radiation during the rice- growing season from 1961 to 2010 in China. In rice production areas with the mean growing season temperature at 12-14°C and above 20°C, a 1 °C growing- season warming decreased rice yield by roughly 4 per cent. This decrease was partly attributed to increased heat stresses and shorter growth period under the warmer climate. In some rice areas of the southern China and the Yangtze River Basin where the rice growing season temperature was greater than 20°C, decrease in the growing season radiation partly interpreted the wide spread yield decline of the simulation, suggesting the significant negative contribution of recent global dimming on rice production in Chinas main rice areas.

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

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

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

2.4. WEATHR INFLUENCES ON THE INCIDENCE OF PEST AND DISEASES

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

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

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

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

According to Gautam *et al.* (2013) climate change affect the agriculture due to increase in the global temperature at the rate of 0.74°C during the last 100 years and atmospheric CO_2 concentration increased from 280ppm in 1750 to 400ppm in 2013. Such changes affect the reproduction, spread and severity of many plant pathogens. They reported that the elevated temperature and CO_2 concentration affect the perception of late blight of potato (*Phytophthora infestans*) and important diseases of rice namely blast (*Pyricularia oryzae*) and sheath blight (*Rhizoctonia solani*).

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

2.5. GROWTH INDICES

Katsura *et al.* (2007) conducted an experiment for analysing the yield attributes and crop physiological traits of hybrid rice variety Liangyoupeijiu which is a two line hybrid variety (Peiai 64S x 9311(Zou *et al.* (2003)) in Japan and compared with Takanari and Nippobare in 2003 and 2004. They reported that the hybrid variety Liangyoupeijiu showed higher grain yield than the other two varieties due to longer growth duration and larger leaf area duration (LAD) before heading and causing larger biomass accumulation before heading.

According to Welbank *et al.* (1966) increased length of vegetative growth increases the LAI, absorbs more solar radiation, increases photosynthesis and leads to higher yield.

Devendra *et al.* (1983) studied the effect of leaf area duration at different growth stages and its relationship to productivity in early cultivars of rice. They observed that higher leaf area duration during flowering to harvest increases the biological yield but not the grain yield.

Gardner *et al.* (1985) reported that the leaf area ratio states the ratio of blade area or photosynthetic tissues to the total respiratory tissues or plant weight. Leaf Area Rate indicates the leafiness of plant.

According to Singh (1994) leaf area index (LAI) and net assimilation rate (NAR) showed a positive correlation with grain yield in rice during all the phenological stages of rice growth.

Gosh and Singh (1998) reported that the combinations of growth indices such as Leaf Area Index, Leaf Area Duration, Absolute Growth Rate, Relative Growth Rate and Net Assimilation Rate explains variations in yield better than any individual growth variables. They also reported that the leaf area index (LAI) showed a strong positive correlation with grain yield in rice and LAI during flowering period showed yield variation of 79 per cent. Thakar and Patel (1998) reported that dry matter production leaf area index; CGR, NAR and RGR influences the higher grain yield of rice.

According to Talaeei *et al.* (1999) the changes in trend of CGR and grain yield in response to different sowing arrangements showed a high correlation between maximum CGR and grain yield. Net assimilation rate is used to determine the rate of photosynthesis minus respiration losses and also for converting the dry matter into grain yield (Sun *et al.*, 1999). They also reported that, LAI at flowering and crop growth rate during vegetative phase have been identified as the major determinants of yield in rice.

According to Hari *et al.* (1999), the net assimilation rate is influenced by temperature, light, CO2, water, age of leaf, mineral nutrients, chlorophyll content and genotype.

The decrease in rate of photosynthesis causes decrease in net assimilation rate and leads to low grain yield in rice (Lu *et al.*, 2000). Sadeghian and Bahrani (2001) reported that maximum leaf area duration was obtained about 65 days after planting in rice. Shimono *et al.* (2002) reported that the CGR increases with duration from transplanting and reduced the rate in the later stages.

Takai *et al.* (2006) reported that a higher CGR during the late reproductive period may be prerequisite to attain a higher grain yield. The cultivar of rice with higher physiological indices has better growth and higher yield (Esfahani *et al*, 2006). Mahdavi *et al.* (2006) reported that RGR depends upon the net assimilation rate.

According to Singh *et al.* (2009) NAR represents the increase in plant dry weight per unit assimilatory surface per unit time. NAR showed a trend similar to RGR. He also reported that the maximum RGR in rice was observed at early growth stage and over the time it is decreased linearly.

Ahmad *et al.* (2009) conducted an experiment in 2004 and 2005 to study the effect of transplanting dates on leaf area index, crop growth rate, leaf area duration and mean net assimilation rate of two rice varieties under diverse agro-environmental conditions. The field study was conducted at Faisalabad, Kala Shah Kaku (KSK) and Gujranwala (GUJ) in Pakistan. They reported that the early transplanted rice showed higher leaf area index than late transplanted rice cultivars. The observed leaf area index (LAI) was 7.79, 6.70 and 5.33 at Faisalabad, Kala Shah Kaku and Gujranwala respectively. Early transplanting significantly increases the LAD by 75.4%, 20.1% and 16.61% for Faisalabad, Kala Shah Kaku and Gujranwala and delayed transplanting significantly increases the net assimilation rate than early plantings at all the three sites. The crop growth rate (CGR) was found to be increased by 10.30% and 8.26% at Faisalabad and Kala Shah Kaku in early transplanted crops while, CGR was significantly higher in late transplanting than early transplanting at Gujranwala and it was increased by 9.65%.

Nicknejad *et al.* (2009) conducted an experiment at Iran Rice Research Insitute- Deputy of Mazandaran (Amol) in 2007 to study the physiological indices of different rice varieties. They selected four rice varieties viz. Tarom, Neda, Shafagh and Fajr. The results showed that the variety Shafagh recorded highest CGR (25.18g/m2/day) and the variety Tarom recorded least CGR (21.1g/m2/day).

According to Anzoua *et al.* (2010) the growth indices like LAI, CGR, RGR, NAR, LAD, LAR, LWR and SLA are often used for evaluation of plant productivity capability and environmental efficiency.

Taleshi *et al.* (2013) studied the rice growth pattern in Fish-rice culture at Iran during 2010. They conducted two field experiments one with fish-rice culture without using any chemicals and other experiment with rice- chemical fertilizer field. The results showed that the LAI increased in both experiment and recorded highest LAI in 80 days after transplanting in both field experiments. The chemical – rice field at 75 DAT recorded highest crop growth rate (33.6 gm^{-2} day^{-1}). The relative growth rate (RGR) and net assimilation rate (NAR) was found to be highest on 20-25 DAT in chemical- rice culture and lowest on fish-rice culture. They concluded that the rice-chemical had more LAI, CGR, RGR and NAR.

According to Azarpour *et al.* (2014) the stability of physiological indices which affecting yield and yield components determines the dry matter production. Leaf area index in rice at early growth stages increased slightly over time and in the later stages, it was raised further. Maximum LAI of rice was observed at flowering stage (65 days after planting) and then it was decreased due to the wilting and falling of lower leaves.

Medhi *et al.* (2016) studied the physiological analysis of growth characteristics, dry matter partitioning and productivity in hybrid rice during rabi seasons of 2012 and 2013. They reported that the leaf area and leaf area index was found to be increased up to 60 days after transplanting and declined thereafter up to harvest period. They also found the hybrid rice maintain higher LAI indicating delayed senescence and superiorly of hybrid rice. They concluded that the decrease in leaf area towards maturity period due to lesser leaf number as a result of senescence in early formed leaves.

2.6. CROP SIMULATION MODELS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

2.7. CHLOROPHYLL AND PROTEIN

Ono *et al.* (1999) reported that the amount of chlorophyll and protein content in flag leaves were decreased after anthesis. This is due to the changes in sucrose-phosphate synthase activity which alter nitrogen remobilization during leaf senescence.

According to Mia *et al.* (2012) the biochemical attributes like chlorophyll and soluble protein content were higher at vegetative stage than panicle initiation and flowering stage. The hybrid varieties BRRIdhan 32 recorded higher amount of chlorophyll at all the stages ant total chlorophyll content decreased from tillering to flowering stages. They also reported that the soluble protein content decreased at flowering stage as compared to that of maximum tillering stage.

According to Akram *et al.* (1985) maximum protein (9.7%) was observed in the crop planted on June 24. Protein content showed a linear relationship with fertiliser levels. At each fertilizer level the transplanting dates did not differ significantly in their effect on protein. Increase in protein content due to transplanting dates over all the fertilizer levels may be due to higher solar radiation effect since the protein content tends to be low with high solar radiation during grain development.

Tang *et al.* (2004) reported that during leaf senescence photosynthetic CO_2 assimilate rate, carboxylase activity of rubisco, chlorophyll and carotenoid content and the chlorophyll a/b ratio decreased significantly.

Nakano *et al.* (1997) studied the effects of CO_2 levels on photosynthetic rates and examined the chlorophyll, rubisco, cytochrome, sucrose phosphate synthase activity and total N content in young, fully expanded leaves of rice. The plants were grown hydroponically under two CO_2 partial pressures of 36 and 100Pa at 3N concentrations. They reported that the amount of rubisco, chlorophyll and total N were decreased in the leaves of the plants grown in 100 Pa CO_2.

Kura-Hotta *et al.* (1987) studied the 3^{rd} and 6^{th} leaves of the rice seedlings to examine the inactivation of photosynthesis during senescence is related to loss of chlorophyll. They reported that the photosynthetic activity decreased more rapidly than chlorophyll content during leaf senescence. They also reported that the ratio of chlorophyll a/b was also decreased with senescence.

Zhenqui *et al.* (1984) reported that there was significant difference were noticed in chlorophyll content and chlorophyll a/b ratio when grown under same conditions. They reported that the chlorophyll content was low in early stages of growth and gradually increased as plant grows and there after decreases.

Hidema *et al.* (1992) studied the effect of irradiance on changes in chlorophyll and light harvesting chlorophyll a/b protein was examined in senescing leaves of rice with two treatments (100% and 20% natural sunlight). The results were examined after the full expansion of the 13^{th} leaf throughout the course of senescence. They reported that, during 20% sunlight chlorophyll content decreased only a little during leaf senescence whereas 100% sunlight chlorophyll decreased appreciably.

Sahebrao (2015) studied the total chlorophyll content in two rice varieties Jyothi and Uma in the Department of Plant Physiology, Kerala Agricultural University, Thrissur. He reported that the total chlorophyll content in both the rice varieties was decreased from tillering to flowering stages and the variety Uma recorded highest value of total chlorophyll content than Jyothi at tillering and flowering stages as 4.34 and 2.95 mg g^{-1} fresh weight.

Liu *et al.* (2013) studied the effect of elevated air temperature on physiological characteristics of flag leaves and grain yield in rice. They studied the impacts of high air temperature after heading stage on soluble sugar, soluble protein and malonaldehyde contents on flag leaves and grain yield attributes. They reported that the high air temperature reduces the soluble sugar, soluble protein.

Materials and methods

3. MATERIALS AND METHODS

The study on "Phasic development model using thermal indices for rice (*Oryza sativa* L.) in the central zone of Kerala" was conducted at the Department of Agricultural Meteorology, College of Horticulture, Vellanikkara, Thrissur during 2015-2016. The details of the experiments conducted and the methods are in the following sections.

3.1. DETAILS OF FIELD EXPERIMENT

3.1.1. Field Location

The field experiments were conducted during the period from May 2015 to November 2015 at Agricultural Research Station, Mannuthy, Kerala Agricultural University, Thrissur.

3.1.2. Soil Characteristics

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

Table 3.1. Mechanical composition of soil in the experimental field

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

3.1.3. Climate and Weather

The experimental area was influenced by a typical warm humid tropical climatic condition and benefited by both southwest and northeast monsoons. The experimental area received maximum amount of rainfall during the months of July and August. The mean maximum and minimum temperatures of the location recorded were 31.5°C and 24.0°C respectively. The average annual sunshine recorded for the location is 4.4 h day^{-1}. The recorded mean annual relative humidity was 81.5% with forenoon and afternoon relative humidity of 92.1% and 70.9% respectively. The average annual wind speed of the experimental field was 1.6 km h^{-1}. Table 3.2 shows the details of weekly weather parameters during the experimental period.

3.1.4. Season

The field experiment was conducted during *Kharif* season from May 2015 to November 2015.

3.2. EXPERIMENTAL MATERIALS AND METHODS

3.2.1. Variety

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

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

3.2.2. Design and Layout

Split plot design was used for conducting the field experiment with five dates of planting at 15 days interval from 5th June to 5th August as main plot treatments

Table.3.2. Weekly weather parameters during the experimental period in 2015

Week No.	Tmax (°C)	Tmin (°C)	VPD I (mmHg)	VPD II (mmHg)	RH I (%)	RH II (%)	WS (kmh^{-1})	BSS (h)	RF (mm)	RD	Epan (mm)
20	32.1	24.8	22.5	25.0	87.0	69.0	2.1	3.6	0.0	0.0	2.7
21	33.3	25.8	25.7	24.4	93.0	64.1	1.4	6.3	3.0	1.0	3.1
22	32.6	24.9	23.0	23.7	89.3	65.4	1.6	5.2	14.8	2.0	2.8
23	32.3	24.2	23.1	22.9	92.4	73.1	1.4	3.9	44.5	3.0	2.5
24	30.4	23.6	22.5	23.8	95.1	75.3	1.1	1.0	160.6	6.0	2.6
25	30.5	24.7	23.4	23.6	93.3	83.3	2.2	0.3	196.8	7.0	2.7
26	30.3	23.7	22.9	24.4	95.9	81.1	1.5	1.8	228.6	7.0	2.6
27	31.8	24.2	23.5	23.2	94.1	70.6	2.1	6.7	57.9	7.0	3.6
28	30.9	23.7	22.7	22.8	94.7	72.0	1.8	4.5	101.4	5.0	3.0
29	28.2	23.5	22.1	22.8	96.3	86.4	0.8	0.1	257.2	7.0	1.7
30	29.4	23.2	22.1	21.6	95.3	71.6	1.0	2.4	85.9	5.0	2.5
31	31.0	23.6	22.7	21.9	93.7	68.9	1.1	5.1	22.0	1.0	2.9
32	30.1	23.6	22.6	22.8	96.4	75.1	1.0	2.9	128.2	7.0	3.4
33	31.2	24.1	23.2	23.2	94.6	69.7	0.9	4.2	114.9	4.0	3.0
34	31.4	23.4	22.8	23.0	95.6	68.4	0.6	6.2	41.0	2.0	2.9
35	31.8	23.8	23.3	22.3	94.0	64.0	0.5	8.5	16.6	2.0	3.5
36	31.6	23.8	23.0	23.4	94.7	73.0	0.3	3.6	88.6	5.0	2.7
37	31.6	23.5	22.9	21.6	93.7	66.3	0.5	6.8	47.2	4.0	3.1
38	31.4	23.7	23.1	22.9	93.9	70.6	0.2	4.2	37.6	2.0	2.7
39	32.8	24.0	23.1	23.9	91.1	68.7	0.4	6.5	73.6	2.0	3.4
40	31.6	23.8	22.6	23.1	90.7	77.3	0.1	3.7	74.6	5.0	2.4
41	31.6	23.7	22.5	23.8	92.9	74.1	0.3	6.1	72.0	5.0	2.7
42	34.1	24.5	23.3	22.9	89.6	59.9	1.3	7.0	22.0	1.0	3.2
43	33.1	24.8	22.4	22.6	87.4	63.1	1.3	5.3	29.3	2.0	3.5
44	32.8	23.9	22.2	22.6	88.0	64.0	1.1	4.8	13.0	2.0	2.5
45	31.2	23.5	21.8	22.7	91.4	70.6	1.1	3.2	115.7	3.0	2.6
46	30.8	23.2	20.5	22.1	83.7	68.7	1.9	2.8	11.5	2.0	2.4
47	32.2	24.6	20.9	21.5	80.3	64.1	4.8	5.5	2.4	0.3	3.1
Mean	31.5	24.0	22.7	23.0	92.1	70.7	1.2	4.4	2060.9	99.3	2.8

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

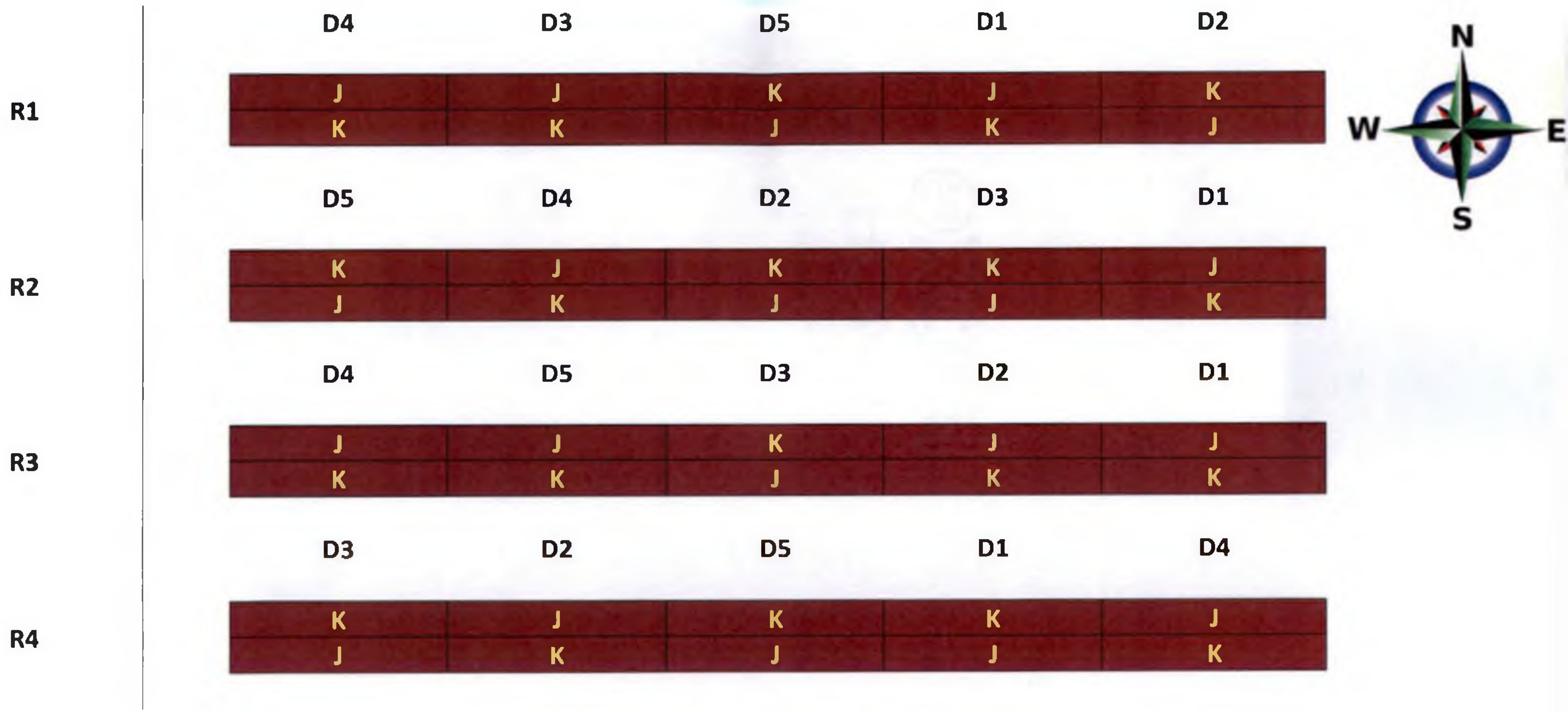
and two rice varieties, Jyothi and Kanchana as sub plot treatments. The varieties were planted at a spacing of 15 cm x10 cm in four replications and there were total of 40 plots each having 5x4 m^2 area. The layout is provided in Fig.3.1.

3.2.3. Treatments

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

Table.3.3. Treatments used in the experiment

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



D1- June 5th , D2- June 20th , D3- July 5th , D4- July 20th , D5- August 5th , J- Jyothi and K- Kanchana

Fig. 3.1. Lay out of experiment in split plot design

3.3. CROP MANAGEMENT

3.3.1. Nursery management

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

3.3.2. Land preparation and planting

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

3.3.3. Application of manures and fertilizers

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

3.3.4. After cultivation

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

3.4. OBSERVATIONS

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

Plate I. Land preparation

Plate II. Transplanting

Plate III. Harvest

Plate IV. Threshing

Plate V. Winnowing

3.4.1. Biometric observations

3.4.1.1. Plant height

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

3.4.1.2. Leaf area

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

3.4.1.3. Biomass

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

3.4.1.4. Number of panicles per unit area

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

3.4.1.5. Number of spikelets per panicle

Number of spikelets from panicle was recorded from 5 plants.

3.4.1.6. Number of filled grains per panicle

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

3.4.1.7. Thousand grain weight

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

3.4.1.8. Grain yield

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

3.4.1.9. Straw yield

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

3.4.2. Phenological Observations

3.4.2.1. Days for active tillering

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

3.4.2.2. Days for panicle initiation

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

3.4.2.3. Days for booting

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

3.4.2.4. Days for heading

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

3.4.2.5. Days for 50 per cent flowering

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

3.4.2.6. Days for physiological maturity

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

3.4.3. Physiological and biochemical observations

a) Physiological observations

3.4.3.1. Leaf Area Index (LAI)

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

Leaf Area Index = Total leaf area of plant/ land area occupied by plant

3.4.3.2. Leaf Area Duration (LAD)

The concept of leaf area duration was put forward by Power *et al.* (1967). The leaf area duration gives the duration and extent of photosynthetic capacity of the crop canopy and expressed in days.

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

Where,

L_1-LAI at the first stage (t_1)

L_2- LAI at the second stage (t_2)

(t_2 - t_1)- Time interval in days

3.4.3.3. Net Assimilation Rate (NAR)

The formula for net assimilation rate (NAR) was given by Williams (1946). The net assimilation rate measures the average photosynthetic efficiency of leaves in a crop community and expressed in $gm^{-2}\ day^{-1}$.

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

Where L_1 and W_1 are leaf area and dry weight of plants at time t_1 and L_2 and W_2 are leaf area and dry weight of plants at time t_2.

3.4.3.4. Crop Growth Rate (CGR)

The method for calculating CGR was suggested by Watson (1956). The crop growth rate explains the dry matter accumulated per unit land area per unit time (g m^{-2} day^{-1}).

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

Where,

W_1- Whole plant dry weight at times t_1

W_2- Whole plant dry weight at times t_2

P- Ground area on which W_1 and W_2 are recorded

b) Biochemical observations

3.4.3.5. Total Chlorophyll content

Total chlorophyll content was calculated by the procedure given by Hiscox and Israelstam (1979). For chlorophyll estimation, 100mg fresh leaf sample was transfered to 10ml Dimethyl Sulfoxide (DMSO) and kept in darkness overnight. Filtered extracts were used to measure the total chlorophyll at two optical densities at 645nm and 663nm by a spectrophotometer (Model-4001/4 Thermo Spectronic Thermo Electron Corporation, USA). The amount of total chlorophyll present in the sample was calculated by using the following formula given by Arnon's.

$$\text{Total Chlorophyll} = [(20.2 \times A645) + (8.02 \times A663)] \times \frac{V}{1000 \times W}$$

Where,

A645- Absorbance at 645 nm wavelength

A663- Absorbance at 663 nm wavelength

V- Total volume of sample

W- Weight of sample

3.4.3.6. Soluble protein content

For soluble protein estimation, 250mg leaf sample was taken and macerate with 10ml of phosphate buffer solution and centrifuge the content at 3000rpm for 10 minutes. The supernatant were collected and the final volume was made up to 25ml. Transfer 5ml ACT (Alkaline Copper Tartarate) and 0.5 ml Folin reagent into 1ml supernatant. Blue colour was developed after 30minutes and measures the optical density at 660nm in a spectrophotometer (Model-4001/4 Thermo Spectronic Thermo Electron Corporation, USA). Standard was prepared using 50mg Bovine Serum Albumin (BSA) and different concentrations of BSA standard solution like 100, 200, 300, 400 and 500ppm were prepared by diluting the stock solution. Plot sample OD in the standard graph to calculate the concentrations (Xμg). The amount of soluble protein present in the sample calculated using the following formula and expressed in mg/g. The soluble protein content was calculated by using the procedure given by Lowry *et al.* (1951).

$$\text{Amount of soluble protein} = \frac{X}{1} \text{ X } \frac{25}{250} \text{ X } 1000$$

3.4.4. Soil Analysis

Three soil samples were collected from the experimental field before transplanting. The samples were collected from different depths such as 5cm and 15cm and the samples were dried individually and powdered well using a mortar. The samples were analysed for pH, Electrical conductivity, available nitrogen, available phosphorous, available potassium and organic carbon content. The results of soil analysis are given in Table 3.4.

Table 3.4. Chemical properties of the soil

Sl. No	Parameter	Sampling depth in cm	
		0-5	5-15
1	pH	5.2	5.2
2	Electrical conductivity (ds m^{-2})	0.11	0.11
3	Available nitrogen (kg ha^{-1})	0.096	0.083
4	Available phosphorous (kg ha^{-1})	91.16	106.16
5	Available potassium (kg ha^{-1})	498.4	492.8
6	Organic carbon (%)	0.96	0.83

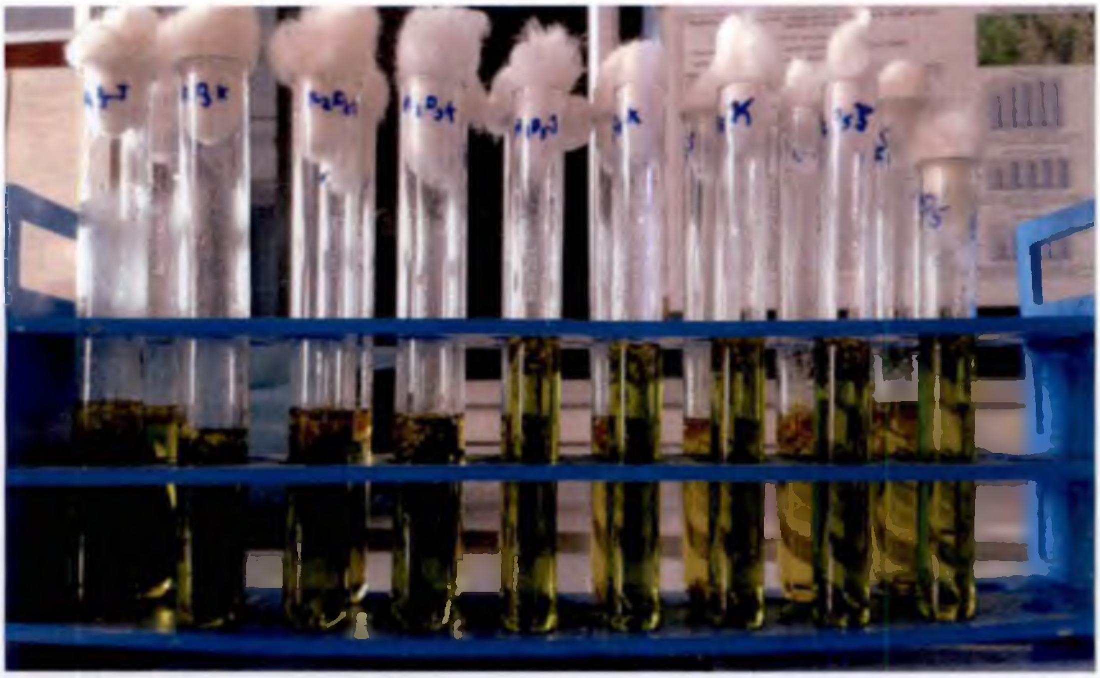


Plate VI. Analysis of total chlorophyll content

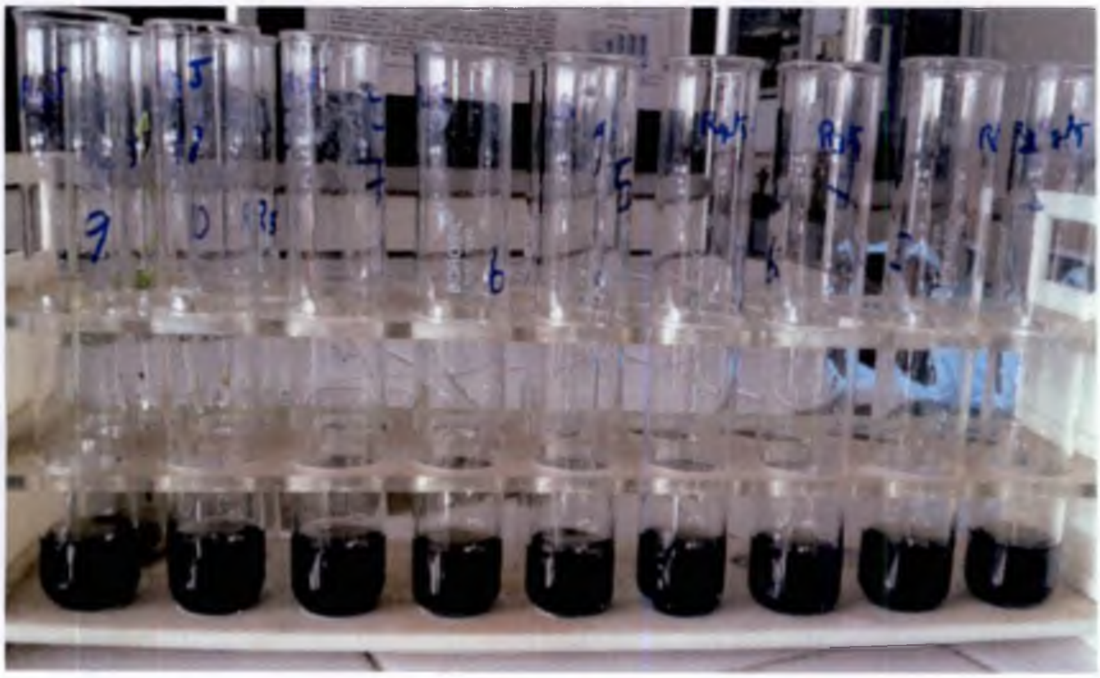


Plate VII. Analysis of soluble protein

3.4.3.6. Soluble protein content

For soluble protein estimation, 250mg leaf sample was taken and macerate with 10ml of phosphate buffer solution and centrifuge the content at 3000rpm for 10 minutes. The supernatant were collected and the final volume was made up to 25ml. Transfer 5ml ACT (Alkaline Copper Tartarate) and 0.5 ml Folin reagent into 1ml supernatant. Blue colour was developed after 30minutes and measures the optical density at 660nm in a spectrophotometer (Model-4001/4 Thermo Spectronic Thermo Electron Corporation, USA). Standard was prepared using 50mg Bovine Serum Albumin (BSA) and different concentrations of BSA standard solution like 100, 200, 300, 400 and 500ppm were prepared by diluting the stock solution. Plot sample OD in the standard graph to calculate the concentrations (Xμg). The amount of soluble protein present in the sample calculated using the following formula and expressed in mg/g. The soluble protein content was calculated by using the procedure given by Lowry *et al.* (1951).

$$\text{Amount of soluble protein} = \frac{X}{1} \text{ X } \frac{25}{250} \text{ X } 1000$$

3.4.4. Soil Analysis

Three soil samples were collected from the experimental field before transplanting. The samples were collected from different depths such as 5cm and 15cm and the samples were dried individually and powdered well using a mortar. The samples were analysed for pH, Electrical conductivity, available nitrogen, available phosphorous, available potassium and organic carbon content. The results of soil analysis are given in Table 3.4.

Table 3.4. Chemical properties of the soil

Sl. No	Parameter	Sampling depth in cm	
		0-5	5-15
1	pH	5.2	5.2
2	Electrical conductivity (ds m^{-2})	0.11	0.11
3	Available nitrogen (kg ha^{-1})	0.096	0.083
4	Available phosphorous (kg ha^{-1})	91.16	106.16
5	Available potassium (kg ha^{-1})	498.4	492.8
6	Organic carbon (%)	0.96	0.83

3.4.5. Weather Data

Daily weather data from the Agrometeorological Observatory of College of Horticulture; Vellanikkara were used for the study. The station is located at 10° 32' N latitude and 76° 20' E longitude at altitude of 22m above sea level. The daily weather data were recorded and converted to weekly data. Daily weather data on maximum temperature, minimum temperature, forenoon and afternoon relative humidity, rainfall, number of rainy days, bright sunshine hours, evaporation and wind speed were recorded. The different weather parameters used for the study are given in Table 3.5.

Table 3.5. Weather parameters used in the experimental period

Sl. No.	Weather parameter	Unit
1	Maximum temperature (Tmax)	°C
2	Minimum temperature (Tmin)	°C
3	Relative humidity (RH) Forenoon relative humidity (RHI) Afternoon relative humidity (RHII)	%
4	Rainfall (RF)	mm
5	Rainy days (RD)	days
6	Bright sunshine hours (BSS)	h
7	Forenoon vapour pressure deficit (VPDI) Afternoon vapour pressure deficit (VPD II)	mm Hg
8	Wind speed (WS)	km hr^{-1}
9	Evaporation (Epan)	mm
10	Growing degree day (GDD)	°C day
11	Heliothermal unit (HTU)	°C day h
12	Photothermal unit (PTU)	°C day h

3.5. HEAT UNITS

3.5.1. Growing Degree Days (GDD)

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

$$\text{GDD} = \sum_{i=1}^{n} \frac{\text{Tmax} + \text{Tmin}}{2} - \text{Tb}$$

Where,

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

Tmax- Maximum temperature (°C)

Tmin- Minimum temperature (°C)

Tb - Base temperature (minimum threshold temperature)

3.5.2. Heliothermal Unit (HTU)

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

$$\text{HTU} = \sum_{i=0}^{n} \text{GDD x BSS}$$

Where, GDD = Growing Degree Days

BSS = Actual bright sunshine hours

3.5.3. Photothermal Units (PTU)

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

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

Where, L is the maximum possible sunshine hours

The maximum possible sunshine hours were calculated using Smithsonian table.

3.6. STATISTICAL ANALYSIS

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

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

$$\text{CD} = t_{\alpha} \text{ x } \text{SE}_1$$

Where, t_{α} = t value at degrees of freedom for main plot error

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

$$\text{SE}_1 = \sqrt{\frac{2 \text{ x } \text{E}_1}{\text{rb}}}$$

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

r = number of replications

b = number of sub plot treatments

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

$$CD = t_\alpha \times SE_2$$

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

SE_2= Standard error of difference between two sub plot treatments

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

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

r = Number of replications

a = Number of main plot treatments

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

$$CD = t_\alpha \times SE_3$$

Where, t_α = t value at degrees of freedom for main plot treatments

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

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

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

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

r = Number of replications

b = Number of sub plot treatments

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

3.7. CROP SIMULATION MODEL

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

3.7.1. CERES-Rice model

Crop Estimation through Resource and Environment Synthesis (CERES-Rice) model (Ritchie and Otter, 1985; Ritchie, 1986 and Godwin *et al.,* 1990) is considered as the basis for simulating the effect of cultivar, plant density, weather, soil water and nitrogen on growth and yield. CERES- Rice model is a part of Decision Support System for Agro-technology Transfer and it has a common input and output data format (Jones, 1993 and Tsuji *et al.*, 1994). Hunt and Boote (1994) provide the minimum data set for the operation and calibration of the CERES-Rice model.

3.7.1.1. Input files

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

Table 3.6. Input files data files of CERES-Rice model

Internal file name			External description	Example file name
Input files	Experiment	FILEX	Experiment details file for a specific experiment (e.g., rice at KAVK): Contains data on treatments, field conditions, crop management and simulation controls	ASSV1501. RIX
	Weather and soil	FILEW	Weather data, daily, for a specific (e.g.,VKMT) station and time period (e.g., for one year)	ASSV1501. WTH
		FILES	Soil profile data for a group of experimental sites in general (e.g.,SOIL.SOL) or for a specific institute (e.g., KASCLAYLOM.SOL)	SOIL.SOIL
	Crop and cultivar	FILEC	Cultivar/variety coefficients for a particular crop species and model; e.g., rice for the 'CERES' model, version 046	RICER046.CUL[1]
		FILEE	Ecotype specific coefficients for a particular crop species and model; e.g., rice for the 'CERES' model, version 046	RICER046.ECO[1]
		FILEG	Crop (species) specific coefficients for a particular model; e.g., rice for the 'CERES' model, version 046	RICER046.SPE[1]
	Experiment data files	FILEA	Average values of performance data for a rice experiment. (Used for comparison with summary model results.)	ASSV1501. RIA
		FILET	Time course data (averages) for a rice experiment. (Used for graphical comparison of measured and simulated time course results.)	ASSV1501. RIT

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

3.7.1.2. Output files

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

Table 3.7. Output files of CERES-Rice model

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

3.7.2. 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 is the adjustment of parameters for comparing simulated values with observed values. The genetic coefficients in CERES-Rice model were derived by adjusting the relevant coefficients to attain the possible match between simulated and observed number of days taken for the occurrence of phenological events. Calibration of genetic coefficients of CERES-Rice model require minimum crop performance data set of dates of emergence, anthesis, beginning of grain filling, maturity duration, grain yield, above ground biomass, grain density and weight. The genetic coefficients of CERES-Rice model are given in the Table 3.8.

Table 3.8. 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 ° 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
PHINT	Phyllocron interval

3.7.4. Hypothesis for the CERES-Rice model

For running the CERES Rice model, genetic coefficients were determined using a range of values of each coefficient. The repetition of coefficients was stopped when the agreement reached ± 10%.

The genetic coefficients were developed separately for Jyothi and Kanchana. Root mean square error (RMSE), Mean Absolute Percentage Error (MAPE) and D – stat (index of agreement) was used to evaluate the model performances. The equations used for RMSE, MAPE and D- stat index are given below.

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

$$\text{MAPE} = \frac{1}{n}\sum_{i=1}^{n} \frac{|\,Oi - Pi|}{Oi} \times 100$$

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

Where,

RMSE - Root mean square error

D - Index of agreement

Oi - Observed value

Pi - Predicted value

Oiavg - Average of observed value

n - No of observation.

Results

4. RESULTS

The results obtained from the study "Phasic development model using thermal indices for rice (*Oryza sativa* L.) in the central zone of Kerala" are presented below.

4.1. PHENOPHASES OF RICE CROP

Phenology is the study of the dates of first occurrence of biological events in their annual cycle and relationships with seasonal climatic changes. The developmental stages of rice are strongly affected by the environmental factors and crop genotypes.

In this present study the phenophases of rice crop is subdivided into six growth and development periods based on their morphological characters and are denoted by P1 to P6. The phenophases of rice crop include:

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

These phenophases are coming under different growth periods such as vegetative period, reproductive period and ripening period. The developmental stages from transplanting to panicle initiation (P1& P2) comes under the vegetative period, panicle initiation to 50% flowering stages (P3-P5) comes under reproductive period and flowering to physiological maturity (P6) under ripening period. The rice varieties Jyothi and Kanchana showed variations in occurrence of their duration of phenophases for five dates of plantings (5^{th} June- 5^{th} August) during the *Kharif* season in 2015. The variations in duration of phenophases for both the varieties are represented in the phenological calendar (Fig. 4.1 a & b). The phenophases of crops were plotted against standard meteorological weeks. Delayed transplanting were decreases the duration of both Jyothi and Kanchana.

4.2. WEATHER PARAMETERS PREVAILED DURING CROP GROWTH PERIOD

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

4.2.1. Air temperature

The temperature experienced during the crop period is graphically represented on weekly basis in Fig. 4.2. The maximum temperature (Tmax), minimum temperature (Tmin), weekly mean temperature and diurnal range temperature (DTR) were recorded. Delayed transplanting experiences more temperature than early transplanted crops and recorded maximum temperature during 42^{nd} week (34.1°C) and minimum temperature experienced during 30^{th} and 45^{th} week (23.2°C).

4.2.2. Relative humidity

Relative humidity (forenoon and afternoon) were recorded for entire crop growing period and were represented graphically against standard meteorological weeks. The forenoon relative humidity (RHI) and afternoon relative humidity (RHII) was prevailed during the crop period was studied and it is given in the Fig. 4.3. The forenoon relative humidity was highest during 32^{nd} week (96.4%) and showed a decreasing trend towards delayed date of transplanting. The lowest forenoon relative humidity was recorded on 47^{th} week (82.3%). Afternoon relative humidity also showed variations and followed a decreasing trend towards delayed

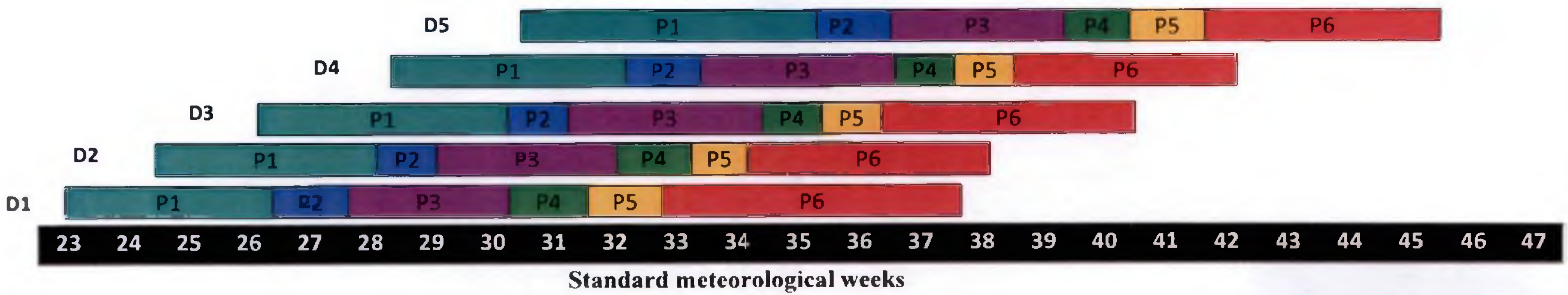


Fig. 4.1.a.Phenological calendar of Jyothi (2015)

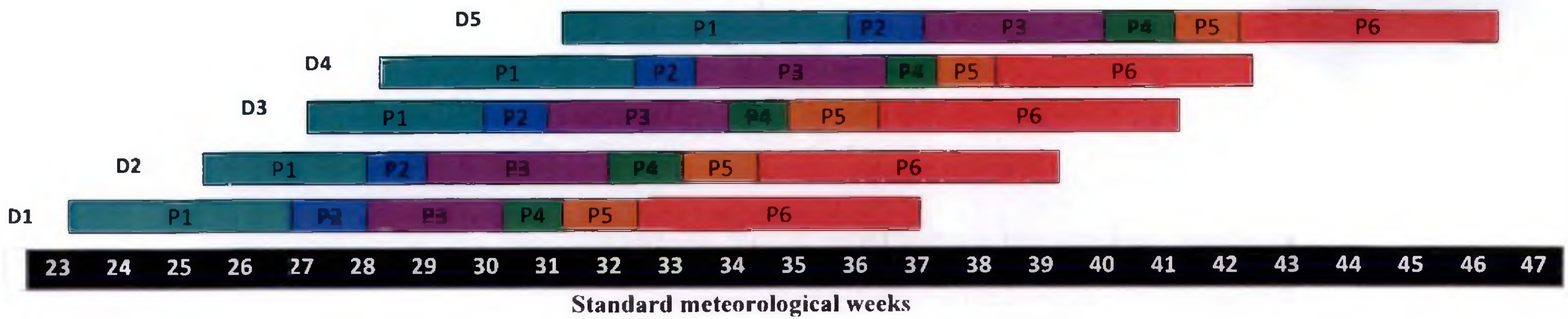


Fig. 4.1.b.Phenological calendar of Kanchana (2015)

P1- Transplanting to active tillering
P2- Active tillering to panicle initiation
P3- Panicle initiation to booting

P4-Booting to heading
P5- Heading to 50% flowering
P6- 50% flowering to physiological maturity

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

4.2. WEATHER PARAMETERS PREVAILED DURING CROP GROWTH PERIOD

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

4.2.1. Air temperature

The temperature experienced during the crop period is graphically represented on weekly basis in Fig. 4.2. The maximum temperature (Tmax), minimum temperature (Tmin), weekly mean temperature and diurnal range temperature (DTR) were recorded. Delayed transplanting experiences more temperature than early transplanted crops and recorded maximum temperature during 42nd week (34.1°C) and minimum temperature experienced during 30th and 45th week (23.2°C).

4.2.2. Relative humidity

Relative humidity (forenoon and afternoon) were recorded for entire crop growing period and were represented graphically against standard meteorological weeks. The forenoon relative humidity (RHI) and afternoon relative humidity (RHII) was prevailed during the crop period was studied and it is given in the Fig. 4.3. The forenoon relative humidity was highest during 32nd week (96.4%) and showed a decreasing trend towards delayed date of transplanting. The lowest forenoon relative humidity was recorded on 47th week (82.3%). Afternoon relative humidity also showed variations and followed a decreasing trend towards delayed

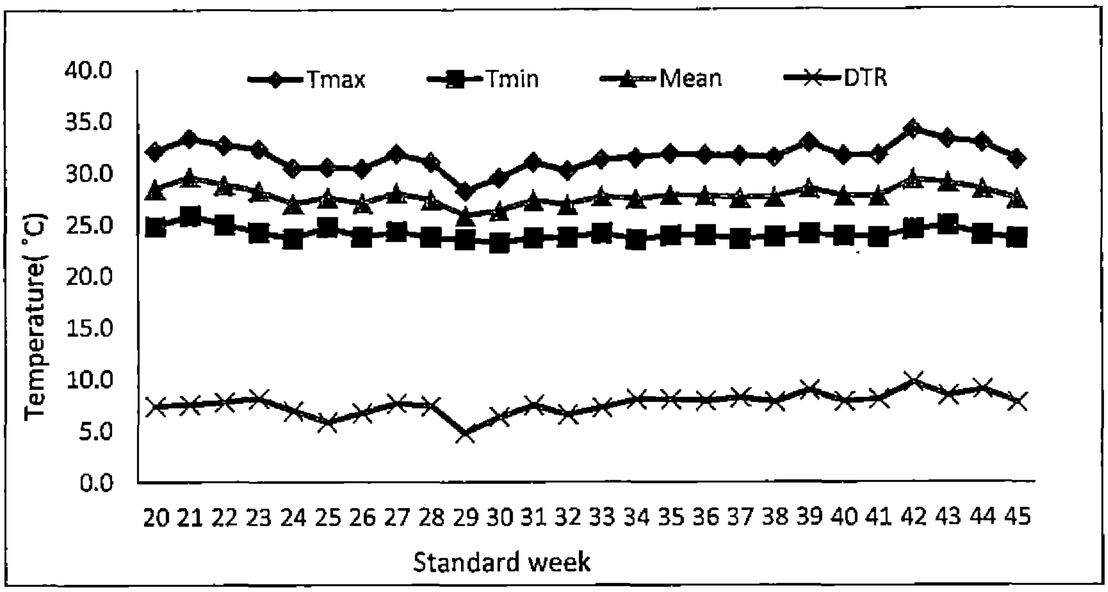


Fig.4.2. Weekly temperature (°C) during the crop period

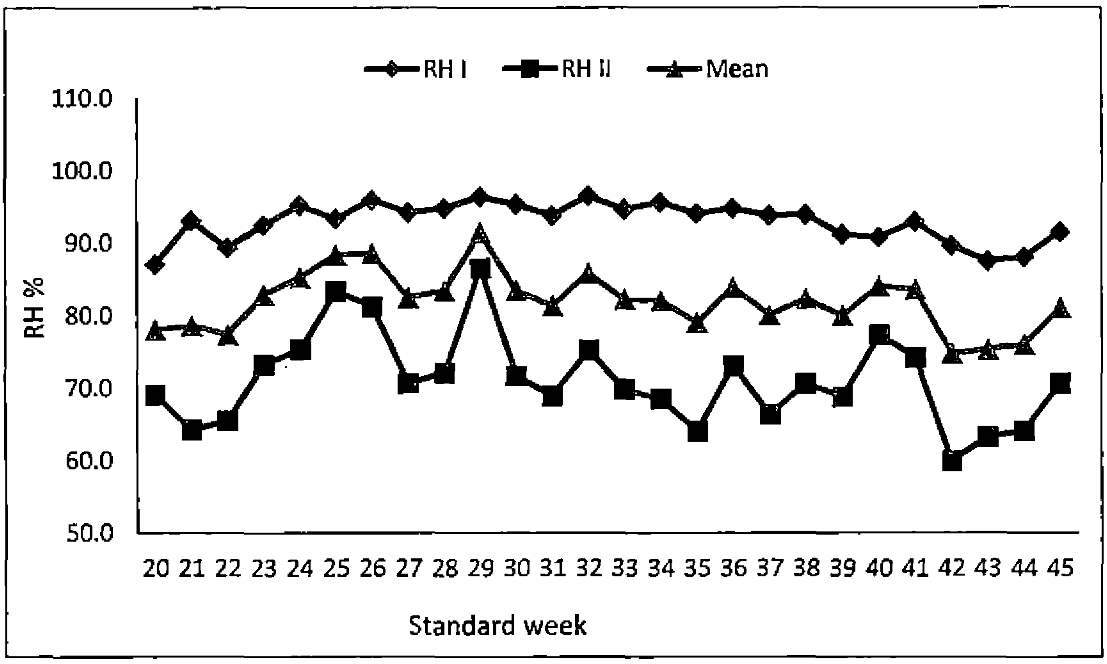


Fig.4.3. Weekly relative humidity (%) during the crop period

transplanting. Highest afternoon relative humidity was recorded during 29th week (86.4%) and lowest afternoon relative humidity was recorded on 42nd week (59.9%).

4.2.3. Rainfall and rainy days

The rainfall and number of rainy days were calculated for the entire crop growing period and for different phenophases of the crop. The rainfall and rainy days are presented against standard meteorological weeks in Fig. 4.4. The highest rainfall of 257.2mm obtained in 29th week. The amount of rainfall showed decreasing trend towards delayed date of transplanting. The amount of rainfall obtained during the entire crop period was 2064.7mm.The total rainy day for entire crop period was 100 days. The number of rainy days reduced with delay in transplanting.

4.2.4. Vapour pressure deficit (VPD)

The dry bulb and wet bulb thermometer was used for calculating the vapour pressure deficit (mmHg) for the entire crop period. The forenoon and afternoon vapour pressure for the entire crop period is presented in Fig. 4.5. The forenoon and afternoon vapour pressure deficit showed a decreasing trend towards delayed date of transplanting. The highest and lowest forenoon vapour pressure deficit were recorded on 21st and 46th weeks and the corresponding values were 25.7mmHg and 20.5mmHg respectively. The highest and lowest values of afternoon vapour pressure deficit recorded were 25.0mmHg and 21.6 mmHg and it was on 20th and 30th & 37th weeks respectively.

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

The bright sunshine hours and pan evaporation for the entire crop season were recorded and are presented in Fig. 4.6. Delayed transplanting showed increasing trend for both bright sunshine hours and pan evaporation. The bright sunshine was found to be highest on 35th week and the recorded value was 8.5h. The lowest value of BSS was recorded on 29th week and the observed value was 0.1h

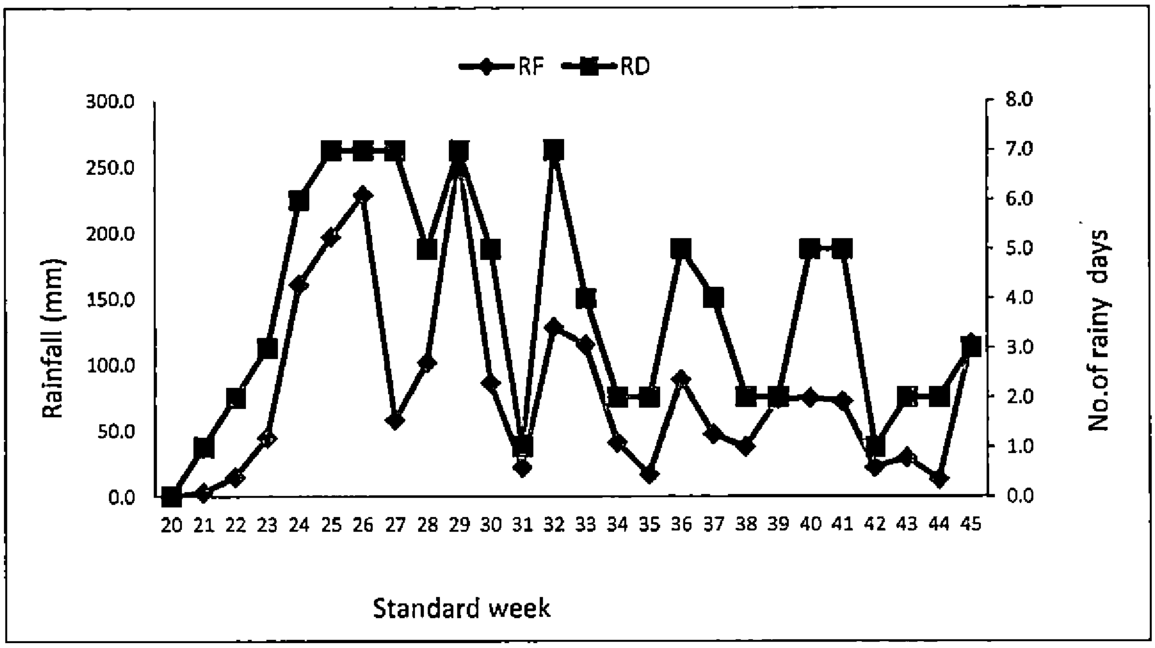


Fig.4.4. Weekly rainfall (mm) during the crop period

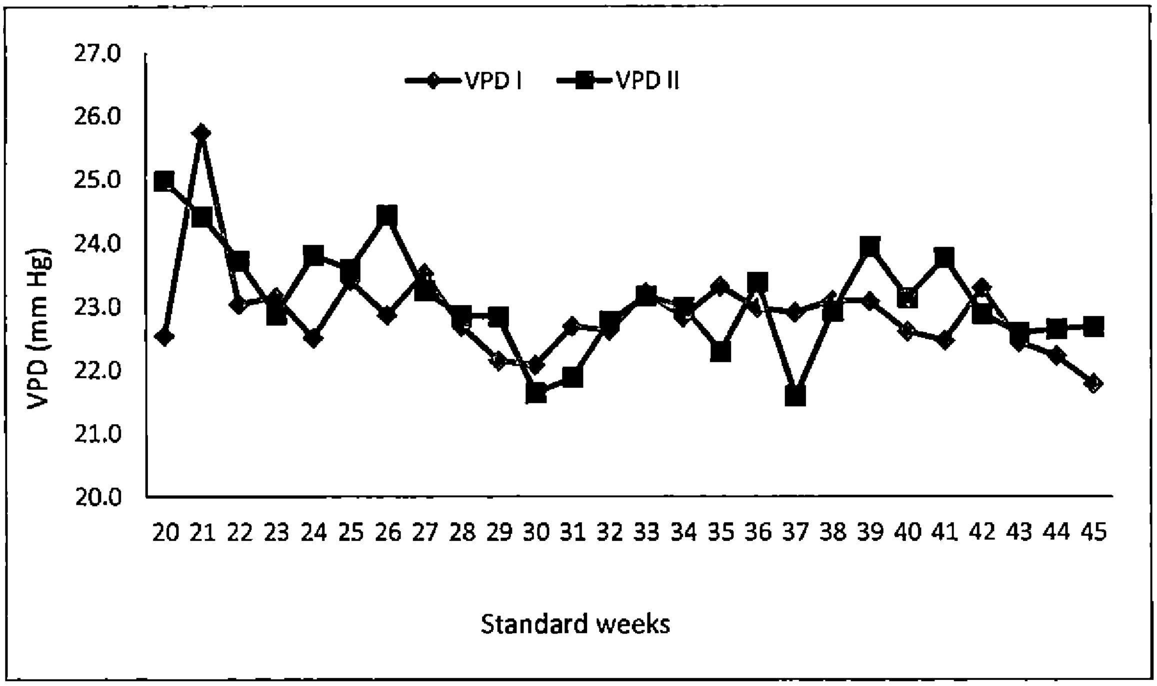


Fig.4.5. Weekly vapour pressure deficit (VPD) (mmHg) during the crop period

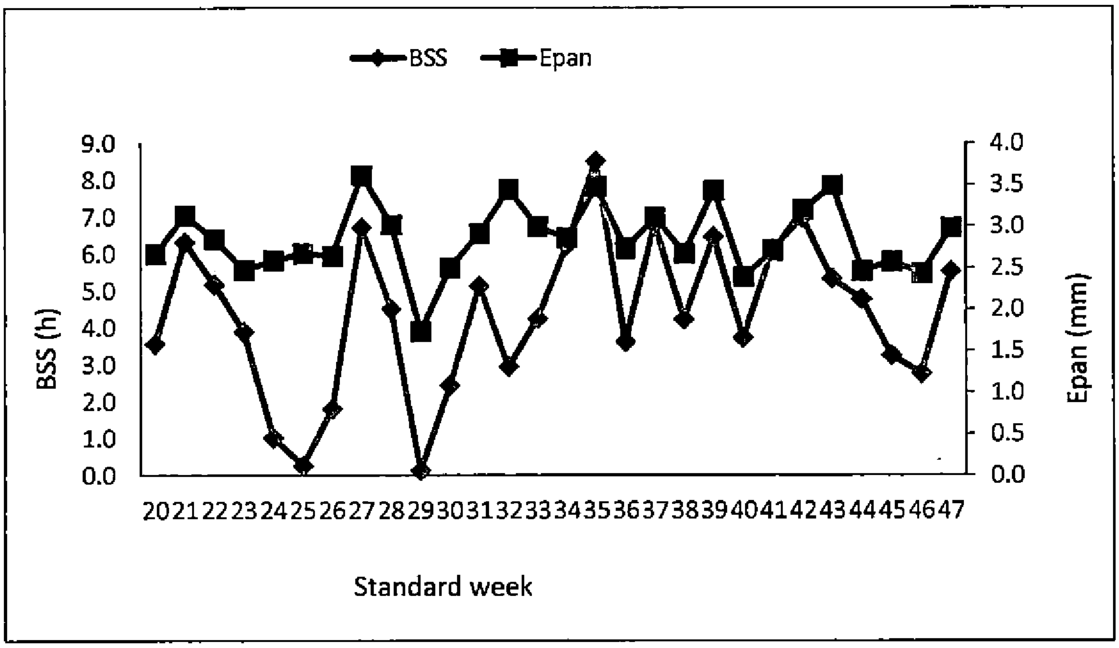


Fig. 4.6. Weekly bright sunshine hours (h) and evaporation (mm) during the crop period

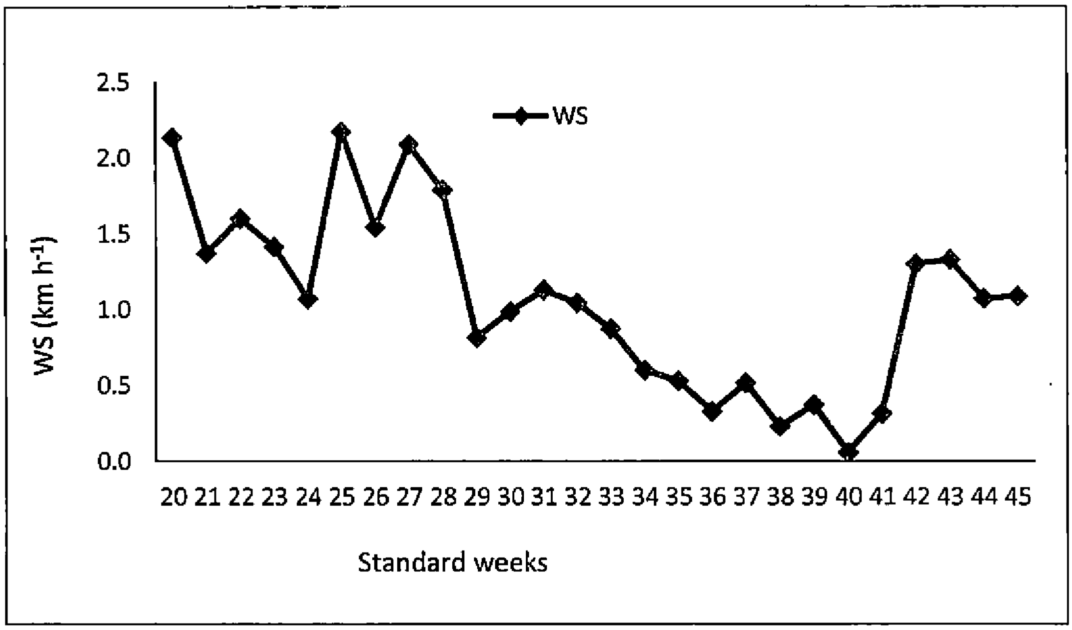


Fig.4.7. Weekly wind speed (km h^{-1}) during the crop period

respectively. Bright sunshine hours showed fluctuations during the entire crop period.

The pan evaporation followed increasing trend towards delayed date of transplanting. The rate of evaporation was highest on 27th week (3.6mm) and lowest on 29th week (1.7mm) respectively.

4.2.6. Wind speed (WS)

The wind speed experienced during the crop period was recorded and presented graphically in Fig.4.7. The wind speed followed a decreasing trend towards delayed date of plantings. It could be noted that the early transplanted crops experienced fluctuations in wind speed and the middle of standard meteorological week, a little fluctuation are noticed in wind speed. The highest wind speed (3.5 km h^{-1}) recorded on 47th week and lowest (0.1km h^{-1}) on 40th week.

4.3. WEATHER PARAMETERS DURING DIFFERENT PHENOPHASES

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

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

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

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

The temperature during transplanting to active tillering stages of experimental period experiences highest maximum temperature during August 5th transplanted crops for both Jyothi and Kanchana (31.0°C). The lowest minimum temperature were recorded during July 5th transplanted crops and the recorded lowest minimum temperature was 23.4°C for Jyothi and Kanchana. The observed maximum and minimum temperature range for Jyothi were 30.0°C to 31.0°C and 23.4°C to 23.8°C

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

Weather parameters	Date of transplanting									
	D1		D2		D3		D4		D5	
	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana
Tmax (ºC)	30.8	30.8	30.7	30.8	30.0	29.8	30.0	30.0	31.0	31.0
Tmin(ºC)	23.8	23.8	23.7	23.8	23.4	23.4	23.5	23.5	23.7	23.7
Tmean(ºC)	27.3	27.3	27.2	27.3	26.7	26.6	26.8	26.8	27.4	27.3
DTR(ºC)	7.0	7.0	7.0	7.0	6.5	6.4	6.4	6.4	7.3	7.3
VP I (mmHg)	23.0	23.0	23.0	23.1	22.4	22.4	22.5	22.5	22.9	22.9
VP II (mmHg)	23.6	23.6	23.5	23.5	22.3	22.3	22.3	22.3	22.8	22.8
RH I (%)	94.5	94.5	94.7	94.6	95.1	95.4	95.2	95.2	95.3	95.4
RH II (%)	77.1	77.1	77.0	76.2	74.3	75.1	74.2	74.2	69.7	70.2
RH mean (%)	85.8	85.8	85.9	85.4	84.7	85.3	84.7	84.7	82.5	82.8
RF (mm)	647.2	647.2	611.1	511.6	467.9	467.9	375.6	375.6	298.8	298.8
RD (days)	24.0	24.0	26.0	24.0	20.0	20.0	17.0	17.0	15.0	15.0
BSS (h)	1.9	1.9	3.3	3.5	3.3	2.9	3.1	3.1	5.1	4.9
E (mm)	2.7	2.7	3.0	3.0	2.6	2.5	2.6	2.6	3.0	2.9
WS (Km h^{-1})	1.6	1.6	1.8	1.9	1.3	1.3	1.0	1.0	0.8	0.8

D1- 5^{th} June D2- 20^{th} June D3- 5^{th} July D4- 20^{th} July D5- 5^{th} August respectively. The maximum and minimum temperature ranges for Kanchana were recorded as 29.8°C to 31.0°C and 23.4°C to 23.8°C respectively. The mean temperature ranges between 26.7°C to 27.4°C for Jyothi and 26.6°C to 27.3 °C for Kanchana. The diurnal temperature range recorded for Jyothi and Kanchana was 6.4°C to 7.3°C.

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

The vapour pressure deficit during the experimental period was recorded as forenoon vapour pressure deficit (VPD I) and afternoon vapour pressure deficit (VPD II). The recorded vapour pressure deficit range for Jyothi was 22.4 to 23.0 mmHg and 22.4 to 23.1 mmHg for Kanchana. The highest forenoon vapour pressure deficits for both varieties were recorded during June 5th and June 20th transplanting. The variety Jyothi recorded highest forenoon vapour pressure deficit during June 5th and June 20th planting (23.0mmHg) and for Kanchana it was on June 20th planting (23.1mmHg). The rice varieties experiences highest afternoon vapour pressure deficit during June 5th planting (23.6mmHg) and lowest afternoon relative humidity (22.3mmHg) during 3rd and 4th date of transplanting (July 5th and 20th).

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

The range of relative humidity experienced during transplanting to active tillering stage of Jyothi was 94.5% to 95.4 % (RH I) and 69.7% to 77.1% (RH II). The crops transplanted during 5th August and 5th June recorded highest (95.3 %) and lowest (94.5%) forenoon relative humidity. The afternoon relative humidity reaches its highest during first date of planting (5th June) and lowest during fifth date of planting (5th August). The mean relative humidity was highest (85.9%) during second date of planting and lowest (82.5%) during fifth date of transplanting. The variety Kanchana experiences highest forenoon relative humidity (95.4%) during 3rd and 5th transplanting and lowest forenoon relative humidity (94.5%) during 1st transplanting. The crops transplanted during first and fifth plantings recorded highest (77.1%) and lowest (69.7%) afternoon relative humidity. The range of mean relative humidity during transplanting to active tillering of Kanchana was 82.8% to 85.8% which was recorded on 5th August and 5th June.

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

Rice varieties Jyothi and Kanchana from transplanting to active tillering stage received highest rainfall during first date of planting (June 5th) while receive lowest rainfall during fifth date of planting (August 5th). The recorded highest and lowest rainfall was 647.2mm and 298.8mm for both the varieties. Transplanting to active tillering, the variety Jyothi got maximum number of rainy days during second date of transplanting (26 RD) whereas Kanchana got maximum rainy days during first transplanting (24RD). In both the varieties the minimum rainy days where observed in the case of last date of planting during the transplanting to active tillering stage (T-AT).

4.3.1.5. Bright sunshine hours (BSS)

The bright sunshine hours recorded for Jyothi was 1.9h to 5.1h and for Kanchana it was 1.9h to 4.9h. The highest sunshine hours recorded during August 5th transplanting and lowest during June 5th transplanting for both varieties. The recorded highest sunshine hours for Jyothi were 5.1h and Kanchana it was 4.9h.

4.3.1.6. Pan evaporation (Epan)

Evaporation occurred during transplanting to active tillering stage was 3mm and it was recorded on June 20th and August 5th transplanting for Jyothi and June 20th planting for Kanchana. The recorded range of evaporation for Jyothi and Kanchana was 2.6mm to 3.0mm and 2.5mm to 3.0mm respectively.

4.3.1.7. Wind speed (WS)

The wind speed decreases towards delayed transplanting for both the varieties. High wind occurs during second date of transplanting. The recorded wind speed for Jyothi was 1.8 km h^{-1} and 1.9 km h^{-1} for Kanchana. The lowest recorded wind speed was 0.8km h^{-1} on fifth date of planting.

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

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

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

The temperature prevailed during transplanting to panicle initiation showed increasing trend towards delayed transplanting. The recorded maximum temperature range for Jyothi was 30.1°C to 31.2°C. The maximum temperature was found to be highest during last date of transplanting for both varieties. The temperature range for Kanchana was 30.1°C to 31.3°C. The lowest minimum temperature for Jyothi showed decreasing trend whereas Kanchana showed increasing trend towards delayed transplanting. The lowest minimum temperature range for Jyothi and Kanchana were 23.5°C and 23.8°C respectively. The mean temperature range for Jyothi and Kanchana recorded was 26.8°C to 27.5°C and 26.8°C to 27.6°C. The diurnal temperature range during transplanting to panicle initiation for Jyothi and Kanchana was 6.5°C to 7.5°C.

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

The delayed transplanting showed decreasing trend in vapour pressure deficit for Jyothi and increasing trend in Kanchana. The forenoon vapour pressure deficit range for Jyothi was 22.5 to 23.0mmHg and for Kanchana it was 22.3 to 23.1mmHg. the lowest VPD was recorded during July 5th transplanting for both varieties. The afternoon vapour pressure deficit range for Jyothi and Kanchana was 22.4 mmHg to 23.6mmHg and it was recorded during third (5th July) and first (5th June) date of transplanting for both varieties.

4.3.2.3. Relative humidity (RH I, RH II and RHmean)

Transplanting to panicle initiation stage of both Jyothi and Kanchana experiences an increasing trend in forenoon relative humidity and decreasing trend in afternoon and mean relative humidity. For Jyothi and Kanchana the lowest

Table. 4.2 . Weather parameter during transplanting to panicle initiation

Weather parameters	Date of transplanting									
	D1		D2		D3		D4		D5	
	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana
Tmax (°C)	30.9	30.9	30.1	30.2	30.1	30.1	30.4	30.4	31.2	31.3
Tmin(°C)	23.8	23.8	23.6	23.6	23.5	23.5	23.6	23.6	23.8	23.8
Tmean(°C)	27.4	27.4	26.9	26.9	26.8	26.8	27.0	27.0	27.5	27.6
DTR(°C)	7.1	7.1	6.5	6.5	6.6	6.6	6.8	6.7	7.5	7.5
VP I (mmHg)	23.0	23.0	22.7	22.8	22.5	22.5	22.7	22.7	23.0	23.1
VP II(mmHg)	23.6	23.6	23.2	23.2	22.4	22.4	22.6	22.6	22.9	22.9
RH I (%)	94.5	94.6	95.1	95.1	95.1	95.1	95.1	95.1	95.1	95.1
RH II (%)	76.2	75.9	78.2	78.2	73.9	73.9	72.4	73.0	70.1	70.0
RH mean (%)	85.4	85.3	86.6	86.6	84.5	84.5	83.8	84.1	82.6	82.6
RF(mm)	732.0	751.4	826.0	841.6	540.9	552.7	499.8	500.7	383.6	436.2
RD(days)	32	33.0	34	35.0	25	26.0	21	22.0	20	23.0
BSS(h)	2.7	2.7	2.6	2.7	3.4	3.4	3.8	3.7	5.1	5.4
E(mm)	2.8	2.8	2.7	2.7	2.6	2.6	2.7	2.7	3.0	3.0
WS(Km h^{-1})	1.7	1.7	1.6	1.6	1.3	1.3	0.9	0.9	0.7	0.7

forenoon relative humidity was 94.5% & 94.6 % and the plantings on June 20th, July 5th, July 20th and August 5th experiences forenoon relative humidity of 95.1%. The afternoon relative humidity was found to be highest (78.2%) in June 20th and lowest (70.0% &70.1%) on August 5th plantings for Jyothi and Kanchana. The mean relative humidity also found same as the afternoon relative humidity. The highest and lowest RHmean was 86.6% to 82.6% for both varieties.

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

The amount of rainfall received during transplanting to panicle initiation showed decreasing trend and highest amount of rainfall received by Jyothi and Kanchana during second date of planting. The recorded highest amount of rainfall for Jyothi and Kanchana was 826.0mm and 841.6mm respectively. For both varieties the lowest amount of rainfall received on 5th August planted varieties and the recorded rainfall was 383.6mm and 436.2mm.

The number of rainy days showed decreasing trend towards delayed transplanting. The crops receive highest rainy days on 20thJune and the number of rainy days for Jyothi was 34days and for Kanchana it was 35days. In case of Jyothi lowest rainy days received on 5th August (20 days) and for Kanchana it was on 20thJuly (22days).

4.3.2.5. Bright sunshine hours (BSS)

The phenological stage experiences increasing trend in bright sunshine hours for both the varieties. The varieties Jyothi and Kanchana received more sunshine hours (5.1h and 5.4h) during fifth transplanting. The obtained sunshine hour range was 2.6 h to 5.1h (Jyothi) and 2.7h to 5.4 h (Kanchana).

4.3.2.6. Pan evaporation (Epan)

The rate of evaporation for both Jyothi and Kanchana showed increasing trend towards delayed transplanting. The rate of evaporation for Jyothi and

Kanchana was found to be more (3.0mm) in last date of planting while less during third planting (2.6mm).

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

Delayed transplanted crops were affected by less wind than early planted crops. The first date of plantings record 1.7 km h^{-1} wind speed for Jyothi and Kanchana. The range of wind speed occurred during the phenological stage was 0.7 km h^{-1} to 1.7 km h^{-1} for Jyothi and Kanchana respectively.

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

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

4.3.3.1 Temperature (Tmax, Tmin, Tmean and DTR)

Transplanting to booting stage of Jyothi and Kanchana received a maximum temperature of 31.5°C and minimum temperature of 23.6°C. In case of Jyothi the highest maximum temperature received during last date of planting and lowest minimum temperature received during third and fourth date of planting whereas Kanchana received a minimum temperature of 23.6°C on first, second, third and fourth date of planting. The recorded maximum and minimum temperature range for Jyothi was 30.3°C to 31.5°C and 23.6°C to 23.7°C. Diurnal temperature becomes highest during last date of planting for both varieties and it was 7.8°C for Jyothi and 7.7°C for Kanchana

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

The forenoon vapour pressure deficit was highest during fifth date of planting for both varieties (23.0mmHg). The range of forenoon relative humidity was 22.7mmHg to 23.0mmHg for both varieties. The variety Jyothi and Kanchana recorded highest afternoon vapour pressure deficit (23.0mmHg) on first date of

Table 4.3. Weather prevailed during Transplanting to Booting

	Date of transplanting									
Weather parameters	D1	D1	D2	D2	D3	D3	D4	D4	D5	D5
	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana
Tmax (°C)	30.4	30.5	30.3	30.3	30.5	30.5	30.9	30.9	31.5	31.5
Tmin(°C)	23.7	23.6	23.7	23.6	23.6	23.6	23.6	23.6	23.7	23.8
Tmean(°C)	27.1	27.1	27.0	26.9	27.0	27.1	27.3	27.2	27.6	27.6
DTR(°C)	6.8	6.8	6.6	6.6	6.9	6.9	7.2	7.2	7.8	7.7
VP I (mmHg)	22.8	22.8	22.7	22.7	22.7	22.8	22.8	22.8	23.0	23.0
VP II(mmHg)	23.0	23.0	22.9	22.9	22.5	22.9	22.4	22.5	22.9	22.8
RH I(%)	94.8	94.7	95.0	95.0	95.1	94.9	94.8	94.8	94.3	94.4
RH II(%)	75.8	75.6	75.6	75.9	72.1	74.3	70.2	70.7	69.5	69.2
RH mean(%)	85.3	85.2	85.3	85.4	83.6	84.6	82.5	82.7	81.9	81.8
RF(mm)	1132.1	1132.9	1023	1038.6	788.7	800.5	645	643.7	541	581.0
RD(days)	47	47.0	46	47.0	36	37.0	31	32.0	28	31.0
BSS(h)	2.8	2.9	3.2	3.1	4.1	3.6	4.8	4.7	5.4	5.3
E(mm)	2.7	2.7	2.8	2.8	2.8	2.8	2.8	2.8	3.0	3.0
WS(Km h^{-1})	1.5	1.5	1.4	1.4	1.1	1.3	0.7	0.7	0.6	0.6

planting. The recorded range of lowest afternoon vapour pressure deficit for Jyothi and Kanchana was 22.4mmHg to 23.0mmHg and 22.5mmHg to 23.0mmHg.

4.3.3.3. Relative humidity (RH I, RH II and RH Mean)

The relative humidity showed decreasing trend towards delayed transplanting and highest forenoon relative humidity recorded on third date of planting for Jyothi (95.1%) and second date of planting for Kanchana (95.0%). In case of afternoon relative humidity, the first date of planting received highest relative humidity for Jyothi (75.8%) and second date of planting for Kanchana (75.9%). The range of mean relative humidity for Jyothi and Kanchana was 81.9% to 85.3% and 81.8% to 85.4%.

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

The amount of rainfall received during transplanting to booting stage of Jyothi and Kanchana followed decreasing trend towards delayed transplanting. The first date of planting of Jyothi and Kanchana received highest rainfall 1132.1mm and 1132.9mm rainfall respectively. The fifth date of planting received lesser amount of rainfall in Jyothi (541.0mm) while Kanchana received lowest amount of rainfall (581.0mm). The recorded range of number of rainy days for Jyothi and Kanchana was 28 days to 47 days and 31days to 47 days respectively and the highest rainy days recorded on June 5^{th} planting.

4.3.3.5. Bright sunshine hours (BSS)

The bright sunshine hours recorded during transplanting to booting showed increasing trend for both Jyothi and Kanchana. The highest bright sunshine hours recorded for Jyothi and Kanchana during August 5^{th} transplanting. The maximum bright sunshine hours recorded was 5.4 h & 5.3h for Jyothi and Kanchana. The range of bright sunshine hours for Jyothi and Kanchana was 2.8 h to 5.4h and 2.9h to 5.3h respectively.

4.3.3.6. Pan evaporation (Epan)

The rate of evaporation recorded during transplanting to booting stage of Jyothi and Kanchana was 2.7mm to 3.0mm and the highest rate of evaporation occurred during fifth date of planting (3.0mm).

4.3.3.7. Wind speed (WS)

The effect of wind speed showed a decreasing trend towards delayed planting and record highest wind speed on June 5th planting in both varieties. The highest wind recorded for Jyothi and Kanchana was 1.5 km h^{-1} and lowest wind speed was 0.6 km h^{-1} respectively.

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

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

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

The fifth date planted varieties received highest maximum temperature and the recorded range of maximum, minimum and mean temperature for Jyothi and Kanchana was 30.5°C to 31.5°C, 23.6°C to 23.7°C and 27.0°C to 27.6 °C respectively. The diurnal temperature showed increasing trend toward delayed date of planting and the range for Jyothi and Kanchana was 6.8°C to 7.7°C and 6.8°C to 7.8°C.

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

The vapour pressure deficit during transplanting to heading stages of both varieties showed a increasing trend towards delayed planting. The highest forenoon vapour pressure deficit was recorded on fifth date of planting and it was 23.0 mmHg for Jyothi and Kanchana. The afternoon vapour pressure deficit showed decreasing trend and record highest VPD II (23.0mmHg) on first planted crops.

4.4. Weather prevailed during transplanting to heading

	Date of transplanting									
Weather parameters	D1	D1	D2	D2	D3	D3	D4	D4	D5	D5
	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana
Tmax (°C)	30.5	30.5	30.4	30.4	30.7	30.6	30.9	30.9	31.5	31.5
Tmin(°C)	23.6	23.7	23.7	23.6	23.7	23.6	23.6	23.6	23.7	23.7
Tmean(°C)	27.1	27.1	27.0	27.0	27.2	27.1	27.3	27.3	27.6	27.6
DTR(°C)	6.8	6.8	6.8	6.8	7.0	7.0	7.3	7.3	7.7	7.8
VP I (mmHg)	22.7	22.8	22.8	22.8	22.8	22.8	22.8	22.8	23.0	23.0
VP II(mmHg)	23.0	23.0	23.0	22.9	22.6	22.6	22.5	22.5	22.9	22.9
RH I(%)	94.8	94.7	95.0	94.9	95.0	95.0	94.8	94.8	93.9	93.9
RH II(%)	75.3	75.4	75.0	75.1	72.0	71.7	70.9	71.0	70.4	70.1
RH mean(%)	85.0	85.1	85.0	85.0	83.5	83.4	82.8	82.9	82.2	82.0
RF(mm)	1205.1	1219.9	1137.8	1153.4	862.9	803.5	666.2	673.1	600.7	663.4
RD(days)	52	53.0	49	50.0	39	38.0	33	34.0	32	34.0
BSS(h)	3.0	2.9	3.4	3.4	4.3	4.3	4.7	4.7	5.3	5.4
E(mm)	2.7	2.7	2.8	2.8	2.8	2.8	2.8	2.8	2.9	3.0
WS(Km h^{-1})	1.4	1.4	1.3	1.3	1.0	1.0	0.7	0.7	0.5	0.5

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

In case of Jyothi and Kanchana the relative humidity showed decreasing trend towards delayed planting. The recorded range of forenoon, afternoon and mean relative humidity for Jyothi was 93.9% (5th August) to 95.0% (20th June &5th July), 70.4% (5th August) to 75.3% (5th June) and 82.2% (5th August) to 85.0% (5th June & 20th June) and for Kanchana recorded 93.9% (5th August) to 95.0 (5th July), 70.1% (5th August) to75.4% (5th June) and 82.0% (5th August) to 85.1% (5th June) respectively.

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

The transplanting to heading stages received highest amount of rainfall during June 5th plantings in both Jyothi and Kanchana followed by June 20th transplanting. The variety Kanchana received higher amount of rainfall than Jyothi. The highest recorded amount of rainfall received for Kanchana was 1219.0mm and for Jyothi it was 1205.1mm on June 5th and 1153.4mm and 1137.8mm on June 20th transplanting. The number of rainy days was found to be more for Kanchana than Jyothi. Highest rainy days received for both varieties on June 5th and lowest on 5th August. The highest recorded rainy days was 52 days for Jyothi and 53 days for Kanchana on 5th June and 32 days and 34 days was the lowest recorded rainy days for Jyothi and Kanchana.

4.3.4.5. Bright sunshine hours (BSS)

Bright sunshine hours for Jyothi and Kanchana showed highest on last date of planting (5.3h and 5.1h). The range of bright sunshine hours for Jyothi and Kanchana was 3.0 h to 5.3 h and 2.9 h to 5.4 h respectively.

4.3.4.6. Pan evaporation (Epan)

The rate of evaporation was found to be highest on last date of planting for both varieties. The recorded range was 2.7 mm to 2.9 mm for Jyothi and 2.7 mm to 3.0 mm for Kanchana.

4.3.4.7. Wind speed (WS)

The wind speed showed a decreasing trend for Jyothi and Kanchana. The recorded wind speed range for Jyothi and Kanchana was 0.5km h^{-1} to 1.4 km h^{-1} respectively.

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

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

4.3.5.1 Temperature (Tmax, Tmin, Tmean and DTR)

Transplanting to 50% flowering of Jyothi and Kanchana recorded highest maximum temperature on 5th August (31.4°C). The lowest minimum temperature recorded during the period was 23.6°C for both varieties. The recorded maximum and minimum temperature range for Jyothi and Kanchana was 30.4°C to 31.4°C and 23.6°C to 23.7°C respectively. The mean temperature range for Jyothi and Kanchana was 27.0°C to 27.6°C respectively. The recorded diurnal temperature range was 6.8°C to 7.7°C.

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

The forenoon and afternoon vapour pressure deficit for Jyothi and Kanchana was recorded as 22.7mmHg to 22.9mmHg, 22.7mmHg to 23.0mmHg, 22.6mmHg to 23.0 mmHg and 22.5 mmHg to 23.0 mmHg respectively.

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

The relative humidity during transplanting to 50% flowering was 93.9% to 95.0%, 70.5% to 75.5% and 82.2% to 85.2% (RH I, RH II and RH mean) for Jyothi and 93.9% to 95.0%, 70.3% to 75.3% and 82.1% to 85.0% for Kanchana (RH I, RH II and RH mean). The first and second date of planting recorded highest RH II, RH mean and RHI for Jyothi. In case of Kanchana the second and third date of

Table 4.5.Weather prevailed during transplanting to 50% flowering

Weather parameters	Date of transplanting									
	D1		D2		D3		D4		D5	
	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana
Tmax (°C)	30.4	30.5	30.5	30.4	30.7	30.7	31.0	30.9	31.4	31.4
Tmin(°C)	23.6	23.6	23.6	23.6	23.6	23.7	23.6	23.6	23.7	23.7
Tmean(°C)	27.0	27.1	27.1	27.0	27.1	27.2	27.3	27.3	27.6	27.6
DTR(°C)	6.8	6.8	6.9	6.8	7.0	7.0	7.3	7.3	7.7	7.7
VP I (mmHg)	22.7	22.7	22.8	22.8	22.7	22.8	22.9	22.8	22.9	23.0
VP II(mmHg)	23.0	23.0	22.9	23.0	22.6	22.6	22.6	22.5	22.9	22.9
RH I (%)	94.8	94.8	95.0	95.0	95.0	95.0	94.7	94.7	93.9	93.9
RH II (%)	75.5	75.3	74.3	74.9	72.0	72.0	70.6	70.6	70.5	70.3
RH mean (%)	85.2	85.0	84.7	84.9	83.5	83.5	82.6	82.6	82.2	82.1
RF(mm)	1253.3	1283.1	1144	1159.6	873.5	881.9	685	692.9	673.4	713.4
RD(days)	54	55.0	49	50.0	41	41.0	34	35.0	34	39.0
BSS(h)	2.9	3.0	3.6	3.4	4.2	4.3	4.8	4.8	5.3	5.2
E(mm)	2.7	2.7	2.8	2.7	2.8	2.8	2.8	2.8	2.9	2.9
WS(Km h⁻1)	1.4	1.4	1.3	1.3	1.0	1.0	0.7	0.7	0.5	0.5

planting experiences highest forenoon relative humidity and first date of planting experiences highest afternoon and mean relative humidity.

4.3.5.5. Bright sunshine hours (BSS)

The bright sunshine hours received during transplanting to 50% flowering stage showed increasing trend for both varieties and 5.3 and 5.2h was the highest sunshine hours for Jyothi and Kanchana on that period. The range was noticed as 2.9h to 5.3h for Jyothi and 3.0h to 5.2h for Kanchana respectively.

4.3.5.6. Pan evaporation (Epan)

The evaporation recorded for Jyothi and Kanchana was 2.7 mm to 2.9 mm. The highest rate of evaporation was found on last date of planting for both Jyothi and Kanchana.

4.3.5.7. Wind speed (WS)

The wind speed prevailed during transplanting to 50% flowering for Jyothi and Kanchana was 0.5 km h^{-1} to 1.4 km h^{-1}. Heavy wind occurred during first date of planting and the wind speed was reduced by delayed transplanting.

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

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

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

Maximum temperature prevailed during transplanting to physiological maturity for Jyothi and Kanchana was 31.8°C and lowest minimum temperature was 23.6°C. The maximum and minimum temperatures were recorded on August 5th and July 5th. The mean temperature was found maximum on August 5th (27.8°C) for both varieties. Diurnal temperatures were recorded highest on fifth date of planting and recorded DTR was 8.0°C for Jyothi and 7.9°C for Kanchana.

Table.4.6. Weather prevailed during transplanting to physiological maturity

Weather parameters	Date of transplanting									
	D1		D2		D3		D4		D5	
	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana
Tmax (°C)	30.8	30.8	30.9	30.9	31.0	31.0	31.5	31.5	31.8	31.8
Tmin(°C)	23.7	23.7	23.7	23.7	23.6	23.6	23.8	23.8	23.8	23.9
Tmean(°C)	27.2	27.2	27.3	27.3	27.3	27.3	27.6	27.6	27.8	27.8
DTR(°C)	7.1	7.1	7.3	7.2	7.3	7.3	7.7	7.7	8.0	7.9
VP I (mmHg)	22.8	22.8	22.9	22.9	22.8	22.8	22.8	22.8	22.7	22.8
VP II(mmHg)	22.8	22.9	22.9	22.8	22.8	22.8	22.8	22.8	22.9	22.9
RH I(%)	94.7	94.7	94.5	94.6	94.2	94.2	93.2	93.3	92.3	92.3
RH II(%)	72.8	73.0	72.3	72.3	72.0	72.0	69.9	69.9	68.8	68.8
RH mean(%)	83.8	83.9	83.4	83.5	83.1	83.1	81.5	81.6	80.6	80.6
RF(mm)	1581.5	1584.7	1372.8	1388.4	1183.5	1185.1	962.5	970.1	877.7	898.3
RD(days)	71	72.0	63	64.0	59	58.0	49	50.0	47	48.0
BSS(h)	3.9	3.9	4.4	4.3	4.6	4.6	5.1	5.1	5.2	5.2
E(mm)	2.8	2.8	2.9	2.9	2.8	2.8	2.9	2.9	2.9	2.9
WS(Km h^{-1})	1.1	1.1	1.0	1.0	0.7	0.7	0.7	0.7	0.7	0.7

4.3.6.2. Vapour pressure deficit (VPI and VP II)

Transplanting to physiological maturity of Jyothi and Kanchana experiences highest forenoon vapour pressure deficit on June 20th and lowest was on August 5th. The range of forenoon vapour pressure deficit experienced by the crops were 22.7mmHg to 22.9mmHg (Jyothi) and 22.8mmHg to 22.9mmHg (Kanchana). The afternoon relative humidity showed increasing trend and it recorded highest (22.9mmHg) value on 5th August for both varieties.

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

The relative humidity from transplanting to physiological maturity experiences decreasing trend. From the Table 4.6. it is clear that the early planted crops (June 5th) experiences highest relative humidity and it decreased on delayed planting. The range of RH I, RH II and RH mean was 92.3% to 94.7%, 80.6% to 83.8% and 68.8% to 72.8% for Jyothi and 92.3% to 94.7%, 80.6% to 83.9% and 68.8% to 73.0% for Kanchana respectively.

4.3.6.4. Rainfall and rainy days (RF and RD)

Early transplanted rice varieties Jyothi and Kanchana received heavy rainfall of 1581.5mm and 1584.7mm on June 5th and it becomes reduced on delayed planting and the lowest amount of rainfall received during transplanting to physiological maturity was 877.7mm and 898.3mm for Jyothi and Kanchana. Number of rainy days received maximum of 71 days for Jyothi and 72 days for Kanchana.

4.3.6.5. Bright sunshine hours (BSS)

The rice varieties Jyothi and Kanchana took 5.2h for completing transplanting to physiological maturity. The maximum BSS was recorded on August 5th and lowest on June 5th. The recorded range of BSS was 3.9h to 5.2h.

4.3.6.6. Pan evaporation (Epan)

The rate of evaporation was found to be 2.8 mm to 2.9mm for both Jyothi and Kanchana.

4.3.6.7. Wind speed (WS)

Delayed transplanting reduces the wind speed during its growth period and the recorded wind speed for Jyothi and Kanchana was 0.7km h^{-1} to 1.1km h^{-1} respectively

4.4. PHENOLOGICAL OBSERVATIONS

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

4.4.1. Number of days taken for Active tillering

The rice varieties Jyothi and Kanchana took 27 days for active tillering for June 5^{th} transplanting while 26 days for August 5^{th} transplanted crops. The number of days taken for active tillering showed a decreasing trend towards late transplanting for both the rice varieties. Delayed transplanting reduces the number of days taken for the completion of active tillering stage in both the rice varieties.

4.4.2. Number of days taken for Panicle initiation

The rice varieties transplanted on June 20^{th} took more days for the completion of panicle initiation stage i.e. Jyothi and Kanchana took 37 & 36 days for the completion of panicle initiation stage. The number of days taken for panicle initiation showed a decreasing trend towards late transplanting. Late transplanted crops (August 5^{th}) took comparatively less days for the completion of panicle initiation stage. The variety Jyothi took more days than Kanchana.

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

Phenophases	Date of transplanting									
	D1		D2		D3		D4		D5	
	J	K	J	K	J	K	J	K	J	K
Active tillering	27	27	28	27	27	26	26	26	26	26
Panicle initiation	35	34	37	36	35	35	36	34	35	34
Booting	56	55	58	57	57	56	57	56	56	54
Heading	65	64	64	63	64	62	61	60	61	60
50% flowering	67	66	68	67	66	65	66	64	65	64
Physiological maturity	102	101	101	100	100	99	100	99	100	99

D1- 5th June D2- 20th June D3- 5th July D4- 20th July D5- 5th August
J - Jyothi K- Kanchana

4.4.3. Number of days taken for Booting

The number of days taken for booting was highest for second date of transplanting (June 20th) and lowest for last date of transplanting (August 5th). For both varieties, the number of days for booting reduced during last date of planting and also showed a decreasing trend. Number of days taken for the completion of booting stage for Jyothi and Kanchana ranged from 56-58 and 54-57 respectively.

4.4.4. Number of days taken for Heading

Number of days from transplanting to heading ranged from 61-65 days for Jyothi and 60- 64 for Kanchana. For first transplanted crops Jyothi took 65 days and Kanchana took 64 days for the completion of heading stage. For July 20th and August 5th transplanted crops took 61 and 60 days for heading stage for Jyothi and Kanchana. It is found that Jyothi took more days than Kanchana for heading stage.

4.4.5. Number of days taken for 50% Flowering

The number of days for 50% flowering showed a decreasing trend towards delayed transplanting. The variety Jyothi took more days for 50% flowering than Kanchana. It is clear that the June 20th transplanting take more days for completing 50% flowering stage for both Jyothi (68) and Kanchana (67).

4.4.6. Number of days taken for Physiological maturity

The number of days for physiological maturity varied for both the varieties. For attaining physiological maturity June 5th planted crops took 102 days for Jyothi and 101 days for Kanchana. Delayed transplanting took less days for the completion of physiological maturity for both Jyothi and Kanchana. The variety Jyothi took more days for physiological maturity than Kanchana.

4.5. STATISTICAL ANALYSIS OF PLANT CHARACTERISTICS

Statistical analysis were performed for biometric observations such as plant height, leaf area, dry matter accumulation at weekly intervals, number of filled grains per panicle, number of spikelets per panicle, number of filled grains per panicle, 1000 grain weight, grain yield, straw yield; physiological observations and biochemical analysis such as leaf area index, leaf area duration, net assimilation rate, crop growth rate, soluble protein and total chlorophyll content. The results of analysis of covariance were presented given below.

4.5.1. Biometric observations

4.5.1.1. Plant height at weekly intervals

Analysis of variance was performed for weekly plant height from first week after transplanting to harvest (13 weeks) for Jyothi and Kanchana varieties of rice. The results of analysis of variance performed on plant height at weekly intervals for Jyothi and Kanchana varieties of rice are given in Annexure-ii. It could be observed that date of planting had no significant influence on plant heights at 1^{st}, 3^{rd}, 4^{th}, 7^{th}, 12^{th} and 13^{th} weeks after transplanting in both varieties of rice. Dates of planting had significant influence on plant heights at 2^{nd}, 5^{th}, 6^{th}, 8^{th}, 9^{th}, 10^{th} and 11^{th} weeks after transplanting in both rice varieties. June 5^{th} planting was superior to all other plantings in both Jyothi and Kanchana. Plant height in the different weeks from first week after transplanting to harvest corresponding to the five dates of transplanting from 5^{th} June to 5^{th} August at 15 days interval for both the rice varieties are provided in the Table.4.8. The comparisons between dates of planting and varieties were made for the plant heights, which showed significance as per ANOVA and is shown in Table.4.8.

A comparison was made between varieties for the plant heights at different weeks after planting and the results are presented in Table.4.9. The plant height was significantly higher in Jyothi and Kanchana in all the dates of plantings excluding 4^{th}, 6^{th}, 7^{th} and 8^{th} weeks after transplanting. In these weeks the plant height of Kanchana was on par with height of Jyothi.

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

Date of plantings	Weekly plant height														
	Week 1			Week 2			Week 3			Week 4			Week 5		
	J	K	Mean	J	K	Mean	J	K	Mean	J	K	Mean	J	K	Mean
D1	25.0	23.2	24.1^{a}	35.1^{a}	34.5^{a}	34.8	47.7	44.6	46.1^{a}	56.1	55.0	55.6^{a}	64.8^{a}	64.0^{a}	64.4^{a}
D2	22.6	21.6	22.1^{b}	30.1^{b}	24.6^{b}	27.4	34.0	33.4	33.7^{b}	38.7	37.7	38.2^{c}	44.9^{c}	43.2^{c}	44.1^{c}
D3	23.3	22.5	22.9^{ab}	27.3^{b}	26.9^{b}	27.1	35.5	34.1	34.8^{b}	44.1	43.8	43.9^{b}	54.0^{b}	55.0^{b}	54.5^{b}
D4	23.0	22.2	22.6^{b}	26.8^{b}	25.6^{b}	26.2	32.7	31.8	32.3^{c}	37.3	36.9	37.1^{cd}	44.0^{c}	41.7^{d}	42.9^{d}
D5	23.1	22.6	22.9^{ab}	26.5^{b}	27.4^{b}	27.0	31.8	32.6	32.2^{c}	36.6	36.8	36.7^{d}	43.3^{c}	42.5^{c}	42.9^{d}
CD	NS		1.3	4.0		2.0	NS		1.3	NS		1.5	1.8		0.9

Date of plantings	Weekly plant height														
	Week 6			Week7			Week 8			Week 9			Week 10		
	J	K	Mean	J	K	Mean	J	K	Mean	J	K	Mean	J	K	Mean
D1	74.2^{a}	73.7^{a}	74.0^{a}	79.0	78.3	78.6^{a}	84.9^{a}	84.7^{a}	84.8^{a}	94.2^{a}	93.5^{a}	93.9^{a}	102.9^{a}	99.9^{a}	101.4^{a}
D2	53.2^{d}	53.0^{c}	53.1^{d}	63.7	62.8	63.3^{c}	75.1^{b}	74.1^{b}	74.6^{b}	84.7^{b}	83.9^{b}	84.3^{b}	94.5^{b}	94.0^{b}	94.2^{b}
D3	62.3^{b}	63.6^{b}	62.9^{b}	67.7	68.3	68.0^{b}	74.0^{b}	75.3^{b}	74.7^{b}	85.1^{b}	83.4^{b}	84.3^{b}	95.8^{b}	93.9^{b}	94.8^{b}
D4	56.2^{c}	53.4^{c}	54.8^{c}	62.8	62.0	62.4^{c}	76.7^{b}	72.1^{b}	74.4^{b}	83.3^{b}	78.4^{c}	80.8^{c}	92.9^{bc}	84.0^{d}	88.4^{d}
D5	52.9^{d}	53.3^{c}	53.1^{d}	62.8	63.6	63.2^{c}	74.5^{b}	74.3^{b}	74.4^{b}	83.1^{b}	83.7^{b}	83.4^{b}	91.6^{c}	89.6^{c}	90.6^{c}
CD	1.7		0.9	NS		0.9	4.0		2.3	3.7		2.0	3.7		1.1

Date of plantings	Weekly plant height								
	Week 11			Week 12			Week 13		
	J	K	Mean	J	K	Mean	J	K	Mean
D1	107.7^{ab}	94.4^{c}	101.0^{c}	114.9	113.8	114.3^{ab}	124.6	117.8	121.2^{ab}
D2	104.4^{bc}	102.9^{b}	103.7^{b}	110.9	109.7	110.3^{c}	125.3	118.5	121.9^{a}
D3	104.1^{c}	99.1^{c}	101.6^{c}	114.9	112.4	113.7^{b}	123.5	117.6	120.5^{b}
D4	110.0^{a}	108.7^{a}	109.3^{a}	116.9	114.5	115.7^{a}	123.8	118.0	120.9^{b}
D5	101.4^{c}	97.7^{c}	99.5^{d}	115.3	113.8	114.6^{ab}	123.0	118.5	120.8^{b}
CD	3.5		1.3	NS		0.9	NS		0.7

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

Variety	Plant height												
	Week												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Jyothi	23.4[a]	29.2[a]	36.3[a]	42.6[a]	50.2[a]	59.8[a]	67.2[a]	77.0[a]	86.1[a]	95.5[a]	105.5[a]	114.6[a]	124.0[a]
Kanchana	22.4[b]	27.8[b]	35.3[b]	42.0[a]	49.3[b]	59.4[a]	67.0[a]	76.1[a]	84.6[b]	92.3[b]	100.6[b]	112.8[b]	118.1[b]
CD	0.9	1.3	0.8	0.6	0.6	0.5	0.5	1.0	1.0	1.4	1.3	1.1	0.7

4.5.1.2. Dry matter accumulation at 15 days interval

Analysis of variance was performed and the results for accumulation of dry matter at 15 days interval were presented Appendix-II- page –iii. Dry matter accumulation at 15 days interval for five dates of planting was given in Table.4.10. The dry matter accumulation was found to be decreasing with delayed transplanting. the dry matter accumulation in Jyothi showed no significant difference in all the dates of plantings, while Kanchana the June 5^{th} dry matter accumulation was on par with June 20^{th} date of planting and are superior to other dates of transplanting. It was observed that dry matter accumulation was highest at 75 days after transplanting for both varieties. The highest dry matter accumulation of 15262.3 kg ha^{-1} was recorded on June 5^{th} transplanting which is on par with July 20^{th}date of transplanting. The dry matter accumulation was recorded lowest on august 5^{th} date of planting which is on par with June 20^{th} and July 20^{th} date of planting.

4.5.1.3. Dry matter accumulation at the time of harvest

The effect of date of planting on dry matter production at the time of harvest was given in the Table.4.11. The date of transplanting showed significant difference on dry matter production at the time of harvest. July 20^{th} transplanting was found to be superior to all other dates of transplanting in both varieties. In Jyothi the dry matter accumulation showed no significant difference in June 5^{th}, June 20^{th} and July 20^{th} date of transplanting. The July 5^{th} and august 5^{th} date of planting was significantly different from other dates of plantings. In rice variety Kanchana the dry matter accumulation had no significant difference in June 20^{th}, July 20^{th} and august 5^{th} dates of planting.

The comparison between varieties showed significant difference during 60 days after transplanting at the time of harvest was given in the Table.4.12. In 60 days after transplanting the dry matter accumulation in Jyothi was on par with dry matter accumulation in Kanchana. At the time of harvest dry matter accumulation showed significant difference in Jyothi and Kanchana.

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

Date of plantings	Dry matter accumulation at 15 days interval								
	15DAT			30 DAT			45 DAT		
	J	K	Mean	J	K	Mean	J	K	Mean
D1	537.6	546.5	542.1	3047.1	2609.3	2828.2^{a}	6532.1	7078.1	6805.1^{a}
D2	511.4	522.4	516.9	3039.2	2416.1	2727.6^{ab}	6035.4	6691.7	6363.5^{ab}
D3	554.9	536.6	545.7	2892.8	2389.8	2641.3^{ab}	6057.5	6191.3	6124.4^{b}
D4	395.3	532.9	464.1	2830.3	2141.5	2485.9^{bc}	6390.8	5953.5	6172.2^{ab}
D5	379.1	473.6	426.3	2579.3	2132	2355.7^{c}	5060.5	5279.9	5170.2^{c}
CD	NS		NS	NS		292.3	NS		649.3

Date of plantings	Dry matter accumulation at 15 days interval								
	60DAT			75 DAT			90 DAT		
	J	K	Mean	J	K	Mean	J	K	Mean
D1	10120.4^{a}	11817.8^{a}	10969.1^{a}	15393	15131.6	15262.3^{a}	13840.1	13683.6	13761.8
D2	9789.2^{a}	11607.8^{a}	10698.5^{ab}	14836.5	14390.3	14613.4^{cd}	14064.8	13503	13783.9
D3	10447.5^{a}	9549.8^{b}	9998.6^{c}	15249.7	14542.5	14896.1^{abc}	13763.4	13463.6	13613.5
D4	10873.8^{a}	9791.3^{b}	10332.5^{bc}	14957.3	14432.3	14694.8^{bcd}	13309.8	13210.1	13259.9
D5	9406.4^{a}	9250.5^{b}	9328.5^{d}	14805	13776	14290.5^{d}	13860	12906.1	13383
CD	1498.7		562.6	NS		439.1	NS		NS

Table.4.11. Effect of dates of planting on dry matter accumulation (kg ha^{-1}) at the time of harvest

Date of plantings	At harvest		
	J	K	Mean
D1	10090.5[a]	9549.8[b]	9820.1[c]
D2	10011.8[a]	10494.8[a]	10253.3[ab]
D3	9765.0[ab]	9929.3[ab]	9847.2[bc]
D4	10284.8[a]	10739.9[a]	10512.3[a]
D5	8972.3[b]	10459.6[a]	9715.9[c]
CD	869.8		463.3

Table.4.12. Comparison between varieties with respect to dry matter accumulation (kg ha^{-1})

Varieties	15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT
Jyothi	475.7	2877.7	6015.2	10127.5[a]	15048.3	13767.6	9824.9[b]
Kanchana	522.4	2337.7	6238.9	10403.4[a]	14454.5	13353.3	10234.7[a]
CD	NS	NS	NS	555.5	NS	NS	250.2

4.5.1.4. Yield and yield parameters

The effect of date of planting on yield and yield parameters such as panicles per unit area, spikelets per panicle, filled grains per panicle and 1000 grain weight were presented in Table.4.13.

The date of planting had significant effect on panicles per unit area, spikelets per panicle and filled grains per panicle. In number of panicles per unit area, June 5th date of planting was found to be superior and on par with June 20th planting. The date of planting had significant effect on number of spikelets per panicle. June 5th planting was superior to all other date of plantings. The date of planting had significant influence on number of filled grains per panicle. June 5th planting recorded highest number of filled grains and are superior to all other date of plantings. The date of planting had no significant effect on yield and 1000 grain weight.

The comparison between yield and yield parameters were given in Table.4.14. In case of yield, number of panicles per unit area, number of filled grains per panicle and 1000 grain weight had no significant interaction with varieties. The number of spikelets per panicle showed significant interaction with varieties. The rice variety Jyothi recorded highest number of spikelets and is superior o Kanchana.

4.5.1.5. Leaf area at 15 days interval

The leaf area at 15 days interval for different dates of planting was presented in Table.4.15. The date of planting was found to be significant at fortnightly intervals. June 5th date of planting was superior to all other date of plantings. During 30 days after planting June 5th date of planting was superior to other plantings in Jyothi and in Kanchana showed no significant difference in leaf area at 30 days after transplanting. During 45 days after transplanting, June 5th date of planting was on par with June 20th and August 5th date of planting and are superior to July 5th and July 20th date of planting. During 60 days after transplanting, leaf area at June 5th date of planting was superior and on par with July 5th and August 5th date of planting. During 75 days after transplanting, leaf area at July 5th date of planting

Table. 4.13. Effect of dates of planting on yield and yield parameters

DOP	Yield (Kg ha)			Number of panicles per unit area			Number of spikelets per panicle			Number of filled grains per panicle			1000 grain weight (g)		
	J	K	MEAN	J	K	MEAN	J	K	MEAN	J	K	MEAN	J	K	MEAN
D1	5807.5	4903	5355	412.1	392	402.0[a]	75.8	66	70.9[a]	70.5	66.6	68.5[a]	27.3	27.1	27.2
D2	4380	4810	4595	355.1	378.6	366.8[a]	64.3	54.4	59.4[b]	66.7	61.6	64.1[b]	27	27.4	27.2
D3	3792.5	4120	3956	325	338.4	331.7[b]	48.3	40.3	44.3[c]	59.9	59.1	59.5[b]	26.8	26.9	26.9
D4	4142.5	4405	4274	325	345.1	335.0[b]	62.8	56.5	59.6[b]	65.5	60	62.7[b]	27	26.7	26.9
D5	3805	3995	3995	308.2	331.7	319.9[b]	51.2	51.3	51.3[c]	61	64.3	62.6[b]	26.7	26.8	26.7
CD	NS		NS	NS		29	NS		8	NS		4.7	NS		NS

Table.4.14. Comparison between varieties and yield attributes

Varieties	Yield (kg ha^{-1})	Panicles per unit area	Spikelets per panicle	Number of Filled grains	1000 grain weight (g)
Jyothi	4385.5	345.1	60.46[a]	64.7	26.9
Kanchana	4452.5	357.1	53.68[b]	62.3	27.0
CD	NS	NS	6.5	NS	NS

Table.4.15. Effect of date of planting on leaf area at 15 days interval

DOP	Leaf area at 15 days interval								
	15DAT			30DAT			45DAT		
	J	K	MEAN	J	K	MEAN	J	K	MEAN
D1	131.4	115.3	123.4^{a}	232.8a	144.2a	188.5^{a}	335.4^{a}	262.7^{a}	299.0^{a}
D2	71.8	88.1	79.9^{b}	148.3b	137.1a	142.7^{b}	210.5^{de}	235.5^{a}	223.0^{c}
D3	68.3	57.0	62.7^{c}	111.9b	102.3a	107.1^{c}	188.3^{e}	139.3^{bc}	163.8^{e}
D4	80.7	70.7	75.7^{bc}	136.0b	117.1a	126.6^{bc}	258.7^{c}	136.0^{c}	197.4^{d}
D5	77.2	62.8	70.0^{bc}	141.2b	135.2a	138.2^{b}	273.8^{bc}	235.5^{a}	254.7^{b}
CD	NS		14.0	83.3		24.1	41.6		25.4

DOP	Leaf area at 15 days interval								
	60DAT			75DAT			90DAT		
	J	K	MEAN	J	K	MEAN	J	K	MEAN
D1	574.9^{a}	423.6^{a}	499.2^{a}	887.5^{a}	664.1^{ab}	775.8^{a}	676.3^{a}	460.6^{a}	568.4^{a}
D2	352.2^{d}	335.7^{b}	343.9^{d}	574.9^{c}	539.9^{bc}	557.4^{c}	476.0^{c}	369.7^{a}	422.9^{c}
D3	369.7^{cd}	369.7^{ab}	369.7^{cd}	660.9^{bc}	669.7^{a}	665.3^{b}	509.9^{bc}	358.7^{bc}	434.3^{c}
D4	442.7^{b}	335.4^{b}	389.0^{bc}	669.7^{bc}	574.9^{abc}	622.3^{b}	539.9^{b}	455.8^{c}	497.8^{b}
D5	473.1^{b}	362.6^{ab}	417.8^{b}	749.6^{b}	533.1^{c}	641.3^{b}	505.5^{bc}	325.6^{c}	415.5^{c}
CD	64.8		35.1	128.8		60.5	59.9		32.2

was superior to all other plantings in Jyothi while in Kanchana July 5th date of planting was superior to all other plantings and on par with June 5th and July 20th date of plantings. During 90 days after transplanting the leaf area at June 5th is on par with July 20th date of plating in Kanchana. Highest leaf area of 664.1cm^2 was recorded on 75 days after transplanting and superior to all other date of plantings. The comparison between varieties and leaf area were given in the Table.4.16.

4.5.2. Growth indices

4.5.2.1. Leaf area index at 15 days interval

Leaf area index at 15 days interval was presented in Table.4.17. Date of planting had significant influence on leaf area index at fortnightly intervals. The leaf area index was found to be highest in June 5th planting at 15 days interval and highest leaf area index of 5.2 was recorded on 75 days after transplanting.

In Jyothi the leaf area index was found to be highest and superior in June 5th date of planting in 15, 30, 45, 60 and 90 days after transplanting and it is on par with August 5th date of planting in 75th days after transplanting. In Kanchana the leaf area index had no significant difference in 30 and 75 days after transplanting. During 45 days after transplanting leaf area index of June 5th planting was superior and on par with June 20th and August 5th planting in Kanchana. At 15 days interval, June 5th planting was significantly superior and on par with June 20th, July 5th, July 20th and August 5th date of planting in Jyothi, while in Kanchana June 5th planting is on par with June 20th planting. During 60 days after transplanting the leaf area index at June 5th is superior and on par with July 5th and August 5th date of planting. During 90 days after transplanting June 5th planting was superior and on par with July 20th planting.

The comparison between leaf area index and varieties were given in Table.4.18. The varieties showed significant interaction with leaf area index at fortnightly intervals. The rice variety Kanchana was found to be superior to Jyothi during 151 days after planting and Jyothi was found to be superior to Kanchana during 30, 45, 60, 75 and 90 days after planting.

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

Varieties	15 DAP	30DAP	45DAP	60DAP	75DAP	90DAP
Jyothi	85.9^{a}	154.0^{a}	253.3^{a}	442.5^{a}	708.5^{a}	541.5^{a}
Kanchana	78.8^{a}	127.2^{a}	201.8^{b}	365.4^{b}	596.3^{a}	394.1^{b}
CD	26.6	44.5	41.6	64.8	128.8	59.9

Table4.17. Effect of date of planting on leaf area index at 15 days interval

DOP	Leaf area index at 15 days interval								
	15 DAP			30 DAP			45 DAP		
	J	K	Mean	J	K	Mean	J	K	Mean
D1	0.3^{a}	0.8^{a}	0.5^{a}	1.6^{a}	1.0^{a}	1.3^{a}	2.2^{a}	1.8^{a}	2.0^{a}
D2	0.2^{a}	0.6^{ab}	0.4^{a}	1.0^{bc}	0.9^{a}	1.0^{b}	1.4^{cd}	1.6^{a}	1.5^{bc}
D3	0.2^{a}	0.4^{b}	0.3^{a}	0.7^{c}	0.7^{a}	0.7^{b}	1.3^{d}	0.9^{b}	1.1^{d}
D4	0.2^{a}	0.5^{b}	0.3^{a}	0.9^{c}	0.8^{a}	0.8^{b}	1.7^{bc}	0.9^{b}	1.3^{dc}
D5	0.1^{a}	0.4^{b}	0.3^{a}	0.9^{c}	0.9^{a}	0.9^{b}	1.8^{b}	1.6^{a}	1.7^{b}
CD	0.2		0.9	0.3		0.2	0.3		0.2

DOP	Leaf area index at 15 days interval								
	60 DAP			75 DAP			90 DAP		
	J	K	Mean	J	K	Mean	J	K	Mean
D1	3.9	2.8	3.3^{a}	5.9^{a}	4.4^{a}	5.2^{a}	3.5^{a}	3.1^{a}	3.3^{a}
D2	2.9	2.2	2.6^{d}	4.5^{c}	3.6^{a}	4.1^{b}	2.3^{c}	2.5^{b}	2.4^{d}
D3	3.0	2.5	2.7^{bcd}	4.4^{bc}	4.5^{a}	4.4^{b}	2.5^{bc}	2.4^{b}	2.4^{d}
D4	3.0	2.2	2.6^{cd}	4.5^{bc}	3.8^{a}	4.1^{b}	2.8^{b}	3.0^{a}	2.9^{b}
D5	3.4	2.4	2.9^{b}	5.0^{ab}	3.6^{a}	4.3^{b}	3.2^{a}	2.2^{b}	2.7^{c}
CD	NS		0.2	0.9		0.4	0.3		0.1

Table.4.18. Comparison between leaf area index and varieties

Varieties	15 DAP	30 DAP	45 DAP	60 DAP	75 DAP	90 DAP
Jyothi	0.2^{b}	1.0^{a}	1.7^{a}	3.2^{a}	4.9^{a}	2.9^{a}
Kanchana	0.5^{a}	0.8^{b}	1.3^{b}	2.4^{b}	4.0^{b}	2.6^{b}
CD	0.1	0.1	0.1	0.2	0.3	0.1

DAP - Days after planting

4.5.2.2. Leaf area duration at 15 days interval

The effect of date of planting on leaf area duration was presented in Table.4.19. The date of planting had significant influence on leaf area duration at 30, 45, 60, 75 and 90 days after transplanting. June 5^{th} date of planting was found to be superior to all other dates of planting. During 30 days after transplanting, June 5^{th} date of planting was superior and significantly different from others in Jyothi. In Kanchana June 5^{th} planting was superior and on par with June 20^{th} date of planting. During 45 days after transplanting, the variety Kanchana was found to be superior and on par with June 20^{th} and August 5^{th} planting. During 60 and 90 days after planting, the rice varieties Jyothi and Kanchana was superior to all other date of plantings. During 75 days after planting, Kanchana was superior and on par with July 5^{th} and July 20^{th} planting.

The comparison between varieties was given in Table. 4.20. The leaf area duration was found to be superior in Jyothi than Kanchana during fortnightly intervals. Both varieties showed no significant interaction during 15 days interval.

4.5.2.3. Crop growth rate at 15 days interval

The crop growth rate at 15 days interval was given in the Table.4.21. The date of planting had significant influence on CGR during fortnightly interval but during 15 to 30 days after planting date of planting had no significant influence on CGR. June 5^{th} date of planting was significantly superior to all other dates of planting. During 0-15days interval August 5^{th} planting was significantly different. During 45 to 60 day after transplanting the crop growth was found to be highest on 5^{th} date of planting and on par with June 20^{th} and July 20^{th} date of planting.

The varieties Jyothi and Kanchana showed significant difference in crop growth rate during 30 to 45, 45 to 60 and 60 to 75 days after planting. During 30 to 45 days after planting, June 5^{th} planting was on par with July 20^{th} planting in Jyothi and in Kanchana no significant difference was noticed. At the interval of 45 to 60 days after planting, the variety Jyothi showed no significant difference and the variety Kanchana, June 20^{th} planting is on par with June 5t, July 5^{th} and July 20^{th}

4.19. Effect of date of planting on leaf area duration at 15 days interval

DOP	15			30			45		
	J	K	Mean	J	K	Mean	J	K	Mean
D1	6.6	5.8	6.2	18.2[a]	13.0[a]	15.6[a]	28.4[a]	20.3[a]	24.4[a]
D2	3.6	4.4	4.0	11.0[b]	11.3[ab]	11.1[b]	17.9[bc]	18.6[a]	18.3[bc]
D3	3.4	2.9	3.1	9.0[b]	8.0[c]	8.5[c]	15.0[c]	12.1[b]	13.5[d]
D4	4.0	3.5	3.8	10.8[b]	9.4[bc]	10.1[bc]	19.7[b]	12.7[b]	16.2[c]
D5	3.9	3.1	3.5	10.9[b]	9.9[b]	10.4[b]	20.8[b]	18.5[a]	19.6[b]
CD	NS		NS	3.0		1.7	3.5		2.1

DOP	60			75			90		
	J	K	Mean	J	K	Mean	J	K	Mean
D1	45.8[a]	36.2[a]	41.0[a]	73.4[a]	56.2[a]	64.8[a]	70.6[a]	54.4[a]	62.5[a]
D2	32.0[c]	30.3[b]	31.1[c]	50.2[c]	45.5[b]	47.9[c]	46.4[d]	43.8[d]	45.1[c]
D3	31.8[c]	25.4[c]	28.6[d]	55.4[bc]	52.0[ab]	53.7[b]	51.5[cd]	51.4[bc]	51.5[b]
D4	33.9[c]	29.6[b]	31.8[c]	54.5[bc]	51.5[ab]	53.0[b]	55.6[bc]	45.5[cd]	50.6[b]
D5	39.0[b]	29.9[b]	34.4[b]	62.8[b]	44.8[b]	53.8[b]	61.1[b]	42.9[d]	52.0[b]
CD	4.0		1.8	8.8		3.8	5.9		2.6

Table 4.20. Comparison between varieties

Varieties	15 DAP	30 DAP	45 DAP	60 DAP	75 DAP	90 DAP
Jyothi	4.3	12.0[a]	20.4[a]	36.5[a]	59.3[a]	57.1[a]
Kanchana	3.9	10.3[b]	16.4[b]	30.3[b]	50.0[b]	47.6[b]
CD	NS	0.8	0.9	1.4	3.0	2.0

DAP – Days after planting

Table.4.21. Effect of date of plating on crop growth rate at 15 days interval

Date of planting	Crop growth rate at 15 days interval (g m^{-1} day $^{-1}$)											
	0-15			15-30			30-45			45-60		
	J	K	Mean	J	K	Mean	J	K	Mean	J	K	Mean
D1	2.8	2.7	2.7^{a}	2.9	3.1	3.0	27.7^{a}	21.8^{a}	24.7^{a}	35.8^{a}	42.8^{ab}	39.3^{a}
D2	2.7	2.6	2.6^{a}	3.1	3.0	3.0	20.3^{b}	20.0^{a}	20.2^{b}	31.0^{a}	44.1^{a}	37.6^{ab}
D3	2.7	2.6	2.6^{a}	3.6	3.1	3.4	15.3^{c}	19.1^{a}	17.2^{c}	29.6^{a}	38.3^{ab}	33.9^{b}
D4	2.5	2.6	2.5^{a}	3.0	3.1	3.0	23.1^{ab}	17.0^{a}	20.1^{bc}	36.4^{a}	39.0^{ab}	37.7^{ab}
D5	2.3	2.5	2.4^{b}	1.6	2.6	2.1	22.6^{b}	17.6^{a}	20.1^{bc}	34.8^{a}	33.3^{b}	34.1^{b}
	NS		0.2	NS		NS	4.9		2.9	8.3		4.1

Date of planting	Crop growth rate at 15 days interval (g m^{-1} day $^{-1}$)								
	60-75			75-90			90-H		
	J	K	Mean	J	K	Mean	J	K	Mean
D1	46.8^{a}	49.0^{a}	47.9^{a}	-40.3	-42.3	-41.3^{d}	-18.1	-21.3	-19.7^{b}
D2	37.0^{b}	48.1^{ab}	42.6^{b}	-26.1	-44	-35.1^{cd}	-10.4	-19.8	-15.1^{ab}
D3	35.9^{b}	38.4^{b}	37.1^{c}	-14.6	-29	-21.8^{a}	-15.7	-18.8	-17.2^{b}
D4	34.3^{b}	39.4^{ab}	36.9^{c}	-32	-29.4	-30.7^{bc}	-15.2	-20.8	-18.0^{b}
D5	34.9^{b}	42.0^{ab}	38.4^{bc}	-28.4	-26.6	-27.5^{ab}	-4.4	-14.2	-9.3^{a}
CD	10.5		5	NS		6.8	NS		6.8

planting. During 60 to 75 days after planting, June 5^{th} planting was superior and significantly different Jyothi and in Kanchana, June 5^{th} planting is on par with June 20^{th}, July 20^{th} and August 5^{th} planting.

The comparison between crop growth rate and varieties were given in the Table.4.22. The varieties showed significant interaction with crop growth rate during 30 to 45 and 45 to 60 days after planting. During the period of 15 to 30 days after transplanting, Jyothi recorded highest CGR and is superior to Kanchana and 45 to 60 days after transplanting, the variety Kanchana was found to be superior to Jyothi.

4.5.2.4. Net assimilation rate

The effect of date of planting on net assimilation rate of Jyothi and Kanchana was presented in Table.4.23. The effect of date of planting on net assimilation rate was significant on 15-30, 45-60 and 75-90 days after planting. During 15 to 30 days after transplanting July 5^{th} planting was superior and on par with June 20^{th} and July 20^{th} date of planting. The interval between 45-60 days after planting, July 20^{th} planting was superior and on par with June 20^{th} and July 5^{th} planting. The period from 60-75, June 20^{th} planting was on par with June 20^{th}, July 5^{th} and August 5^{th} date of planting for Jyothi. In Kanchana, no significant difference was noticed.

The comparisons between net assimilation rate and varieties were given in the Table.4.24. The varieties Jyothi and Kanchana showed no significant interaction with net assimilation rate at fortnightly intervals.

4.5.3. Biochemical analysis

The soluble protein and chlorophyll content shows the photosynthetic efficiency of the crop. With increase in photosynthetic efficiency the yield of the crop will also increase.

Table.4.22. Comparison between crop growth rate and varieties

Varieties	0-15 DAP	15-30 DAP	30-45 DAP	45-60 DAP	60-75 DAP	75-90 DAP	90-Harvest
Jyothi	2.6	2.8	21.8^{a}	33.5^{b}	37.8	-28.3	-12.8
Kanchana	2.6	3	19.5^{b}	39.5^{a}	43.4	-34.3	-19
CD	NS	NS	1.8	3.3	NS	NS	NS

Table.4.23. Effect of net assimilation rate at 15 days interval

DOP	NAR														
	15-30			30-45			45-60			60-75			75-90		
	J	K	Mean	J	K	Mean	J	K	Mean	J	K	Mean	J	K	Mean
D1	3.9	3.9	3.9^{b}	12.9	15.2	14.1	16	17.7	16.9^{b}	7.9^{a}	15.0^{a}	11.4	-8.7	-10.9	-9.8^{c}
D2	7.1	4.1	5.6^{ab}	15.4	14.4	14.9	17.3	17.4	17.4^{ab}	9.1^{a}	16.4^{a}	12.8	-6.6	-10.3	-8.4^{bc}
D3	9.1	6.4	7.8^{a}	16.2	14.9	15.6	17.4	18.2	17.8^{ab}	8.3^{a}	16.0^{a}	12.2	-4.4	-7.7	-6.0^{a}
D4	6.8	7.4	7.1^{a}	12.9	15.4	14.2	18.9	18.3	18.6^{a}	9.4^{a}	15.0^{a}	12.2	-9	-5.8	-7.4^{ab}
D5	4.1	4.2	4.2^{b}	14.2	14.7	14.4	15.9	17	16.4^{b}	9.4^{a}	14.3^{a}	11.8	-9.4	-9.5	-9.4^{bc}
	NS		2.2	NS		NS	NS		1.4	2.6		NS	NS		2.3

Table.4.24. Comparison between net assimilation rate and varieties

Varieties	15-30 DAP	30-45 DAP	45-60 DAP	60-75 DAP	75-90 DAP
Jyothi	6.2	14.3	17.1	8.8	-7.6
Kanchana	5.2	14.9	17.7	15.3	-8.8
CD	NS	NS	NS	NS	NS

4.5.3.1. Soluble protein content at 15 days interval

Soluble protein content at 15 days interval for Jyothi and Kanchana for different dates of planting was presented in Table.4.25. The dates of planting had significant difference during 15, 45, 60 and 90 days after transplanting. The soluble protein content at 15 days interval was found to be superior in June 5th transplanting than other dates of plantings. During 45, 60, 75 and 90 days after transplanting June 5th planting was found to be superior and on par with June 20th date of planting.

The comparison between varieties showed no significant difference in soluble protein content at fortnightly intervals in both Jyothi and Kanchana (Table4.26)

4.5.3.2. Total chlorophyll content at 15 days interval

Total chlorophyll content at 15 days interval after transplanting was presented in Table.4.27. The dates of planting had significant difference during 15 and 45 days after transplanting. During 15 days after transplanting, June 5th planting was superior to all other dates plantings. During 45 days after planting, June 5thplanting was on par with June 20th, July 5th and July 20th plantings. During 60 days after transplanting June 5th date of planting was on par with June 20th, and July 5th date planting in Jyothi, while in Kanchana date of planting had no significant difference in all the dates of plantings. At 30, 75 and 90 days after transplanting had no significant interaction between dates of planting and total chlorophyll content in both varieties. The comparison between varieties showed significant effect on 60 days after transplanting (Table.28). During 60 days after transplanting the total chlorophyll content in Jyothi was on par with Kanchana.

4.6. HEAT UNIT REQUIREMENT OF RICE CROPS

The heat unit requirement of rice crops such as growing degree days (GDD), heliothermal units (HTU) and photothermal units were worked out for each phenological stage of Jyothi and Kanchana. The heat unit requirement was presented below.

Table.4.25. Effect of date of planting on soluble protein content

Soluble protein (mg g^{-1}) at 15 days interval									
	15			30			45		
DOP	J	K	Mean	J	K	Mean	J	K	Mean
D1	35.4	39.0	37.2^{a}	33.6	32.8	33.2	26.6	29.5	28.1^{a}
D2	26.1	27.8	26.9^{b}	33.0	30.3	31.6	25.5	26.0	25.8^{ab}
D3	24.6	25.4	25.0^{b}	32.1	30.4	31.3	24.4	22.8	23.6^{bc}
D4	25.6	26.9	26.2^{b}	30.1	30.9	30.5	23.3	25.0	24.1^{b}
D5	22.9	23.9	23.4^{b}	28.9	30.5	29.7	18.5	23.1	20.8^{c}
CD	NS		5.2	NS		NS	NS		3.0

Soluble protein (mg g^{-1}) at 15 days interval									
	60			75			90		
DOP	J	K	Mean	J	K	Mean	J	K	Mean
D1	26.4	26.9	26.6^{a}	26.0	18.0	22.0^{a}	18.6	12.3	15.4^{a}
D2	22.5	23.1	22.8^{ab}	22.4	17.9	20.1^{ab}	13.3	11.9	12.6^{ab}
D3	19.1	21.1	20.1^{b}	13.8	14.3	14.0^{bc}	10.8	11.1	10.9^{b}
D4	18.3	22.3	20.3^{b}	12.8	12.5	12.6^{c}	9.8	10.5	10.1^{b}
D5	16.9	21.7	19.3^{b}	12.6	10.1	11.4^{c}	9.3	9.7	9.5^{b}
CD	NS		4.2	NS		7.2	NS		3.6

Table.4.26. Comparison between soluble protein and varieties

Soluble protein content (mg g^{-1})						
Varieties	15	30	45	60	75	90
Jyothi	28.9	31.6	23.7	20.6	17.5	12.3
Kanchana	28.6	31.0	25.3	23.0	14.6	11.1
CD	NS	NS	NS	NS	NS	NS

Table.4.27. Effect of date of planting on total chlorophyll content at 15 days interval

Total chlorophyll content ($mg\ g^{-1}$)									
DOP	15			30			45		
	J	K	Mean	J	K	Mean	J	K	Mean
D1	3.5	3.1	3.3^{a}	3.1	3.5	3.3	2.6	2.8	2.7^{a}
D2	3.1	3.2	3.2^{ab}	3.3	3.3	3.3	2.8	2.7	2.8^{a}
D3	3.2	2.8	3.0^{bc}	3.3	3.4	3.3	2.5	2.7	2.6^{a}
D4	3.0	3.0	3.0^{bc}	3.3	3.2	3.2	2.7	2.9	2.8^{ab}
D5	3.0	2.9	2.9^{c}	3.1	3.2	3.1	2.2	2.3	2.3^{b}
CD	NS		0.2	NS		NS	NS		0.3

Total chlorophyll content ($mg\ g^{-1}$)									
DOP	60			75			90		
	J	K	Mean	J	K	Mean	J	K	Mean
D1	2.6^{a}	2.1^{a}	2.4	1.8	2.2	2.0	1.3	1.2	1.3
D2	2.2^{ab}	2.2^{a}	2.2	1.8	1.8	1.8	1.1	1.1	1.1
D3	2.0^{ab}	2.4^{a}	2.2	1.8	2.2	2.0	1.0	1.2	1.1
D4	2.2^{b}	2.2^{a}	2.2	1.8	2.1	1.9	1.1	1.1	1.1
D5	2.0^{b}	2.3^{a}	2.1	1.6	1.7	1.6	1.1	1.1	1.1
CD	0.4		NS	NS		NS	NS		NS

Table.4.28.Comparison between total chlorophyll and varieties

Total chlorophyll content ($mg\ g^{-1}$)						
Varieties	15	30	45	60	75	90
Jyothi	3.2	3.2	2.6	2.2a	1.8	1.1
Kanchana	3.0	3.3	2.7	2.2a	2.0	1.1
CD	NS	NS	NS	0.1	NS	NS

4.6.1. Heat units prevailed during the crop period

The heat units required during the entire crop period was recorded over standard meteorological weeks. The heat units required for the entire crop season was presented in Table.4.29.

4.6.1.1. Weekly accumulated growing degree days

The accumulated growing degree days required for Jyothi and Kanchana was given in Fig.4.8. The highest and lowest accumulated growing degree days recorded highest on 42nd and 29th week respectively. The recorded highest and lowest accumulated GDD was 134.8 day °C and 110.8 day °C.

4.6.1.2. Weekly accumulated heliothermal unit

The accumulated heliothermal units required for the entire crop season was presented in Fig.4.9. The accumulated HTU showed fluctuations in their entire crop period. The highest (1068.0 day °C h) and lowest (15.1 day °C h) accumulated heliothermal units were recorded on 35th and 29th week.

4.6.1.3. Weekly accumulated photothermal unit

The accumulated photothermal unit during the entire crop season was given in the Fig.4.10. Accumulated photothermal units were recorded highest (1594.8 day °C h) on 42nd week and lowest (1374.6 day °C h) on 29th week.

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

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

4.6.2.1. Heat units required during transplanting to active tillering

The heat units required during transplanting to active tillering stage of Jyothi and Kanchana at different date of transplanting was given in the Table.4.30.

Table.4.29. Heat units required for the crop growing season

Week No.	AGDD	AHTU	APTU
23	127.6	508.6	1595.2
24	119.1	125.8	1494.2
25	123.0	31.7	1549.0
26	119.1	222.2	1495.8
27	125.9	849.8	1574.9
28	121.1	552.1	1508.8
29	110.8	15.1	1374.6
30	114.2	292.9	1411.3
31	121.1	628.1	1491.1
32	118.3	356.4	1451.2
33	123.6	530.4	1510.6
34	122.0	766.5	1485.6
35	124.7	1068.0	1513.6
36	124.2	462.3	1502.1
37	122.7	834.2	1478.5
38	123.0	530.2	1476.7
39	128.8	835.0	1540.8
40	123.9	468.6	1476.1
41	123.5	759.5	1466.5
42	134.8	940.1	1594.8
43	132.8	719.3	1564.6
44	128.4	632.4	1506.9
45	121.5	406.0	1420.4
46	119.3	338.8	1389.1
47	129.3	699.2	1499.6
Total	3213.6	14258.5	39009.7

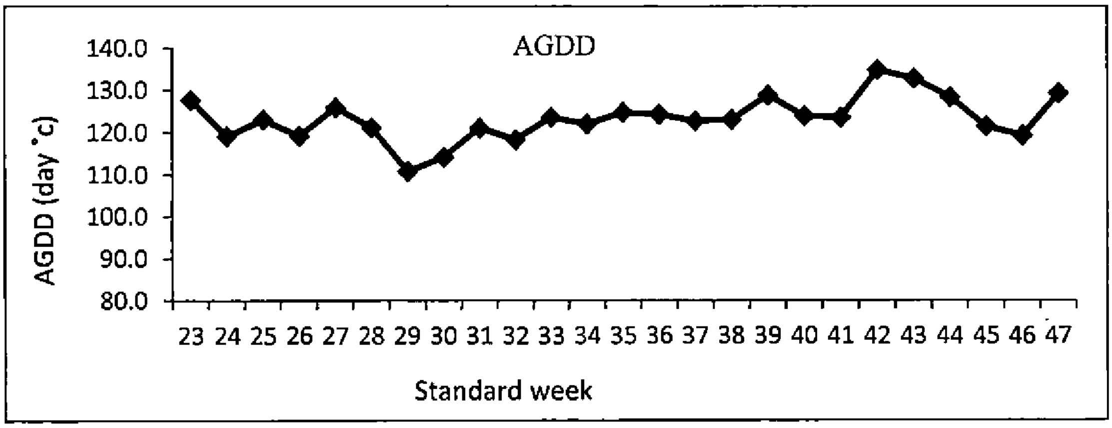


Fig.4.8. Weekly growing degree days (day °C) for entire crop period

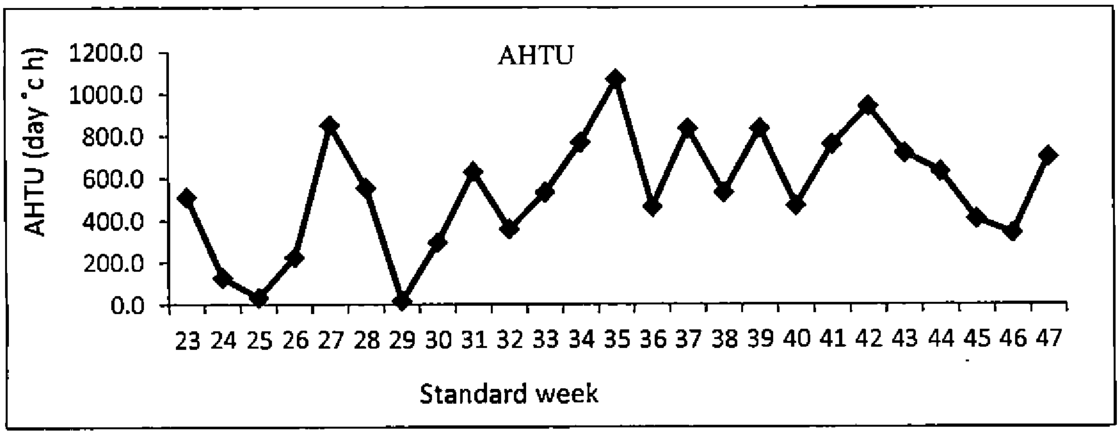


Fig.4.9.Weekly heliothermal units (day °C h) during entire crop period

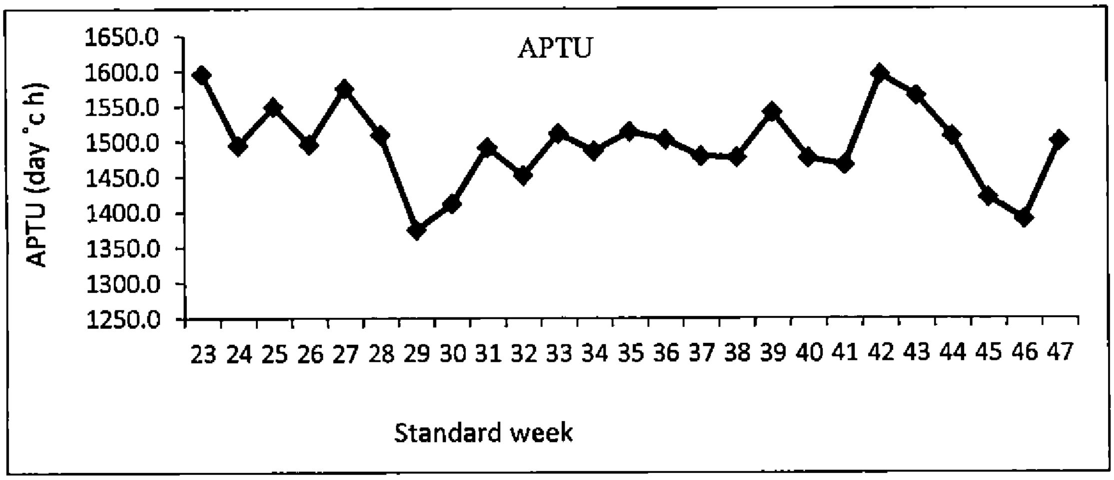


Fig.4.10. Weekly photothermal units (day °C h) during entire crop period

Table.4.30. Heat units experienced during transplanting to active tillering stage of rice varieties at different dates of planting

Date of planting	Jyothi			Kanchana		
	GDD	HTU	PTU	GDD	HTU	PTU
D1	467.0	933.1	5636.1	467.0	933.1	5862.6
D2	482.2	1629.0	5790.4	449.7	1624.0	5630.0
D3	450.8	1571.2	5409.7	415.4	1253.2	5162.0
D4	435.6	1394.3	5228.1	435.6	1394.3	5366.7
D5	451.7	2351.4	5421.2	433.7	2171.9	5299.9

GDD- Growing degree days HTU- Heliothermal units PTU- Photothermal units
D1- 5th June D2- 20th June D3- 5th July D4- 20th July D5- 5th August

4.6.2.1.1. Accumulated growing degree days (GDD)

The accumulated growing degree day (GDD) during transplanting to active tillering stage of Jyothi and Kanchana was highest on second date of planting and the recorded value of accumulated GDD was 482.2 day °C and 467.0 day°C respectively. The fourth date of planted crops recorded lowest accumulated GDD (435.6 day°C) for Jyothi and Kanchana accumulated lowest GDD (415.4 day°C) was found on third date of planting. The recorded range of accumulated GDD was 435.6 to 482.2 day°C and 415.4 to 467.0 day°C for Jyothi and Kanchana respectively.

4.6.2.1.2: Accumulated heliothermal unit (HTU)

The delayed transplanting showed an increase in accumulated heliothermal units for Jyothi and Kanchana. The recorded range of HTU for both rice varieties was 933.1 (D1) to 2351.4 (D5) day °C h and 933.1(D1) to 2171.9 (D5) day °C h respectively. The rice variety Jyothi and Kanchana recorded highest accumulated HTU on 5^{th} date of planting followed by second date of planting (1629.0 day°C h and 1624.0 day °C h). Accumulated heliothermal unit was found to be lowest on first date of plantings for both Jyothi and Kanchana.

4.6.2.1.3. Accumulated photothermal units (PTU)

The variety Jyothi recorded highest (5790.4 day °C h) accumulated PTU on second date of planting and lowest (5228.1 day °C h) on fourth date of planting. The accumulated PTU for Jyothi was 5636.1, 5790.4, 5409.7, 5228.1 and 5421.2 day °C h for D1, D2, D3, D4 and D5 respectively.

The variety Kanchana recorded highest accumulated PTU on first date of planting and lowest on third date of planting. The observed values of accumulated photothermal units for Kanchana was 5862.6, 5630.0, 5162.0, 5366.7 and 5299.9 day °C h for D1, D2, D3, D4 and D5 respectively.

4.6.2.1. Heat units required during active tillering to panicle initiation

The accumulated growing degree days required during active tillering to panicle initiation was given in the Table.4.31.

4.6.2.2.1. Accumulated growing degree day (GDD)

Accumulated growing degree day was highest in fourth date of planting in Jyothi and third date of planting in Kanchana. The recorded highest value of GDD was 176.6 day °C and 172.2 day °C for Jyothi and Kanchana respectively. The lowest value of GDD for Jyothi and Kanchana was 136.9 and 141.5 day °C respectively. In case of Jyothi and Kanchana, the third date of planting and second date planting recorded lowest value of accumulated GDD.

4.6.2.2.2. Accumulated heliothermal units (HTU)

The accumulated HTU was highest (1008.1 and 1003.5 day °C h) on fourth and fifth date of plantings in Jyothi and Kanchana. The accumulated HTU was found to be lowest (56.1 and 51.1 day °C h) on second date of plantings for both Jyothi and Kanchana.

4.6.2.2.3. Accumulated photothermal units (PTU)

The highest (2120.0 day °C h) and lowest (1642.2 day °C h) values of accumulated PTU were recorded on fourth and third date of planting for Jyothi. The variety Kanchana recorded highest (2119.5 day °C h) and lowest (1737.0 day °C h) accumulated PTU on third and fourth date of planting.

4.6.2.3. Heat units required during panicle initiation to booting

The accumulated growing degree days required during panicle initiation to booting was given in the Table.4.32.

4.6.2.3.1. Accumulated growing degree days (GDD)

The highest accumulated GDD was recorded on third (382.9 day ° C) date of planting for Jyothi and fifth (371.0 day ° C) date of planting for Kanchana respectively. For Jyothi (347.1 day °C) and Kanchana (347.6 day °C), lowest accumulated GDD was recorded on first date of planting.

4.6.2.3.2. Accumulated heliothermal unit (HTU)

The delayed transplanting showed an increase in accumulated heliothermal units for Jyothi and Kanchana. The recorded range of HTU for both rice varieties was 1080.8 day °C h (D1) to 2428.6 day °C h (D4) and 1220.9 day °C h (D1) to 2431.2 day °C h (D4) day °C h respectively. The rice varieties Jyothi and Kanchana recorded highest accumulated HTU on 4^{th} date of planting followed by fifth date of planting (2198.7 day °C h and 1984.3 day °C h). Accumulated heliothermal unit was found to be lowest on first date of plantings for both Jyothi (1080.8 day °C h) and Kanchana (1220.9 day °C h).

4.6.2.3.3. Accumulated photothermal units (PTU)

Accumulated photothermal units during panicle initiation to booting stage of Jyothi and Kanchana followed an increasing trend towards delayed transplanting. The highest and lowest values of accumulated PTU were recorded on third and first date of planting for Jyothi and fourth and first date of planting for Kanchana respectively. In case of Jyothi the highest and lowest recorded value for accumulated PTU was 4596.3 day°C h and 4193.8 day°C h respectively. In case of Kanchana the highest and lowest recorded value for accumulated PTU was 4487.1 day°C h and 4307.2 day°C h respectively.

4.6.2.4. Heat units required during booting to heading

The accumulated growing degree days required during booting to heading was given in the Table.4.33.

Table.4.33. Heat units experienced during booting to heading stage of rice varieties at different dates of planting

Date of planting	Jyothi			Kanchana		
	GDD	HTU	PTU	GDD	HTU	PTU
D1	154.5	657.6	1894.1	102.7	338.8	1262.7
D2	106.3	586.7	1279.7	90.1	572.7	1100.5
D3	128.3	824.0	1539.7	91.5	742.9	1109.5
D4	69.5	260.0	834.4	122.1	522.6	1469.0
D5	87.2	380.6	1046.7	106.8	603.2	1274.7

GDD- Growing degree days HTU- Heliothermal units PTU- Photothermal units
D1- 5th June D2- 20th June D3- 5th July D4- 20th July D5- 5th August

.4.6.2.4.1. Accumulated growing degree day (GDD)

Accumulated growing degree day was highest in first date of planting in Jyothi and fourth date of planting in Kanchana. The recorded highest value of GDD was 154.5 day °C and 122.1 day °C for Jyothi and Kanchana respectively. The lowest value of GDD for Jyothi and Kanchana was 69.5 day °C (D4) and 90.1 day °C (D2) respectively

4.6.2.4.2. Accumulated heliothermal units (HTU)

The accumulated HTU during booting to heading was highest (824.0 day °C h and 742.9 day °C h) on third date of planting for both Jyothi and Kanchana. The accumulated HTU was found to be lowest (260.0 day °C h and 338.8 day °C h) on fourth and first date of plantings for Jyothi and Kanchana.

4.6.2.4.2. Accumulated photothermal units (PTU)

The highest (1894.1 day°C h) and lowest (834.4 day°C h) values of accumulated PTU were recorded on first and fourth date of planting for Jyothi. The highest (1469.0 day°C h) accumulated PTU for Kanchana were recorded on fourth date of planting while lowest (1100.5 day°C h) accumulated PTU were recorded on second date of planting.

4.6.2.5. Heat units required during heading to 50% flowering

The accumulated growing degree days required during heading to 50% flowering was given in the Table.4.34.

4.6.2.5.1. Accumulated growing degree days (GDD)

The highest accumulated GDD was recorded on fourth (89.3 day ° C) date of planting for Jyothi and second (69.3 day°C) date of planting for Kanchana respectively. For Jyothi (32.7 day°C) and Kanchana (34.2 day°C), lowest accumulated GDD was recorded on first date of planting.

Table.4.34. Heat units experienced during heading to 50% flowering stage of rice varieties at different dates of planting

Date of planting	Jyothi			Kanchana		
	GDD	HTU	PTU	GDD	HTU	PTU
D1	32.7	22.2	393.5	34.2	142.8	419.8
D2	69.4	542.2	834.9	69.3	269.8	843.8
D3	32.8	8.2	393.0	54.7	260.6	661.9
D4	89.3	525.9	1071.2	53.3	329.4	639.6
D5	68.4	354.5	821.3	66.9	232.0	796.7

GDD- Growing degree days HTU- Heliothermal units PTU- Photothermal units
D1- 5th June D2- 20th June D3- 5th July D4- 20th July D5- 5th August

4.6.2.5.2. Accumulated heliothermal unit (HTU)

The delayed transplanting showed fluctuations in accumulated heliothermal units for Jyothi. The recorded range of HTU for both rice varieties was 8.2 day °C h (D3) to 542.2 day °C h (D2) and 142.8 day °C h (D1) to 329.4day °C h (D4) day °C h respectively. The rice varieties Jyothi and Kanchana recorded highest accumulated GDD on 2nd and 4th date of planting.

4.6.2.5.3. Accumulated photothermal units (PTU)

Accumulated photothermal units during heading to 50 % flowering stage of Jyothi and Kanchana recorded highest and lowest values of accumulated PTU on D4 (1071.2 day ° C h) and D1 (393.0 day ° C h) in Jyothi and D2 (843.8 day ° C h) and D1 (419.8 day ° C) in Kanchana.

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

The accumulated growing degree days required during 50% flowering to physiological maturity was given in the Table.4.35.

4.6.2.6.1. Accumulated growing degree days (GDD)

The accumulated growing degree day (GDD) during 50% flowering to physiological maturity stage of Jyothi and Kanchana recorded highest accumulated GDD on fifth (639.5 and 639.7day ° C) date of planting. For Jyothi (587.7day °C) and Kanchana (595.9day °C), the lowest accumulated GDD was recorded on second and third date of planting.

4.6.2.6.2. Accumulated heliothermal unit (HTU)

The recorded range of accumulated HTU for Jyothi and Kanchana was 3280.6 day °C h (D3) to 3575.6 day °C h (D1) and 3102.8day °C h (D3) to 3843.8day °C h (D2 respectively. The rice varieties Jyothi and Kanchana recorded highest accumulated HTU on 1st and 2nd date of planting.

Table.4.35. Heat units experienced during 50% flowering to physiological maturity stage of rice varieties at different dates of planting

Date of planting	Jyothi			Kanchana		
	GDD	HTU	PTU	GDD	HTU	PTU
D1	616.3	3575.6	7561.6	631.3	3516.6	7672.5
D2	587.7	3487.5	7119.0	621.7	3843.8	7499.0
D3	599.3	3280.6	7195.5	595.9	3102.8	7140.9
D4	621.1	3569.4	7457.8	602.8	3612.7	7164.2
D5	639.5	3343.8	7677.0	639.7	3310.1	7539.3

GDD- Growing degree days HTU- Heliothermal units PTU- Photothermal units
D1- 5th June D2- 20th June D3- 5th July D4- 20th July D5- 5th August

4.6.2.6.3. Accumulated photothermal units (PTU)

Accumulated photothermal units during 50 % flowering to physiological maturity stage of Jyothi and Kanchana recorded highest and lowest values of accumulated PTU on D5 (7677.0 day ° C h)and D2 (7119.0day ° C h) in Jyothi and D1 (7672.5 day ° C h) and D3 (7140.9 day ° C) in Kanchana.

4.7. CROP WEATHER RELATIOSHIPS

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

4.7.1. Influence of weather parameters on crop duration

The correlation between weather elements and duration of different phenological stages of rice varieties Jyothi and Kanchana were presented in the Table.4.36 and 4.37 respectively.

4.7.1.1. ***Transplanting to active tillering (P1)***

The weather variables such as afternoon vapour pressure deficit, afternoon relative humidity, WS, rainfall and number of rainy days had significant positive correlation and forenoon relative humidity showed significant negative correlation with number of days taken for transplanting to active tillering in Jyothi.

In Kanchana the weather variables such as minimum temperature, forenoon and afternoon vapour pressure deficit, afternoon relative humidity, WS, rainfall and rainy days has significant positive correlation and forenoon relative humidity showed significant negative correlation with number of days taken for transplanting to active tillering stage in Kanchana.

Table.4.36. correlation between weather and duration of each phenophases of Jyothi

Crop stages	TMAX	TMIN	DTR	VP1	VP2	RH1	RH2	WS	BSS	RF	RD	E
P1	0.162	0.328	0.078	0.389	0.580**	-0.633**	0.627**	0.761**	-0.377	0.704**	0.764**	0.190
P2	0.296	0.185	0.302	0.333	0.263	-0.260	-0.401	-0.456*	0.338	0.022	-0.274	-0.020
P3	-0.059	0.070	-0.087	0.107	-0.014	0.309	-0.149	0.065	0.049	0.065	0.157	0.107
P4	-0.147	0.113	-0.223	-0.151	-0.780**	0.449*	-0.473*	0.588**	-0.165	0.605**	0.761**	0.064
P5	-0.007	0.477*	-0.272	0.047	0.611**	-0.260	0.507*	0.112	-0.316	0.284	0.306	-0.182
P6	-0.588**	-0.632**	-0.528*	0.923**	0.017	0.946**	0.240	-0.805**	0.865**	0.758**	0.871**	0.669**
P7	-0.253	-0.030	-0.303	-0.028	0.152	0.147	0.294	0.083	-0.219	0.305	0.188	-0.210
P8	-0.481*	-0.308	-0.244	-0.299	-0.285	0.542*	0.269	0.494*	-0.438	0.521*	0.501*	-0.274
P9	0.132	0.251	0.056	-0.385	-0.375	-0.282	-0.417	0.423	-0.317	-0.228	-0.239	-0.242

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

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

Table.4.37. Correlation between weather and duration of each phenophases of Kanchana

Crop stages	TMAX	TMIN	DTR	VP1	VP2	RH1	RH2	WS	BSS	RF	RD	E
P1	0.402	0.570**	0.307	0.561*	0.658**	-0.624**	0.453*	0.619**	-0.233	0.532*	0.624**	0.358
P2	-0.304	-0.322	-0.291	-0.342	-0.396	0.136	0.299	-0.279	-0.290	0.278	-0.046	-0.374
P3	0.148	0.162	0.135	0.222	0.172	0.288	-0.218	-0.139	0.356	-0.059	-0.047	0.282
P4	-0.531*	0.050	-0.644**	-0.244	-0.350	0.248	-0.025	0.711**	-0.334	-0.073	0.048	-0.281
P5	-0.355	-0.197	-0.398	0.077	-0.013	-0.190	-0.055	-0.343	-0.281	0.021	-0.186	-0.454*
P6	0.205	0.345	0.097	-0.280	0.227	-0.259	-0.122	0.373	-0.221	0.190	0.111	-0.106
P7	-0.279	-0.175	-0.307	-0.063	0.200	0.155	0.458*	0.361	-0.242	0.414	0.388	-0.146
P8	-0.650**	-0.385	-0.636**	-0.557*	-0.483*	0.410	0.569**	0.633**	-0.579**	0.591**	0.595**	-0.546*
P9	0.205	0.345	0.097	-0.280	0.227	-0.259	-0.122	0.373	-0.221	0.190	0.111	-0.106

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

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

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

The duration of active tillering to panicle initiation stage of Jyothi was found to be negatively correlated with wind speed. There is no positive correlation was observed between weather and duration of active tillering to panicle initiation stage in Jyothi. In Kanchana, there is no correlation was observed between weather and duration.

4.7.1.3. *Panicle initiation to booting (P3)*

There is no correlation was noticed between weather and duration of panicle initiation to booting stage of Jyothi and Kanchana.

4.7.1.4. *Booting to heading (P4)*

The weather parameters such as forenoon relative humidity, wind speed, rainfall and rainy days positively affect the duration where as afternoon vapour pressure deficit and afternoon relative humidity negatively affect the duration of booting to heading in Jyothi.

In Kanchana, wind speed positively influences the days taken for booting to heading. The significant negative weather variables include maximum temperature and diurnal temperature.

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

Minimum temperature, afternoon vapour pressure deficit and relative humidity influences the duration of heading to 50% flowering in Jyothi and the weather parameters showed a positive correlation with duration.

In Kanchana evaporation had negative influence on duration and there is no positive influence was noticed in duration heading to flowering in Kanchana.

4.7.1.6. *50 % flowering to physiological maturity (P6)*

The duration of rice variety Jyothi showed positive correlation with forenoon vapour pressure deficit, forenoon relative humidity, BSS, rainfall, number of rainy days ad evaporation. The weather variables such as maximum temperature, minimum temperature, diurnal temperature and wind speed showed significant negative correlation with duration of 50% flowering to physiological maturity stage.

Duration of Kanchana has no correlation with weather variables during 50% flowering to physiological maturity stage.

4.7.1.7. *Vegetative period (P7)*

The duration of vegetative period of Jyothi and Kanchana has no significant correlation with weather variables.

4.7.1.8. *Reproductive period (P8)*

Forenoon relative humidity, wind speed, rainfall and number of rainy days showed significant positive correlation while maximum temperature showed significant negative correlation in case of Jyothi.

Afternoon relative humidity, wind speed, rainfall and number of rainy days showed significant positive correlation and maximum temperature, diurnal temperature, forenoon and afternoon vapour pressure deficit, BSS and evaporation showed significant negative correlation.

4.7.1.9. *Ripening period (P9)*

The duration of ripening period of Jyothi and Kanchana had no significant correlation with weather variables..

4.7.2. Correlation between weather and yield of Jyothi

The correlation between weather and yield of Jyothi was worked out and presented in Table 4.38.

Table.4.38. Correlation between yield and weather during different phenophases of Jyothi

Crop stages	TMAX	TMIN	DTR	VP1	VP2	RH1	RH2	WS	BSS	RF	RD	E
P1	-0.908*	-0.886*	-0.899*	0.865	-0.609	0.989**	0.226	-0.651	0.638	0.522	0.517	0.423
P2	-0.515	-0.313	-0.564	-0.431	-0.306	0.415	0.638	0.880*	-0.431	0.197	0.886*	-0.052
P3	-0.968**	-0.491	-0.986**	-0.857	-0.354	0.794	0.912*	0.970**	-0.952*	0.837	0.929*	-0.867
P4	0.088	-0.118	0.204	-0.250	-0.690	0.683	-0.877	0.804	0.374	0.695	0.522	0.555
P5	-0.665	-0.083	-0.607	-0.128	-0.619	0.962**	0.441	0.722	-0.374	-0.264	-0.096	-0.251
P6	-0.908*	-0.886*	-0.899*	0.865	-0.609	0.989**	0.226	-0.651	0.638	0.522	0.517	0.423
P7	-0.258	0.160	-0.398	0.092	0.641	-0.628	0.877	0.980**	-0.877	0.872	0.931*	-0.156
P8	-0.912*	-0.520	-0.949*	-0.731	-0.598	0.820	0.639	0.975**	-0.864	0.841	0.824	-0.725
P9	-0.908*	-0.886*	-0.899*	0.865	-0.609	0.989**	0.226	-0.651	0.638	0.522	0.517	0.423

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

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

4.7.2.1. Transplanting to active tillering (P1)

The weather elements like maximum temperature, minimum temperature and diurnal temperature range showed significant negative correlation with yield and forenoon relative humidity showed significant positive correlation with yield in Jyothi during transplanting to active tillering.

4.7.2.2. Active tillering to panicle initiation (P2)

Active tillering to panicle initiation stage of Jyothi showed significant positive correlation with afternoon relative humidity and number of rainy days.

4.7.2.3. Panicle initiation to booting (P3)

The phenological stage of panicle initiation to booting has significant positive correlation with afternoon relative humidity, wind speed and number of rainy days while maximum temperature, diurnal temperature, bright sunshine hours, heliothermal unit and photothermal unit showed significant negative correlation with yield.

4.7.2.4. Booting to heading (P4)

The weather variables had no significant correlation with yield in booting to heading stage in Jyothi.

4.7.2.5. Heading to 50% flowering (P5)

Heading to flowering stage of Jyothi showed significant positive correlation with forenoon relative humidity.

4.7.2.6. 50% flowering to physiological maturity (P6)

The weather parameters like maximum temperature, minimum temperature and diurnal temperature have significant negative correlation and the forenoon relative humidity has significant positive correlation with yield.

4.7.2.7. Vegetative period (P7)

Wind speed and number of rainy days showed significant positive correlation and there is no significant negative correlation was found between vegetative period and yield.

4.7.2.8. Reproductive period (P8)

Maximum temperature and diurnal temperature have negative influence and wind speed has positive influence on yield during the reproductive period of Jyothi.

4.7.2.9. Ripening period (P9)

Maximum temperature, minimum temperature and diurnal temperature showed significant negative correlation while forenoon relative humidity showed significant correlation with yield.

4.7.3. Correlation between weather and yield of Kanchana

The correlation between weather and grain yield of Kanchana was worked out and given in the Table.4.39.

4.7.3.1. Transplanting to active tillering (P1)

The grain yield showed significant positive correlation with afternoon relative humidity, rainfall and number of rainy days during transplanting to active tillering stage.

4.7.3.2. Active tillering to panicle initiation (P2)

Among the weather variables studied, wind speed and number of rainy days showed significant positive correlation with grain yield during active tillering to panicle initiation.

Table.4.39. Correlation between yield and weather during different phenophases of Kanchana

Crop stages	TMAX	TMIN	DTR	VP1	VP2	RH1	RH2	WS	BSS	RF	RD	E
P1	0.109	0.409	-0.025	0.317	0.674	-0.808	0.893*	0.787	-0.854	0.997**	0.904*	-0.189
P2	-0.398	-0.356	-0.407	-0.347	-0.150	0.450	0.346	0.966**	-0.402	0.208	0.881*	-0.060
P3	-0.969**	-0.734	-0.951*	-0.893*	-0.599	0.720	0.942*	0.936*	-0.798	0.963**	0.995**	-0.844
P4	-0.621	0.269	-0.867	0.076	-0.691	0.656	-0.367	0.984**	-0.302	-0.231	-0.206	-0.119
P5	0.110	-0.165	0.212	-0.682	0.139	0.603	0.193	0.944*	-0.093	-0.100	0.219	0.050
P6	-0.874	-0.695	-0.927*	0.782	-0.527	0.947*	0.343	-0.578	0.218	0.769	0.734	0.237
P7	-0.192	0.090	-0.296	0.064	0.617	-0.826	0.754	0.919*	-0.845	0.843	0.899*	-0.231
P8	-0.936*	-0.384	-0.965**	-0.698	-0.640	0.776	0.772	0.971**	-0.79	0.884*	0.804	-0.679
P9	-0.874	-0.695	-0.927*	0.782	-0.527	0.947*	0.343	-0.578	0.218	0.769	0.734	0.237

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

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

4.7.3.3. Panicle initiation to booting (P3)

Maximum temperature, diurnal temperature and forenoon vapour pressure deficit have significant negative correlation while afternoon relative humidity, wind speed and rainfall have significant positive correlation with grain yield in Kanchana.

4.7.3.4. Booting to heading (P4)

The weather parameter which positively influencing the grain yield during booting to heading was wind speed.

4.7.3.5. Heading to 50% flowering (P5)

The weather parameter which positively influencing the grain yield during heading to 50% flowering was wind speed.

4.7.3.6.50%flowering to physiological maturity (P6)

The weather parameters such as diurnal temperature range showed significant negative and forenoon relative humidity showed significant positive influence on grain yield.

4.7.3.7. Vegetative period (P7)

The positive correlation of wind speed and rainy days during vegetative period significantly affect the grain yield in Kanchana.

4.7.3.8. Reproductive period (P8)

The weather parameters like maximum temperature, diurnal temperature wind speed and rainfall influences the grain yield in Kanchana. Maximum temperature and diurnal temperature negatively influences and wind speed and rainfall positively influences the grain yield.

4.7.3.9. Ripening period (P9)

In ripening period diurnal temperature showed negative correlation and forenoon relative humidity showed positive correlation with yield.

4.7.4. Correlation between weather parameters on yield parameters of rice

The correlation between yield and yield parameters such as number of filled grains per panicle, number of spikelets per panicle and 1000 grain weight for Jyothi and Kanchana were worked out and presented below.

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

The correlation between weather and number of filled grains per panicle for Jyothi were worked out and presented in Table 4.40.

The weather elements like afternoon vapour pressure deficit, afternoon relative humidity, wind speed, rainfall and number of rainy days were positively influences the filled grains while morning relative humidity and bright sunshine hours negatively influences the filled grains during transplanting to active tillering (P1). In case of P2 stage only wind speed showed positive correlation with filled grains. Maximum temperature, minimum temperature, diurnal temperature, morning and afternoon vapour pressure deficit, bright sunshine hours and evaporation have negative correlation with filled in P3 and the weather parameters which positively influencing the filled grains was afternoon relative humidity, wind speed, rainfall and number of rainy days. The number of filled grains per panicle was positively influenced by forenoon relative humidity, wind speed and rainy days and negatively influenced by afternoon vapour pressure deficit, bright sunshine hours and evaporation during booting to heading (P4). In phenophase P5 the weather variables such as forenoon vapour pressure deficit, wind speed and evaporation showed positive correlation and diurnal temperature and rainy days showed negative correlation in filled grain development. Phenophase P6 the weather variables showed only positive correlation with filled grains and the positively correlated

Table.4.40. Correlation between weather and number of filled grains per panicle at different phenophases of Jyothi.

Crop stages	TMAX	TMIN	DTR	VP1	VP2	RH1	RH2	WS	BSS	RF	RD	E
P1	0.190	0.441	0.067	0.363	0.615**	-0.629**	0.578**	0.504*	-0.582**	0.619**	0.606**	-0.010
P2	-0.188	0.095	-0.247	0.027	0.329	0.294	0.272	0.530*	-0.160	0.303	0.303	0.129
P3	-0.632**	-0.572**	-0.585**	-0.676**	-0.674**	0.353	0.446*	0.625**	-0.493*	0.449*	0.590**	-0.539*
P4	-0.412	-0.353	-0.306	-0.426	-0.478*	0.816**	0.102	0.732**	-0.627**	0.288	0.562**	-0.652**
P5	-0.329	0.407	-0.549*	0.627**	0.041	0.518*	0.323	0.645**	-0.123	0.183	-0.597**	0.702**
P6	-0.180	-0.158	-0.182	0.507*	-0.247	0.544*	-0.249	-0.358	0.600**	0.463*	0.564**	0.628**
P7	0.058	0.540*	-0.096	0.427	0.737**	-0.537*	-0.539*	0.537*	-0.561*	0.617**	0.577**	-0.026
P8	-0.657**	-0.756**	0.244	-0.615**	-0.692**	0.469*	0.431	0.657**	-0.572**	0.423	0.301	-0.525*
P9	-0.180	-0.158	-0.182	0.507*	-0.247	0.544*	-0.249	-0.358	0.600**	0.463*	0.564**	0.628**

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

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

weather variables are forenoon vapour pressure deficit, forenoon relative humidity, bright sunshine hours, rainfall, rainy days and evaporation.

The vegetative period (P7) of rice growth, the weather elements such as minimum temperature, afternoon vapour pressure deficit, wind speed, rainfall and rainy days positively influences the filled grain development and forenoon and afternoon relative humidity and bright sunshine hours negatively influences the filled grain. In reproductive period (P8) maximum temperature, minimum temperature, forenoon and afternoon relative humidity, bright sunshine hours and evaporation had significant negative correlation and forenoon relative humidity and wind speed had significant positive correlation on filled grain development. Ripening period, the weather variables showed only positive correlation with filled grains and the positively influencing weather elements included forenoon vapour pressure deficit, bright sunshine hours, rainfall, rainy days and evaporation.

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

The correlation between weather variables and number of spikelets per panicle of Jyothi were presented on Table.4.41. The afternoon vapour pressure deficit and relative humidity, wind speed, rainfall, rainy days showed significant positive correlation and forenoon relative humidity and bright sunshine hours showed negative correlation in P1. The phenological stage P2, only wind speed showed positive correlation. In P3 stage maximum temperature, minimum temperature, diurnal temperature, forenoon and afternoon vapour pressure deficit, bright sunshine hours and evaporation negative correlation while wind speed, rainfall and rainy days showed positive correlation. In the phenological stage P4, the weather variables such as forenoon relative humidity, wind speed and rainy days showed positive correlation and afternoon vapour pressure deficit, bright sunshine hours and evaporation showed negative correlation. The weather such as diurnal temperature and rainy days showed negative correlation and forenoon vapour pressure deficit and relative humidity, wind speed and evaporation showed significant positive correlation. In phenological stage P6, the weather variables and number of spikelets showed significant positive correlation. The positively

Table.4.41. Correlation between weather and number of spikelets per panicle at different phenophases of Jyothi.

Crop stages	TMAX	TMIN	DTR	VP1	VP2	RH1	RH2	WS	BSS	RF	RD	E
P1	0.181	0.424	0.061	0.342	0.583**	-0.606**	0.547*	0.467*	-0.574**	0.590**	0.572**	-0.037
P2	-0.136	0.137	-0.197	0.074	0.365	0.247	0.224	0.533*	-0.110	0.250	0.271	0.175
P3	-0.618**	-0.595**	-0.563**	-0.675**	-0.671**	0.336	0.438	0.595**	-0.474*	0.460*	0.580**	-0.539*
P4	-0.427	-0.318	-0.340	-0.410	-0.473*	0.797**	0.127	0.730**	-0.635**	0.265	0.568**	-0.630**
P5	-0.335	0.414	-0.559*	0.605**	0.077	0.480*	0.351	0.633**	-0.166	0.219	-0.555*	0.658**
P6	-0.176	-0.137	-0.188	0.483*	-0.241	0.523*	-0.246	-0.341	0.579**	0.461*	0.554*	0.597**
P7	0.083	0.547*	-0.066	0.431	0.717**	-0.540*	0.500*	0.511*	-0.534*	0.575**	0.539*	-0.011
P8	-0.648**	-0.756**	0.207	-0.612**	-0.680**	0.445*	0.438	0.631**	-0.570**	0.429	0.321	-0.532*
P9	-0.176	-0.137	-0.188	0.483*	-0.241	0.523*	-0.246	-0.341	0.579**	0.461*	0.554*	0.597**

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

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

influencing weather variables in P6 are forenoon vapour pressure deficit, forenoon relative humidity, BSS, rainfall, rainy days and evaporation.

In vegetative period (P7), the number of spikelets per panicle was positively influenced by minimum temperature, afternoon vapour pressure deficit and relative humidity, wind speed, rainfall and rainy days and negatively influenced by forenoon relative humidity and BSS. The number of spikelets per panicle was positively influenced by forenoon relative humidity and wind speed and negatively influenced by maximum temperature, minimum temperature, forenoon and afternoon vapour pressure deficit, bright sunshine hours and evaporation during reproductive period (P8). In case of ripening period (P9) the weather parameters were positively influences the spikelets per panicle. The weather variables which positively influence the spikelet per panicle are forenoon vapour pressure deficit and relative humidity, BSS, rainfall, rainy days and evaporation.

4.7.4.3. Correlation between weather and 1000 grain weight of Jyothi

The correlation between weather parameters and 1000 grain weight of Jyothi was presented in Table. 4.42.

Transplanting to active tillering stage, the weather variable bright sunshine hours showed significant negative correlation on 1000 grain weight. In phenophase P2 the weather variables such as minimum temperature and afternoon vapour pressure deficit showed positive influence on 1000 grain weight. Minimum temperature and afternoon vapour pressure deficit had significant negative and rainy days had significant positive correlation on 1000 grain weight in P3. Weather elements such as forenoon relative humidity and wind speed showed significant positive correlation on grain weight in P4. In phenological stage P5, HTU and PTU showed significant negative correlation while in P6 BSS, rainfall and rainy days showed significant positive correlation. In vegetative period, there is no significant correlation was found between weather and 1000 grain weight while in reproductive period weather showed negative correlation and in ripening period exhibit positive

Table. 4.42. Correlation between weather and 1000 grain weight at different phenophases of Jyothi.

Crop stages	TMAX	TMIN	DTR	VP1	VP2	RH1	RH2	WS	BSS	RF	RD	E
P1	-0.203	-0.049	-0.267	-0.141	0.066	-0.147	0.344	0.170	-0.527*	0.273	0.218	-0.433
P2	0.200	0.492*	0.109	0.370	0.520*	-0.012	-0.162	0.442	0.213	-0.213	-0.221	0.346
P3	-0.370	-0.550*	-0.286	-0.400	-0.588**	0.334	0.097	0.258	-0.118	0.390	0.452*	-0.267
P4	-0.192	0.199	-0.317	0.057	-0.183	0.473*	0.316	0.551*	-0.361	-0.125	0.355	-0.165
P5	-0.321	0.141	-0.394	0.245	0.112	0.103	0.280	0.287	-0.436	0.401	-0.197	0.145
P6	-0.145	0.020	-0.231	0.371	0.132	0.361	0.095	-0.357	0.457*	0.519*	0.500*	0.328
P7	-0.016	0.237	-0.093	0.093	0.244	-0.215	0.211	0.266	-0.349	0.160	0.097	-0.180
P8	-0.378	-0.513*	0.022	-0.276	-0.546*	0.301	0.173	0.291	-0.298	0.287	0.318	-0.265
P9	-0.145	0.020	-0.231	0.371	0.132	0.361	0.095	-0.357	0.457*	0.519*	0.500*	0.328

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

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

correlation. Bright sunshine hours, rainfall and rainy days are the weather which positively influencing the ripening period.

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

The correlation between weather and number of filled grains per panicle of Kanchana was worked out and presented in Table.4.43.

The amount of rainfall and number of rainy days showed significant positive correlation with filled grain development in P1 stage. The phenological stage P2 wind speed and number of rainy days showed significant positive correlation with filed grain. Maximum temperature, diurnal temperature, forenoon vapour pressure deficit and GDD influence negatively and afternoon relative humidity, wind speed, rainfall and number of rainy days influence positively during P3 stage. In case of phenological stage P4 and P5 only wind speed showed positive correlation. In P6 maximum temperature and diurnal temperature showed negative correlation and forenoon relative humidity showed positive correlation.

In vegetative period (P7), the weather parameters such as wind speed, rainy days and growing degree days has positive influence on filled grain. Reproductive period maximum temperature, diurnal temperature, growing degree days and photothermal units showed significant negative correlation. Wind speed and rainfall showed positive correlation. In the ripening period of Kanchana, the filled grain development showed positive correlation with forenoon relative humidity and significant negative correlation with maximum temperature and diurnal temperature.

4.7.4.5. Correlation between weather and number of spikelets per panicle of Kanchana

The correlation between weather and number of spikelets per panicle of Kanchana was presented in Table. 4.44.

Table. 4.43. Correlation between weather and number of filled grains per panicle at different phenophases of Kanchana.

Crop stages	TMAX	TMIN	DTR	VP1	VP2	RH1	RH2	WS	BSS	RF	RD	E
P1	0.140	0.415	0.016	0.347	0.693	-0.781	0.872	0.815	-0.805	0.993**	0.922*	-0.146
P2	-0.443	-0.399	-0.453	-0.401	-0.243	0.441	0.396	0.960**	-0.440	0.228	0.891*	-0.088
P3	-0.981**	-0.683	-0.975**	-0.882*	-0.539	0.729	0.962**	0.949*	-0.849	0.967**	0.987**	-0.849
P4	-0.533	0.349	-0.807	0.117	-0.609	0.585	-0.418	0.956*	-0.205	-0.229	-0.246	-0.046
P5	0.092	-0.137	0.177	-0.702	0.256	0.693	0.303	0.936*	-0.183	0.006	0.308	0.028
P6	-0.916*	-0.753	-0.953*	0.759	-0.594	0.962**	0.352	-0.602	0.167	0.730	0.724	0.163
P7	-0.197	0.066	-0.293	0.058	0.613	-0.795	0.764	0.937*	-0.827	0.850	0.914*	-0.216
P8	-0.932*	-0.318	-0.979**	-0.682	-0.547	0.765	0.795	0.974**	-0.810	0.920*	0.815	-0.668
P9	-0.916*	-0.753	-0.953*	0.759	-0.594	0.962**	0.352	-0.602	0.167	0.730	0.724	0.163

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

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

Table.4.44. Correlation between weather and number of spikelets per panicle of Kanchana

Crop stage	TMAX	TMIN	DTR	VP1	VP2	RH1	RH2	WS	BSS	RF	RD	E
P1	0.396	0.695	0.246	0.621	0.882*	-0.945*	0.815	0.859	-0.646	0.936*	0.938*	0.180
P2	-0.563	-0.446	-0.601	-0.440	-0.128	0.660	0.587	0.817	-0.571	0.478	0.974**	-0.249
P3	-0.979**	-0.756	-0.957*	-0.975**	-0.761	0.527	0.963**	0.984**	-0.899*	0.845	0.959**	-0.856
P4	-0.559	0.114	-0.710	-0.040	-0.477	0.612	-0.271	0.930*	-0.361	0.141	0.079	-0.280
P5	-0.155	-0.406	-0.047	-0.794	0.082	0.544	0.117	0.922*	-0.298	-0.192	0.050	-0.318
P6	-0.731	-0.552	-0.795	0.810	-0.739	.918*	0.019	-0.429	0.403	0.504	0.443	0.399
P7	-0.100	0.250	-0.236	0.268	0.821	-0.776	0.832	0.923*	-0.793	0.933*	0.958*	-0.084
P8	-0.972**	-0.497	-0.974**	-0.821	-0.657	0.640	0.817	0.987**	-.918*	0.862	0.878	-0.801
P9	-0.731	-0.552	-0.795	0.810	-0.739	0.918*	0.019	-0.429	0.403	0.504	0.443	0.399

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

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

In the phenological stage P1, the weather elements such as afternoon vapour pressure deficit, rainfall and number of rainy days showed positive correlation and forenoon relative humidity showed negative correlation. In P2 stage rainy day is the only one parameter which shows significant positive correlation with spikelets. The weather elements such as maximum temperature, diurnal temperature, and forenoon vapour pressure, bright sunshine hours, growing degree days, heliothermal units and photothermal units showed significant negative correlation and afternoon relative humidity, wind speed and rainy days showed significant positive correlation in P3 stage. The phenological stages P4 and P5, wind speed showed significant positive correlation with spikelets while in P6 forenoon relative humidity showed significant positive correlation with number of spikelets.

The weather elements such as wind speed, rainfall, rainy days and growing degree days showed significant positive correlation during vegetative period. In reproductive period, maximum temperature, diurnal temperature, BSS, HTU, and PTU showed significant negative correlation and wind speed showed significant positive correlation. Forenoon relative humidity showed significant positive correlation in ripening period.

4.7.4.6. Correlation between weather and 1000 grain weight of Kanchana

The correlation between weather and 1000 grain weight was presented in the Table.4.45.

The weather parameters such as maximum temperature, diurnal temperature, forenoon vapour pressure deficit and growing degree days has significant negative correlation and afternoon relative humidity, wind speed, rainfall and rainy days has positive correlation with 1000 grain weight in P3 stage. The phenological stage P4 and P5, wind speed showed significant positive correlation. Forenoon relative humidity has significant positive correlation in 1000 grain weight on P6 stage.

In vegetative period, the weather variables such as wind speed, rainfall, rainy days and growing degree days has significant positive correlation. Wind

Table. 4.45. Correlation between weather and 1000 grain weight of Kanchana

Crop stage	TMAX	TMIN	DTR	VP1	VP2	RH1	RH2	WS	BSS	RF	RD	E
P1	0.263	0.588	0.109	0.487	0.797	-0.926*	0.873	0.825	-0.769	0.972**	0.925*	0.011
P2	-0.481	-0.394	-0.508	-0.379	-0.073	0.604	0.472	0.882*	-0.494	0.376	0.944*	-0.171
P3	-0.976**	-0.789	-0.947*	-0.961**	-0.752	0.603	0.947*	0.967**	-0.829	0.891*	0.988**	-0.850
P4	-0.651	0.117	-0.819	-0.019	-0.625	0.695	-0.279	0.981**	-0.412	0.004	0.000	-0.273
P5	-0.036	-0.335	0.084	-0.738	0.016	0.503	0.059	0.942*	-0.151	-0.246	0.040	-0.167
P6	-0.761	-0.570	-0.829	0.832	-0.614	0.929*	0.137	-0.479	0.387	0.634	0.560	0.407
P7	-0.142	0.202	-0.275	0.191	0.753	-0.819	0.811	0.920*	-0.840	0.908*	0.938*	-0.161
P8	-0.969**	-0.504	-0.969**	-0.790	-0.728	0.712	0.785	0.990**	-0.861	0.847	0.846	-0.765
P9	-0.761	-0.570	-0.829	0.832	-0.614	0.929*	0.137	-0.479	0.387	0.634	0.560	0.407

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

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

speed showed significant positive correlation while maximum temperature, diurnal temperature, GDD, HTU and PTU has significant negative correlation in reproductive period. In case of ripening period, forenoon relative humidity is the only weather variable which showed significant positive correlation.

4.8. OPTIMUM WEATHER REQUIRED FOR JYOTHI AND KANCHANA

The optimum weather variables required for Jyothi and Kanchana were presented in Table.4.46 and Table 4.47.

Transplanting to active tillering stage in Jyothi was favoured by optimum temperature of 31.5-31.9°C. The temperature above 31.9°C had harmful effect on crop. The optimum range of minimum temperature for Jyothi was 23.7-23.8°C. The minimum temperature beyond 23.8 °C had negative influence on Jyothi. The optimum range of forenoon and afternoon vapour pressure deficit was 22.9-23.1mmhg and 22.6-22.8mmhg respectively. The VPI less than 22.9 mmHg and VPII more than 22.8 mmHg had negative influence on the crop. The optimum range of forenoon and afternoon relative humidity were 93.5-94.5% and 67.7-68.1% respectively. The RHI and RHII less than 93.5% and 67.7% negatively influences the crop. The rainfall less than 228.8mm negatively influences the crop. The BSS greater than 3.3 had negative effect on crop. The optimum range of GDD required for Jyothi was 450.8-467.0 day°C. The GDD greater than 467.0 negatively affects the crop. Optimum HTU was 1571.2-1629.0 day°C h. Optimum PTU range was 5409.7-5636.1 day°C h.

During active tillering to panicle initiation the optimum temperature required was 28.3-31.3°C. The temperature greater than 31.3°C had a negative impact on crop. The optimum VPI and VPII ranges from 21.9-23.1mmHg and 22.2-23.4mmHg. VPI more than 23.1 had negative impact on crop. The VPII less than 22.2 had negative influence on crop. The optimum range of RHI and RHII were 94.8-96.6 and 73.1- 81.7%. RHI less than 94.8 % had negative influence on crop. RHII less than 73.1 % negatively influences the crop. The optimum range of rainfall was 84.8- 214.9mm. The rainfall less than 84.8mm negatively influences

Table4.46. Optimum weather temperature required for Jyothi

Jyothi	TMAX	TMIN	VP1	VP2	RHI	RH II	BSS	RF	GDD	HTU	PTU
P1	31.5-31.9	23.7-23.8	22.9-23.1	22.6-22.8	93.5-94.5	67.7-68.1	1.9-3.3	228.8-328.2	450.8-467.0	1571.2-1629.0	5409.7-5636.1
P2	28.3-31.3	23.2-23.9	21.9-23.1	22.2-23.4	94.8-96.6	73.1-81.7	0.4-2.0	84.8-214.9	136.9-140.9	56.1-748.7	1642.2-1746.1
P3	29.7-30.6	23.4-23.8	22.4-22.8	22.1-22.4	94.8-95.2	71.1-75.0	2.9-4.2	197.0-400.1	371.3-382.9	1080.8-2039.1	4458.0-4596.3
P4	30.7-31.8	23.6-24.3	22.2-23.0	22.5-23.6	94.6-94.7	69.3-72.3	4.2-5.5	73.0-114.8	106.3-154.5	586.7-657.6	1279.7-1894
P5	28.9-31.4	23.3-23.8	21.9-22.9	21.7-23.0	96.3-97.0	63.3-83.5	0.7-7.8	6.2-48.2	32.8-69.4	8.2-542.2	393.0-834.9
P6	31.5-31.9	23.7-23.8	23.0-23.1	22.6-22.8	93.5-94.5	67.7-68.1	5.7-5.9	228.8-328.2	587.7-616.3	3280.6-3575.6	7119.0-7561.6

Table.4.47. Optimum weather temperature required for Kanchana

Kanchana	TMAX	TMIN	VP1	VP2	RH I	RH II	BSS	RF	GDD	HTU	PTU
P1	29.9-30.8	23.5-23.9	22.5-23.0	22.5-23.7	94.4.-95.3	75.7-77.4	1.9-3.4	479.7-648.0	415.4-467.0	933.1-1624.0	5162-5862.6
P2	28.4-31.2	23.1-23.9	21.9-23.1	22.5-23.3	95.1-96.4	72.3-84.0	0.3-4.9	103.4-290.1	141.5-157.9	51.1-784.5	1754.3-1973.0
P3	29.8-30.4	23.3-23.7	22.7-23.0	22.3-22.8	94.8-95.3	69.8-72.0	3.7-5.0	218.1-247.8	347.6-357.6	1220.9-1358.2	4307.2-4397.9
P4	31.3-32.3	23.5-24.3	23.0-23.7	22.5-23.1	92.6-94.9	64.4-73.1	4.3-8.1	47.6-87.0	90.1-102.7	338.8-572.7	1100.5-1262.7
P5	31.0-32.3	23.7-24.1	22.7-23.3	22.5-24.1	92.7-96.3	62.3-78.0	3.8-6.0	31.8-74.2	54.7-69.3	260.6-269.8	661.9-843.8
P6	31.5-32.5	23.6-24.1	22.8-23.1	22.6-23.3	90.6-93.9	67.6-72.1	5.1-6.1	234.2-310.4	595.9-631.3	3102.8-3843.8	7140.9-7672.5

the crop. The optimum BSS required for the crop is 2h. The optimum range of GDD, HTU and PTU for growth and development of Jyothi was 136.9-140.9 respectively

During panicle initiation to booting stage the optimum temperature was 29.7-30.6°C. The temperature more than 30.6°C had negative impact on crop. The minimum temperature range for Jyothi was 23.2-23.9°C. The optimum range of VPD I is 22.4-22.8 mm Hg. The optimum VPD II required during panicle initiation to booting stage is 22.1-22.4 mm Hg. The optimum range of forenoon and afternoon RH I and RHII required was 94.8-95.2 and 71.1-75.0 respectively. The optimum range of BSS, RF, GDD, HTU and PTU affects the growth and development of rice variety Jyothi is 2.9-4.2h, 197.0-400.1mm, 371.3- 382.9 day °C, 1080.8-2039.1day °Ch and 4458.5-2039.1 1day °C respectively.

During booting to heading stage require an optimum temperature of 30.7-31.8°C influences the growth and development of Jyothi. The minimum temperature rage required during this stage is 23.6-24.3°C. The optimum range of VPD I and VPD II is 22.2-23.0 and 22.5-23.6 mmHg. The optimum range of RHI and RH II is 94.6-94.7 and 69.3-72.3%. The optimum range of BSS is 4.2-5.5h. The optimum range of rainfall 73.0-114.8mm is good for the growth and development of Jyothi. GDD of 106.3-154.5day°C is good for Jyothi. The optimum value of HTU is 586.7-657.6 day °C h. The optimum range of PTU is 1279.7-1894.1day °C h.

During heading to flowering stage, the optimum range of Tmax and Tmin was 28.9-31.4 and 23.3-23.8°C. Optimum range of VPD I and VPD II was 21.9-22.9 and 21.7-23.0mm Hg. The optimum ranges of RH I and RH II which if favourable for the growth and development of Jyothi was 96.3-97.0% and 63.3-83.5% respectively. BSS of 0.7-7.8 h is good for the development of Jyothi. The optimum range of rainfall required was 6.2-48.2mm. The optimum range of GDD, HTU and PTU was 32.8-69.4°C, 8.2-542.2°C h and 393.0-834.9day°Ch respectively.

Flowering to physiological maturity required optimum range of 31.5-31.9°C, minimum temperature of 23.7-23.8°C respectively. The optimum range of VPDI and VPD II was 23.0-23.1mm Hg and 22.6-22.8mmHg. The optimum value of 93.5-94.5 (RHI %) and 67.7-68.1(RH II %) is good for the growth and development of Jyothi. The optimum value of 5.7-5.9h BSS affects the growth in Jyothi. The rainfall of 228.8-328.2mm is good for growth development. The heat unit such as GDD, HTU and PTU required is 587.7-616.3°C h, 3280.6-3575.6 day°C h and 287.3-289.7 day°C h.

The optimum temperature required during transplanting to active tillering stage of Kanchana was 29.9-30.8°C. The optimum value of Tmin is 23.5- 23.9 °C respectively. The optimum value of RH I and RHII is 94.4.-95.3% and 75.7-77.4%. The optimum value of VPDI and VPD II is 22.5-23.0 and 22.5-23.7 respectively. The optimum BSS required for Kanchana was 1.9-3.4h. The optimum amount of rainfall required was 479.7-648mm respectively. The optimum range of GDD, HTU and PTU required is 415.4-467.0 day°C, 933.1-1624.0day°C h and 5162.0-5862.6day°C h.

During active tillering to panicle initiation, the optimum Tmax and Tmin is 28.4-31.2 °C and. 23.1-23.9°C. The optimum VPD I and VPD II is 21.9-23.1and 22.5-23.3 mmHg. The optimum RH I and RH II is 95.1-96.4 and 72.3-84.0 % respectively. The optimum BSS required is 0.3-4.9h. The optimum rainfall range of 103.4-290.0mm is good for growth and development of Kanchana. The optimum range of GDD, HTU and PTU is 141.5-157.9, 51.1-784.5 and 1754.3- 1973.0. During panicle initiation to booting stage, the optimum Tmax is 29.8-30.4and Tmin is 23.3-23.7°C. The optimum range of VPD I and VPD II is 22.7-23.0 and 22.3-22.8mmHg. The optimum temperature of RH I and RH II is 94.8-95.3 and 69.8-72.0 respectively. BSS of 3.7-5.0h. The amount of rainfall range of 218.1-247.8 % is good for the growth and development. The heat units required for growth and development of Kanchana is 347.6-357.6, 1220.9-1358.2 and 4307.2-4397.9.

During booting to heading the optimum temperature range for Kanchana was31.3-32.3 °C. the optimum range of Tmin is 23.5-24.3°C influences the growth and development of Kanchana. The optimum VPD I and VPD II is 23.0-23.7 and 22.5-23.1mmHg. The optimum RH I and RH II is 92.6-94.9% and 64.4-73.1%. The optimum range of BSS is 4.3-8.1h. The optimum range of rainfall affecting growth and development of Kanchana is 47.6-87.0mm. The optimum value of GDD, HTU and PTU is 90.1-102.7, 338.8-572.7 and 1100.5-1262.7 respectively.

During heading to flowering stage, the optimum Tmax and Tmin was 31.0-32.3 and 23.7-24.1. VPD I and VPD II is 22.7-23.3mmHg and 22.5-24.1mmHg. The optimum values of RH I and RH II of 92.7-96.3% and 62.3-78.0 respectively. The optimum amount of 31.8-74.2mm rainfall is favourable for the growth of Kanchana. The het units of GDD, HTU and PTU required for Kanchana is 54.7-69.3, 260.6-269.8 and 661.9-843.8 respectively. During flowering to physiological maturity the optimum range of Tmax of 31.5-32.5°C and Tmin of 23.6-24.1 °C. The VPD I and VPD II required is 22.8-23.1and 22.6-23.3mmHg. The optimum range of RH I and RHII of 90.6-93.9 and 67.6-72.1 is favourable for growth and development of Kanchana. The amount of rainfall of 234.2-310.4mm favours the growth and development of crop. The optimum range of GDD, HTUU and PTU was 595.9-631.3, 3102.8-3843.8 and 7140.9-7672.5 respectively.

4.8. INFLUENCE OF HEAT UNITS ON THE YIELD OF CROP

The correlation between heat units such as accumulated growing degree days (GDD), heliothermal units (HTU) and photothermal units with grain yield of Jyothi and Kanchana were worked out for different phenophases and the results were presented in Table. 4.48. and Table. 4.49.

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

In phenophase P4 (booting to heading), the accumulated GDD showed significant positive correlation with grain yield. Accumulated heliothermal unit showed significant negative correlation with phenophases P3 (panicle initiation to booting) and P7 (vegetative period). Accumulated photothermal units has significant positive correlation in P4 (booting to heading) stage.

Table.4.48. Influence of heat units on yield of Jyothi

Phenophase	GDD	HTU	PTU
P1	0.771	-0.668	0.797
P2	-0.835	-0.572	-0.780
P3	-0.679	-0.942*	-0.660
P4	0.882*	0.737	0.884*
P5	-0.689	-0.477	-0.686
P6	-0.630	0.268	-0.386
P7	-0.035	-0.886*	0.129
P8	0.513	-0.847	0.803
P9	-0.630	0.268	-0.386

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

Table.4.49. Influence of heat units on yield of Kanchana

Phenophase	GDD	HTU	PTU
P1	0.673	-0.824	0.783
P2	0.368	-0.314	0.482
P3	-0.969**	-0.807	-0.908*
P4	-0.397	-0.589	-0.318
P5	-0.710	-0.665	-0.679
P6	-0.176	0.228	0.546
P7	0.935*	-0.818	0.977**
P8	-0.961**	-0.849	-0.925*
P9	-0.176	0.228	0.546

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

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

Accumulated GDD showed significant negative correlation with grain yield in Kanchana on P3 (panicle initiation to booting) and P8 (reproductive period) and significant positive correlation in P7 (vegetative period). Accumulated HTU showed no significant correlation with grain yield. The accumulated PTU showed significant positive correlation in P7 (vegetative period) and negative correlation in P3 (panicle initiation to booting) and P8 (reproductive period).

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

The correlation between heat units and duration of different phenophases of Jyothi and Kanchana were worked out using accumulated growing degree days, heliothermal unit and photothermal units. The correlation results were presented in Table. 4.50 and 4.51.

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

Accumulated growing degree days showed significant positive correlation with duration in phenophase P1 (transplanting to active tillering), P2 (active tillering to panicle initiation), P4 (booting to heading), P7 (vegetative period), P8 (reproductive period) and P9 (ripening period). The accumulated growing degree days showed significant negative correlation with duration in 50%flowering to physiological maturity. Accumulated heliothermal unit showed significant positive correlation in P4 (booting to heading) and P6 (50 % flowering to physiological maturity). Accumulated photothermal unit showed significant positive correlation in P1 (transplanting to active tillering), P2 (active tillering to panicle initiation), P4 (booting to heading), P7 (vegetative period), P8 (reproductive period) and P9 (ripening period). Accumulated PTU showed significant negative correlation in P6 (50% flowering to physiological maturity).

Table4.50.Influence of heat units on duration of different growth stages of Jyothi

Phenophase	GDD	HTU	PTU
P1	0.728**	-0.303	0.726**
P2	0.620**	0.384	0.606**
P3	0.219	0.047	0.226
P4	0.840**	0.659**	0.841**
P5	-0.056	-0.176	-0.056
P6	-0.719**	0.599**	-0.500*
P7	0.576**	-0.167	0.521*
P8	0.576**	-0.167	0.521*
P9	0.568**	0.049	0.609**

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

Table.4.51. Influence of heat units on duration of different growth stages of Kanchana

Phenophase	GDD	HTU	PTU
P1	0.535*	-0.189	0.584**
P2	-0.070	-0.292	-0.088
P3	0.156	0.343	0.250
P4	-0.322	-0.556*	-0.267
P5	0.550*	0.218	0.545*
P6	0.153	-0.163	0.165
P7	-0.006	-0.252	0.073
P8	-0.603**	-0.599**	-0.583**
P9	0.153	-0.163	0.165

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

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

Accumulated growing degree days showed significant positive correlation in phenological stages P1 and P5 and significant negative correlation in P8 stage. Accumulated heliothermal unit showed significant negative correlation in P4 and P8. The accumulated photothermal units exhibit significant positive correlation in phenophase P1 and P5 while significant negative correlation in P8.

4.10. MODEL FOR PREDICTION OF GRAIN YIELD AND DURATION

Multiple linear regression equations were used for predicting the grain yield and duration for Jyothi and Kanchana using weather variables and heat units such as accumulated GDD, HTU and HTU experienced during different phenophases. Some of the prediction equation developed is given in Table 4.52. Table 4.53. Table.4.54. The models could predict the yield satisfactory with an adjusted R^2 between yield and weather variables.

4.11. INCIDENCE OF PEST AND DISEASES

During the crop period, incidence of various pests and diseases were comparatively less. The incidence of pests was more in delayed planting crops compared to early plantings. The different pests noticed in the field during the crop season are Leaf folder (*Cnaphalocrocis medinalis*), Stem borer (*Scirphophaga incertulas*) and Rice bug (*Leptocorisa acuta*). Incidence of diseases was very less compared to pests and the two important diseases noticed in the field were sheath rot (*Sarocladium oryzae*) and sheath blight (*Rhizoctonia solani*)(Table.4.55).

4.14. CERES- RICE SIMULATION RESULTS

4.14.1. Calibration of genetic coefficient

The CERES-Rice model was calibrated with experimental data collected during the 2015 rice crop season. Calibration of genetic coefficients of Jyothi and Kanchana were estimated with the independent data sets of two rice varieties.

Table.4.52.Yield prediction model for Jyothi and Kanchana using weather variables.

Phase	Model	Adjusted R^2
Jyothi		
T-AT	Yield = -70.029 ** +0.805 RH1	0.978
AT-PI	Yield= -1.016+ 0.844 RD	0.714
PI-B	Yield= 20.113**-2.184 DTR	0.963
H-F	Yield=-101.654**+1.113RH1	0.925
F-PM	Yield=-70.029**+0.805RH1	0.971
Ripening	Yield=-70.029**+0.805RH1	0.971
Kanchana		
T-AT	Yield=0.831*+0.199**RF	0.986
AT-PI	Yield=2.557**+1.1497**WS+0.117*RD	0.910
PI-B	Yield=-1.064*+0.461**RD	0.987
H-F	Yield=3.274**+1.652*	0.855
F-PM	Yield=-31.176*+0.382*RH1	0.863
Vegetative	Yield=376.016*-3.917*RH1	0.883
Reproductive	Yield=14.377**-1.379**DTR	0.952
Ripening	Yield=-31.176*+0.382*RH1	0.863

Table.4.53. Yield prediction model for Jyothi and Kanchana based on heat units

Phase	Model	Adjusted R^2
Jyothi		
PI-B	Yield= 9.814**-0.003HTU*	0.849
B-H	Yield= -1.042+0.004PTU*	0.709
Vegetative	Yield= 9.610*-0.003HTU*	0.713
Kanchana		
PI-B	Yield= 36.028*-0.088GDD*	0.919
Vegetative	Yield =- 16.627* + 0.003PTU*	0.939
Reproductive	Yield = 21.508*- 0.033 GDD*	0.897

Table.4.54. Prediction model for duration of Jyothi and Kanchana based on heat units

Phase	Model	Adjusted R^2
	Jyothi	
T-AT	Duration= 7.765**+ 0.042GDD**	0.766
AT-PI	Duration= 0.302+0.054GDD**+0.005HTU*-0.054PTU*	0.999
PI-B	Duration= 17.796**+0.003PTU**+0.008GDD*	0.693
B-H	Duration=1.613** + 0.048 GDD**-0.019HTU*+0.216PTU*	0.995
H-F	Duration=4.827**-0.005HTU**+0.012GDD*	0.823
Vegetative	Duration=1.683+0.038GDD**+0.000HTU**	0.878
Ripening	Duration=29.589**-0.006 PTU**	0.929
	Kanchana	
T-AT	Duration= 12.071**+0.034GDD**-0.003HTU*+0.032 PTU	0.952
AT-PI	Duration = 0.827+ 0.052GDD**	0.652
PI-B	Duration = 29.005**- 0.023GDD**	0.204
B-H	Duration =0.029+0.061GDD**-0.010PTU**	0.999
F-PM	Duration =4.877+0.048GDD**	0.593
Vegetative	Duration =20.778**-0.014 PTU**+ 0.028GDD**	0.954

Table 4.55. Pests and diseases observed in different dates of planting

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

Accuracy in simulation of yield, phenology and growth requires the accurate genetic coefficients. These coefficients were adjusted until there was a close between the observed and simulated dates of panicles initiation, anthesis, physiological maturity and grain yield (Table 4.56).

4.14.2. Simulated V/s Observed Grain yield

The observed grain yield for Jyothi and Kanchana during different planting dates varied from 3792 (D3) to 5807 (D1) and 3995 (D5) to 4902 (D1) kg ha^{-1}. In Jyothi the CERES-Rice model underestimated the grain yield in D1and overestimated in D2, D3, D4 and D5 while in Kanchana the grain yield was under estimated in D1, D2 and D4 and over estimated in D3 and D5. The error percent of simulated grain yield from observed grain yield was presented in Table 4.57.

4.14.3. Simulated V/s observed Phenological development

The accurate simulation of phasic development is important for getting 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 different.

4.14.3.1. Days to panicle initiation

The difference between observed and simulated duration of panicle initiation with error percent are given in the Table 4.58. The results showed that the observed duration of panicle initiation was varied from 35(D1) to 37(D2) and simulated duration of panicle initiation varied from 34(D1) to 37(D4) in Jyothi while in Kanchana the observed duration of panicle initiation varied from 33(D5) to 36(D1) and simulated duration varied from 31(D5) to 35(D2). The number of days to panicle initiation was under estimated in all the dates of plantings except D4 in both Jyothi and Kanchana. The duration of panicle initiation was over estimated in D4.

Table. 4.56. Genetic coefficients of the rice varieties Jyothi and Kanchana

Cultivar trait	Genetic coefficients	Jyothi	Kanchana
Time from seed emergence to the end of juvenile phase	P1	569.0	466.3
Extent to which development is delayed for each hour increase in photoperiod above the longest photoperiod	P2O	26.9	137.7
Extent to which phasic development from vegetative to panicle initiation is delayed for each hour increase in photoperiod above P2O, i.e., 12.5 h	P2R	525.8	500.0
Time starting from grain filling to physical maturity	P5	10.2	12.1
Maximum spikelet number coefficient	G1	55.0	49.8
Maximum possible single grain size	G2	0.0224	0.0225
Scalar vegetative growth coefficient for tillering relative to IR64	G3	1.15	1.30
Temperature tolerance scalar coefficient	G4	1.00	1.10
Phyllocron interval	PHINT	80	77

Table. 4.57. Observed and predicted grain yield (kg ha^{-1}) of Jyothi and Kanchana with their percent error

Planting dates	Jyothi			Kanchana		
	Observed	Simulated	Error %	Observed	Simulated	Error %
D1	5807	4985	-14.2	4902	4527	-7.6
D2	4380	4912	12.1	4810	4525	-5.9
D3	3792	4891	29.0	4120	4542	10.2
D4	4142	4550	9.9	4405	4267	-3.1
D5	3805	4754	24.9	3995	4276	7.0
Average	4385	4818	12.4	4446	4427	0.1

Error percent = $[(\text{simulated} - \text{observed})/\text{observed}] * 100$

Table.4.58. Observed and simulated duration of panicle initiation of Jyothi and Kanchana with their percent error

Planting dates	Jyothi			Kanchana		
	Observed	Simulated	Error %	Observed	Simulated	Error %
D1	35	34	-2.9	36	34	-5.6
D2	37	35	-5.4	35	35	0.0
D3	35	34	-2.9	35	33	-5.7
D4	36	37	2.8	34	35	2.9
D5	35	34	-2.9	33	31	-6.1
Average	36	35	-2.2	35	34	-2.9

Table.4.60. Observed and simulated maturity days for Jyothi and Kanchana with their percent error

Planting dates	Jyothi			Kanchana		
	Observed	Simulated	Error %	Observed	Simulated	Error %
D1	102	102	0	101	101	0.0
D2	101	101	0	100	101	1.0
D3	100	100	0	98	99	1.0
D4	100	101	1	98	100	2.0
D5	100	99	-1	99	97	-2.0
Average	101	101	0	99	100	0.4

4.14.3.4. Model performance

Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE) and D-stat index for yield and phenophases of two varieties given in Table 4.61.

Table.4.61. RMSE, MAPE and D- index for Jyothi and Kanchana

Variable Name	Jyothi			Kanchana		
	RMSE	MAPE	d-Stat.	RMSE	MAPE	d-Stat.
Yield (kg ha^{-1})	822.1	18.5	0.517	315.6	6.8	0.546
Anthesis day	0.775	0.9%	0.837	1.183	1.5	0.673
Panicle initiation day	1.265	3.4	0.632	1.612	4.1	0.646
Maturity day	0.632	0.4	0.873	1.414	1.2	0.682

Discussion

5. DISCUSSION

The present study was taken up with a view to estimate the different growth phases of rice using thermal indices *viz.* GDD, HTU, PTU and to validate the phenology of the rice varieties using CERES model based on the crop weather relationship. The results of the experiment details are discussed below.

5.1. EFFECT OF WEATHER ON GROWTH AND DEVELOPMENT OF RICE

5.1.1. Plant height

The plant height at weekly intervals from transplanting to harvest was influenced by different dates of planting. The plant height decreases significantly with delayed transplanting for both varieties (Fig.5.1). The rice variety transplanted on June 5^{th} planted crops recorded highest and the crop transplanted on August 5^{th} recorded lowest value of plant height for both varieties. This result was in agreement with Bashir *et al.* (2010) and Safdar *et al.* (2013). The reduction in plant height was due to shorter growing period during late transplanting period. These results are in line with Khakwani *et al.* (2006). Increased temperature on delayed transplanting reduces the plant height in Jyothi and Kanchana. This was in agreement with findings of Cheng *et al.* (2009). 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 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. Dry matter accumulation

It was observed that the delayed transplanting reduces the dry matter accumulation in both Jyothi and Kanchana. The effect of weather parameters on dry matter production was given in Table.5.2. The maximum, minimum and diurnal range temperature showed negative influence on dry matter accumulation on delayed planting (Fig.5.2. (a) and 5.2.(b)). The same type of result was reported by Peng *et al.* (2004). Forenoon and afternoon relative humidity was positively

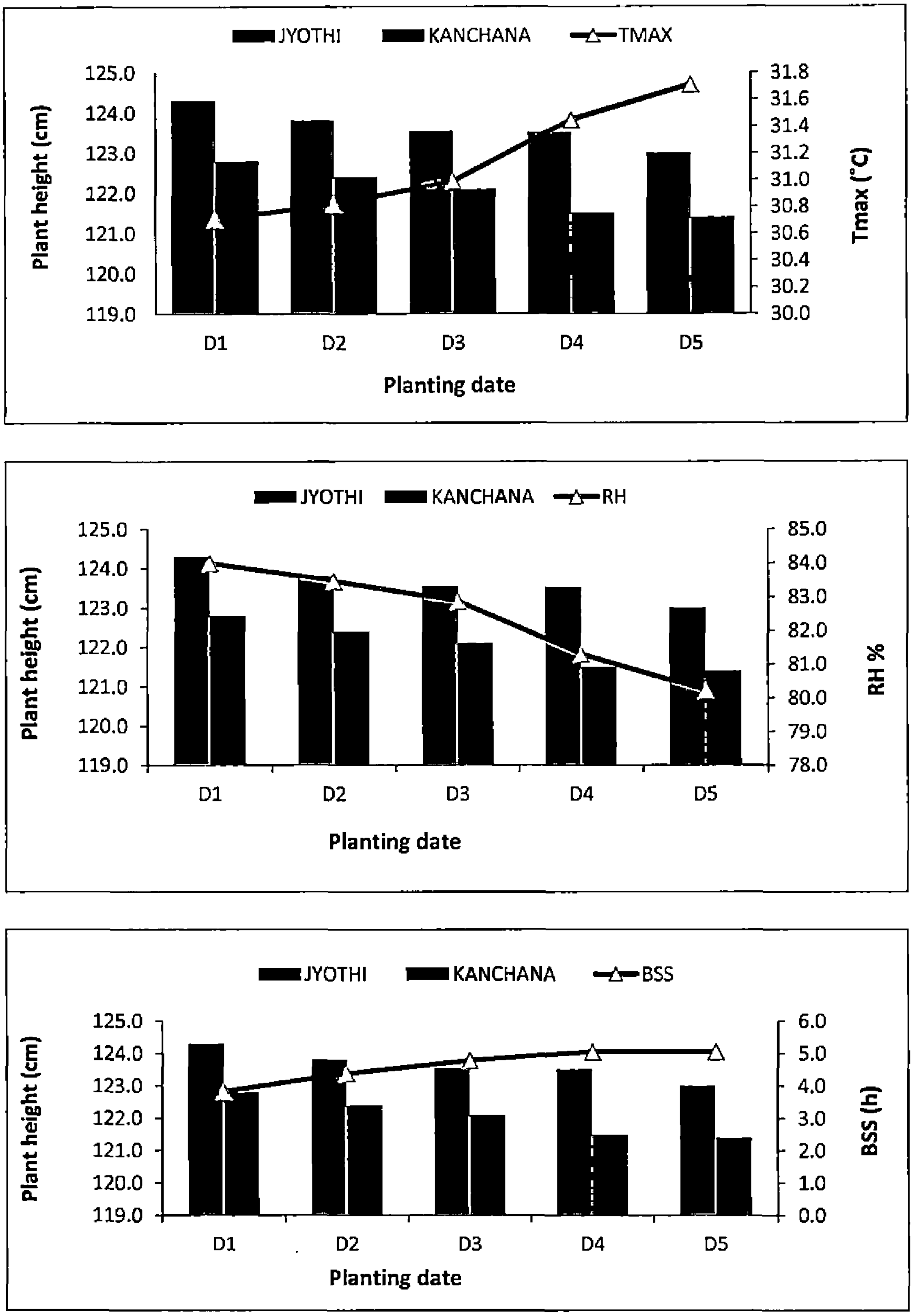


Fig.5.1 Effect of weather parameters on plant height with respect to different planting date

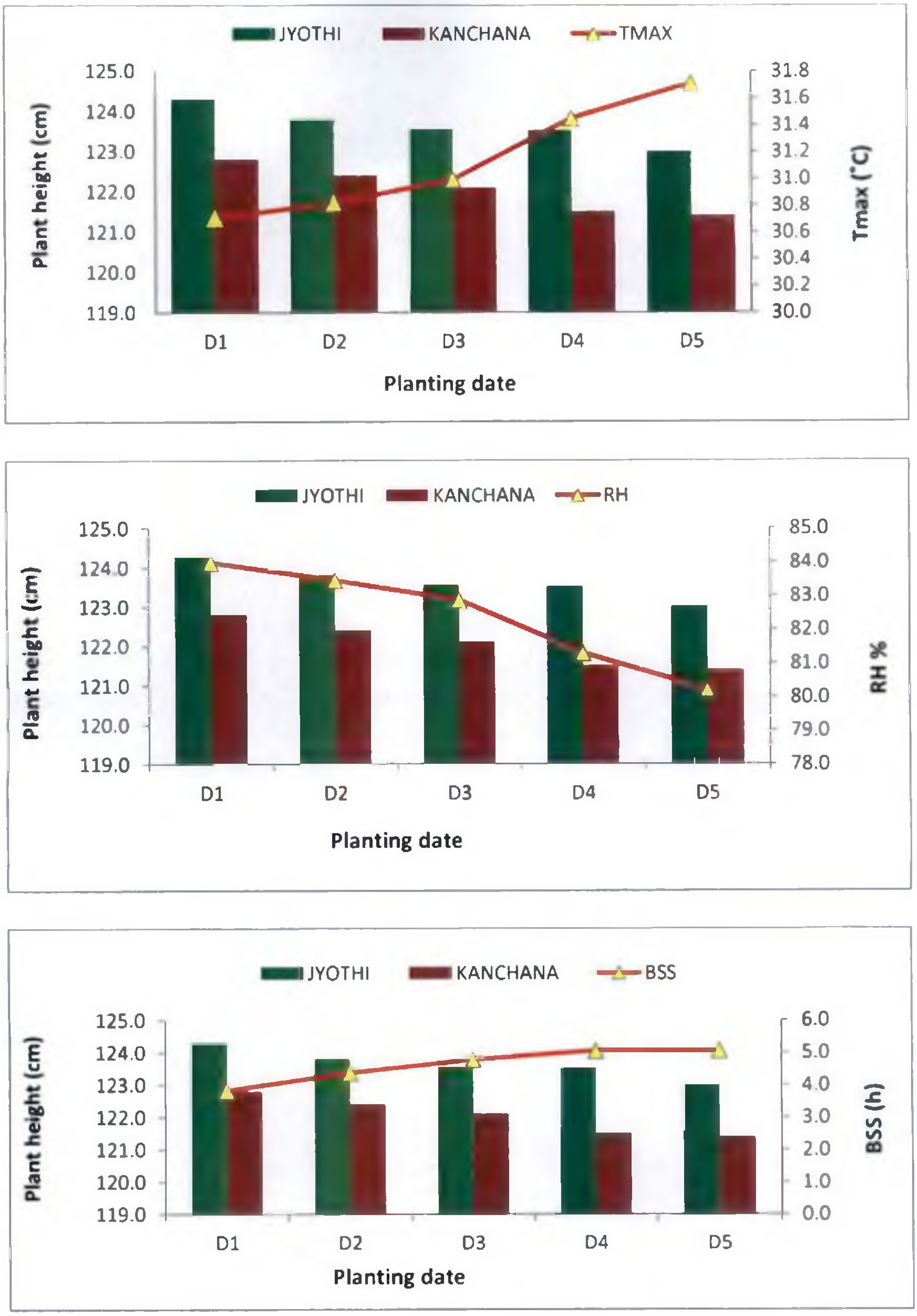


Fig.5.1 Effect of weather parameters on plant height with respect to different planting date

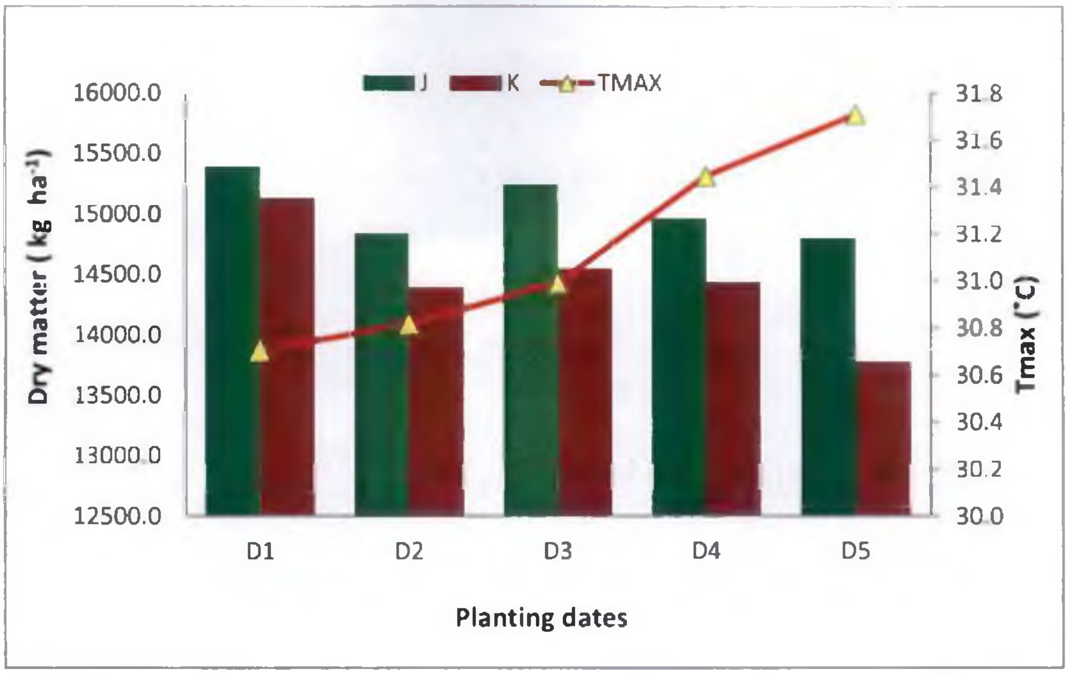


Fig.5.2.(a). Effect of maximum temperature on dry matter accumulation in rice varieties

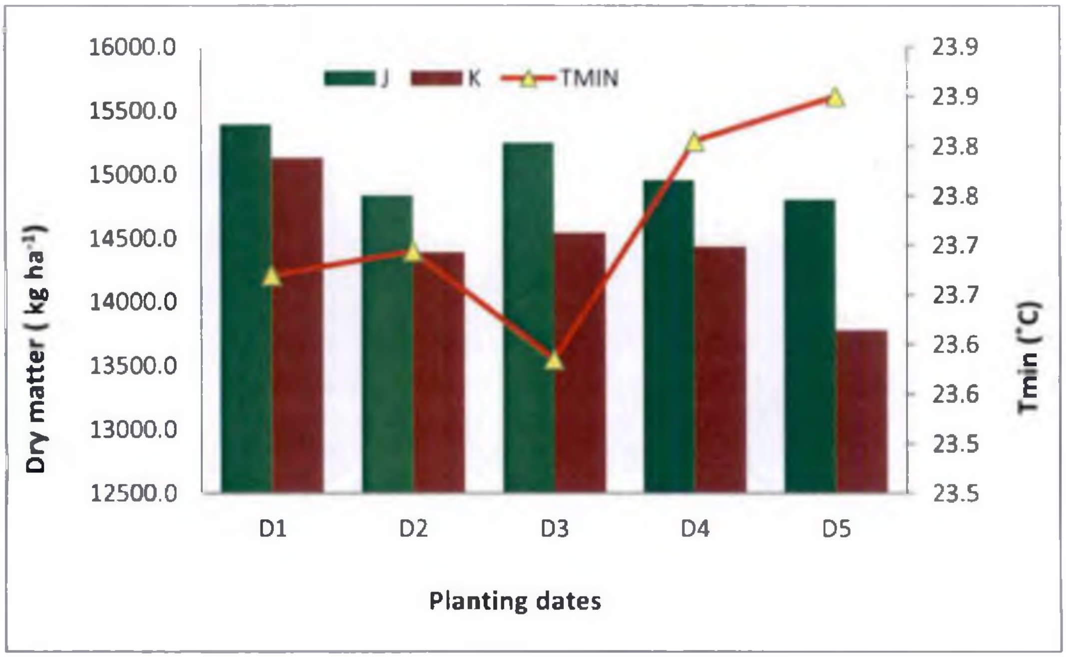


Fig.5.2.(b). Effect of minimum temperature on dry matter accumulation in rice varieties

affecting the dry matter production in Jyothi and Kanchana on delayed planting (Fig.5.2. (c) and 5.2.(d)). These results were supported by studies of Roy and Biswas (1980), Hirai *et al,* (1993), Kaladevi *et al.* (1999) and Singh *et al.* (2012). The rainfall also showed positive influence on dry matter production in both Jyothi and Kanchana (Fig.5.2.(e)). That is why higher dry matter production was observed in June 5th date of planting.

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

Varieties	Tmax (°C)	Tmin (°C)	DTR (°C)	RHI (%)	RH II (%)	Rain (mm)	Epan (mm)
Jyothi	-0.623**	-0.705**	-0.554*	0.682**	0.601**	0.590**	-0.891**
Kanchana	-0.823**	-0.653**	-0.818**	0.881**	0.801**	0.820**	-0.901**

5.1.3. Number of panicles per m^{-2}

The number of panicles per m^{-2} is one of the important parameter which determines the final yield of rice. Early transplanted crops recorded highest number of panicles per m^{-2} and these data are in agreement with those reported by Khalifa *et al.* (2014). Delayed transplanting reduces the number of panicles per m^{-2} in rice due to increased temperature (Fig.5.3).

5.1.4. Number of spikelets per panicle

The planting dates had significant influence on number of spikelets production in rice varieties Jyothi and Kanchana. The number of spikelets per panicle was found to be reduced with delay in transplanting. Same results were also reported by Singh *et al.* (2012). The delayed transplanting reduces the number of spikelets per panicle due to increased temperature (Fig.5.4).

5.1.5. Number of filled grains per panicle

The number of filled grains per panicle was affected significantly by different transplanting dates. The crops transplanted at 5th June (D1) produced the maximum number of filled grains per panicle. The lowest number of filled grains

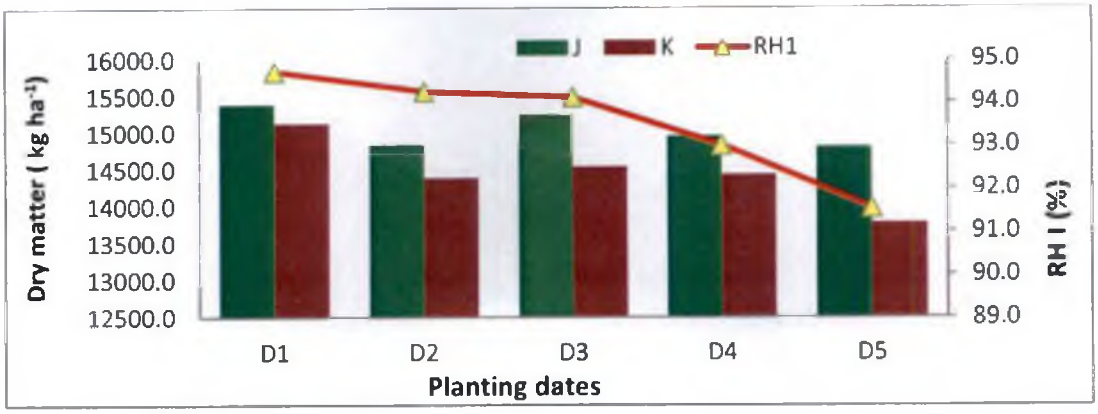


Fig.5.2.(c). Effect of forenoon RH on dry matter accumulation in rice varieties

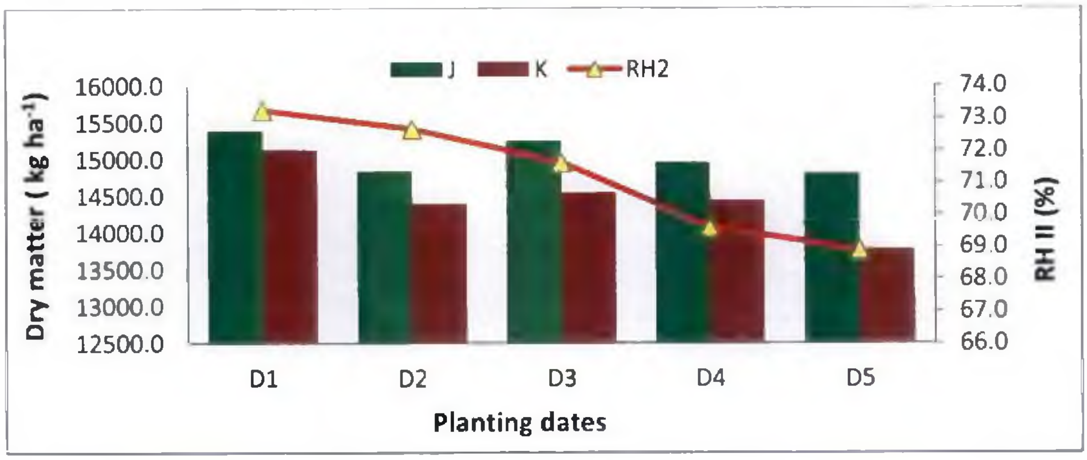


Fig.5.2.(d). Effect of afternoon relative humidity on dry matter accumulation in rice varieties.

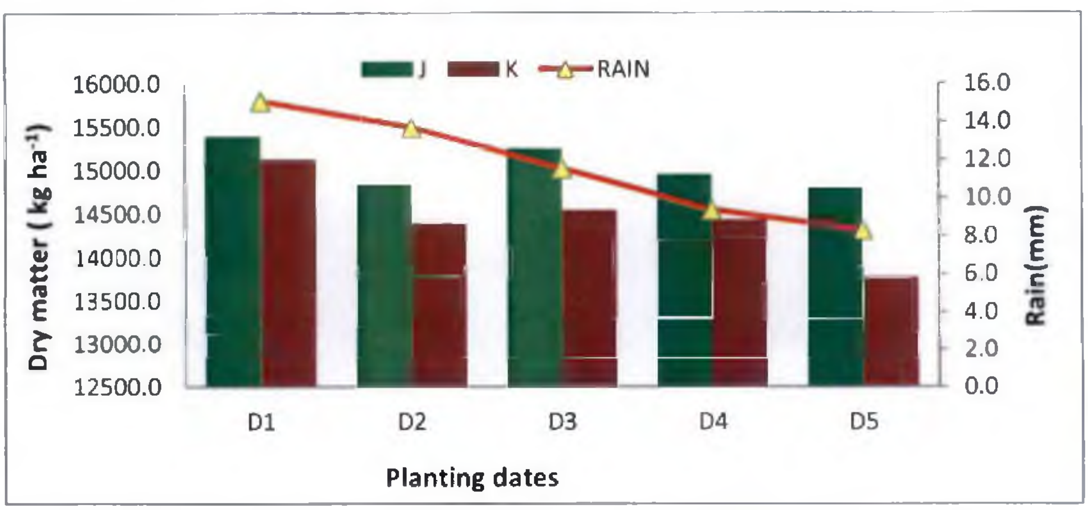


Fig.5.2.(e). Effect of rainfall on dry matter accumulation in rice varieties

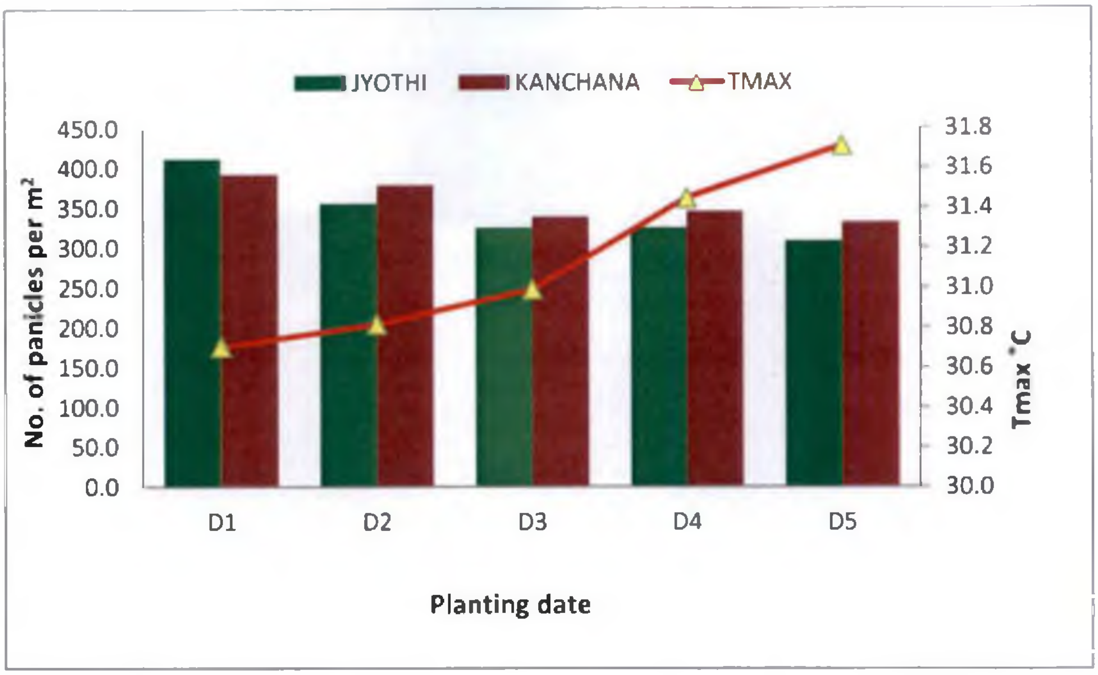


Fig.5.3. Effect of maximum temperature on number of panicles with respect to different planting date.

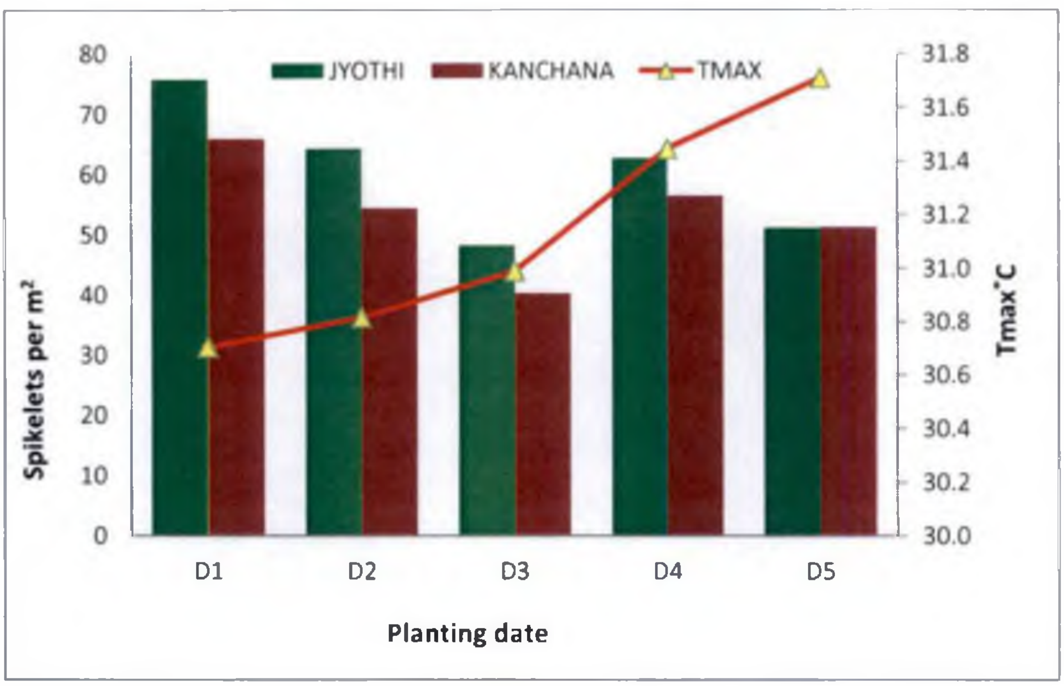


Fig.5.4. Effect of maximum temperature on number of spikelets with respect to different planting date.

per panicle was observed when rice was transplanted on 5th August (D5) (Fig.5.5). This showed that number of filled grains per panicle decreases as the transplanting was delayed. These results are similar to that of Khalifa (2009).

5.1.6. 1000 grain weight

Date of planting had significant influence on 1000 grain weight. It was more during the early transplanting (June 5th) compared to late transplanting (Fig.5.6). This result was in agreement with findings of Biswas and Salokhe (2001) and Nahar *et al.* (2009).

5.1.7. Straw yield

The straw yield was significantly affected by different date of plantings in both Jyothi and Kanchana. The straw yield was found to be highest in early plantings than late plantings. Khalifa *et al.* (2014) also reported the same in straw yield. Fig.5.7 and Fig.5.8.

5.1.8. Grain yield

Grain yield was significantly affected by planting date in both Jyothi and Kanchana. The highest grain yield was obtained in Jyothi and Kanchana for June 5th planting. Number of panicles per unit area, filled grains per panicle and 1000 grain weight contributed the high yield which was in agreement with findings of Safdar *et al.* (2006). The reduction in grain yield on delayed plantings was due to increased temperature during heading stage which might have induced grain sterility and thus reduced the grain yield (Fig. 5.9). Akram *et al.* (2007) and Huda *et al.* (1975) also reported the same. Delayed transplanting showed reduction in grain yield due to increased temperature in both varieties (Fig.5.9.). Same findings were reported by Wahid *et al.* (2007).

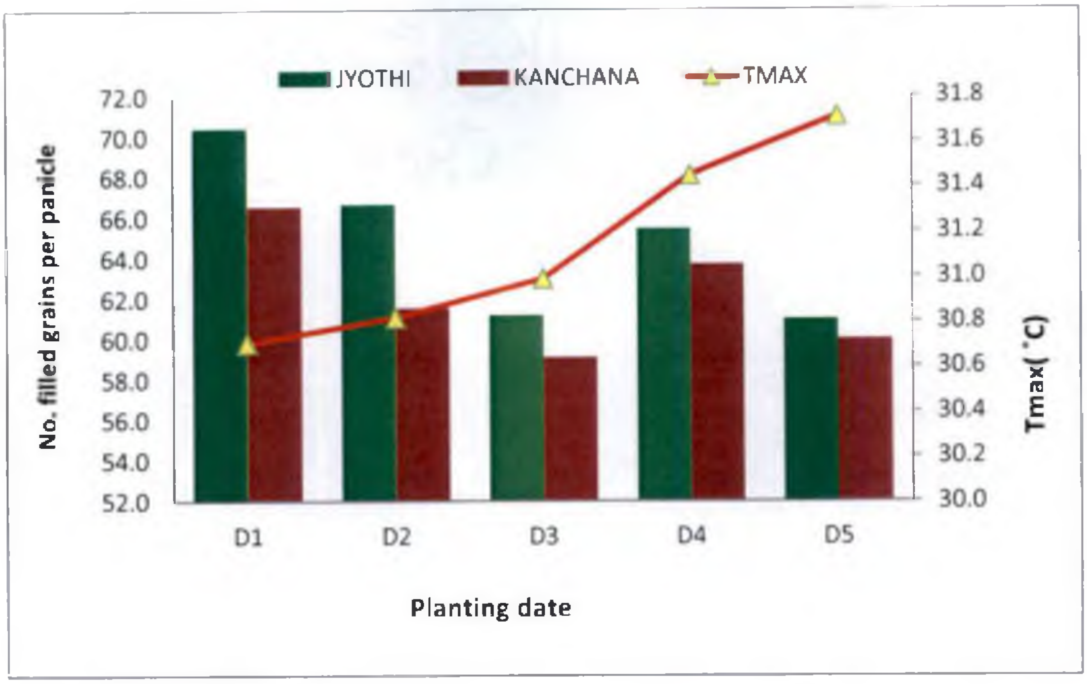


Fig.5.5. Effect of maximum temperature on filled grains with respect to different planting date

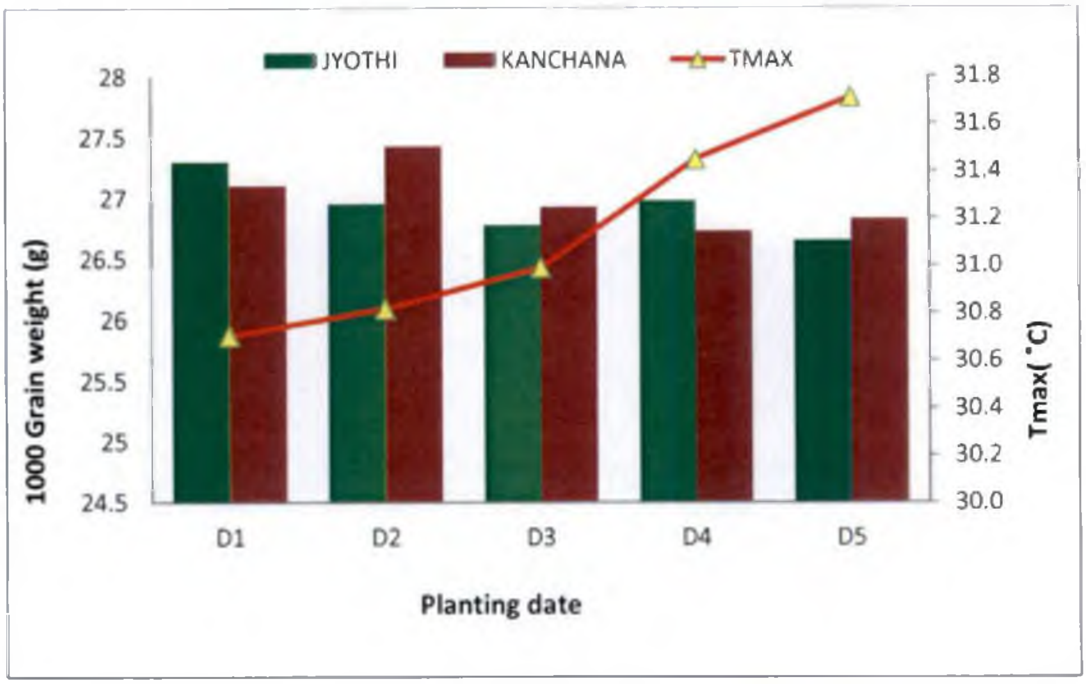


Fig.5.6. Effect of maximum temperature on 1000 grain weight with respect to different planting date

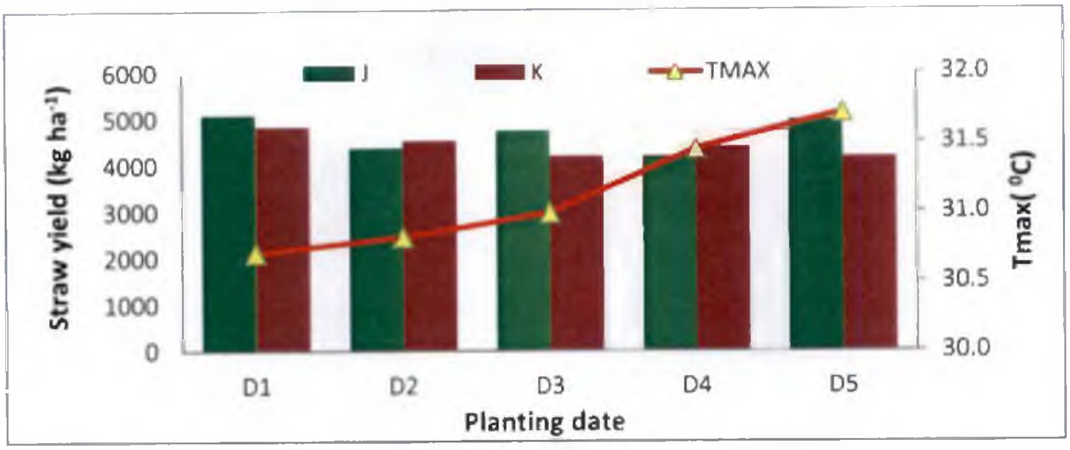


Fig.5.7. Effect of maximum temperature on straw yield with respect to date of planting.

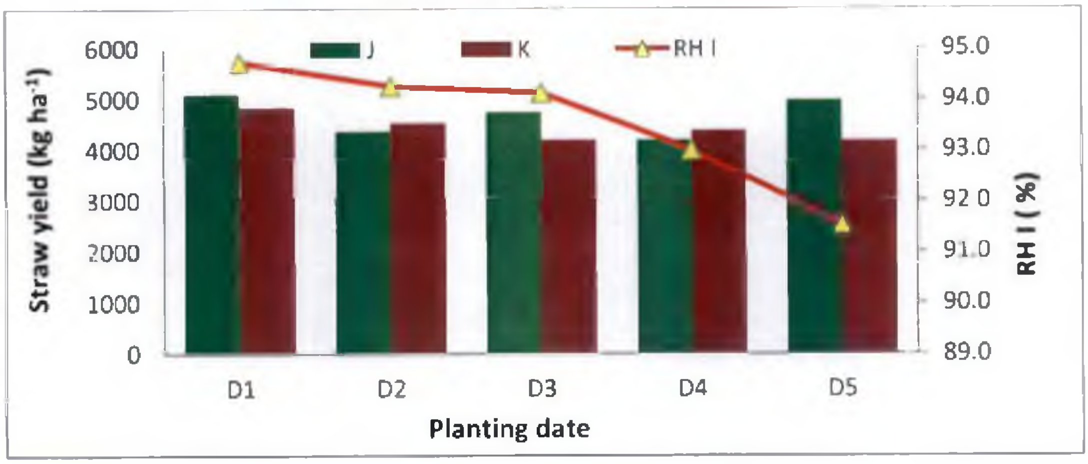


Fig.5.8. Effect of forenoon relative humidity on straw yield with respect to date of planting

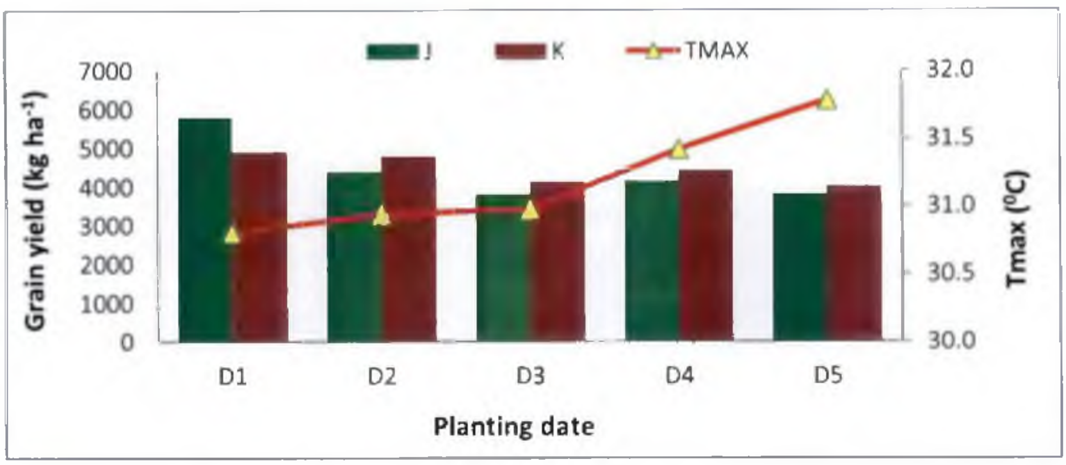


Fig.5.9. Effect of maximum temperature on yield with respect to different planting date

5.2. EFFECT OF WEATHER ON THE DURATION OF PHENOLOGICAL STAGES

The days taken for each phenophases were found to be different for the varieties Jyothi and Kanchana planted at different planting dates. For Jyothi and Kanchana, the days taken to attain its physiological maturity was more in early transplanted varieties. The results showed that the days taken to complete life cycle was reduced with delayed transplanting. It might be due to the fact that the weather conditions prevailed during each dates were not the same for all the planting dates even though the season was same. This result was in accordance with the findings of Lamsal *et al.* (2013).

Increased temperature during delayed transplanting reduces the duration of physiological maturity in both varieties (Fig.5.10). Various phenological stages like active tillering, panicle initiation, 50% flowering and harvest was found to be shorter for the crops grown under increased temperature (Fig.5.11). This result was supported by Rani and Maragatham (2013).

From the correlation analysis, the results showed that the minimum temperature during active tillering to panicle initiation, bright sunshine hours during panicle initiation to booting, maximum and minimum temperature during booting to heading, bright sunshine hours and rainfall during flowering to physiological maturity reduces the duration of phenophase in Jyothi. The amount of rainfall and number of rainy days during booting to heading increases the duration of phenophases in Jyothi. In case of Kanchana minimum temperature during active tillering to panicle initiation, maximum and minimum temperature and BSS during panicle initiation to booting and maximum temperature during flowering to physiological maturity reduces the duration of Kanchana in late planting.

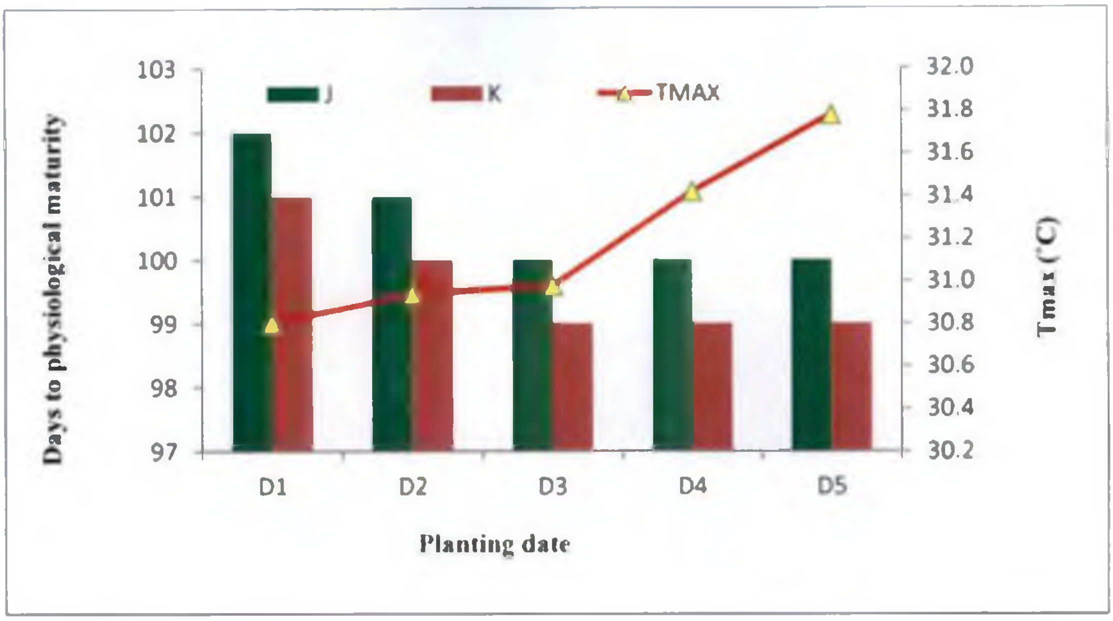


Fig.5.10. Effect of maximum temperature on duration of rice varieties on duration of physiological maturity

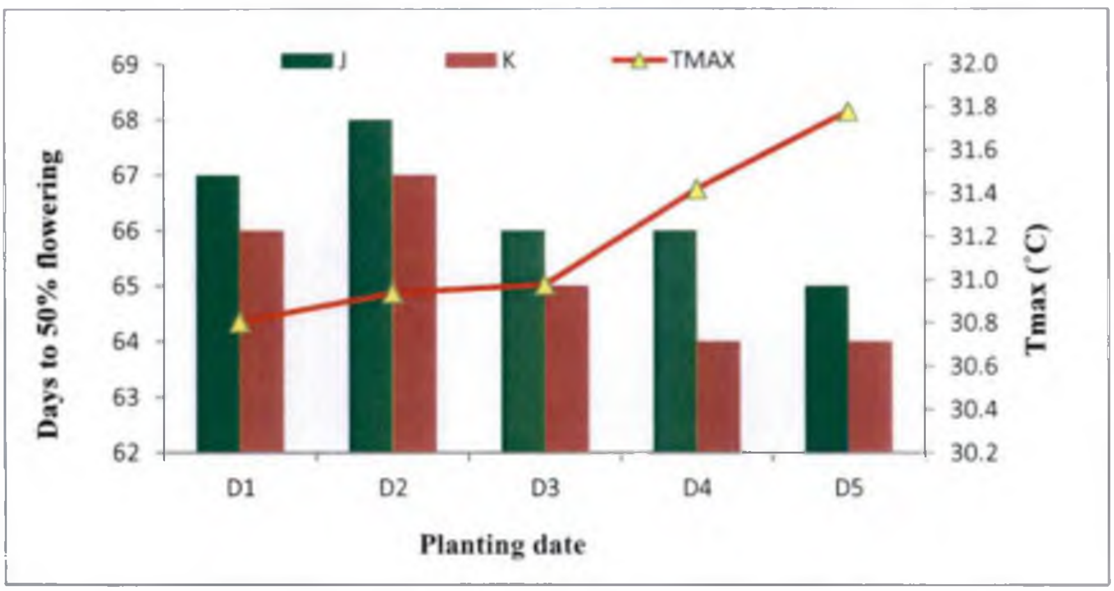


Fig.5.11. Effect of maximum temperature on duration of 50% flowering

5.3. GROWTH INDICES

5.3.1. Leaf area index (LAI)

The rice varieties Jyothi and Kanchana recorded highest value of leaf area index during 75 days after transplanting. Early transplanted rice varieties showed highest value of leaf area index in both varieties (Fig.5.12 and 5.13). Same result was reported by Khalifa *et al.* (2014) and Ahmad *et al,* (2009). In both varieties the leaf area index was found to be increased and reached its maximum value at 75 days after transplanting and there after it decreases. This was in conformity with Medhi *et al.* (2016) and Azharpour *et al.* (2014). The decrease in leaf area towards maturity may be due to lesser leaf number as a result of senescence in early formed leaves. This result was in accordance with the findings of Sharma and Haloi (2001).

5.3.2. Leaf area duration (LAD)

The rice varieties Jyothi and Kanchana recorded maximum leaf area duration on 75 days after transplanting. Same result was reported by Sadeghi and Bohrani (2001). Leaf area duration was increased during earlier period and then decreased in the later stages of both varieties (Fig.5.14). These results were supported by Devendra *et al.* (1983). Reduction in leaf area duration towards late planting may be due to increase in maximum temperature.

5.3.3. Crop growth rate (CGR)

Crop growth rate for Jyothi and Kanchana was found to be highest in 60-75 days after transplanting in both Jyothi and Kanchana (Fig.5.15. and 5.16). Similar type of observations was recorded by Taleshi *et al.* (2013) on rice crops during 75- 80 days after transplanting. The crop growth rate in Jyothi and Kanchana was first increased slightly up to 75 days after transplanting and there after it decreases. Incomplete plant canopy and low amount of light absorbance reduces the crop growth rate in early growth stages of rice. Increase in leaf area increases the crop growth rate there by increases the absorbance of light by plants. Similar findings were also reported by Mojaddam and Noori (2015).

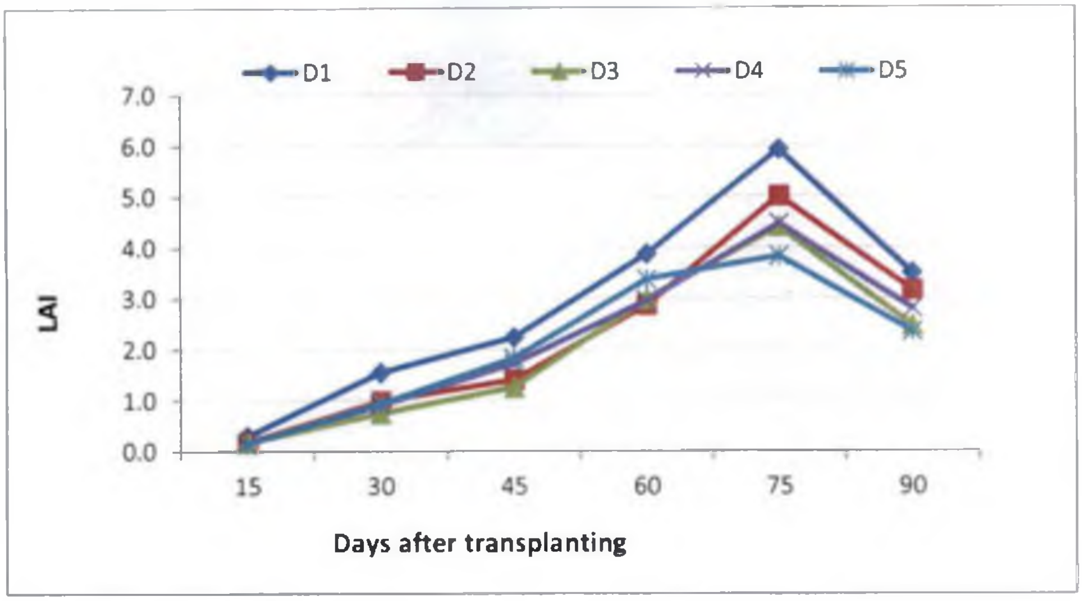


Fig.5.12.Leaf area index (LAI) in Jyothi

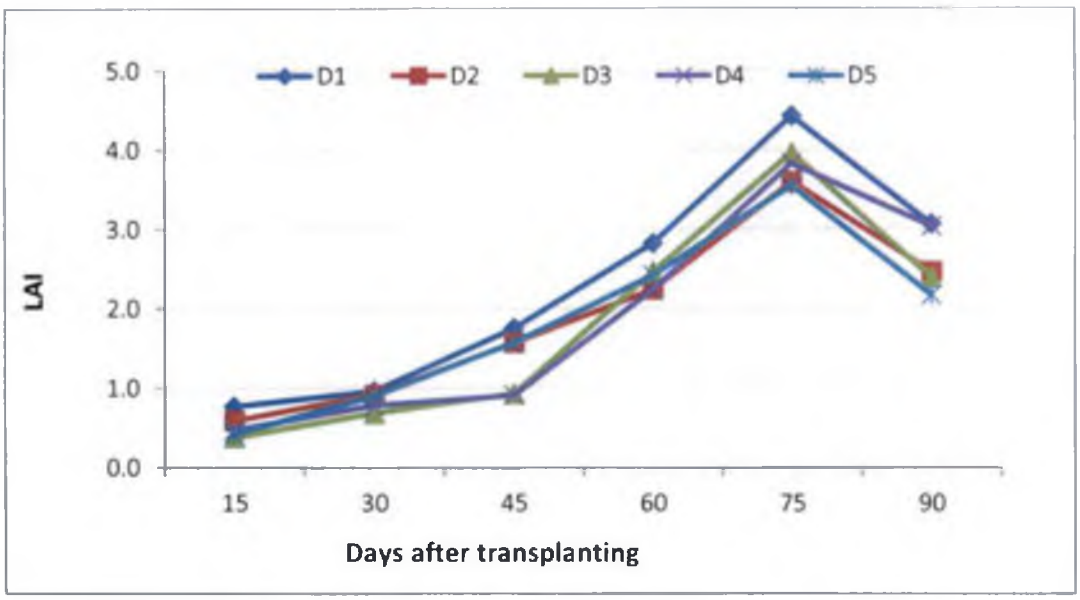


Fig.5.13. Leaf area index (LAI) Kanchana

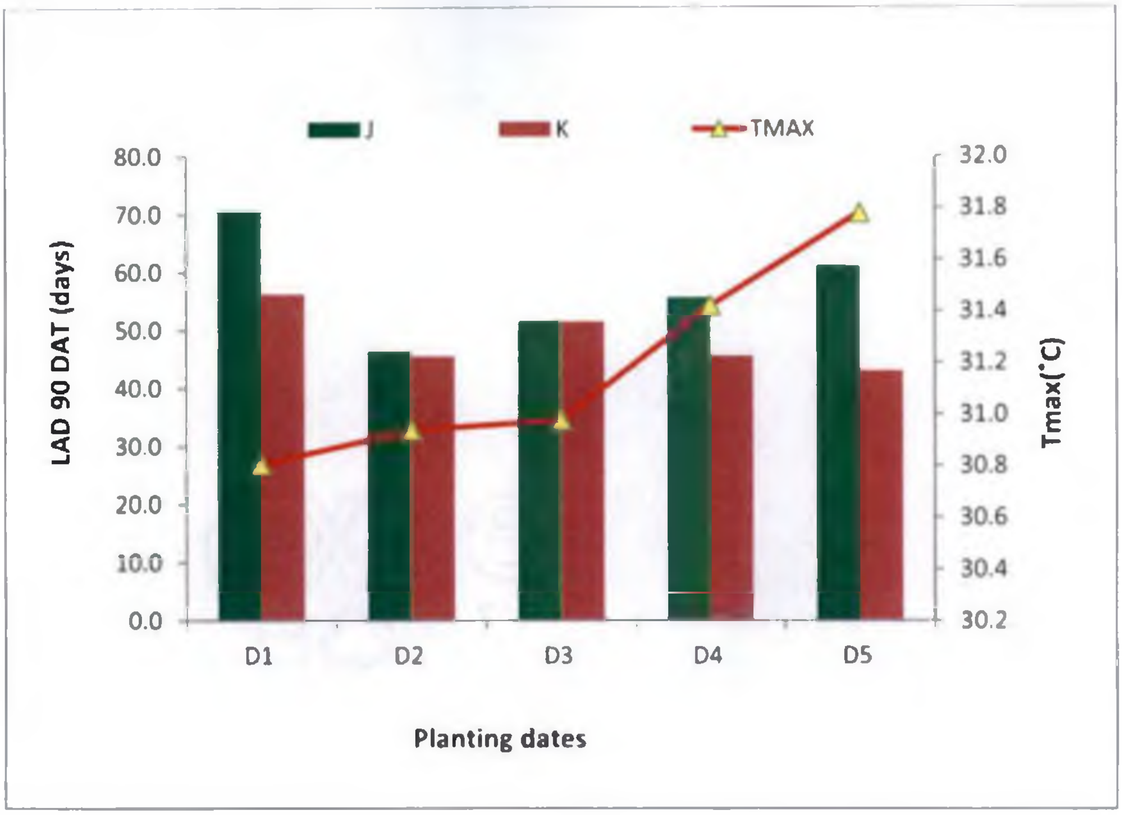


Fig.5.14. Effect of maximum temperature on Leaf area duration for Jyothi and Kanchana during 90 DAT

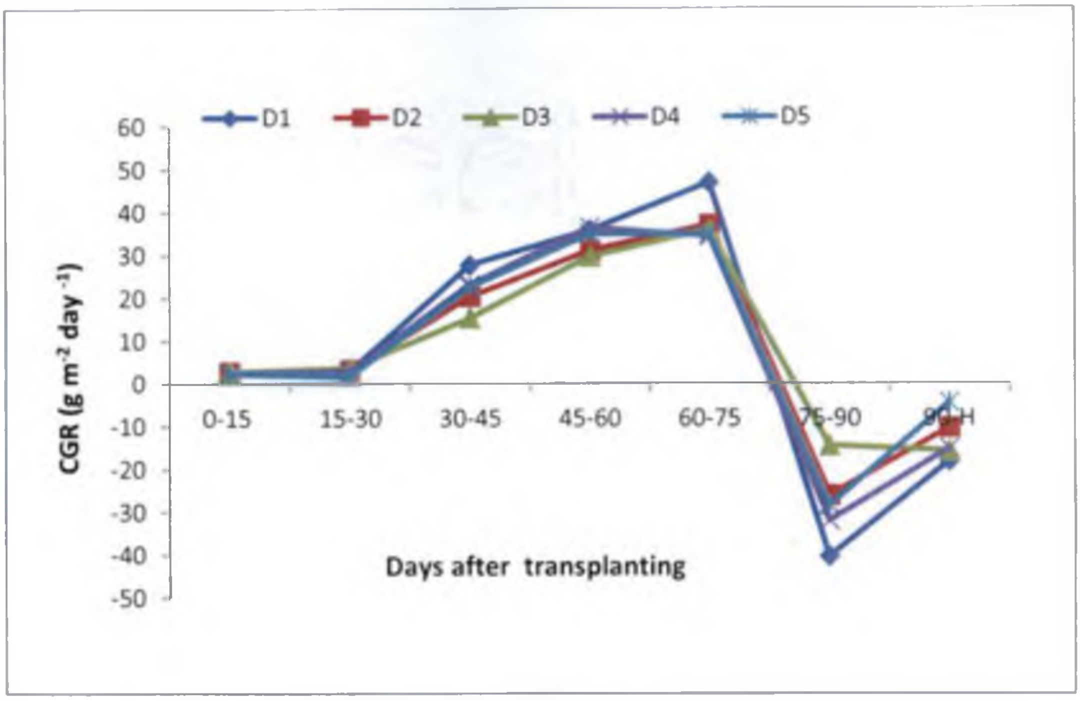


Fig.5.15. Crop growth for Jyothi

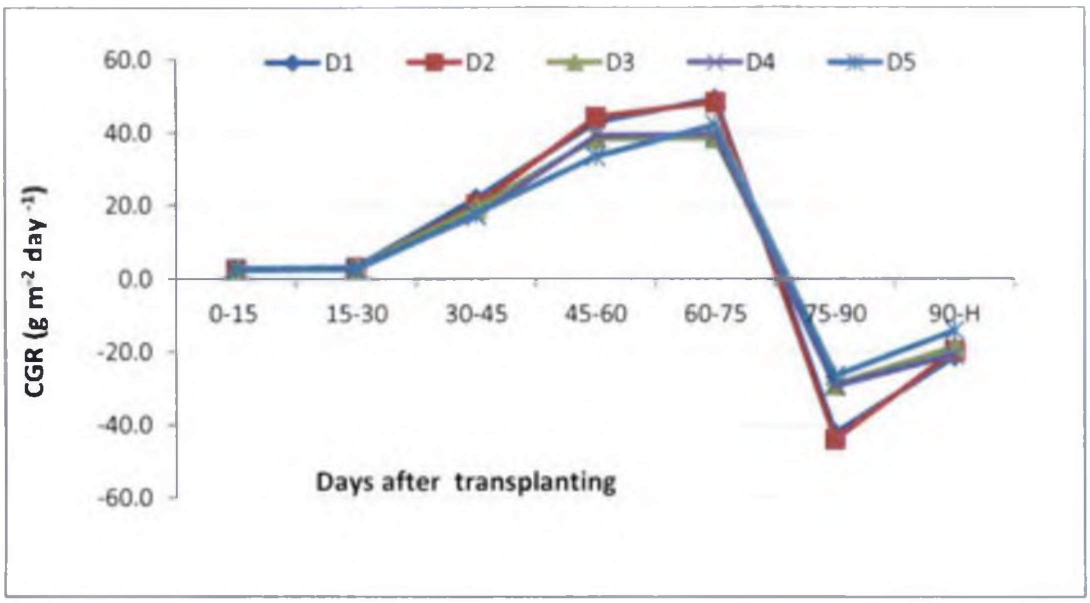


Fig.5.16. Crop growth rate for Kanchana

Crop growth rate reduction was observed after flowering stage. After flowering stage due to senescence and abscission, active photosynthesis tissues were reduced and structural tissues were increased, also LAI was so increased which lower leaves can not absorb sufficient light for having high CGR. This result was in agreement with the findings of Azarpour *et al*. (2014).

5.3.4. Net assimilation rate

Net assimilation rate is the physiological potential for converting the total dry matter into grain yield. The net assimilation rate for Jyothi was recorded highest on 30-45 days after transplanting and it decreases slightly from 45-60 days after transplanting and reached to negative (Fig.5.17). The net assimilation rate for Kanchana was found to be highest during 45-60 days after transplanting (Fig.5.18). Esfahani *et al*. (2006) reported same pattern of net assimilation rate. During early growth stage, due to more penetration of light into canopy and less shadow of the leaves on each other, net assimilation rate was more. As time passes and vegetative and organs grow more, the mutual shading of leaves on each other increased and NAR decreased. This result was in conformity with the study of Mojaddam and Noori (2015).

5.4. BIOCHEMICAL ANALYSIS

5.4.1. Total chlorophyll content

The total chlorophyll content for Jyothi and Kanchana was found to be decreased 30 days after transplanting. The early transplanted crops recorded maximum chlorophyll content (Fig.5.19). This result was in agreement with Khalifa *et al*. (2014) and Ali *et al*. (2012). Decreased light penetration during early transplanting gave highest value of total chlorophyll content in rice. This result was in agreement with those reported by Song *et al*. (1990) and Khalifa (2005). It is observed that the temperature influences the chlorophyll content during the crop period. This result was in conformity with the results of Jun *et al*. (1999). The increased temperature decreases the SPAD value results in reduction of total chlorophyll content in rice. This result was supported by Perveen *et al*. (2013) and Begum and Nessa (2014) (Fig5.20 (a) and 5.20(b)).

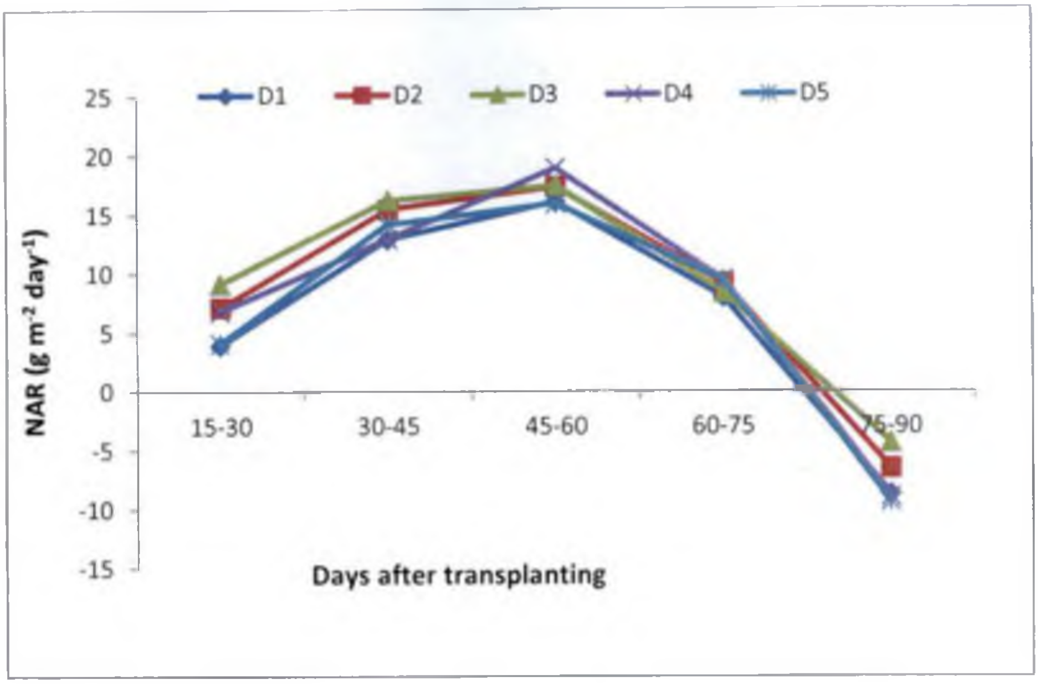


Fig.5.17.Net assimilation rate for Jyothi

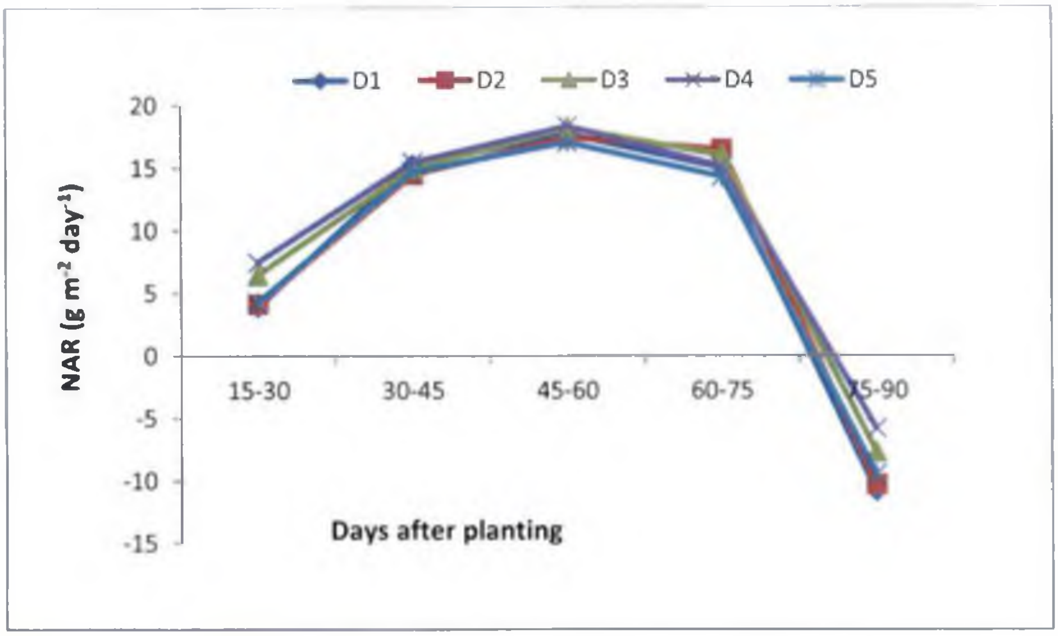


Fig.5.18. Net assimilation rate for Kanchana

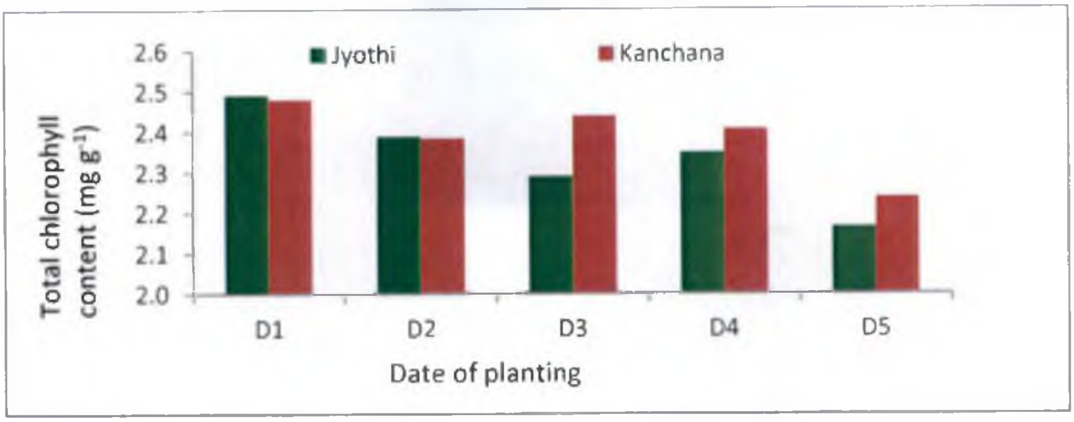


Fig.5.19. Total chlorophyll content in rice varieties with respect to different date of planting

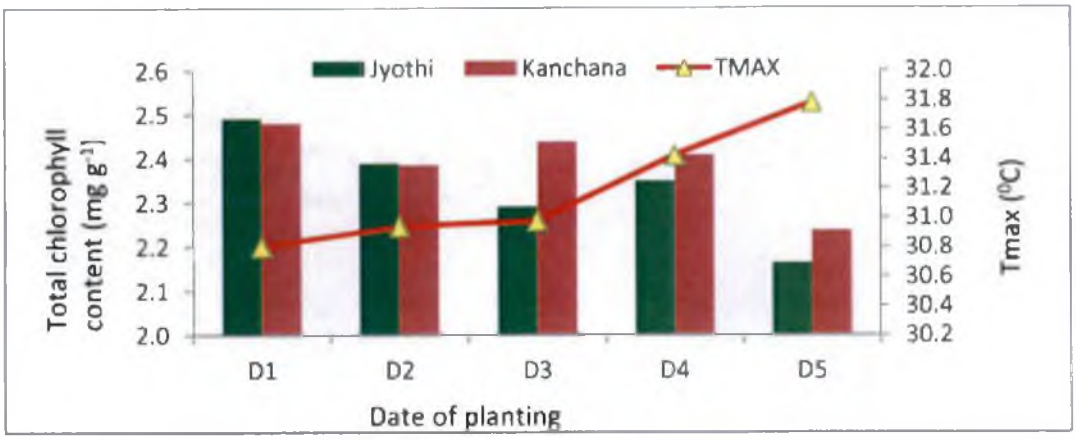


Fig.5.20 (a). Effect of maximum temperature on total chlorophyll content in rice with respect to different planting date

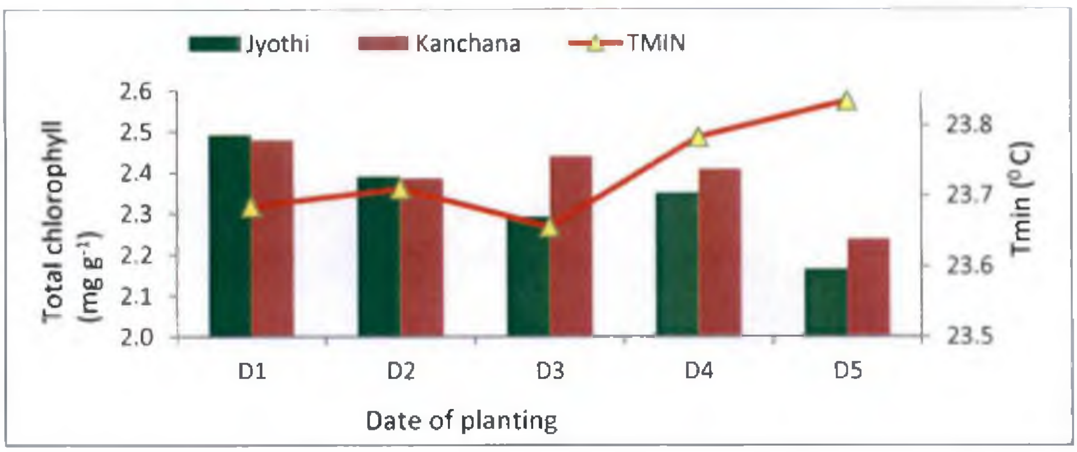


Fig.5.20 (b). Effect of minimum temperature on total chlorophyll content with respect to different date of planting

The amount of total chlorophyll content was negatively affected by maximum and minimum temperature in both rice varieties of Jyothi and Kanchana.

5.4.2. Soluble protein content

The soluble protein content in Jyothi and Kanchana was found to be decreased 30 days after transplanting. Soluble protein content in rice was decreased due to high air temperature (Fig.5.21). Same result was reported by Liu *et al.* (2013).

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

5.5.1. Grain yield

The grain yield was significantly influenced by dates of planting in Jyothi and Kanchana. The highest grain yield was recorded in Jyothi for June 5th transplanting. The rice varieties Jyothi and Kanchana recorded highest accumulated growing degree days during June 5th planting (Fig.5.22 and 5.23). Higher grain yields in Jyothi and Kanchana due to higher accumulation of GDD. This result was in agreement with Sandhu *et al.* (2013).

The delayed transplanting recorded highest HTU in Jyothi and Kanchana (Fig.5.24 and 5.25). This result was in agreement with Khavse *et al.* (2015). The highest HTU for Jyothi and Kanchana was recorded on July 20th date of planting in both varieties. In Jyothi and Kanchana HTU and PTU was found to be increased with delay in transplanting due to more sunshine hours. In Jyothi and Kanchana, increase in HTU and PTU with delay in transplanting decreases the yield. The PTU increased with delayed transplanting in both varieties (Fig.5.26 and 5.27). Khavse *et al.* (2015) reported that during grain filling and maturity, the PTU was more in delayed transplanting.

5.5.2. Phenology

The duration of different phenological stages of rice was influenced by different date of planting in both Jyothi and Kanchana. The results showed that the early transplanted rice varieties accumulated more heat units to attain physiological

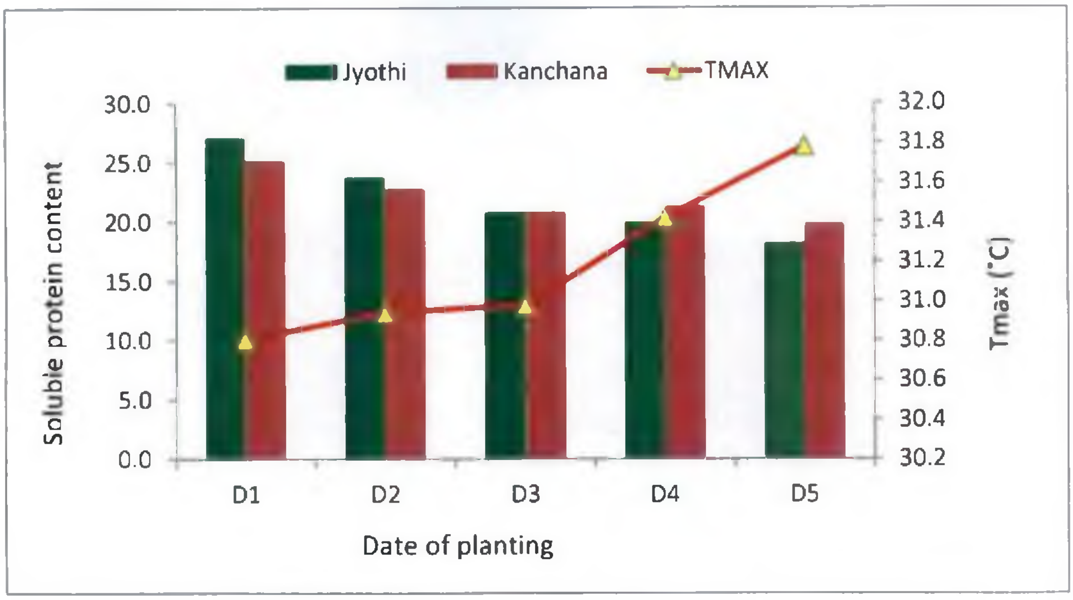


Fig.5.21. Effect of maximum temperature on soluble protein content in rice varieties with respect to different planting dates

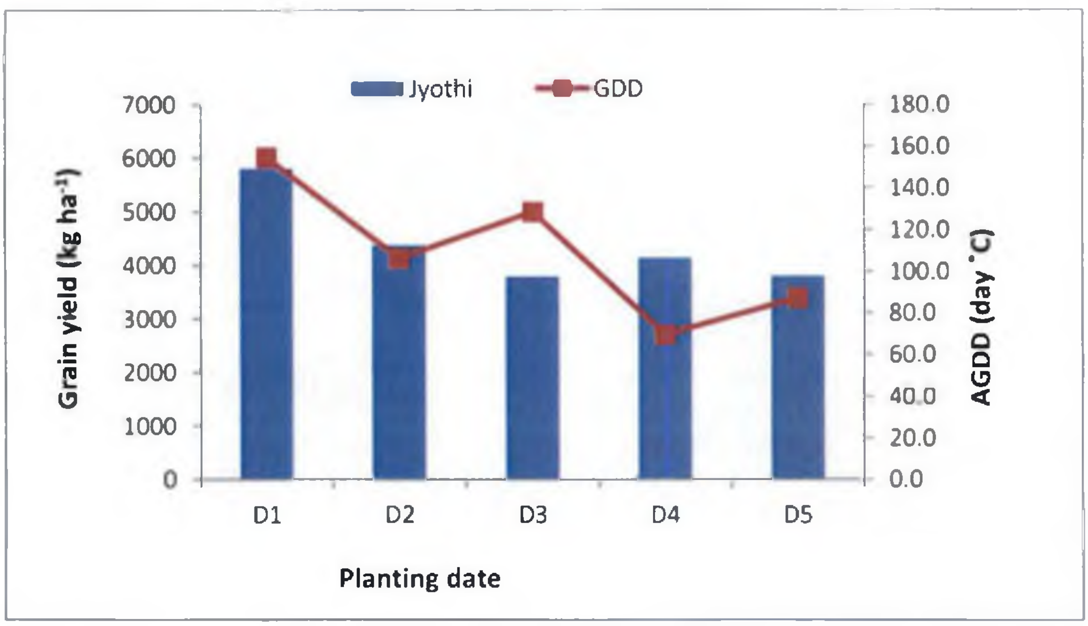


Fig.5.22. Effect of GDD on grain yield in Jyothi

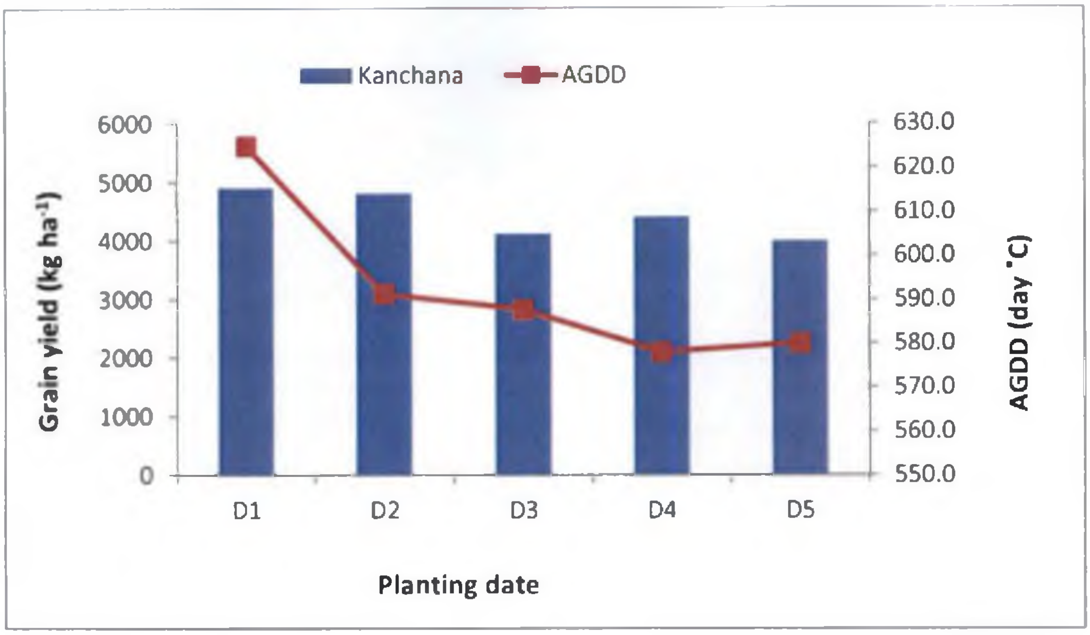


Fig.5.23. Effect of GDD on grain yield in Kanchana

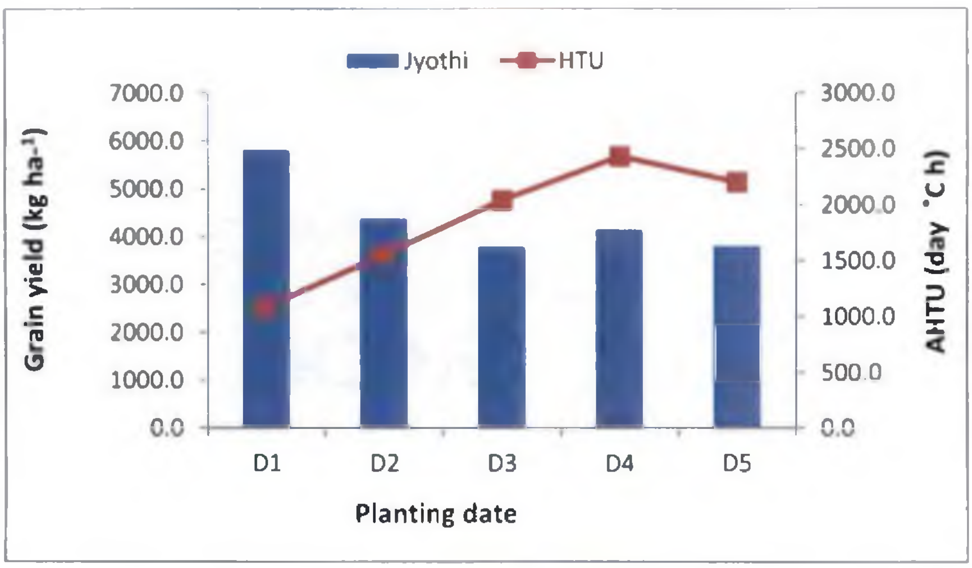


Fig5.24.Effect of HTU on grain yield in Jyothi

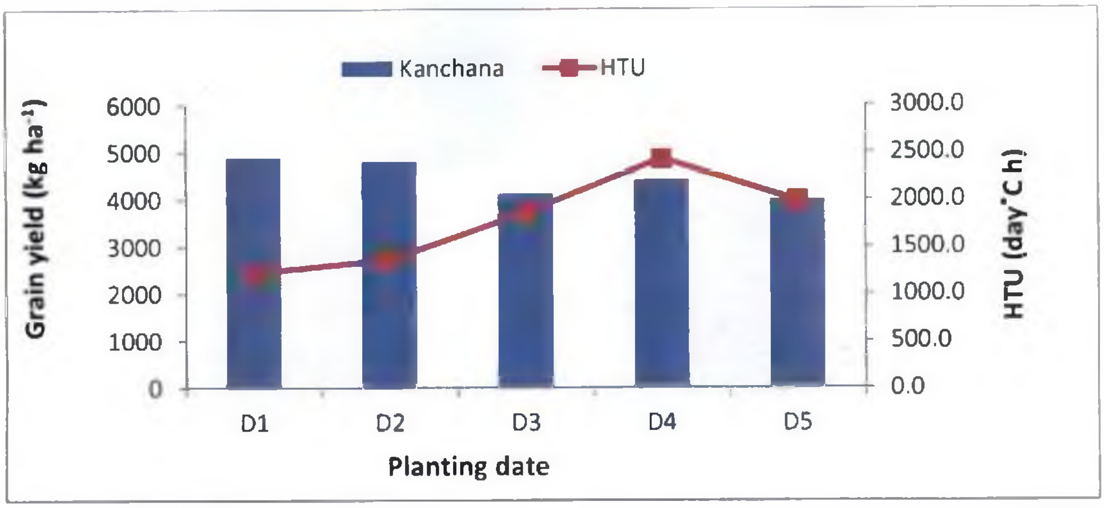


Fig.5.25.Effect of HTU on grain yield in Kanchana

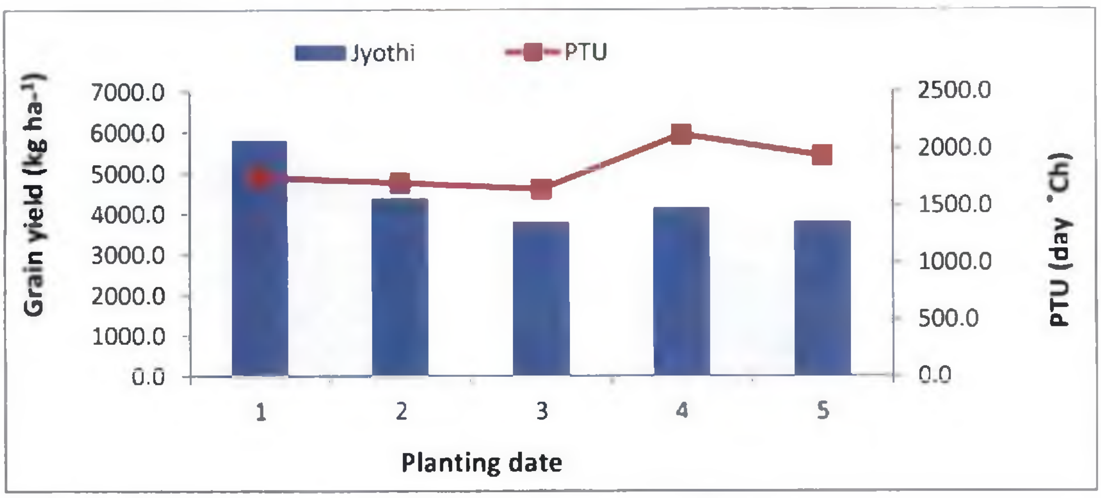


Fig.5.26. Effect of PTU on grain yield in Jyothi

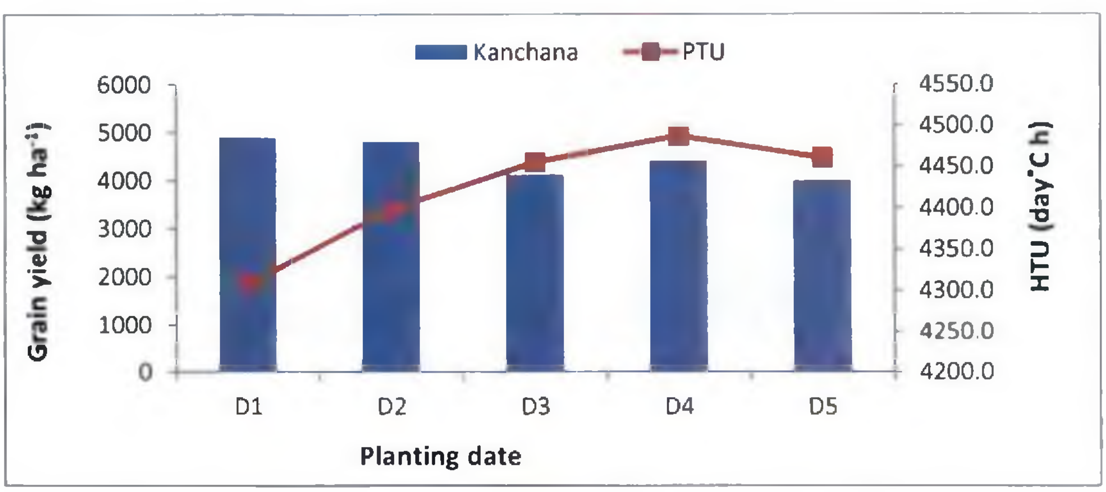


Fig.5.27. Effect of PTU on grain yield in Kanchana

maturity as compared to late planted varieties, similar results in rice were also reported by Sandhu *et al.* (2013).

The growing degree days (GDD) showed significant negative correlation with crop duration on 50% flowering to physiological maturity (P6). The duration to attain physiological maturity was reduced due to increased growing degree days in delayed date of planting in Jyothi and Kanchana. Same result was reported by Rani and Maragatham (2013). The number of days taken for transplanting to maturity was decreased in delayed plantings due to increased GDD (Fig.5.28.(a) &(b)). The same results were reported by Praveen *et al.* (2013) and Sandhu *et al.* (2013). The accumulated heliothermal unit showed significant positive correlation in booting to heading (P4) and 50% flowering to physiological maturity (P6) (Fig.5.29 .(a) &(b)). Early transplanted crops required maximum PTU to complete physiological maturity than delayed planting in Jyothi and Kanchana (Fig.5.30.(a) &(b)). This result was in conformity with Amrawat *et al.* (2013).

The highest heat unit such as GDD, HTU and PTU was observed at physiological maturity dates for both the varieties. Same result was reported by Sikder (2009).

5.6. CERES-RICE SIMULATION

The CERES-Rice model was evaluated using the calibrated genetic coefficients of Jyothi and Kanchana for different planting dates. The results of simulation studies of Jyothi and Kanchana for five dates of planting were compared with observed values from field experiment. The model could predict the phenophases more accurately. The predicted yield of both Jyothi and Kanchana under different dates of planting was reasonably close to the observed values.

The performance of the CERES-Rice model was evaluated by using Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE) and index of agreement (D-index) (Willmott *et al.*, 1985). The value of D- index should be unity and the RMSE and MAPE should approach zero for good performance of a model (Willmott, 1982). The RMSE is the best measure and it summarises the mean

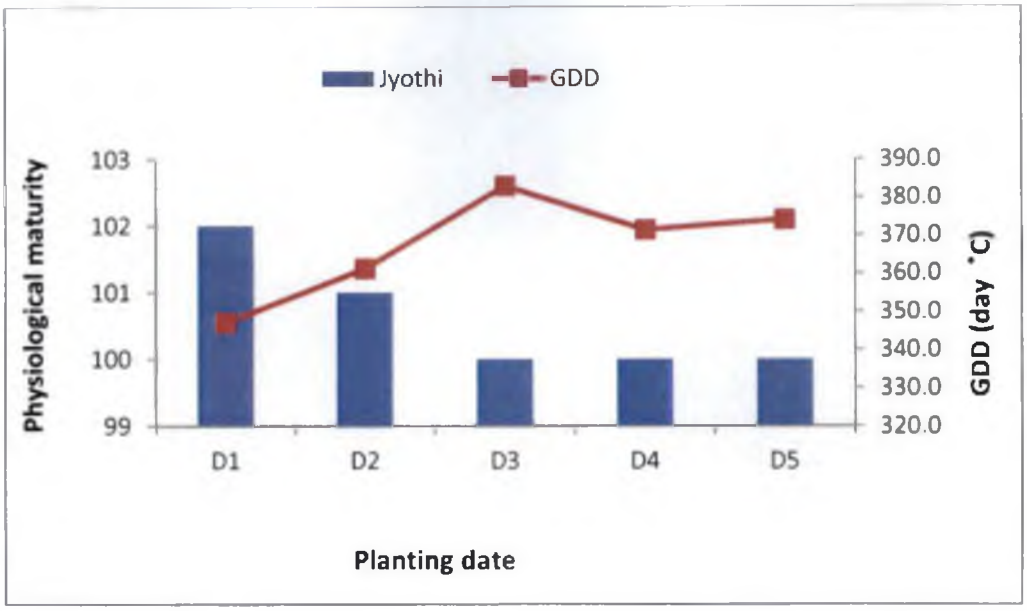


Fig.5.28 (a).Effect of GDD on duration of physiological maturity in Jyothi

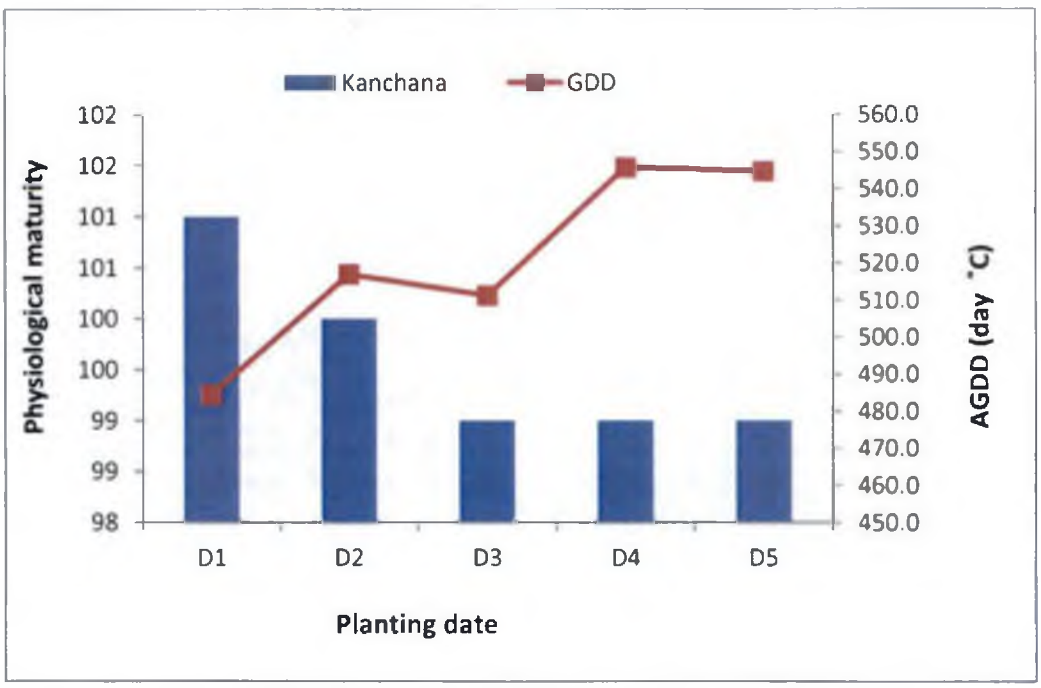


Fig.5.28.(b).Effect of GDD on duration of physiological maturity in Kanchana

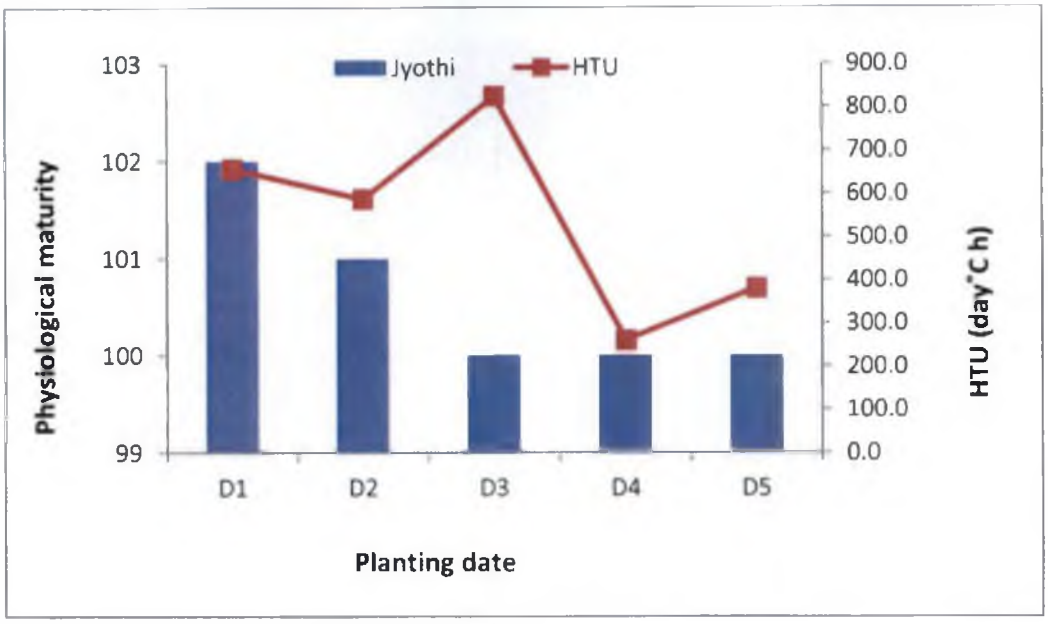


Fig.5.29 (a).Effect of HTU on duration of physiological maturity in Jyothi

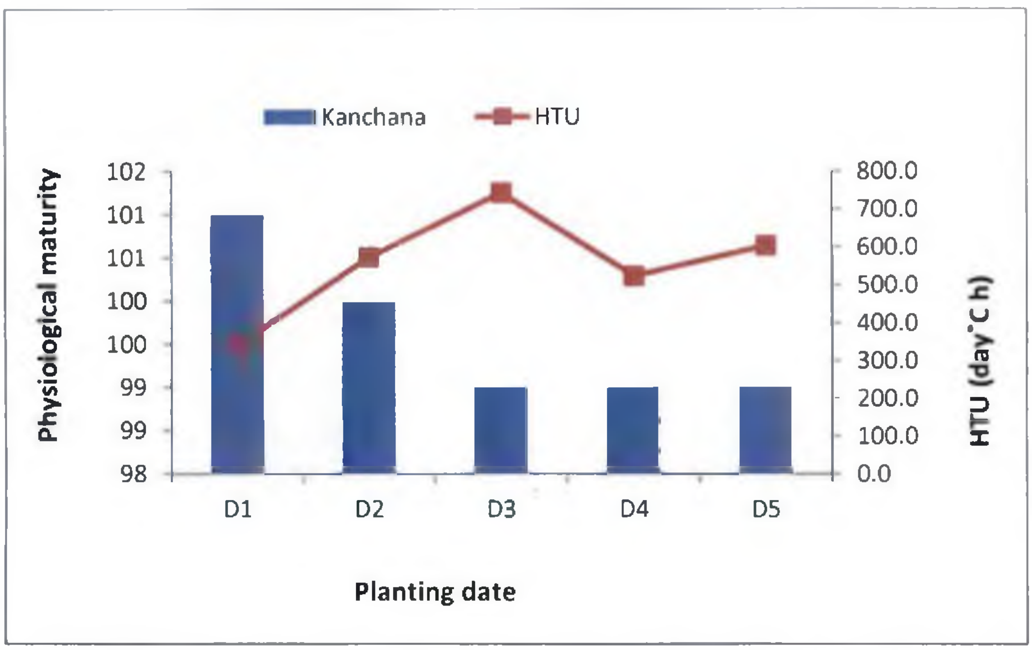


Fig.5.29. (b).Effect of HTU on duration of physiological maturity in Kanchana

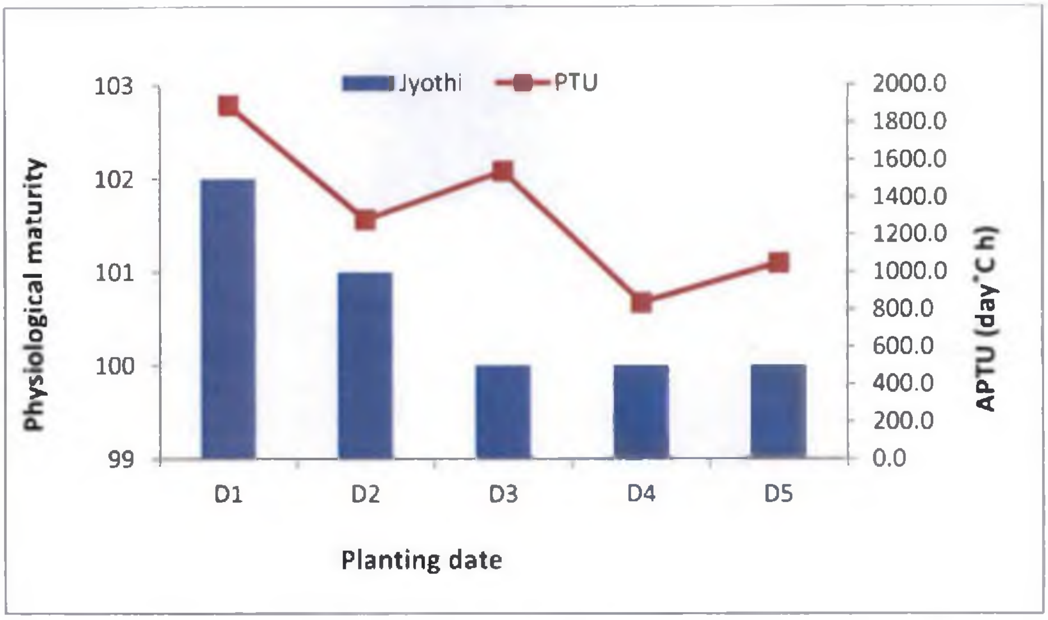


Fig.5.30.(a).Effect of PTU on duration of physiological maturity in Jyothi

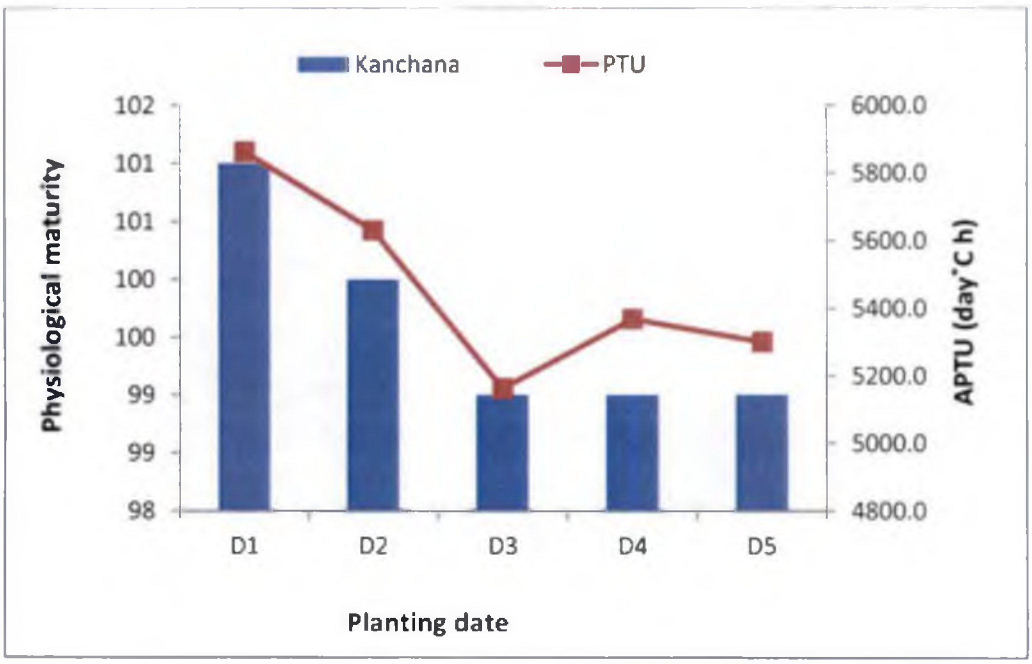


Fig.5.30.(b).Effect of PTU on duration of physiological maturity in Kanchana

difference in the units of observed and predicted values (Timsina *et al.*, 2008). The computed values of RMSE and D-index determine the degree of agreement between the predicted values with their respective observed values (Ahmed *et al.*, 2011).

The genetic coefficients calibrated during 2013-2014 using DSSAT v 4.6 for the varieties Jyothi and Kanchana were initially used for calibrating the genetic coefficients for the year 2015-2016. The calibrated genetic coefficients as derived by GENCALC for CERES-Rice were given in the Table.4.47. Fine tuning of the genetic coefficients were made with 6000 iterations using DSSAT v 4.6. The validation of grain yield and phenology of Jyothi and Kanchana were discussed.

5.6.1. Grain yield

In case of Jyothi, the simulated grain yield was satisfactorily agreed with an RMSE of 822.1 kg ha^{-1}, MAPE of 18.5 % and D-index of 0.5, indicating good performance of the model. The graphical comparison between observed and simulated grain yield is presented in Fig.5.31 (a) and (b). Similar results were also reported by Timsina *et al.*, (2008). They observed that the predicted grain yield was agreed with observed grain yield with an RMSE of 617kg $ha^{-1}$and D-stat index of 0.92. The predicted grain yield in Kanchana also satisfactorily agreed with the observed grain yield with RMSE of 315.6 kg ha^{-1}, MAPE of 6.8% and D-stat index of 0.5 (Fig5.32(a) and (b)). Similar results were also reported by Timsina *et al.*, (2006) who reported that, predicted grain yield agreed with observed yields with RMSE of 815 kg ha^{-1} and D-stat index of 0.74. The Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE) and D-stat index for grain yield of Jyothi are given in the Table.5.2.

Table5.2. RMSE, MAPE and D-stat index values of yield for Jyothi and Kanchana

Variety	RMSE	MAPE	D-index
Jyothi	822.1	18.5	0.5
Kanchana	315.6	6.8	0.5

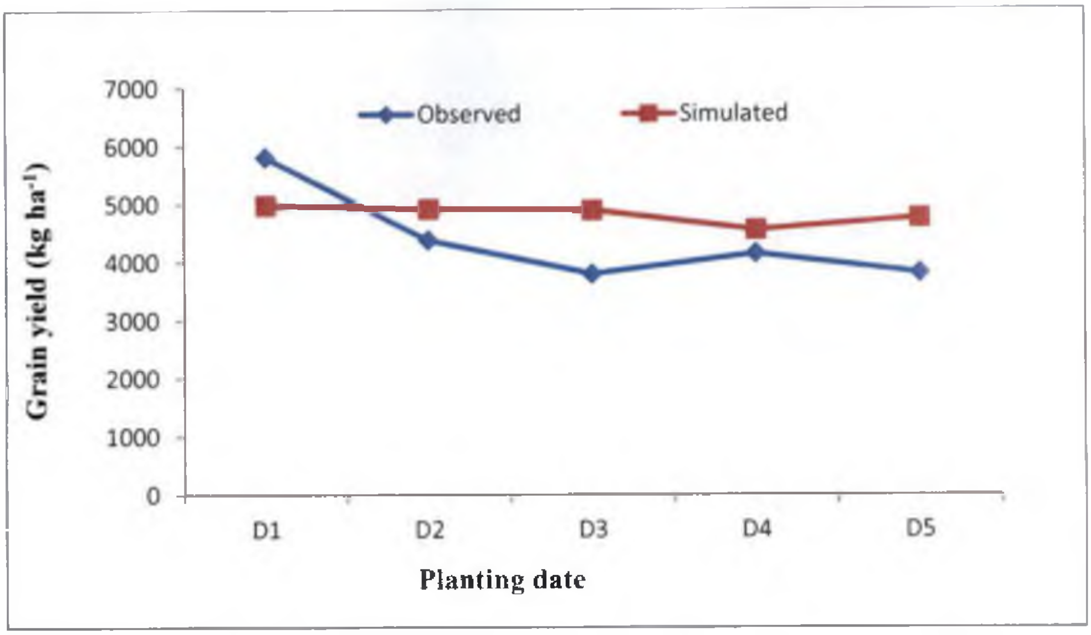


Fig. 5.31. (a). Comparison between observed and simulated yield in Jyothi

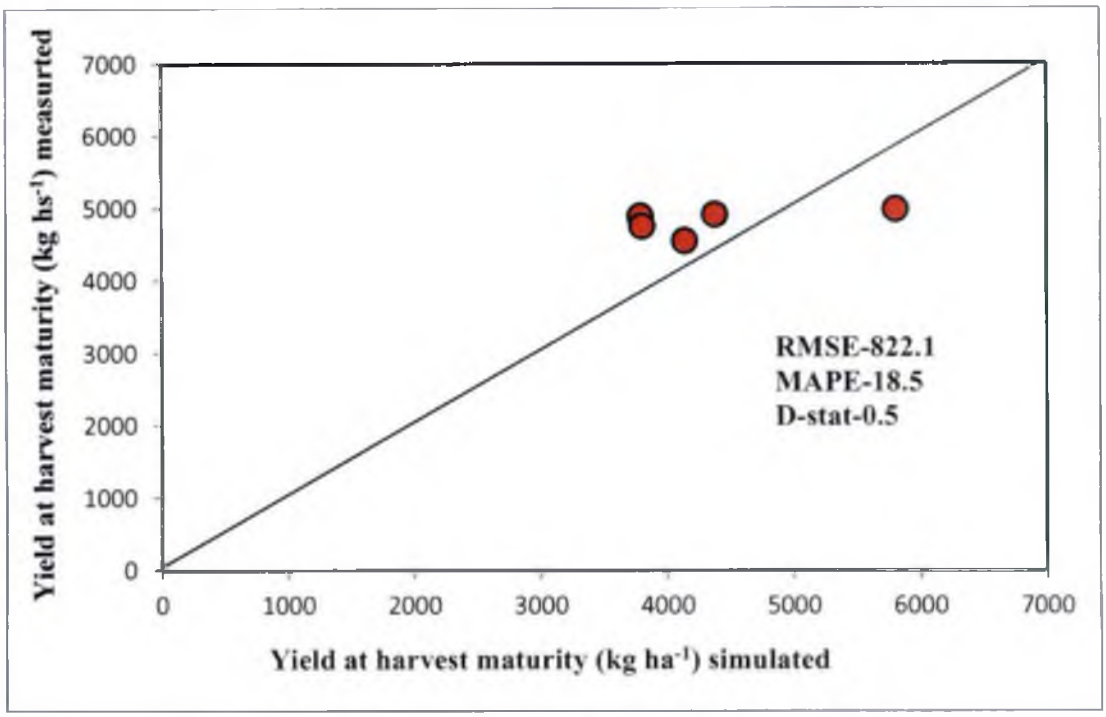


Fig.5.31.(b). Scatter diagram of observed and simulated grain yield in Jyothi

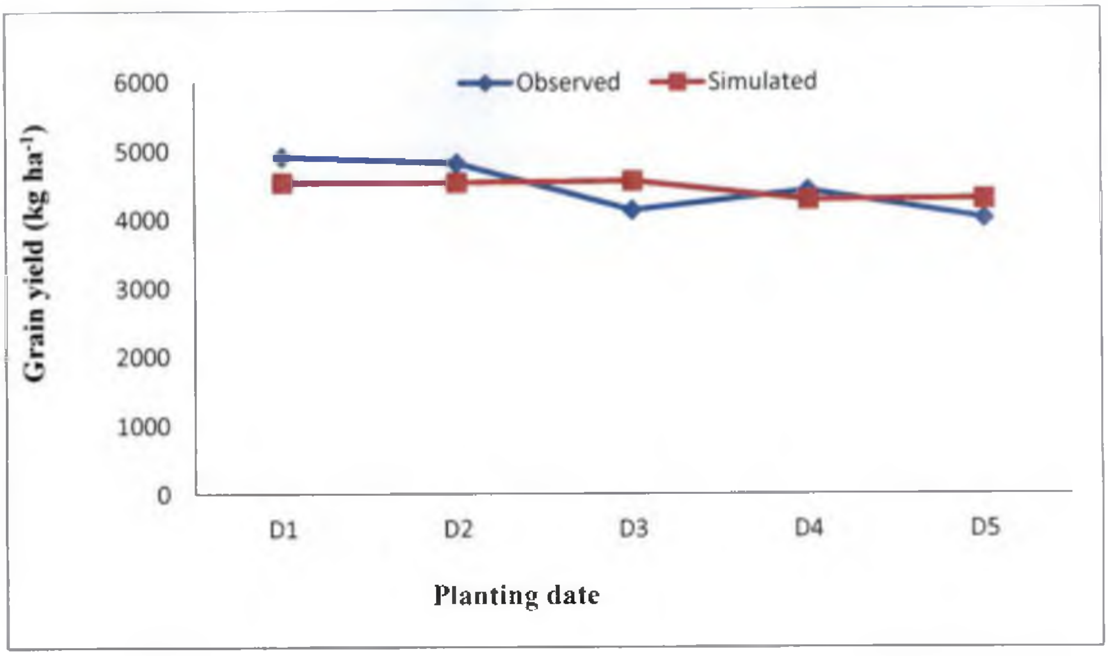


Fig.5.32.(a).Comparison between observed and simulated yield in Kanchana

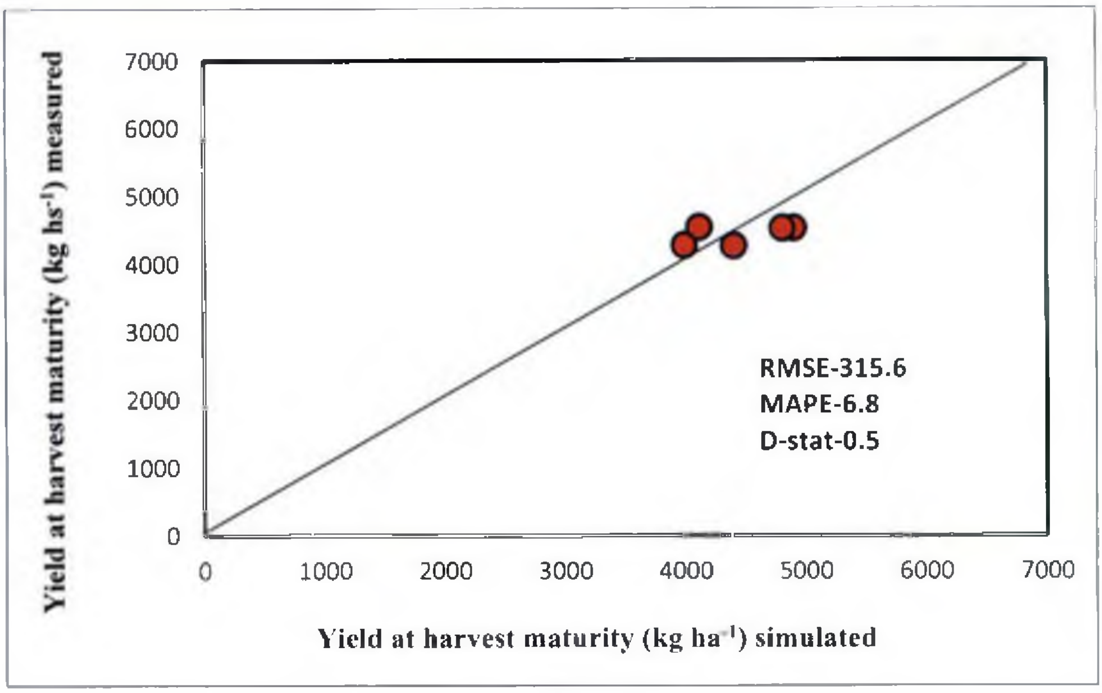


Fig.5.32.(b). Scattered diagram of observed and simulated yield in Kanchana

5.6.2. Simulation of phenology

Observed and simulated phenology of Jyothi and Kanchana showed reasonably good agreement. The Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE) and D-stat index values of panicle initiation day, anthesis day and physiological maturity day for both varieties are given in the Table.5.3.

Table.5.3. RMSE, MAPE and D-stat index values of phenology of rice varieties

Phenophase	Jyothi			Kanchana		
	RMSE	MAPE	D-index	RMSE	MAPE	D-index
Panicle initiation day	1.265	3.4%	0.6	1.6	4.1%	0.6
Anthesis day	0.8	0.9%	0.8	1.2	1.5%	0.7
Maturity day	0.6	0.4%	0.9	1.4	1.2%	0.7

5.6.2.1. *Panicle initiation day*

The predicted duration of panicle initiation days for Jyothi and Kanchana showed good agreement with the observed duration of panicle initiation with RMSE of 1.3, MAPE of 3.4 and D-index of 0.6 in Jyothi and RMSE of 1.6, MAPE of 4.3 and D-index of 0.6 for Kanchana respectively. The graphical comparison between observed and simulated grain yield is presented in Fig.5.33 (a) and (b) and Fig. 5.34(a) and (b)). The average error percentage was less in Jyothi than Kanchana. The CERES-Rice model accurately predicted the panicle initiation day in both varieties.

5.6.2.2. *Anthesis day*

The results of predicted duration of anthesis showed good agreement with observed duration in both varieties. The predicted duration of anthesis in Jyothi showed good agreement with RMSE of 0.8, MAPE of 0.9 and D- index of 0.8 (Fig.5.35(a) and (b)). In Kanchana, the duration of anthesis showed good agreement with RMSE of 1.2, MAPE of 1.5 and D- index of 0.7 Fig. 5.36(a) and (b)). The CERES-Rice model satisfactorily predicted the duration of anthesis day in both rice

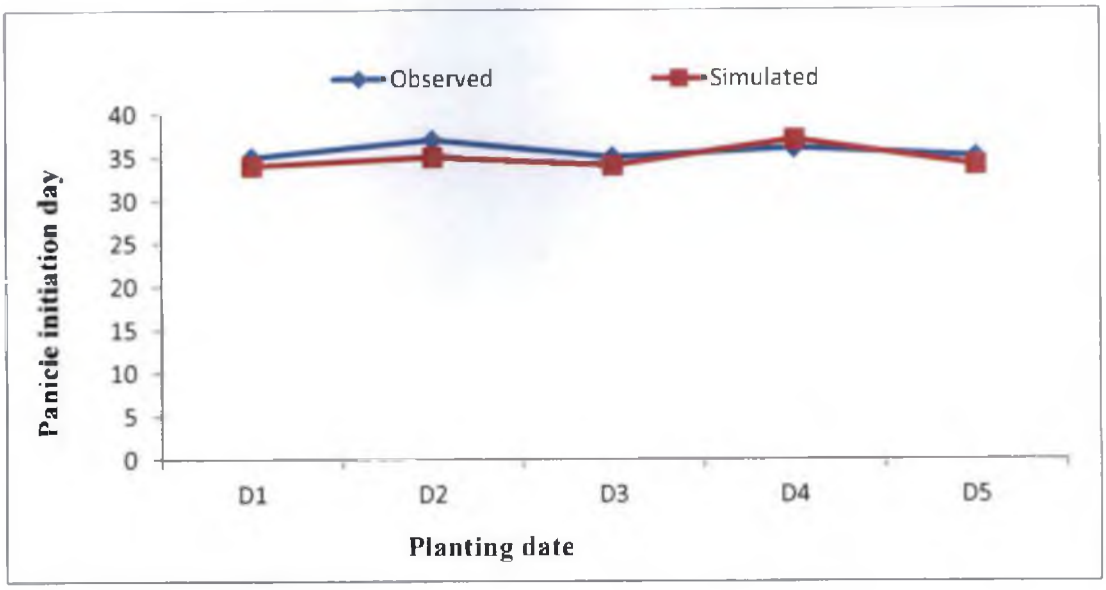


Fig.5.33.(a). Observed and simulated panicle initiation day in Jyothi

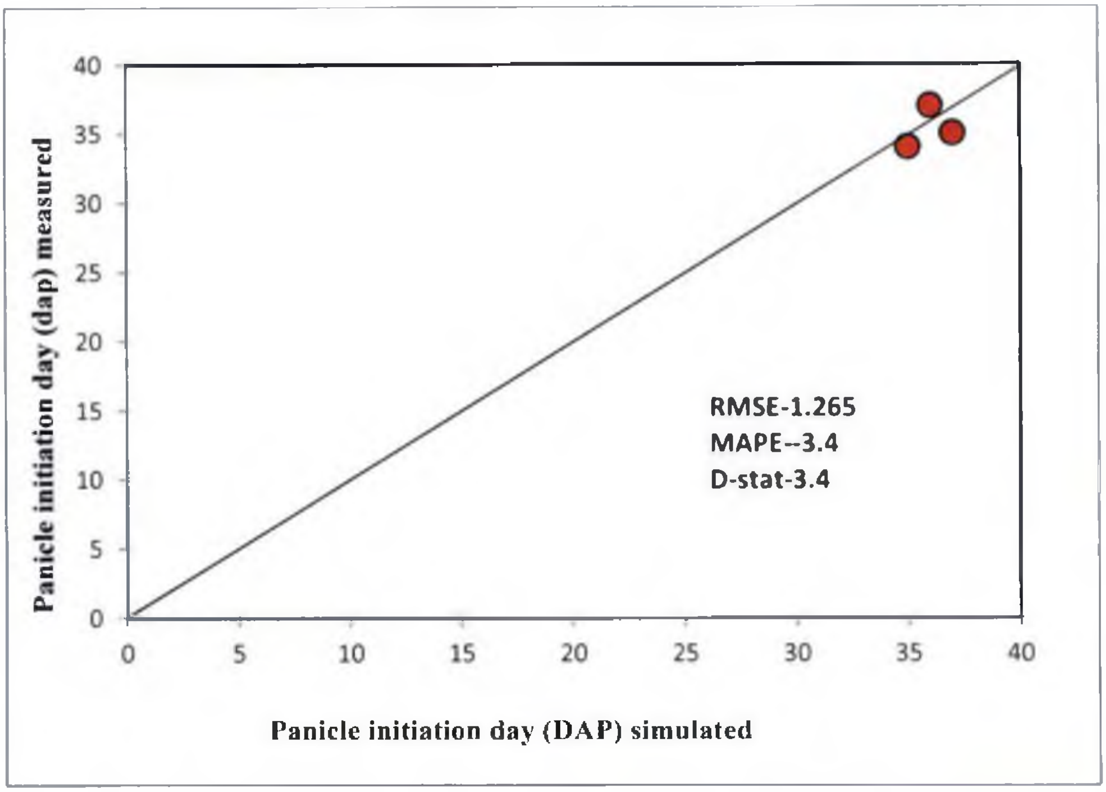


Fig.5.33.(b). Scatter diagram of observed and simulated panicle initiation day in Jyothi

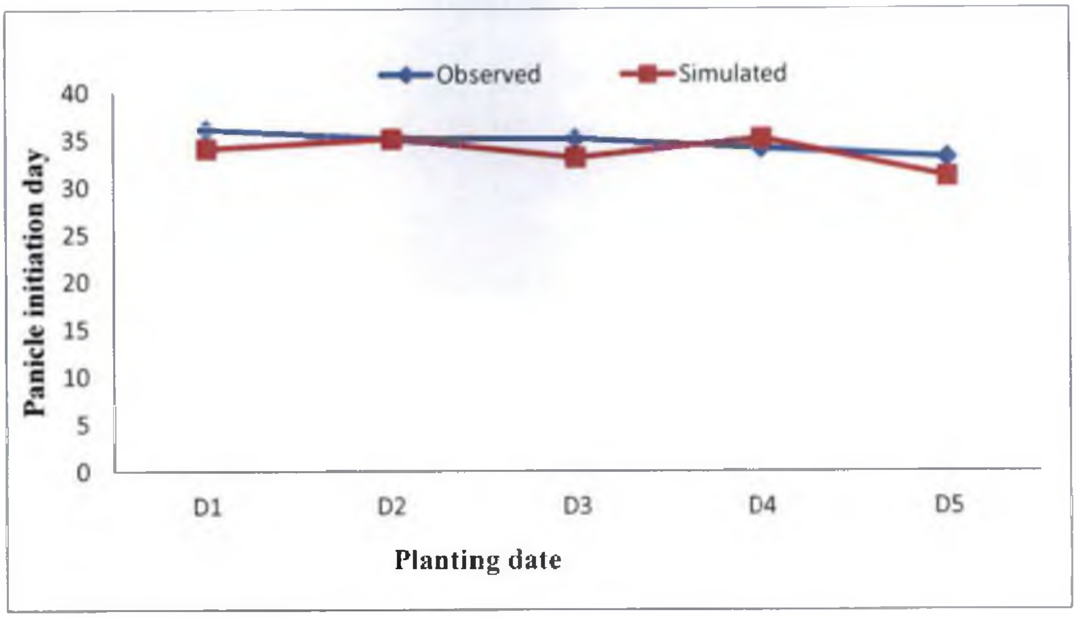


Fig.5.34.(a). Observed and simulated panicle initiation day in Kanchana

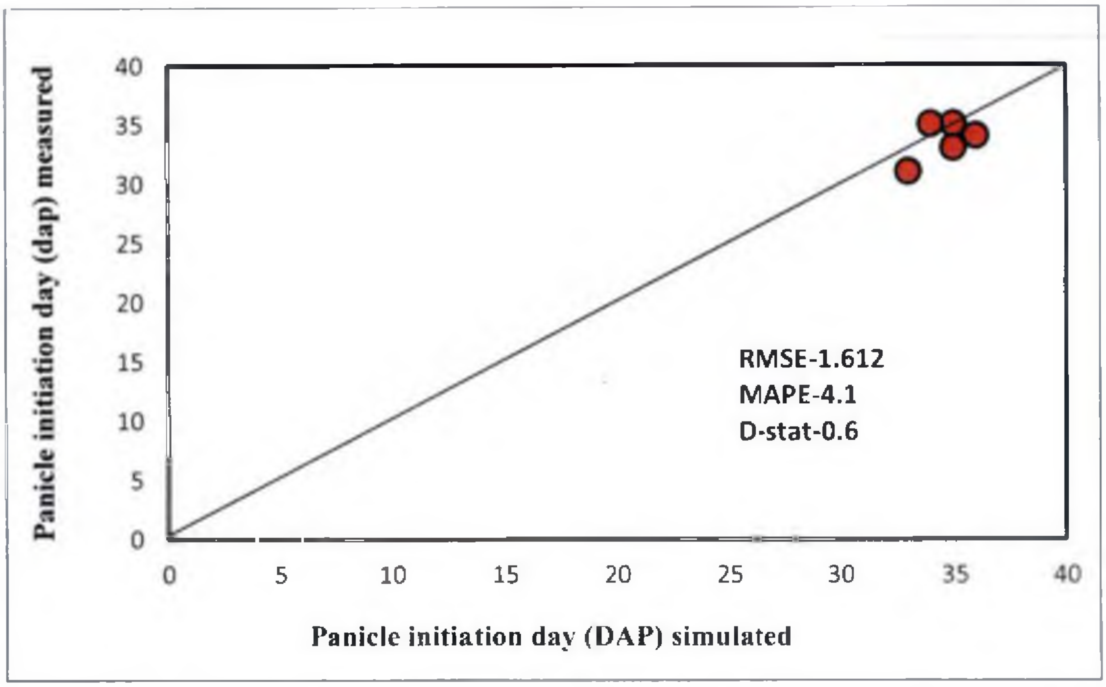


Fig.5.34.(b).Scatter diagram of observed and simulated panicle initiation day in Kanchana

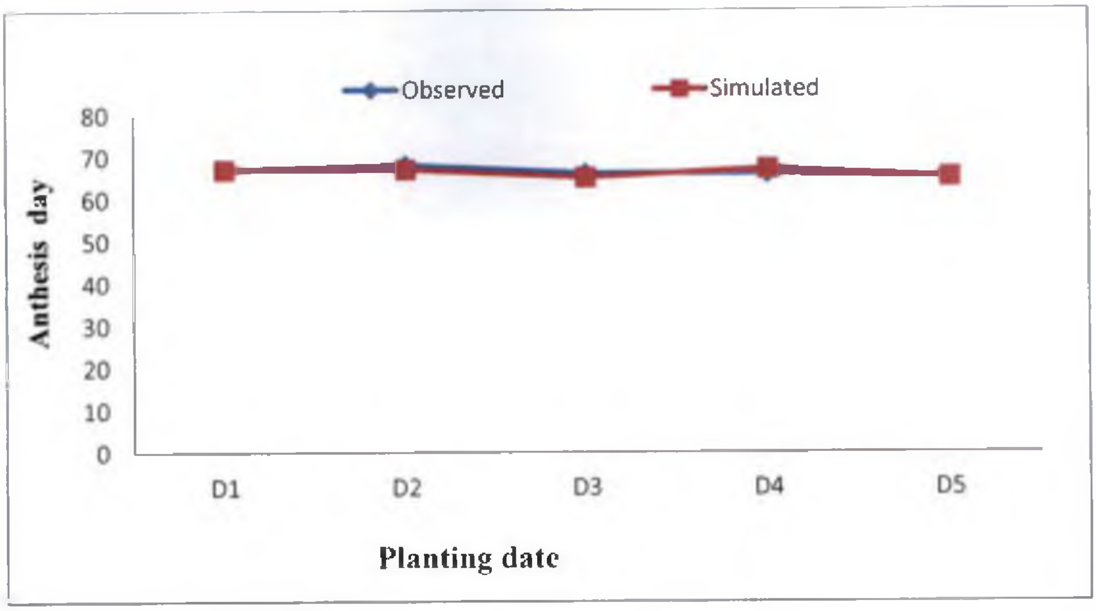


Fig.5.35.(a). Observed and simulated anthesis day in Jyothi

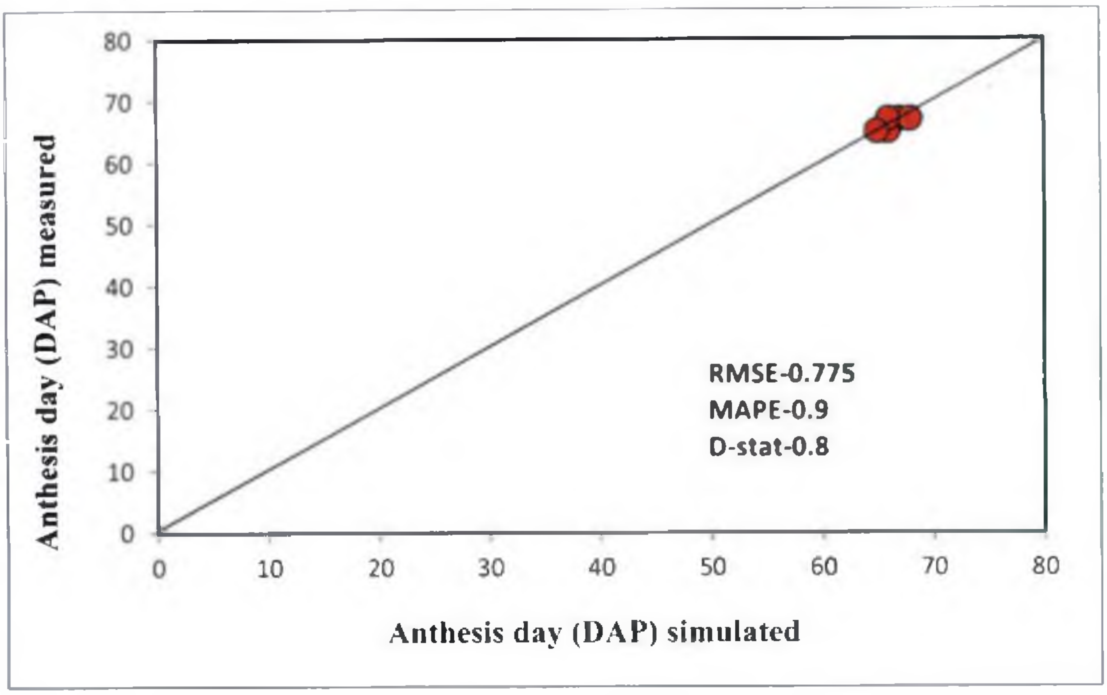


Fig.5.35.(b). Scatter diagram of observed and simulated anthesis day in Jyothi

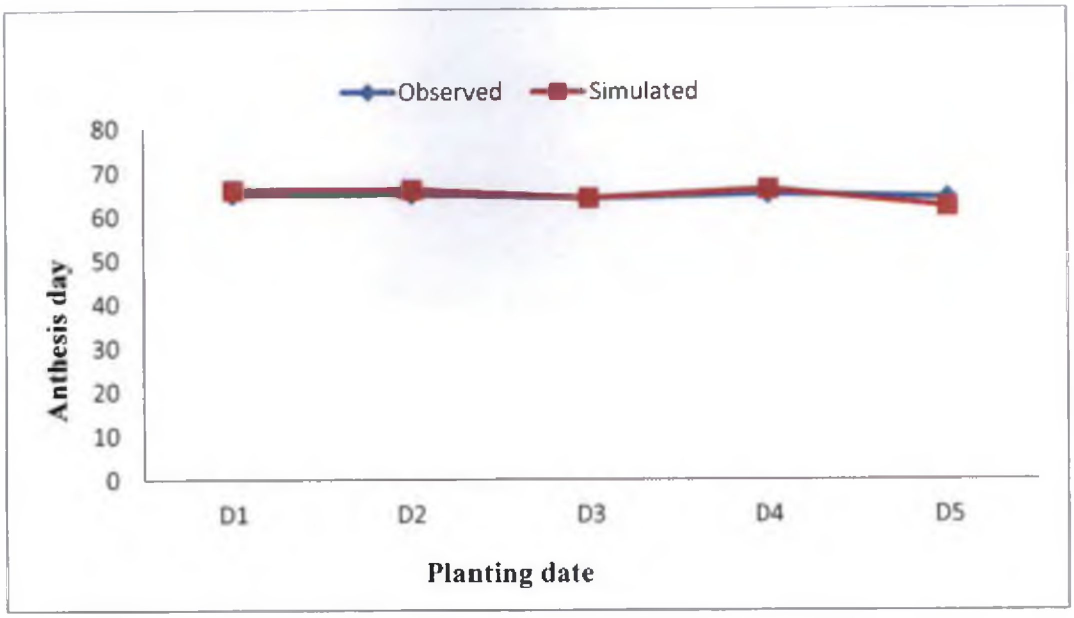


Fig.5.36.(a). Observed and simulated anthesis day in Kanchana

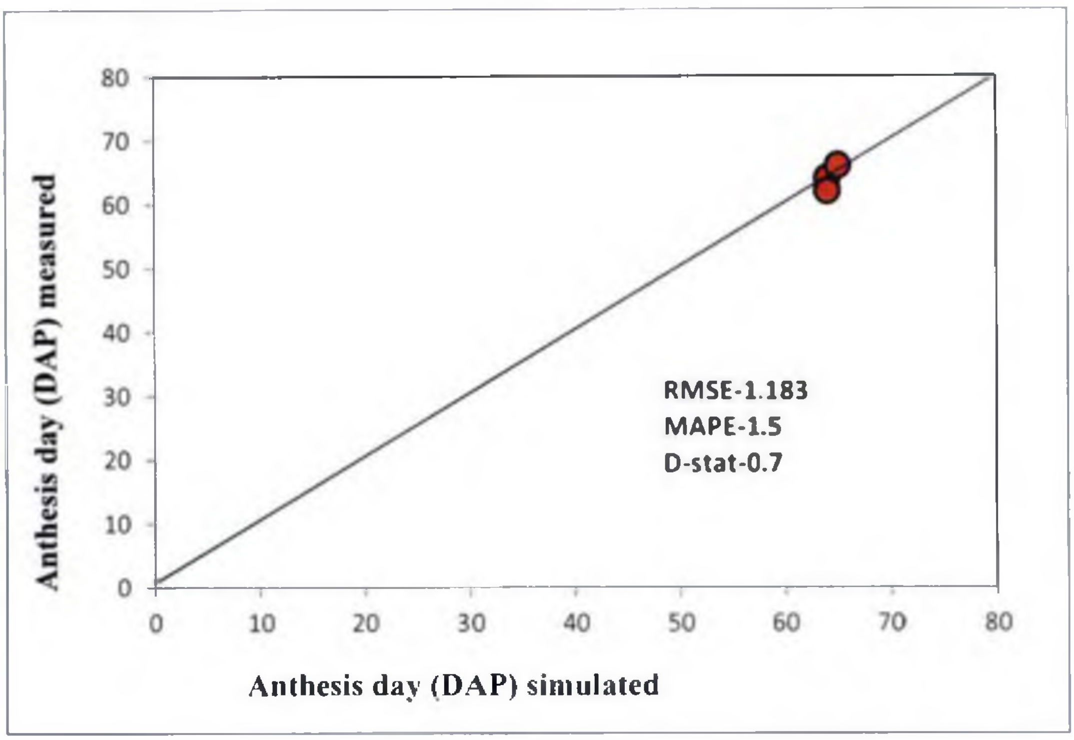


Fig.5.36.(b). Scatter diagram of observed and simulated anthesis day in Kanchana

varieties, which was in conformity with Timsina *et al.* (2008) with RMSE of 5.3 and D-index of 0.7.

5.6.2.3. *Physiological maturity day*

The results of predicted duration for physiological maturity for Jyothi and Kanchana showed good agreement with observed duration of physiological maturity. The graphical comparison between observed and simulated duration of physiological maturity for Jyothi and Kanchana is presented in Fig.5.37.(a) and (b) and Fig. 5.38.(a) and (b)). In Jyothi, the predicted duration was good agreement with RMSE of 0.6, and D-index of 0.9, while, the predicted yield with RMSE of 1.4 and D-index of 0.7 showed good agreements with observed duration of physiological maturity in Kanchana.

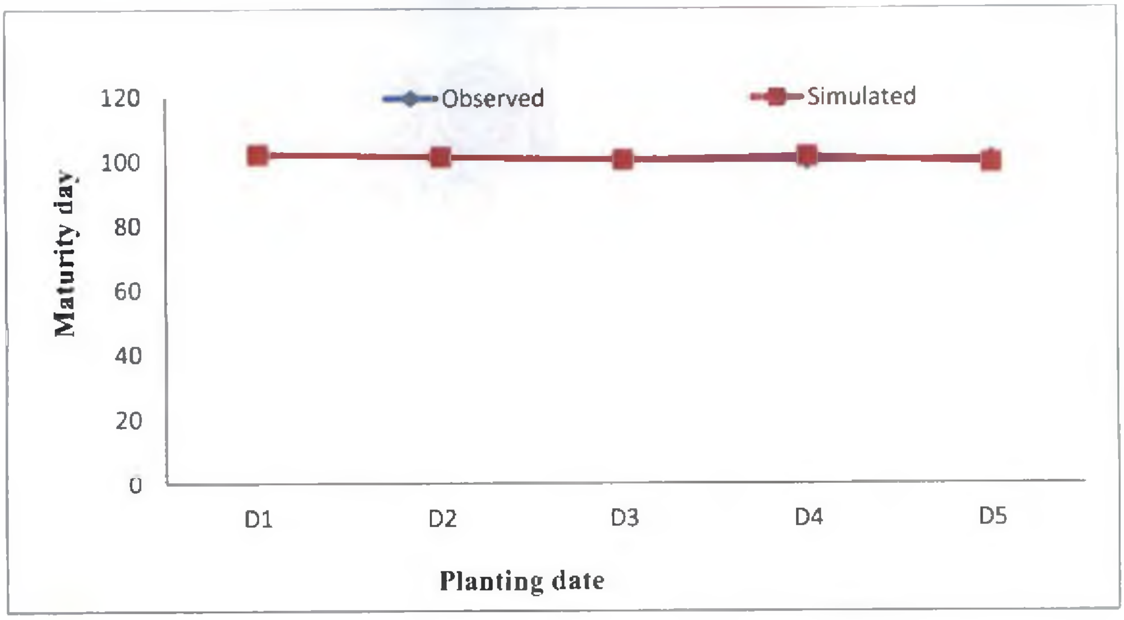


Fig.5.37.(a). Observed and simulated maturity day in Jyothi

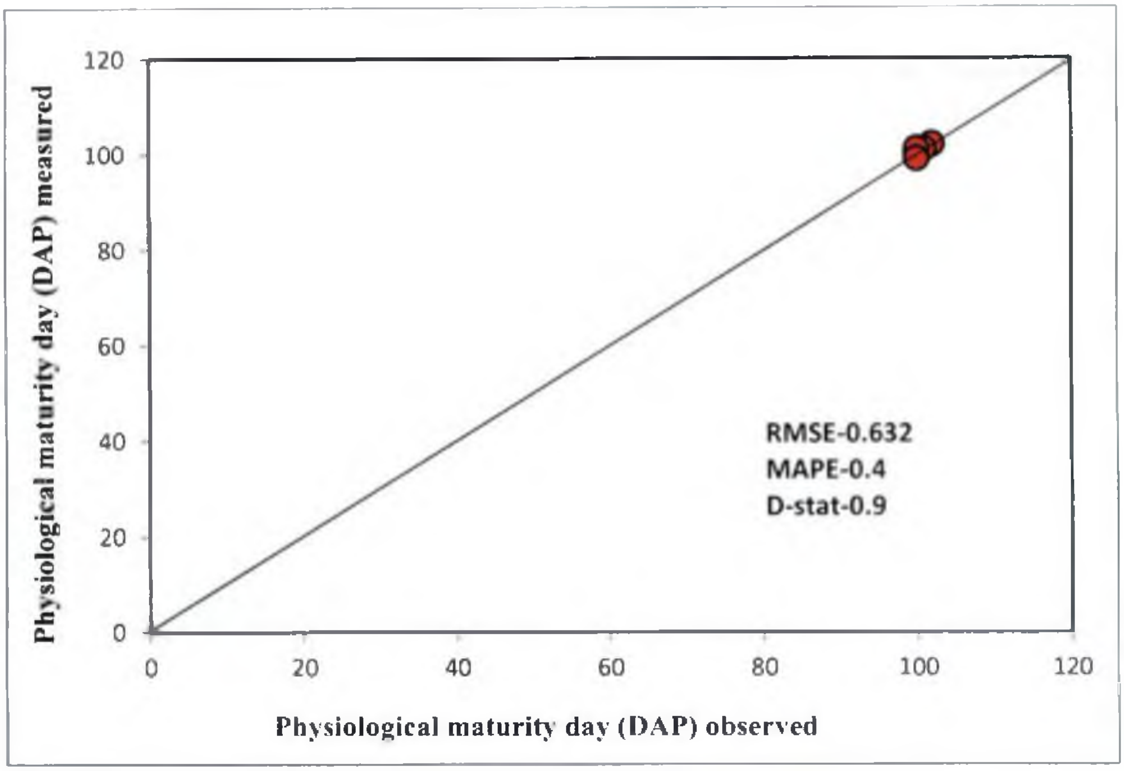


Fig.5.37.(b). Scatter diagram of observed and simulated maturity day in Jyothi

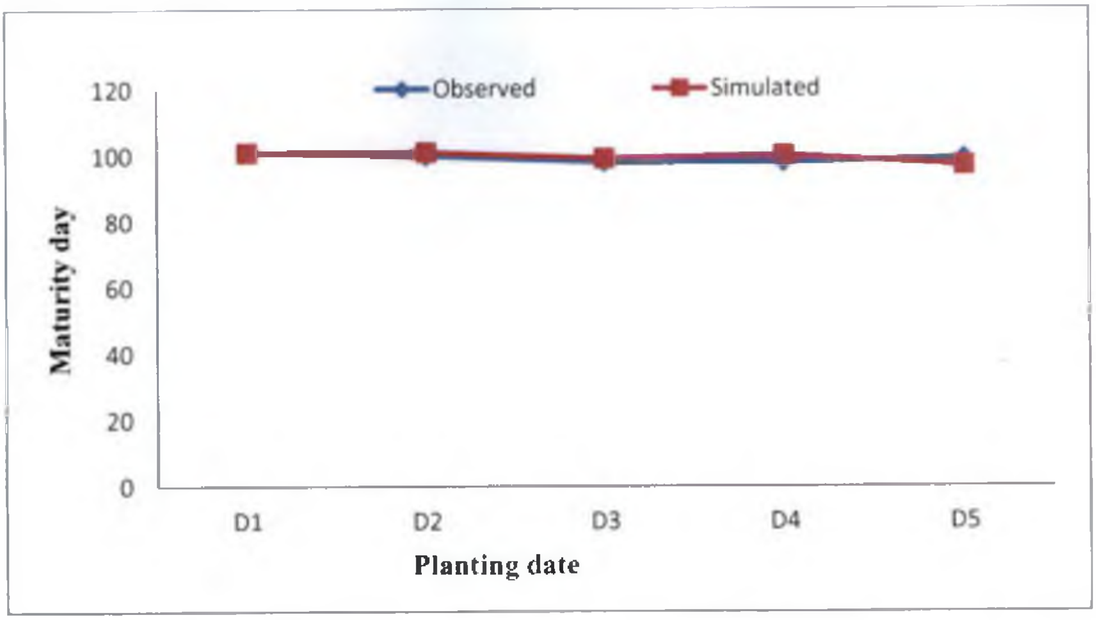


Fig.5.38.(a). Observed and simulated maturity day in Kanchana

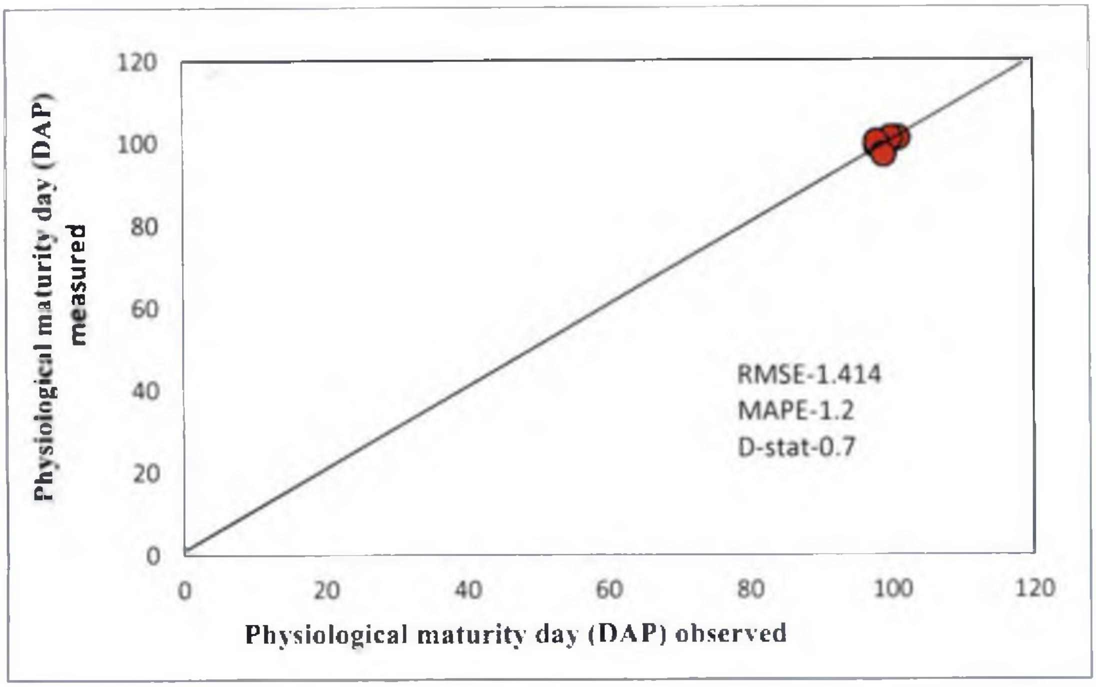


Fig.5.38.(b). Scatter diagram of observed and simulated maturity day in Kanchana

Summary

6. SUMMARY

The study on "Phasic development model using thermal indices for rice (*Oryza sativa* L.) in the central zone of Kerala" was conducted at the Department of Agricultural Meteorology, College of Horticulture, Vellanikkara, Thrissur during 2015-2016.The study was taken up with a view to estimate the different growth phases of rice using thermal indices viz. GDD, HTU, PTU and to validate the phenology of the rice varieties using CERES model based on the crop weather relationship.

The observations such as weather, soil data, biometric, phenological, physiological and biochemical analysis for Jyothi and Kanchana were recorded on time. Growth indices were worked out based on the biometric observations. Crop weather relationship and effect of heat units were also worked out. The CERES-Rice model was validated and calibrated new genetic coefficients for Jyothi and Kanchana varieties. The results obtained from the study are summarized as follows.

The plant height at weekly intervals from transplanting was found to be influenced by the dates of planting for Jyothi and Kanchana. The plant height was decreased towards delayed transplanting in both rice varieties. The rice variety Jyothi recorded highest plant height of 124.3cm than Kanchana which record maximum height of 122.8cm. 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 dry matter accumulation for Jyothi and Kanchana was decreased with delayed transplanting due to increased maximum, minimum and diurnal range temperature. The weather elements such as forenoon and afternoon relative humidity and rainfall during early transplanting increase the dry matter production in Jyothi and Kanchana. Dry matter accumulation was highest on 75 days after for both varieties. The maximum, minimum and diurnal range temperature showed negative influence on dry matter accumulation on delayed planting.

The number of panicles per unit area, number of spikelets per panicle, number of filled grains per panicle, 1000 grain weight and straw yield were found to be highest for June 5^{th} date of planting in Jyothi and Kanchana.). Delayed transplanting reduces the number of panicles per m^{-2} and number of spikelets per panicle in rice due to increased temperature in Jyothi and Kanchana.

Highest grain yield in Jyothi (5807.5 kg ha^{-1}) and Kanchana (4903 kg ha^{-1}) recorded highest on June 5^{th} date of planting. The reduction in grain yield on delayed plantings was due to increased temperature during heading stage which might have induced grain sterility and thus reduced the grain yield. Delayed transplanting showed reduction in grain yield due to increased temperature and reduced amount of rainfall in both varieties.

The days taken for each phenophases were found to be different for the varieties Jyothi and Kanchana planted at different planting dates. For Jyothi and Kanchana, the days taken to attain its physiological maturity was more in early transplanted varieties. Increased temperature during delayed transplanting reduces the duration of physiological maturity in both varieties.

The rice varieties Jyothi and Kanchana recorded highest value of leaf area index during 75 days after transplanting. Early transplanted rice varieties showed highest value of leaf area index in both varieties. The rice varieties Jyothi and Kanchana recorded maximum leaf area duration on 75 days after transplanting. Reduction in leaf area duration towards late planting may be due to increase in maximum temperature. Crop growth rate for Jyothi and Kanchana was found to be highest in 60-75 days after transplanting in both Jyothi and Kanchana. Increase in leaf area increases the crop growth rate there by increases the absorbance of light by plants. The net assimilation rate for Jyothi was recorded highest on 30-45 days after transplanting and it decreases slightly from 45-60 days after transplanting and reached to negative. The net assimilation rate for Kanchana was found to be highest during 45-60 days after transplanting.

The total chlorophyll content for Jyothi and Kanchana was found to be decreased 30 days after transplanting. The early transplanted crops recorded maximum chlorophyll content. The amount of total chlorophyll content was negatively affected by maximum and minimum temperature in both rice varieties of Jyothi and Kanchana. The soluble protein content in Jyothi and Kanchana was found to be decreased 30 days after transplanting. Soluble protein content in rice was decreased due to high air temperature.

Higher grain yields in Jyothi and Kanchana due to higher accumulation of GDD. In Jyothi and Kanchana, increase in HTU and PTU with delay in transplanting decreases the yield. The growing degree days (GDD) showed significant positive correlation with crop duration on transplanting to active tillering (P1) and 50% flowering to physiological maturity (P6). The number of days taken for transplanting to maturity was decreased in delayed plantings due to increased GDD.

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

Varieties	P1	P2R	P5	P20	G1	G2	G3	G4	PHINT
Jyothi	569.0	525.8	10.2	26.9	55.0	0.0224	1.15	1.00	80
Kanchana	466.3	500.0	12.1	137.7	49.8	0.0225	1.3	1.1	77

In case of Jyothi, the simulated grain yield was satisfactorily agreed with an RMSE of 822.1 kg ha^{-1}, MAPE of 18.5 % and D-index of 0.5, indicating good performance of the model. The predicted grain yield in Kanchana also satisfactorily agreed with the observed grain yield with RMSE of 315.6 kg ha^{-1}, MAPE of 6.8% and D-stat index of 0.5.

The predicted duration of panicle initiation days for Jyothi and Kanchana showed good agreement with the observed duration of panicle initiation with RMSE of 1.3, MAPE of 3.4 and D-index of 0.6 in Jyothi and RMSE of 1.6, MAPE of 4.3 and D-index of 0.6 for Kanchana respectively.

The results of predicted duration of anthesis showed good agreement with observed duration in both varieties. The predicted duration of anthesis in Jyothi showed good agreement with RMSE of 0.8, MAPE of 0.9 and D- index of 0.8. In Kanchana, the duration of anthesis showed good agreement with RMSE of 1.2, MAPE of 1.5 and D- index of 0.7

In Jyothi, the predicted duration was good agreement with RMSE of 0.6, and D-index of 0.9, while, the predicted yield with RMSE of 1.4 and D-index of 0.7 showed good agreements with observed duration of physiological maturity in Kanchana.

References

REFERENCE

Abeysiriwardena, D. S., De, Z., Ohba, K., and Maruyama, A. 2002. Influence of temperature and relative humidity on grain sterility in rice. *J. Nat. Sci. Foundation Sri Lanka.* **30**:33–41.

Agarwal, R., Jain, R. C., and Jha, M. P.1983.Joint effects of weather variables on rice yield. *Mausam.* **34**(2):189-194.

Agrawal, R. And Mehta, S. C. 2007. Weather based forecasting of crop yields, pests and diseases- IASRI models. *J. Ind. Soc. Agric. Statist.* **61**(2): 255-263.

Ahmad, A., Iqbal, S., Ahmad, S., Khaliq, T., Nasim, W., Husnain, Z., Hussain, A., Zia-Ul-Haq, M., and Hoogenboom, G. 2009. Seasonal growth, radiation interception, its conversion efficiency and biomass production of Oryza sativa L. under diverse agro-environments in Pakistan. *Pak. J. Bot.* **41**(3): 1241-1257.

Ahmad, S., Ahmad, A., Soler, C. M. T., Ali, H., Zia-UI-Haq, M., Anothai, J., Hussain, A., Hoogenboom, G. and Hasanuzzaman, M. 2012. Application of the CSM-CERES-Rice model for evaluation of plant density and nitrogen management of fine transplanted rice for an irrigated semiarid environment. *Precision Agric.*13. 200-218pp.

Ahuja, L. R., Ma, L., and Howell, T. A. 2002. Whole system integration and modelling: Essential to agricultural science and technology in the 21st century. In: Ahuja, L. R., Ma, L., and Howell, T. A. (eds), *Agricultural system models in field research and technology transfer.* CRC Press, Boca Raton, pp. 271-313.

Akbar, N., Iqbal, A., Khan, H. Z., Hanif, M. K., and Bashir, M. U. 2010. Effect of different sowing dates on the yield and yield components of direct seeded fine rice (*Oryza sativa* L.). *J. Plant Breed. Crop Sci.* **10**(2): 312-315.

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

Akram, H. M., Ali, A., Nadeem, M. A., and Iqbal, M. S. 2007. Yield and yield components of rice varieties as affected by transplanting dates. *J. Agric. Res.* 45(2):105-111.

Akram, M., Cheema, A. A., Awan, M. A., and Ahmad, M. 1985. Effect of planting dates and fertilizer level on grain yield and protein content of rice. *Pak. J. Agric. Res.* 6(3)

Ali, A. A., Khalifa, A., and Rewaing, I. M. 2012. Study some physiological characters, yield and yield component for five new rice varieties under different sowing dates. *Adv. Appl. Sci. Res.* 3(1): 440-445.

Amrawat, T., Solanki, N. S., Sharma, S. K., Jajoria, D. K., and Dotaniya, M. L. 2013. Phenology growth and yield of wheat in relation to agrometeorological indices under different sowing dates. *Afr. J. Agric. Res.* 8(49):6366-6374.

Anzoua, K. G., Junichi, K., Toshihiro, H., Kazoto, L., and Yutska, J. 2010. Genetic improvements for high yield and low soil nitrogen tolerance in rice (Oryza sativa L.) under a cold environment. *Field Crops Res.* 116: 38-45.

Auffhammer, M., Ramanathan, V., and Vincent, J. R. 2011. Climate change, the monsoon and rice yield in India. *Climatic Change.*

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

Azdawiyah, A. T. S., Hariz, A. R. M., Fairuz, M. S. M., and Zabawi, A. G. M. 2015. Simulating the effects of changing planting date towards rice production in MADA area, Malaysia. *J. Trop. Agric. Food Sci.* 43(1):73-82.

Basak, J. K., Ali, M. A., Islam, N., and Alam, J. B. 2008. Assessment of the effect of climate change on boro rice production in Bangladesh using CERES-Rice model.

Basak, J. K., Ali, M. A., Islam, N., and Rashid, A. 2010. Assessment of the effect of climate change on boro rice production in Bangladesh using DSSAT model. *J. Civil Eng.* **38**(2):95-108.

Bashir, M. U., Akbar, N., Iqbal, A., and Zaman, H. 2010. Effect of different sowing dates on yield and yield components of direct seeded coarse rice (*Oryza sativa*). *J. Agric. Sci.* **47**(4): 361-365.

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

Begum, F. And Nessa, A. 2014. Effects of temperature on some physiological traits of wheat. *J. Bangladesh Academy Sci.***38**(2): 103-110.

Bhat,T., Ahmad, L., and Kotru, R. 2015. Relation between agrometeorological indices, crop phenology and yield of rice genotypes as influenced by real time N management. *J. Agrometeorol.* **17**(1):90-97.

Bhattacharya, T. and Panda, R. K. 2013. Effect of climate change on rice yield at Kharagpur, West Bengal. *J. Agric. Vet. Sci.* **4**(2): 2319-2372.

Biswas, P. K. and Salokhe, V. M. 2001. Effects of planting date, intensity of tiller separation and plant density on the yield of transplanted rice. *J. Agric. Sci.* **137**(3):279-287.

Buddhaboon, C., Jintrawet, A., and Hoogenboom, G. 2011. Effects of planting dates and variety on flooded rice production in the deepwater area of Thailand. *Field Crops Res.* **124**: 270-277.

Chahal, G. B. S., Sood, A., Jalota, S. K., Choudhury, B. U., and Sharma, P. K. 2007. Yield, evapotranspiration and water productivity of rice (*Oryza sativa* L.)- wheat (*Triticum aestivum* L.) system in Punjab (India) as influenced by transplanting date of rice and weather parameters. *Agric. Water Manag.* **88**:14-22.

Chang, W., Sakai, H., Yagi, K., and Hasegawa, T. 2009. Interactions of elevated CO_2 and night temperature on rice growth and yield. *Agric. Forest Meteorol.* 149: 51-58.

Choudhary, T. N. and Sodhi, J. S. 1979. Effect of weather factors on growth of rice planted at different dates in humid tropical area. *RISO.* **28**(3):255-263.

Chowdhury, S. I. and Wardlaw I. F. 1978. The effect of temperature on kernel development in cereals. *Aust. J. Agri. Res.* **29** (2): 205 – 223.

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

Dixit, A.J., Gaikwad, V.V., Jadhav, M.G. ., and Thorat, S.T. 2004. Effect of sowing time on the phenology and growth of hybrid rice parents. *J. Agrometeorol.,* 6: 72-76.

Esfahani, M., Sadrzadeir, S., Kavoossi, M., and Dabagh, M, N, A. 2006. Study the effect of different levels of nitrogen and potassium fertilizer on growth, grain yield, yield components of rice cultivar Khazar. *Iranian J. Crop Sci.*3: 226-242.

Fayaz, A., Singh, P., Qayoom, S., Ahmad, L., Lone, B., Singh, L., and Singh, K. N. 2015. Influence of different dates of sowing and spacings on growth and yield of scented rice cv. pusa sugandh-3 under temperate conditions of Kashmir. *J. Cereals and Oilseeds.* **6**(4): 20-23.

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

Gardner, F., Pearce, R., and Mitchell, R. L. 1985. *Physiology of Crop Plants*, Lowa, State University Press, Ames, USA, 467p.

Gautam, H. R., Bhardwaj, M. L., and Kumar, R. 2013. Climate change and its impact on plant diseases. *Current Sci.* **105**(12): 1685-1691.

Ghosh, A. K., Mahana, N. K., and Nayak, B. B. 1973. *Crop weather studies. Effect of weather factors on yield attributes.* Annual report: Central Rice Res. Institute, Cuttack, India. pp. 219-221.

Ghosh, D. C. and Singh, B. P. 1998. Crops growth modelling for upland rice management. *Environ. Ecol.* **16**(2):446-449.

Godwin, D., Singh, U., Buresh, R. J., and De Datta, S. K. 1990. Modelling N dynamics in relation to rice growth and yield. In. Transactions of the 14th Int. Cong. Soil Sci., Kyoto, Japan. Int. Soc. Soil Sci. pp.320-325.

Godwin, D., Singh, U., Buresh, R. J., and De Datta, S. K. 1990. Modelling N dynamics in relation to rice growth and yield. In: Transactions of the 14th Int. Cong. Soil Sci., Kyoto, Japan. *Int. Soc. Soil Sci.* pp. 320-325.

Goswami, B., Mahi, G. S., and Saikia, S. U. 2006. Effect of few important climatic factors on phenology, growth and yield of rice and wheat – a review. *J. Agric. Res.* **27**(3): 223-228.

Gupta, V. K., Agrawal, K. K., Upadhyay, A. P., and Shanker, U. 2000. Effect of rainfall, number of rainy days and length of rainy season on productivity of rice crop at Jabalpur. *J. Agrometeorol.* **2**(1): 61-64.

Hari, O. M., Katyal, S. K., Dhiman, S. D., and Sheoran, O. P. 1999. Physiological parameters and grain yield as influenced by time of transplanting and rice (Oryza *sativa*) hybrids. *Indian J. Agron.* **44**(4):696-700.

Hidema, J., Makino, A., Kurita., Mae, T., and Ojima, K. 1992. Changes in the leaves of chlorophyll and light harvesting chlorophyll a/b protein of PS II in rice leaves aged under different irradiance from full expansion through senescence. *Plant Cell Physiol.* **33**(8): 1209-1214.

Hirai, G., Chiyo, H., Tanaka, O., Okumara, T., Takeuchi, S., Hirano, T., and Omori, M. 1993. Studies on the effect of ambient humidity on dry matter production and nitrogen absorption at various temperature. *Japanese J. Crop. Sci.*62(3): 395- 400.

Hirai, G., Takeuchi, S., Tanaka, O., and Chujo, H. 2000. Studies on the effect of the relative humidity of the atmosphere on the growth and physiology of rice plants: effects of relative humidity during the light and dark periods on the growth. *Plant Prod. Sci.* 3(2): 129-133.

Hiscox, J. D. and Israelstam, G. F. 1979. A method for extraction of chlorophylls from leaf tissue without maceration. *Can. J. Bot.* **57**: 1332-1334.

Huda, A. K. S., Ghildyal, B. P., Tomar, V. S., and Jain, R. C. 1975. Contribution of climatic variables in predicting rice yield. *Agric. Meteorol.***15**(1):71-86.

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

Islam, M. R. and Sikder, S. 2011. Phenology and degree days of rice cultivars under organic culture. *Bangladesh J. Bot.* **40**(2): 149-153.

Jand, V., Bains, G. S., Mavi, H. S., and Mathauda, S. S. 1994. Validation of CERES-Rice model under Punjab conditions. *Indian J. Plant Phys.* **37**(1): 46-49.

Ji, B., Sun, Y., Yang, S., and Wan, J. 2007. Artificial neutral networks for rice yield prediction in mountainous regions. *J. Agric. sci.* 4(2): 12-14

Jones, J. W. 1993. Decision Support System for Agricultural development. In: Penning de Vries, F. W. T., Teng, P., and Metselaar, K. (ed.), *System Approaches for Agricultural Development,* Vol. 2, Kluwer Academic Publishers, Dordrecht, the Netherlands, pp.459-471.

Jones, J. W., Hoogenboom, G., Porter, C. H., Boote, K. J., Batchelor, W. D., Hunt, L. A., Wilkens, P. W., Singh, U., Gijsman, A. J., and Ritche, J. T. 2003. The DSSAT cropping system model. *Eur. J. Agron.* 18: 235-265.

Kaladevi, R. Geethalakshmi, V., Selvaraju, R., and Balasubramanian, T. N. 1999. Agrmeteorological aspects of rabi season rice. *Madras Agric. J.* **86**(7): 473-477.

Katsura, K., Maeda, S., Horie, T., and Shiraiwa, T. 2007. Analysis of yield attributes and crop physiological traits of Liangyoupeijiu, a hybrid rice recently bred in China. *Field Crops Res*. pp. 170-177.

KAU [Kerala Agricultural University]. 2012. *Package of Practices Recommendations: Crops* (14^{th} Ed.). Kerala Agricultural University, Thrissur, 334p.

Khakwani, A. A., Zubair, M., Mansoor, M., Naveed, K., Shah, I. H., Wahab, A., Ilyas, M., and Ahmed, I. 2006. Agronomic and morphological parameters of rice crop as affected by date of transplanting. *J. Agron.* **5**(2):248-250.

Khalifa, A. A. A., Elkhoby, W., and Okasha, E. M. 2014. Effect of sowing dates and seed rates on some rice cultivars. *Afr. J. Agric. Res.* **9**(2): 196-201.

Khalifa, A. A. B. A. 2009. Physiological evaluation of some hybrid rice varieties under different sowing dates. *Aust. J. Crop Sci.* **3**(3): 178-183.

Khan, A. and Rahman, H. 2014. Effect of different planting dates on yield and yield components of rice (*Oryza sativa* L.). *An. Agrarian Sci.* **9**(2):146-152.

Khavse, R., Deshmukh, R., and Verma, N. 2015. Thermal requirement of different rice varieties under Raipur condition. *Plant Archives.* **15**(1): 319-322.

Kulkarni, N., Reddy, P. P., Rao, S., Chandrasagar, G., and Reddy, N. S. R. 1989. Studies of sterility in winter rice. *J. Res*. **17**(1): 47-48.

Kura-Hotfa, M., Satoh, K., and Katoh, S. 1987. Relationship between photosynthesis and chlorophyll content during leaf senescence of rice seedlings. *Plant Cell Physiol.* **28**(7): 1321-1329.

Lalitha, K., Reddy, D. R., and Rao, S. B. S. N. 2000. Influence of temperature on duration of tillering in lowland rice varieties. *J. Agrometeorol.***2** (1): 65-68.

Lamsal, A., Amgai, L. P., and Giri, A. 2013. Modeling the sensitivity of CERES-Rice model: an experience of Nepal. *Agron. J. Nepal.*3: 11-22.

Liu, Q., Wu, X., Li, T., Jia-QugMa., and Zhou, X. 2013. Effects of elevated air temperature on physiological characteristics of flag leaves and grain yield in rice. *Chilean J. Agricul. Res.* **73**(2).

Lomas, J. And Herrera, H. 1985. Weather and rice yield relationships in tropical Costa Rica. *Agric. J. Agron.* **5**(2):248-250.

Lowry, O. H., Rosenbrough, N. J.,Farr, A. L., and Randall, R. J. 1951. Protein measurement with the folin phenol reagent. *J. Biol. Chem.* 193. 265-275.

Lu, J., Ookawa, T., and Hirasawa, T. 2000. The effects of irrigation regimes on the water use, dry matter production and physiological responses of paddy rice. *Plant Soil.* **223**(1): 209-218

Mahdavi, F., Esmaeili, M., Failah, A., and Pirdashti, H. 2006. Study of morphological characteristics, physiological indices, grain yield and its components in rice (*Oryza sativa* L.) landraces and improved cultivar. *Iranian J. Crops. Sci.*, **7**(4): 280-297.

Mahmood, R. 1998. Air temperature variations and rice productivity in Bangladesh: a comparative study of the performance of the YIELD and CERES-Rice models. *Ecological Modelling.* **106**(2): 201-212.

Maity, K. and Mahapatra, P, K. 1988. Response of rice varieties to planting time during the dry season. *Int. Rice Res. Newsletter.*3(4):15.

Mariappan, N., Manoharan, V. E., Ravichandran, M., and Dadhwal, V. K. 2008. Rice yield prediction of Chengalpattu district in Tamilnadu using crop simulation model (CERES-Rice model). Proceedings of international conference on emerging scenarios in space technology and applications.13 - 15: 729-734.

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

Mia, M. A. B., Das, M. R., Kamruzzaman, M., and Talukder, N. M. 2012. Biochemical traits and physio-chemical attributes of aromatic fine rice in relation to yield potential. *Am. J. Plant Sci.* 3:1788-1795.

Mojaddam, M. and Noori, A. 2015. The effect of sowing date and plant density on growth analysis parameters of cowpeas. *Indian J. Fund. Appl. Life Sci.* **5**(1): 224-230.

Mote, B. M., Kumar, N., and Ban, Y. G. 2015. Thermal requirements for attainment of phenophases of rice cultivars under variable weather conditions. *Plant Archives.***15**(2):987-990.

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

Nakano, H., Makino, A., and Mae, T. 1997. The effect of elevated partial pressures of CO_2 relationship between photosynthetic capacity and N content in rice leaves. *Plant Physiol.* 115:191-198.

Naziya. 2014. Simulation of environment and varietal effects in rice using CERES model. M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur.

Nicknejad, Y., Zarghami, R., Nasiri, M., Pirdashti, H., Tari, D. B., and Fallah, H. 2009. Investigation of physiological indices of different rice (*Oryza sativa* L.) varieties in relation to source and sink limitation. *Asian. J. Plant Sci.* **8**(5):385-389.

Nigam, R. and Mishra, H. S. 2003. Effects of weather variables on rice in the Tarai Region. *Environ. Ecol.* **21**(3): 645-648.

O'Toole, J. C. and Stockle, C. O. 1987. The role of conceptual and simulation modelling in plant breeding. *International Symposium on improving winter cereals under temperature and soil salinity stresses.* Cordoba. pp.26-29.

Ohsumi, A., Furuhata, M., and Matsumura, O. 2014. Climatic responses of biomass production and grain yield in Japanese high yielding rice cultivars under different transplanting times. *Field Crops Res.*168: 38-47

Ono, K., Ishimaru, K., Aoki, N., and Ohsugi, R. 1999. Transgenic rice with low sucrose-phosphate synthase activities retain more soluble protein and chlorophyll during flag leaf senescence. *Plant Physiol. Biochem.* **37**(2):949-953.

Oort, P. A. J., Tiany, Z., de Vries, M. E., Heinemann, A. B., and Meinke, H. 2011. Correlation between temperature and phenology prediction error in rice (*Oryza sativa L*). *Agric. For. Meteorol.* **151**(12):1545-1555.

Oteng-Darko, P., Kyei-Baffour, N., and Ofori, E. 2012. Simulating rice yields under climate scenarios using the CERES-Rice model. *Afr. Crop Sci. J.* **20**(2): 401-408.

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

Peng, S, J., Huang, J. E., Sheehy, R. C., Laza, R. M., Visperas, X., Zhong, G. S., Centeno, G. S., Khush, K. G., and Cassman, 2004. Rice yields decline with higher night temperature from global warming. *Proceedings of the National Academy of Sciences of the United States of America.* 101: 9971-9975.

Perveen, S., Shinwari, K. I., Jan, M., Malook, I., Rehman, S., Khan, M. A., and Jamil, M. 2013. Low temperature stress induced changes in biochemical parameters, protein banding pattern and expression of Zat12 and Myb genes in rice seedling. *J.Stress Physiol. Biochemistry.*9(4):193-206.

Peterson, R. F. 1965. Wheat crop series, Ed. Polunin, N., Science Publication Inc. New York, P.422.

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

Praveen, K. V., Patel, S. R., Chuodhary, J. L., and Bhelawe, S. 2013. Heat unit requirement of different rice varieties under Chattisgarh plain zones of India. *J. Earth Sci. Climate change.* 5(1):2-4.

Qadir, G., Ahmad, S., Hassan, F. U., and Cheema, M. 2006. Oil and fatty acid accumulation in sunflower as influenced by temperature variations. *Pak. J. Bot.* pp.1137-1147.

Qi- Hua Liu., Wu, X., Tian Li., Jia-Qing Ma. and Zhou, X. 2013. Effects of elevated air temperature on physiological characteristics of flag leaves and grain yield in rice. *Chilean J. Agric. Res.* 73(2).

Rajput, R. P. 1980. Response of soybean crop to climatic and soil environments. Ph.D. thesis, IARI, New Delhi, India.

Ramdoss, G. and Subramanian, S. 1980. Influence of weather parameters on rice yield. *Madras Agric. J.* 67(9): 608-609.

Rani, B. A. and Maragatham, N. 2013. Effect of elevated temperature on rice phenology and yield. *Indian J. Sci. and Technol.* 6(8): 5095-5097.

Rao, N. N. P. 1978. Weather and productivity of rice at Mwea irrigation scheme in Kenya. *Bull. American Meteorol. Soc.*59 (11): 1512.

Rauff, K. O. and Bello, R. 2015. A review of crop growth simulation models as tools for agricultural meteorology. *Agric. Sci.* 6: 1098- 1105.

Reddy, G. V. and Reddy, P. S. 1986. Effect of time of planting on yield of four Nallore rice varieties during wet season. *Oryza.* **23**(3):190-193.

Reddy, K. S. and Reddy, P. S. 1992. Correlation coefficients for crop weather relationships in rice. *J. Res.* **20**(1-2):85-87.

Ritche, J. T. 1986. CERES-Wheat: A general documentation. USDA-ARS. Grassland, Soil and Water Resource Laboratory, Temple, Texas.

Ritchie, J. T. and Otter, S. 1985. Description and performance of CERES-Wheat: A user oriented wheat yield model. In: ARS Wheat yield project, ARS-38, National Technical Information Service, Springfield, pp. 159-175.

Roy, S. K. B. and Biswas, S. 1980. Effect of low temperature on boro rice West Bengal. *Int. Rice Res. Newsl.* **5**(2):10-15.

Sadeghian, H. and Bahrani, M. J. 2001, Effect of plant density and nitrogen rates on physiological indices of corn (*Zea mays*). *Iranian J. Crop Sci.* 3(1): 13-25.

Sandhu, S. S., Kaur, P., and Gill, K. K. 2013. Weather based agro indices and grain yield of rice cultivars transplanted on different dates in Punjab. *Int. J. Trop. Agric. Food Sci.* **43**(1):73-82.

Safdar, M. B., Ullah, A. I., and Gul, H. 2006. Growth and yield of rice affected by transplanting dates and seedlings per hill under high temperature of Dera Ismail Khan, Pakistan. *J. Zhejiang Univ. Sci.*7(7): 572-579.

Safdar, M. E., Ali, A., Muhammad, S., Sharwar, Ghulam., and Awan, T. H. 2006. Effect of planting dates on paddy yield of fine grain rice genotypes. *Pak. J. Bot.* **40**(6): 2403-2411.

Safdar, M. E., Noorka, I. R., Tanveer, A., Tariq, S. A., and Rauf, S. 2013. Growth and yield of advanced breeding lines of medium grain rice as influenced by different transplanting dates. *J. Anim. Plant. Sci.* **23**(1): 227-231.

Sahebrao, W. Y. 2015. Effect of UV-B radiation on physiological and phenological plasticity in rice (*Oryza sativa* L.). M.Sc.(Ag) thesis, Kerala Agricultural University, Thrissur,145p.

Sandhu, S. S., Kaur, P., and Gill, K. K. 2013. Weather based agro indices and grain yield of rice cultivars transplanted on different dates in Punjab. *Int. J. Agric. Food Sci. Technol.*4: 1019-1026.

Saseendran, S. A., Singh, K. K., Rathore, L. S., Rao, G. S. L. H. V. P., Mendiratta, N., Lakshmi, N., and Singh, S. V. 1998. Evaluation of the CERES- Rice version 3.0 for the climate conditions of the state of Kerala, India. *Meteorol. Appl.* 5: 385-392.

Shah, F., Huang, J., Cui, K., Nie, L., Cohen, and Wangi, K. 2011. Impact of high temperature stress on rice plant and its traits related to tolerance. *J. Agric. Sci.***149** (05):545-556.

Shamim, M., Singh, D., Gangwar, B., Singh, K. K., and Kumar, V. 2013. Agrometeorological indices in relation to phenology, biomass accumulation and yield of rice genotypes under Western Plain zone of Uttar Pradesh. *J. Agrometeorol.*2(15): 50-57.

Sharma, R. M. and Haloi. B. 2001. Characterization of crop growth variables in some scented rice cultivars of Assam. *Indian J. Plant Physiol.*6: 166-171.

Shi, C. H. and Shen, Z. T. 1990. Effect of high humidity and low temperature on spikelet fertility in indica rice. *Int. Rice Res. Newsl.* 15(3):10-11.

Shi, P., Tang, L., Wang, L., Sun, T., Liu, L., Cao, W.,and Zhu, Y. 2015. Post – heading heat stress in rice of south-China during 1981- 2010.

Shimono, H., Toshihiro, H., and Iwama, K. 2002. Response of growth and grain yield in paddy rice to cool water at different growth stages. *Field Crop Res.* 73: 67-79.

Sikder, S. 2009. Accumulated heat units and phenology of wheat cultivars as influenced by late sowing heat stress condition. *J. Agric. Rural Dev.* 7(1& 2): 57-64.

Singh, A. K., Chandra, N., and Bharti, R. C. 2012. Effects of genotypes and planting time on phenology and performance of rice (*Oryza sativa* L.) *Indian J.* 25(1): 151-156.

Singh, B. N., Sahu, S. P., Prasad, Y., and Singh, R. S. 1986. Seedling age in relation to sheath rot occurrence in rice. *Int. Rice Res. Newsl.* **11**(4): 26.

Singh, H., Singh, K. N., and Hasan, B. 2007. Evaluation of CERES-Rice model (V. 4.0) under temperate conditions of Kashmir valley, India. Cereal Research Communications.**35**(4).1723-1732.

Singh, P. K., Singh, K. K., Rathore, L. S., Baxla, A. K., Bhan, S. C., Guptha, A., Gohain, G. B., Balasubramanian, R., Singh, R. S., and Mall, R. K. 2016. Rice (*Oryza sativa L.*) yield gap using the CERES-rice model of climate variability for different agroclimatic zones of India. *Curr. Sci.* **110**(3):405-413.

Singh, P., Agrawal, M., Agrawal, S. B. 2009. Evaluation of physiological growth and yield responses of tropical oil crops (Brassica campestris L. Var Kranti) under ambient ozone pollution at varying NPK levels. *Environ. Pollut.* 157: 871-880.

Singh, V. P. 1994. Correlation studies in rice. *Agric. Sci. Digest.* **14**(3-4):185-188.

Soleymani, A. and Shahrajabian, M. H., 2011. The influence of different planting dates, plant densities on yield and yield components of rice on the basis of different nitrogen levels. *Int. J. Agron. Plant. Prod.* **2** (2): 80-83.

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

Sun, Y. F., Liang, J. M., Ye, J., and Zhu, W. Y. 1999. Cultivation of super- high yielding rice plants. *China Rice.* 5: 38-39.

Takai, T., Mastsuura, S., Nishio, T., Ohsumi, A., Shiraiwa, T., and Horie, T. 2006. Rice yield potential closely related to crop growth rate during late reproductive period. *Field Crops Res*. 96: 328-335.

Taleei, A., Poustini, K., and Davazdeh, E. C. 1999. Effects of plant population density on physiological characteristics of common Bean (*Phaseolus vulgaris* L.). *J. Agric. Sci.* **31**(3):477-487.

Taleshi, K., Nooshin., Osoli., and Moradi, M. 2013. Rice growth pattern analysis in fish-rice culture. *World Appl. Sci. J.* **22**(7): 1019-1023.

Tang, Y., Wan, X., and Lu, C. 2004. Differential changes in degradation of chlorophyll- protein complex of photosystem I and II during flag leaf senescence of rice. *Plant Physiol. Biochem.* **43**(2): 193-201.

Thakur, D. S. and Patel, S. R. 1998. Growth and sink potential of rice as influenced by the split application of potassium with FYM in inceptisols of eastern central India. *J. Potassium Res*. **14**(1):73-77.

Timsina, J. Godwin, D., Humphreys, E., Yadvinder-Singh. Bijay- Singh, Kukal, S. S., and Smith, D. 2008. Evaluation of options for increasing yieldand water productivity of wheat in Punjab, India using the DSSAT-CSM-CERES-Wheat model.*Agrcul. Water Mange*. 95:1099-1110.

Timsina, J. and Humphreys, E. 2006. Applications of CERES-Rice and CERES-Wheat in research, policy and climate change studies in Asia. A review. *Int. J. Agric. Res.* **1**(3): 202-225.

Timsina, J. Pathak, H., Humphreys, E., Godwin, D., Singh, B., Shukla, A. K., and Singh, U. 2004. *Int. Crop Sci.Cong.*

Tripathi, S. K., Patel, R. P., and Tiwari, K. L. 1997. Influence of weather factors on rice blast (*Pyricularia oryzae*) and its chemical control. *Adv. Plant Sci.* 10(2): 89-93.

Tsuji, G. Y., Uehara, G., and Balas, S. (Eds), 1994. DSSAT v3 (Decision Support System for Agrotechnology Transfer), University of Hawaii, Honolulu, Hawaii.

Van, T. K. 1974. The effects of climate on rice yields in Malaysia. *Malaysian Agric. J.* 49 (3): 296-301.

Vange, T. and Obi, I. U. 2006. Effect of planting date on some agronomic traits and grain yield of upland rice varieties at Makurdi, Benue state, Nigeria. *J. Sust. Develop.* **2**(1):1-9.

Vijayalaxmi, G., Sreenivas, G., and Rani, P. L. 2016. Evaluation of CERES-Rice model under various plant densities and age of seedlings in transplanted rice of southern Telangana zone of Telangana state, India. *Int. J. Curr. Microbiol. Appl. Sci.*5(4):667-674.

Viswambharan, K., Rajaram, K. P., Alexander, D., Chinnamma, N. P., and Nair, N. R. 1989. Climatic constraints of high yielding photo insensitive winter rice in Kerala. *Curr. Sci.* **58** (1): 12-21.

Vysakh, A. 2015. Validation of CERES model to calibrate the genetic coefficients of rice (*Oryza sativa* L.). M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur,156p.

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

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

Weerakoon, W. M. W., Maruyama, A., and Ohba, K. 2008. Impact of humidity on temperature-induced grain sterility in rice (*Oryza sativa* L). *J. Agron. Crop Sci.* 194:135–140.

Welbank, P. J., French, S. A. W., and Witts, K. J. 1966. Dependence of yield of wheat varieties on their leaf area. *Ann. Bot.* 30:291-299.

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

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

Willmott, C. J., Ackleson, S. G., Davis, R. E., Feddema, J. J., Klink, K. M., Legates, D.R., O'Connell, J., and Rowe, C.M. 1985. Statistics for the evaluation and comparison of models. *J. Geophys. Res.*90(5):8995-9005.

Wilsie, C. P. 1962. *Crop adaptation and distribution*. Freeman, W. H. and Co. London. Pp.52-59.

Yan, C., Ding, Y.,Wang, Q., Liu, Z., Li, G., Muhammad, I., and Wang, S. 2010. The impact of relative humidity, genotypes and fertilizer application rates on panicle, leaf temperature, fertility and seed setting of rice. *J. Agric. Sci.* 148: 329–339.

Yang-Jie, W., Wei, X., Xiao-guang, Y., Yang, C., and Ling-zhi, F. 2014. Geographic variation of rice yield response to past climate change in China. *J. Integrative Agric.* **13**(7): 1586-1598.

Yang, P. S. and Chu, Y. I. 1988. The development of nymphs of the brown plant hopper [Nilaparvatha lugens (stal)] under low, dynamic and constant temperature. *Quoli Taiwan Daxuė Yuan Yanjiu Baogoa*. 28: 6-13.

Zhang, S., Tao, F., and Zhang, Z. 2016. Changes in extreme temperatures and their impacts on rice yields in southern China from 1981 to 2009. *Field Crops Res.* 189:43–50.

Zhenqui, L., Zenye, L., Dapeng, M., and Shufen, Z. 1984. A study on the relation between chlorophyll content and photosynthetic rate of rice. *Acta Agron. Sinica.*

Zou, J., Lu, C., Wang, C., Zheng, K., Zong, S., Zhao, L., and Sun, Y. 2003. Breeding of two-line hybrid rice variety "Liangyoupeijiu" and preliminary studies on its cultivation characters. *Sci. Agric. Sin.* 869- 872.

Appendices

Appendix I

Abbreviations and units used

Weather parameters

Tmax: maximum temperature

Tmin:minimum temperature

Tmean: mean temperatre

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

Epan: Evaporation

BSS: Bright sunshine hours

Penophases

T-AT: Transplanting to active tillering

AT-PI: Active tillering to panicle initiation

PI-B: Panicle initiation to booting

B-H: Booting to heading

H- F: Heading to flowering

F-PM: Flowering to physiological maturity

Heat units

GDD: Growing degree days

HTU: Heliothermal units

PTU: Photothermal unit

GROWTH INDICES

LAI: Leaf area index

LAD: Leaf area duration

CGR: Crop growth rate

NAR: Net assimilation rate

Units

g: gram

kg: kilogram

Km h^{-1}: Kilometer per hour

Kg ha^{-1}: kilogram per hectare

%: per cent

°C: degree Celsius

Day °C: day degree Celsius

Day °C h: day degree Celsius hour

Appendix II

ANOVA for different plant growth characters of 2015 experiment

Plant height at different weeks after transplanting

Sources of variation	DF	Mean sum of squares							
		Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8
Date of planting	4	4.316	101.306**	275.273**	505.9**	728.732**	650.802**	372.607**	168.295**
Error	12	1.471	3.381	1.362	1.927	0.725	0.669	0.711	4.652
Variety	1	9.663	17.983*	10.920*	2.470	8.780**	1.274	0.354	9.006
Date X variety	4	0.438	11.546*	3.974	0.568	3.123*	4.796**	1.474	9.788**
Error	15	1.740	3.499	1.504	0.896	0.705	0.501	0.533	2.035

Sources of variation	DF	Mean sum of squares				
		Week9	Week10	Week11	Week12	Week13
Date of planting	4	197.727**	195.709**	117.073**	33.112**	2.286*
Error	12	3.454	1.075	1.469	3.239	0.473
Variety	1	21.904**	103.665**	245.818**	31.613**	355.574
Date X variety	4	8.300*	21.446*	47.779**	0.864	1.763
Error	15	2.258	4.601	3.779	2.591	1.138

Dry matter accumulation at 15 days interval

Sources of variation	DF	Mean sum of squares						
		15DAT	30DAT	45DAT	60DAT	75DAT	90DAT	At harvet
Date of planting	4	21722.282	284958.875*	2866417.147**	3272469.882**	1033233.343**	430153.440	143375.678*
Error	12	10300.235	71976.676	355134.636	266627.038	162396.008	378647.139	917235.514
Variety	1	21832.256	2916162.002**	500193.225	761428.836	3525687.506*	1716693.489	180857.095**
Date X variety	4	8736.486	24730.067	368008.712	3904842.934**	169606.946	245740.470	1679483.342**
Error	15	5939.572	67107.374	183547.654	679518.599	472882.058	433572.163	1066140.267

LAI at 15 days interval

Sources of variation	DF	Mean sum of squares					
		15DAT	30DAT	45DAT	60DAT	75DAT	90DAT
Date of planting	4	0.202**	0.322**	0.964**	1.269**	2.262**	1.503**
Error	12	0.007	0.022	0.024	0.046	0.137	0.039
Variety	1	0.023	0.321**	1.181**	2.642**	5.595**	9.661**
Date X variety	4	0.016	0.108	0.257**	0.381**	0.981**	0.254**
Error	15	0.006	0.015	0.008	0.033	0.173	0.028

LAD at 15 days interval

Sources of variation	DF	Mean sum of squares					
		15DAT	30DAT	45DAT	60DAT	75DAT	90DAT
Date of planting	4	11.407	57.023**	131.330**	160.022**	294.717**	335.252**
Error	12	0.416	2.390	3.548	2.606	12.465	5.822
Variety	1	1.225	28.900**	153.664**	480.249**	996.004**	764.750**
Date X variety	4	0.889	8.617**	26.085**	22.383**	125.078**	129.963**
Error	15	0.331	1.476		4.091	19.928	8.671

CGR AT 15 DAYS INTERVAL

Sources of variation	DF	Mean sum of squares						
		15DAT	30DAT	45DAT	60DAT	75DAT	90DAT	Harvest
Date of planting	4	0.167*	1.747	58.624**	45.553	177.400**	436.798**	128.090
Error	12	0.045	0.955	7.110	14.253	21.186	38.831	39.304
Variety	1	0.006	0.169	71.824**	359.400**	316.406**	355.812	383.780
Date X variety	4	0.052	0.568	36.998**	63.190	27.033	182.477	21.383
Error	15	0.023	0.626	2.871	14.637	25.471	80.356	106.674

NAR at 15 days interval

Sources of variation	DF	Mean sum of squares						
		15DAT	30DAT	45DAT	60DAT	75DAT	90DAT	Harvest
Date of planting	4	0.167*	1.747	58.624**	45.553	177.400**	436.798**	128.090
Error	12	0.045	0.955	7.110	14.253	21.186	38.831	39.304
Variety	1	0.006	0.169	71.824**	359.400**	316.406**	355.812	383.780
Date X variety	4	0.052	0.568	36.998**	63.190	27.033	182.477	21.383
Error	15	0.023	0.626	2.871	14.637	25.471	80.356	106.674

Soluble protein at 15 days interval

Sources of variation	DF	Mean sum of squares					
		15DAT	30DAT	45DAT	60DAT	75DAT	90DAT
Date of planting	4	466.487**	14.009	57.763**	71.649	179.386*	45.562*
Error	12	22.354	5.768	7.482	15.099	44.188	11.028
Variety	1	1.122	3.025	26.082	57.121	86.436	15.376
Date X variety	4	23.019	5.884	11.198	7.680	23.824	17.864
Error	15	12.760	5.529	17.115	17.639	21.559	16.879

Total chlorophyll content at 15 days interval

Sources of variation	DF	Mean sum of squares					
		15DAT	30DAT	45DAT	60DAT	75DAT	90DAT
Date of planting	4	0.189*	0.052	0.331*	0.062	0.203	0.047
Error	12	0.051	0.049	0.077	0.041	0.239	0.031
Variety	1	0.196*	0.130	0.083	0.007	0.468*	0.001
Date X variety	4	0.077	0.068	0.036	0.239**	0.061	0.015
Error	15	0.038	0.057	0.218	0.041	0.072	0.029

Yield and yield parameters

Sources of variation	DF	Mean sum of squares				
		Yield	Panicle	Spikelets	Filled grains	1000 grain
Date of planting	4	1828958.750	8894.954**	799.524**	85.851*	0.366
Error	12	1597993.750	710.010	53.379	18.518	0.281
Variety	1	44890.000	1454.436	459.684*	57.121	0.049
Date X variety	4	1472458.750	680.083	34.046	26.744	0.178
Error	15	1286025.000	811.013	92.862	28.499	0.511

PHASIC DEVELOPMENT MODEL USING THERMAL INDICES FOR RICE (*Oryza sativa* L.) IN THE CENTRAL ZONE OF KERALA

By

ASWANY K S

(2014-11-174)

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the requirement for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

Department of Agricultural Meteorology

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

2016

ABSTRACT

The present study, "Phasic development model using thermal indices for rice (*Oryza sativa* L.) in the central zone of Kerala" was carried out at the Department of Agricultural Meteorology, College of Horticulture, Vellanikkara, Thrissur during 2015-2016. The experiment was laid out in split plot design with five dates of planting viz., 5th June, 20th June, 5th July, 20th July and 5th August as the main plot treatments and two varieties viz., Jyothi and Kanchana as subplot treatments and there were four replications. Location of the experiment was Agricultural Research Station, Mannuthy.

Growth and yield characters like plant height, leaf area index, dry matter accumulation, 1000 grain weight, grain yield, straw yield, number of panicles per unit area, spikelets per panicle, filled grains per panicle and duration of different growth phases were recorded along with monitoring of the incidence of various pests 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 recorded during the experimental period.

Heat units viz., Growing Degree Days (GDD), Heliothermal Units (HTU), and Photothermal Units (PTU) were found to affect the yield of both Jyothi and Kanchana varieties of rice. In both varieties, early dates of planting accumulated more heat units to attain physiological maturity compared to later plantings. Reduction in yield in the later plantings was noticed due to the increase in GDD, HTU and PTU.

The weather parameters such as minimum temperature (23.8°C), forenoon (23.0mmHg) and afternoon vapour pressure deficit (23.6mmHg), forenoon relative humidity (94.7%) and afternoon relative humidity (77.1%), rainfall (1581.5 mm) and rainy days (71days) were found to be higher in early dates of planting, while maximum temperature (31.8°C), bright sunshine hours (5.2h) , evaporation (2.9mm).

Number of days taken to complete different phenological stages of both varieties was low for late planted crops. Plant height, dry matter accumulation, yield and yield parameters such as number of panicles per unit area , spikelets per panicle, filled grains per panicle and 1000 grain weight were highly variable among the different planting dates. The total chlorophyll content (soluble protein and growth indices such as LAI, CGR, LAD and NAR were found to be highest on June 5th planting. Grain yield was highest for June 5th planting for both varieties. The recorded grain yield for Jyothi and Kanchana was

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. 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.