Comparison of different weather based models for forecasting rice yield in central zone of Kerala

By

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(2016-11-070)

THESIS

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DECLARATION

I hereby declare that this thesis entitled **"Comparison of different weather based models for forecasting rice yield in 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, fellowship or other similar title, of any other University or Society.

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03/09/18

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INTRODUCTION

1. INTRODUCTION

India is an agrarian country with 60.45% of its land area under cultivation. Agriculture provides employment opportunities to more than half of the population in India. It is the back bone of Indian economy. Wide ranges of crops are grown in India like cereals, pulses, fruits, vegetables etc.

Rice is one of the major crops produced in India and is the dominant food crop of the rural people. It is a nutrient rich food which can provide carbohydrates, calcium, iron, thiamine, folate and vitamin E and relatively a good source of energy. Total area coverage under *kharif* food grains is estimated to have decreased to 703.52 lakh hectares as compared to 724.19 lakh hectares in 2016-17. Area coverage under rice is estimated to have decreased from 389.49 lakh hectares in 2016-17 to 387.16 lakh hectare in 2017-18 (Annual Report 2017-18, MoA & FW). Some of the reasons for this declining trend are seasonal shortage of labour supply, small size holdings, decline in the number of full time farmers, lack of proper marketing system, low level of profitability, growing aversion of new generation to paddy cultivation, pressure of population on land inadequate irrigation facilities and due to vagaries of weather. Although India ranks third in the production of rice, its yield is lower than Brazil, China and the United States.

Climate decides the geographical distribution of the crops while weather variables decide the quantum of production over an area. Weather influences crop growth and development thereby leading to large seasonal yield variability. Thus the impact of weather and climate is vital in agricultural production. Due to the unpredictable changes in weather, yield losses are resulted throughout the country which causes losses to farmers. Growing population in India demands increased production now a days. But decrease in availability of cultivable land makes it difficult when it is negatively influenced by increased risks posed by changes in weather patterns. Therefore, for optimizing crop yields, yield forecasting forms an important tool.

Reliable crop yield forecasts are essential to estimate production, assisting farmers, agribusiness firms, exporters and government in decision making for efficient resource allocation, price adjustment and export planning (Horie *et al.*, 1992). Crop-weather models by using mathematical or statistical techniques provide a simplified representation of the complex relationships between weather/climate and crop performance (growth, yield and yield components) (Baier, 1979).

A crop simulation model is a simulation model that helps estimate crop yield as a function of weather conditions, soil conditions, and choice of crop management practices. Crop Simulation Models (CSM) are computerized representations of crop growth, development and yield, simulated through mathematical equations as functions of soil conditions, weather and management practices (Hogenboom *et al.*, 2004). CSM have played important roles in the interpretation of agronomic results, and their application as decision support systems for farmers is increasing.

Crucial challenges for the sound planning and policy making in the agricultural sector of the country are crop acreage estimation and crop yield forecasting. FASAL (Forecasting Agricultural output using Space, Agro-meteorology and Land based observations) is a scheme started by Directorate of Economics & Statistics (DES), Ministry of Agriculture and Farmers Welfare in 2006 in collaboration with various national and state level organizations to tackle these challenges. Under this scheme, forecasting is done based on multiple components; agromet forecast, remote sensing forecast and econometric forecast. Agromet component of FASAL scheme is being implemented through the network of 47 AMFUs and 23 State AAS Units of IMD located in each state. IMD and State Agriculture Universities are focusing on the Agromet model based forecast development with the help of ICAR-IASRI and CCAFS using weather and climate data.

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

On this context, the present study titled "Comparison of different weather based models for forecasting rice yield in central zone of Kerala" is aimed:

- To compare the accuracy of different weather based models for forecasting rice yield
- To validate the results with experimental data.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The significance of rice production is on paramount in the emerging climate changing scenarios as rice being the most staple food grain in the world. This research focusses on the importance of predicting the rice yields at the zenith of climate change adaptation demands. This review of literature covers:

1. Significance of rice cultivation
2. Effect of weather parameters on growth and yield of rice
3. Effect of dates of planting on growth and yield of rice
4. Growth indices
5. Weather influences on the incidences of pests and diseases
6. Crop simulation models
7. Statistical models
8. Comparison of different weather based models.

The literature review in this chapter is a solid background to undertake the research in the emerging area of predicting crop yields.

2.1. SIGNIFICANCE OF RICE CULTIVATION

India is the second largest producer and consumer of rice in the world. Rice production in India crossed the mark of 100 million tonnes in 2011-12 accounting for 22.81 per cent of global production in that year. Rice is grown on an area of 43.95 million ha with a production of 106.95 million tonnes (Anon, 2013). There are two common methods of growing rice: direct seeded rice and transplanted rice. Transplanting method of growing rice is more popular among farmers because of 10-15 per cent increase in yield than direct seeded rice. In recent years, the area under rice crop is decreasing year by year due to low profitability. But demand for rice is growing every year and it is estimated that in 2025 AD the requirement would be 140 million tonnes.

To prolong the present food self-sufficiency and to attain future food requirements, India needs to increase its rice productivity by 3 per cent per annum (Thiyagarajan and Selvaraju, 2001). Manual transplanting of rice is one of the laborious and time-consuming operations requiring about 300-350 men-hrs. per ha, which is roughly 25 per cent of the total labour requirement of rice production. During transplanting season, often there is an acute labour shortage. This results in increased labour wages and delayed transplanting operation. Transplanting at right time has a pronounced influence on rice yield. It was reported that one-month delay in transplanting reduces the yield by 25 per cent and two months' delay by 70 per cent (Rao and Pradhan, 1973). Also the labour transplants non-uniformly and tends to transplant a lower plant population in the centre of the field.

Rice, wheat, and maize are the most consumed food crops in the world; together they directly supply not less than 50 per cent of all calories consumed by the entire human population. Wheat is the pioneer in area harvested each year with 214 million ha, followed by rice with 154 million ha and maize with 140 million ha. Human consumption accounts for 85 per cent of total production for rice, compared with 72 per cent for wheat and 19 per cent for maize.

Rice provides 21 per cent of global human per capita energy and 15 per cent of per capita protein. In southeast nations like Bangladesh, Vietnam and Myanmar, the per-capita rice consumption 150-200 kg annually, which accounts for two-thirds or more of caloric intake and approximately 60 per cent of daily protein consumption.

Rice is the major food for the 1.7 billion South Asian population and a source of livelihood for more than 50 million households. About 60 million hectares of cultivation and 225 million tonnes of production of paddy, accounting for 37.5 per cent of the global area and 32 per cent of global production in 2013. India has the largest rice area in the world with 43.9 million hectares (more than a quarter of the global rice area) and contributes a little less than a quarter of global production. Bangladesh has more than 11 million hectares of rice area and produces 50 million tonnes of paddy (IIR, 2014).

Total global consumption of milled rice amounted to approximately 485 million metric tonnes in 2014/2015. China consumes around 148.4 million tonnes of milled rice per year, and is by far the world's leading rice consumer. On average, every human around the world consumes about 57.5 kilograms of rice annually.

Rice is grown in India from 8° to 25° N latitude and an altitude of about 2,500 metre above mean sea level. It requires high temperature and high humidity for its successful growth. The temperature requirement for rice crop is high with mean monthly of 24°C, 20- 22°C at the time of sowing, 23- 25°C during growth and 25- 30°C at the harvesting time. The mean annual rainfall required by rice is 150 cm.

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

Weather parameters being the most predominant abiotic factor in controlling the crop growth was pragmatically understood by various scientists. One of the such studies was made by Huda *et al.* (1975). He assessed the influence of intensity of different weather parameters during different growth stages of rice. Second-degree polynomial multiple regression equation was formulated for this purpose and found that above average weekly rainfall is harmful during vegetative and ripening stage but favorable during nursery stage. Above average minimum and maximum temperatures also were found to be beneficial during nursery stage. He also found that daily maximum temperature has more negative effect on period from vegetative lag to reproductive phase.

The size of rice grain was found to be more stable at night temperature than wheat by Choudhary and Wardlaw (1978). They also used regression equation to find out the influence of weather on rice for ascertaining the productivity of rice in Kenya. The radiation variable exhibited negative and mean temperature exhibited positive effect on rice productivity

Vishwambharan *et al.* (1989) in his studies in rice found out high wind speed especially during flowering and maturity stages caused spikelets sterility, which yielded poor.

Hirai *et al*. (1993) studied the impact of relative humidity on nitrogen absorption and dry matter production at different temperature levels. The rice plants were nurtured for 4 days providing 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 nurtured under 90% relative humidity with 24/20 and 28/24°C enhanced the dry matter in roots and leaves than that of plants nurtured under 60% relative humidity. From these observations, they conclude humidity and temperature are influential variables in dry matter accumulation.

.A specific delay in heading and near total spikelet sterility was observed in rice when the minimum temperature dropped below 18^0C. (Dingkunh *et al.,* 1995)

According to the study conducted by Matsui *et al*. (1997) a wind speed above 0.85 ms^{-1} caused an extreme decrease in spikelet fertility by affecting the number of pollen grains shed on the stigma.

Increased leaf area, plant height and accelerated leaf emergence were observed under high humidity conditions during dark period. It might be due to increased photosynthesis and increased allocation of photosynthates to the late emerging leaves in plants. (Hirai *et al*., 1998)

Kaladevi *et al*. (1999) studied the effect of meteorological parameters such as maximum and minimum temperature, solar radiation, relative humidity, evaporation, wind speed and rainfall on the yield of *Rabi* rice in Tamil Nadu for three dates of transplanting (15^{th} October, 1^{st} November and 15^{th} November). They concluded increased dry matter production was favored by lower minimum temperature.

The influence on temperature on tillering duration in lowland rice varieties were reported in Andhra Pradesh by Lalitha *et al.* (2000). They observed that the temperature prevailed during the tillering stage has direct control on tillering period. Daily mean temperature not less than 26 °C during tillering stage declined the duration of tillering to 5 weeks after transplanting while, the temperature between 22.9 to 25.8 °C enhanced the duration of tillering stage up to 8 weeks.

The productivity of rice influenced by agro meteorological variables such as rainfall, number of rainy days and length of rainy season in Jabalpur was systematically studied by Gupta *et al*. (2000). They found out that the variables such as rainfall amount, length of rainy season and number of rainy days had significant correlation with rice yields. They also observed that use of surplus rainwater to overcome the moisture stress during reproductive phase or selection of short duration varieties to minimize moisture stress risk during grain filling stage for obtaining efficient rice yields in rainfed rice.

Under controlled environment, Abeysiriwardena *et al*. (2002) conducted an experiment to assess the impact of high temperature at very high and low humidity levels and normal temperature at normal and low humidity levels on surface temperature of spikelets and grain sterility in rice at heading stage. It was found that high temperature (30^0C night/ 35^0C day) along with high humidity (85-90%) induced complete grain sterility in rice.

Morita *et al*. (2005) concluded that grain yield is negatively affected by high temperature at flowering and grain filling due to spikelet sterility and a shorter grain filling period. Comparing with high daytime temperature of 34/22 ^{0}C and the control (22/22^0C), High night-time temperature of 22/34^0C highly suppressed the grain weight.

Goswami *et al*. (2006) analysed the impact of weather variables on phenology, growth and yield of rice. They observed the relevant relationship of two or more weather variables and grain yield of crops which could predict the actual harvesting time of rice crop.

Wahid *et al*. (2007) observed the effect of high temperature on rice growth stages and the stage if exposed to more high temperature causes more damages. Low and high temperature during both vegetative and reproductive stages may lead to poor tillering, productiveless tillers and poor seed setting in rice.

According to Weerakoon *et al*. (2008), high relative humidity along with high temperature decreased the pollen shedding on stigma whereas high relative humidity along with low air temperature did not show a decrease in pollen shedding. They concluded that spikelet sterility can be caused by high relative humidity along with high temperature conditions. Yan *et al.* (2010) also made similar reports where spikelet fertility is affected by high relative humidity at flowering stage at increased temperature conditions.

Murthy and Rao (2010) studied the influence of low temperatures stress on growth and yield of rice. Early sowing resulted in significantly higher yield followed by normal sowing. A strong positive correlation was found between minimum temperatures at flowering and yield in comparison with minimum temperatures from PI to 50% flowering and 50%flowering to maturity.

Aryal (2012) conducted an experiment to find out the water requirement of rice and to analyze it with the quantity of rainfall received in the study area. He measured the evaporation rate which was found to be highest in the month of September and lowest in June. The rate of evapotranspiration followed an increasing trend from June to September. Water required was more with the increase in days after plantation and successive developmental stage of rice. The total water requirement for rice was 711.45 mm and the total rainfall received during the study period over the area was 549.59mm. It indicates that the crop failed to meet its water requirement during the study period.

Gopika *et al.* (2014) attempted to analyze the relationship between rainfall variability and rice yield in Kerala. A decreasing trend was observed in the case of *kharif* season average rainfall whereas; *rabi* season average rainfall followed an increasing trend. It was also concluded that the harvest during *kharif* and transplanting during *rabi* is negatively affected by the heavy rainfall during September and October months due to which it is not productive for the rice crop.

Laza *et al.* (2015) studied the effect of high night temperatures on growth and physiological responses of rice in controlled environment chambers. High night temperatures treatments were given at different growth stages. Lowest number of spikelets per panicle were observed when high night temperature was given at early reproductive stage. The study also showed that when the rice plants are exposed to high night temperatures during the reproductive period, yield get reduced by increasing dark respiration rate and spikelet degeneration which leads to decreased biomass production.

Through the study conducted by Kuthe *et al.* in 2015 at Navasari, it is evident that during rainy season, the main component, which governs the other weather parameters, is rainfall. Germination and initial growth is found to be affected by the onset of monsoon. Condusive atmosphere for insect and pest attacks was created by the joint effect of rainfall and temperature on relative humidity.

In 2015, Pandey *et al.* conducted a study in the district of Faizabad, Uttar Pradesh, India to analyze the individual and combined effect of weather variables on rice yield. It was found that sunshine hours are more important which is followed by wind velocity and rainfall based on R^2. The combined effect of weather variables is also crucial in the case of rice. Among those, rainfall and wind velocity is more influential followed by rainfall & sunshine hours and wind velocity & sunshine hours.

Bheemanahalli *et al.* (2016) concluded that a threshold temperature beyond 33^0C induces large increases in sterility in rice.

According to Shi *et al.* (2016), decrease in spikelet fertility and grain-filling duration was noticed due to heat stress at anthesis whereas the 1000-grain weight remained unaffected. Average grain yield was reduced by 3.4% /^{0}C/day and 2.3% /^{0}C/day in Nanjing and by 3.2%/^{0}C/day and 1.7%/^{0}C/day in Wuxiangjing, at anthesis and 12 days after anthesis respectively.

Zhang *et al.* (2016) studied changes in extreme temperatures and their impacts on rice yields in southern China from 1981 to 2009. It was reported that due to increase in GDD (Growing degree day) rice yield increased by 5.83%, 1.71%, 8.73% and 3.49% 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 respectively. It decreased by 0.14%, 0.32%, 0.34% and 0.14% due to increase in HDD (High temperature degree day) and increased by 1.61%, 0.26%, 0.16% and 0.01% due to decrease in CDD (Cold degree day), respectively. Also, decreases in solar radiation resulted in yield reduction by 0.96%, 0.13%, 9.34% and 6.02%. They showed that for the previous three decades, the positive effects of increment in GDD and the negative effects of abatement in solar radiation assumed predominant parts in deciding general atmosphere impacts on yield.

The influence of spatial-temporal characteristics of high temperature episodes on booting and flowering stages of rice was studied by Sun *et al.* (2018) to analyze its impact on grain yield of rice in China. Last 30-year maximum temperature records were collected from 219 stations to formulate three high-temperature indices [high-temperature hours (HH), high-temperature intensity (HI), and high-temperature degree hours (HDH)] in order to compute intensity, frequency and duration of high temperature. Impacts of high temperature variability episodes on grain yield were found to be significantly negative. It was concluded that high temperature episodes were unfavourable for middle-season rice production in China.

2.3. EFFECT OF DATES OF PLANTING ON GROWTH AND YIELD OF RICE

The yield of boro rice sown in the Gangetic plains was affected by date of sowing which was studied by Roy and Biswas in 1980. According to their study, with delayed sowing and decreasing day and night temperatures, different plant characters like seedling height, plant dry matter content, number of productive tillers per plant and crop duration decreased. Different dates of planting under study were 12 November, 26 November and 10 December. Grain yield also was reduced with delay in dates of planting.

Ramdoss and Subramanian (1980) studied the impact of weather variables on last 45 days of crop growth on rice yield. They observed that there was positive correlation with rice yield which is effected by maximum temperature and sunshine hours and has negative effect on straw yield.

Agarwal *et al.* (1983) studied the combined effects of climatic parameters on rice yield at different stages of crop growth. Above average maximum temperature and increase in humidity during vegetative phase exhibited positive effect on rice yield and had negative effects on other growth stages.

According to a study conducted by Reddy and Reddy (1986), early-transplanted rice had higher yields than delayed transplanted rice cultivars. A delay in date of planting affected the rice growth duration in Nellore variety, along with the increase in number of days taken for production. Harvest index was also increased in the in early-transplanted crops than later transplanted crops.

Maity and Mahapatra (1988) concluded that the higher production was observed in rice varieties planted on 5 to 10th January and 20 to 25th December and the yield was observed to be 3.7 and 2.6 t ha^{-1} in 1985 and 1986 respectively. The occurrence of high temperature conditions prevailed during late and early transplanting stages reduced the yield.

Shi and Shen (1990) perceived the effect of high humidity and low temperature on spikelet fertility in their studies with 12 Indica rice varieties in China. It was concluded that spikelet fertility was reduced by high relative humidity along with low temperature and relative humidity was the most relevant weather variable influencing spikelet fertility along with mean temperature at 3 days after heading.

Reddy and Reddy (1992) studied the productive tillers per unit area production in the early transplanted and later planted rice variety Surekha. Less amount of solar radiation was available for early-transplanted rice variety leading to mortality of rice.

Mahmood *et al*. (1995) studied the influence of three dates of transplanting and three irrigation treatments on rice yield by recording different yield and agronomic characters. Significant decrease in yield and yield related traits was observed with late transplanting. Marked decline in yield was noticed due to water shortage during flowering which led to increased spikelet sterility.

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

Biswas and Salokhe (2001) observed that the 1000-grain weight was considerably influenced by sowing date. Rice varieties which were early sown (20th June) produced heavier grains while crop sown on 20th July yielded minimum grain weight.

Khakwani *et al*. (2006) determined the influence of planting dates on agronomic and physiological traits of rice crop through an experiment which included six planting dates as treatments. It was divided into two groups as early and late. Late transplanted plants failed to produce increased yield due to heavy stem borer infestation while early transplanted plants yielded better.

Safdar *et al*. (2006) made a study on impact of transplanting dates and number of seedlings per hill under elevated temperature on rice productivity of 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 observed that the June 20th planted crop exhibited higher grain yield and net return with one seedling per hill. They referred the timely planting will be in requirement of 1 seedling per hill or 4 seedlings per hill to compensate for the yield gap in late planted rice varieties.

In 2007, Akram *et al*. studied the impact of different transplanting dates on six rice varieties (98801, PK-5261-1-2-1, 97502, 98409, Basmati-385 and Super Basmati) which were planted from 1st July to 31st July with 10 days interval at Agronomic Research Institute, Faisalabad. Among various yield and yield parameters noted, plant height, number of tillers, 1000 grain weight, number of grains /spikelet and sterility were found to be significantly affected. Basmati 385 planted on 11th July and Super Basmati planted on 1st July produced maximum yield. On 21st July transplanted crop, minimum sterility was obtained.

In 2010, Akbar *et al*. evaluated the effect of six different sowing dates (31st May, 10th June, 20th June, 30th June, 10th July and 20th July) on yield and yield components of direct seeded fine rice. Significant response was shown by different yield components like 1000 kernel weight, tillers per metre square and number of kernels per panicle to different dates of sowing. The maximum number of productive tillers per meter square, kernel per panicle, 1000-kernel weight and paddy yield was shown by June 20th sown crop.

According to Bashir *et al.* (2010), the optimum sowing date for direct seeding of coarse rice variety KS 282 is 20th June which gave maximum yield and net income. He also concluded that there was gradual reduction in yield when sowing was delayed after 20th June.

Brar *et al.* (2011) studied the effect of different dates of transplanting (June 15th, June 25th, July 5th) on phenology, dry matter partitioning behavior and heat unit accumulation of two rice cultivars PAU 201 and PR 118. It was observed that there was a yield reduction of 5.4 percent in the case of long duration cultivar PR 118 with delay in transplanting from June 25th to July 5th and no significant reduction in grain yield was observed with delay in transplanting.

A study for analyzing the influence of dates of planting and seedling age on yield and yield components of two rice varieties was carried out by Faghani *et al.* (2011) at Iran. The experiment was laid out in split plot design with four replications. The observations of total tiller number, fertile tiller number, total spikelet per panicle, total sterile spikelet per panicle, panicle number per m^2, 1000 grains weight, biological yield, plant height, grain yield and harvest index were recorded. Results indicate a significant influence of dates of planting on plant height, total tiller number, total sterile spikelet per panicle, panicle number per m^2, 1000 grains weight, grain yield and harvest index. Grain yield decreases when date of planting is delayed because total sterile spikelet per panicle increases and the 1000 grains weight decreases. Singh *et al.* (2012) reported that earlier planted crop produced maximum dry matter and plant height than late planted crop. Yield and yield attributes also followed the same trend.

Studies conducted by Ahmed *et al.* (2014) showed that the optimum date of sowing for dry seeded rice on the high Ganges river flood plain of Bangladesh is late May to early June. Delayed sowing reduced the crop duration and biomass production.

Khalifa *et al.* (2014) laid out an experiment in split-split plot design with three sowing dates (20th April, 1st May and 10th May) as main plot treatments, seeding rates as sub plot treatments and three rice varieties as sub-sub plot treatments with four replications to assess the influence of sowing dates and seed rates on selected rice cultivars. They studied characters like maximum tillering, panicle initiation, heading dates, leaf area index, chlorophyll content, 1000-grain weight, and panicle length, number of panicles per hill and grain yield. All studied characters showed highest value with early sown crop.

Ali *et al.* (2015) laid out an experiment at Allahabad to analyze the response of different rice cultivars to different dates of transplanting. Highest yield was recorded for the plants planted during mid of July when temperature was observed to be 35^0C. Lowest grain yield was obtained for the crop planted during first week of August when temperature was 30^0C. It was concluded that late planting is not favourable for rice production.

Mote *et al.* (2015) studied the total GDD requirement of three rice cultivars (Jaya, Gurjari, GNR 2) under three dates of planting (12 July, 27 July and 11 August). Results indicated that Gurjari has higher GDD requirement followed by GNR-2 and Jaya. Grain yield showed a progressive decreasing trend with dates of transplanting where higher grain yield was observed with first date of transplanting. The reduction in grain yield is supposed to be occurred due to reduction in GDD during grain filling to physiological maturity phase with delayed transplanting. Also it was evident that delayed transplanting resulted in reduction of total GDD.

According to Biswas *et al.* (2018), 5-10% yield reduction was observed with rise in temperature upto 2^0C with the normal date of sowing (4th week of May). It was evident that the yield decrease occurs mainly due to the lower LAI throughout the crop growth stages and shorter crop growth period under elevated thermal condition. They also concluded that to obtain higher yield of *kharif* rice in the study region, sowing should be done before 15th July.

2.4. GROWTH INDICES

The relationship between leaf area duration at various growth stages and productivity in different cultivars of rice was studied by Devendra *et al.* in 1983. From his study it became evident that grain yield was not influenced by the higher leaf area duration (LAD) from flowering to harvest stage instead biological yield increased.

During all phenophases of rice, grain yield increased with increase in leaf area index (LAI) and net assimilation rate which was reported by Singh (1994).

The leaf area duration was found as maximum at about 65 days after planting in rice (Sadeghian and Bahrani, 2001). CGR was initially found to be increasing and decreasing during later stages of the rice crop as reported by Shimono *et al.* (2002). Improved growth and higher yields were exhibited by rice cultivars having higher physiological indices (Esfahani *et al.*, 2006).

A systematic study on transplanting date effect on mean net assimilation rate, leaf area duration, leaf area index and crop growth rate was carried out in two rice varieties under varied agro-environmental conditions by Ahmad *et al.* (2009). The field experiment was carried out at three locations. They found that leaf area index was higher for early transplanted crop than late transplanted crop. Leaf area duration was significantly increased during early transplanting while net assimilation rate was found more with delayed plantings. Increased crop growth rates were recorded during early transplantings at Faisalabad and Kala Shah Kaku while late transplanting showed higher crop growth rates at Gujranwala in Pakistan.

Research findings of Azarpour *et al.* (2014) showed that at early growth stages of rice, leaf area index showed a little increase over time which was raised further during later stages. Flowering stage (65 DAP) recorded maximum leaf area index after which lower leaf falling and wilting made it to decrease.

According to Mani and Noori (2015) a decrease in net assimilation rate (NAR) and relative growth rate (RGR) was observed as the age of the plant progressed in cow pea.

Productivity, dry matter partitioning and growth characteristics in hybrid rice were studied by Medhi *et al.* (2016) during 2012 and 2013 *rabi* seasons. It was reported that up to 60 days after planting leaf area and leaf area index increased while it reduced when approached to harvest period. They also inferred that due to senescence of early leaves it results in its lesser number and thereby decrease in leaf area index towards crop maturity.

2.5. WEATHER INFLUENCES ON THE INCIDENCE OF PEST AND DISEASES

Incidence of blast disease in rice mainly occur during tillering stage of the crop. Lower minimum temperature is found to have positive influence on the occurrence of this disease in mid hills of Himachal Pradesh (Prasad and Rana, 2002).

Anand Kumar *et al.* (2003) investigated the effect of different weather variables on the occurrence of whorl maggot and leaf folder in rice at Rajendranagar (A.P). The study showed that the maximum activity of these pests occurred during first fortnight of August and October in *kharif* and during February in *rabi*. Significant negative correlation was observed between leaf folder and morning relative humidity. Significant positive correlation was observed between whorl maggot and number of rainy days.

Correlation studies between light trap catches and weather data for gall midge, stem borer, rice bug, leaf folder and green jassid were carried out to know their relationship. Most predominant weather parameters were found using step wise regression technique and forewarning models for each rice pest were prepared which showed 76% variation for gall midge, 67% variation for stem borer, 90% variation for rice bug, 85% variation for leaf folder and 71% variation for green jassid (Samui *et al.*, 2004).

According to the research conducted by Sabale *et al.* (2010) at Pattambi, Kerala, three peaks were identified for the incidence of two species of green leaf hopper

(*Nephotettix nigropictus* and *Nephotettix virescens*) first during 38th to 41st standard meteorological weeks, second during 45th standard week and third during 52nd to 2nd standard week. Tillering to panicle initiation stages were found to be more affected stages during the crop season. Lower minimum temperature, low rainfall and ample sunshine were found to be favouring the incidence and spread of green leaf hoppers.

A study was undertaken by Pal *et al.* (2017) in Odisha, to analyze the influence of weather parameters on the incidence and development of sheath blight disease of rice by selecting seven weather parameters as independent variables and increase in percent disease index (both cumulative and periodic) as dependent variables. Results showed that heavy rainfall followed by low and intermittent showers is highly favorable for the incidence and development of sheath blight respectively. The most favorable maximum temperature range is from 31^0C to 34^0C, minimum temperature range is from 17^0C to 23^0C and evening relative humidity range is from 70 to 83%.

According to Dhaliwal *et al.* (2018), the incidence of brown leaf spot in rice crop is significantly affected by minimum temperature and evening relative humidity. Due to increased humidity within plant canopy, disease incidence is found to be more in high plant population context compared to lower plant population.

2.6. CROP SIMULATION MODELS

Jand *et al.* (1994) evaluated CERES-Rice model in Punjab using three dates transplanting *viz.* 13th June, 27th June and 13th July with two varieties. They concluded that the yield and yield components predictions made by the model had a variation from 8.34 to 10.9 percent of the observed yield.

Aggarwal and Mall, 2002, used two crop simulation models CERES-Rice and ORYZA1N to assess the impact of different climate change scenarios on grain yields of irrigated rice at different N management levels. An increase between 1.0 and 16.8% in pessimistic scenarios and an increase between 3.5 and 33.8% in optimistic scenarios of climate change was obtained based on the management level and model used. At low nitrogen management, the response to climate change is found small compared to optimum management.

Rai and Kushwaha (2005) conducted an experiment on validation of CERES-Rice model for prediction of upland rice yield at Pantnagar using the upland rice variety Pant Dhan-4 transplanted on three dates during *kharif* seasons of 1997 and 1998. The days taken to panicle initiation and 50 per cent flowering were predicted well by the model but days taken to maturity was overestimated during both the years. The results showed a significant effect of change in dates of transplanting on number of days taken for panicle initiation.

Sharma and Kumar, in 2006, parameterized and validated CERES-Rice model by using experimental data derived using four varieties (RP24721, HPR 1064, HPR 2027 and Nagga Dhan) and two dates of transplanting (June 23 and July 8). Genetic coefficients specific to cultivar were calibrated for four varieties. Good agreement between observed and simulated grain yield was observed during validation, which was done using several independent sets of yield data along with different locations, years, nitrogen and irrigation water treatments.

Rice yields for the period of 1979 to 1998 was evaluated by Mariappan *et al.* (2008) using CERES-Rice model and simulated the seasonal yield variability and yield prediction during a period of 1999 to 2001 of Chengalpattu 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 concluded that the pattern of weather induced yield variability can be simulated by CERES-Rice model in Chengalpattu over a period of 19 years.

Patel *et al.* (2010) calibrated and validated CERES-Wheat model for the variety GW-496 using experimental data collected during 1995-2007 collected under different management practices at Anand. Three dates of sowing and levels of irrigation were the treatments used. Results showed that the model performed fairly under under optimum sowing and optimum irrigation than early/late sowing and moisture stress conditions.

In 2010, Shamim *et al.* tried to develop genetic coefficients of Pankhali, Narmada, GR-104, and Pusa Basmati-1 genotypes of aromatic rice transplanted on 8th July, 22nd July and 8th August. They carried out sensitivity analysis of the model relating to different scenarios of duration of photoperiods, maximum and minimum temperatures, solar radiation and CO_2 concentration. A linear increase in the grain yield was observed when there was a unit increase in solar radiation, day length, reduction of maximum temperature and *vice versa.*

Dass *et al.* (2012) used DSSAT v 4.5/ CERES- Rice model to simulate the yields of two varieties Pant Dhan 4 and Hybrid 6444 cultivated under SRI method with three irrigation levels and two planting spacings. Model calibration was done using 2009 data and validation was done using 2008 data. Fair accuracy was obtained in the yield prediction of both the varieties. An overall gap of 5% and 11.4% was found between simulated and observed yield of Pant Dhan and Hybrid 6444 respectively. So it was concluded that the model used is acceptable for predicting the maturity and yield of these rice varieties grown under SRI method.

According to findings by 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.

Shamim *et al*. (2012) conducted a study using CERES-Rice model to simulate the phenology, growth and yield of aromatic rice cultivars under different environments. Field experiments were conducted at Nawagam under middle Gujarat agro-climatic zone during 2007 and 2008 *kharif* season. Treatments used were four aromatic cultivars of rice and three dates of planting. The biomass production was overestimated and test weight and LAI were underestimated by the model. The grain yield was simulated well which was in close agreement with the observed grain yield.

Zhang and Tao (2013) calibrated and validated five rice phenological models/modules (i.e., CERES-Rice, ORYZA2000, RCM, Beta Model, SIMRIW) based on a large number of rice phenological observations across China. Results demonstrated these models simulated rice phenological development over a substantial region genuinely well after calibration, in spite of the fact that the relative performance of the models shifted in various locations.

Simulation of growth and yield of new rice variety in Nigeria (NERICA 2) was carried out by Akinbile in 2013 by using CERES-Rice model. Different irrigation rates were the main treatment for study. Measured parameters were plant height, leaf area index, biomass, crop shading, root depth and grain yield relating to water use and they were compared with the CERES model simulated values. The results were analyzed statistically. Slightly higher values were predicted for biomass yield, grain yield and total yield than the observed values at 100% ET treatment level. It was concluded that recalibration and revalidation is required for the CERES-Rice model under nitrogen limiting and soil conditions.

Naziya (2014) calibrated the genetic coefficients of rice varieties Jyothi and Kanchana and Vysakh (2015) validated them at the Department of Agricultural Meteorology, College of Horticulture, Kerala Agricultural University.

Indian Agricultural Research Institute designed and developed a crop simulation model web based application; Web InfoCrop – Wheat, to simulate the growth and development of the wheat crop based on weather, soil conditions, and variety and

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management practices. For input variables, management conditions and result outputs separate modules are provided in this web based crop simulation model. Under various irrigation and nitrogen management conditions it performed well for the observed and simulated yield and biomass with significant R^2 (0.958 and 0.947 respectively) and RMSE (0.054 and 1.318, respectively). In this way, Web-based InfoCrop model becomes a novel and dynamic approach to the emerging crop simulation models as a decision support system for agriculture (Krishnan *et al.*, 2016)

Rao *et al.* (2016) modeled rice phenology, growth phase, and yield with the "Decision Support System for Agro technology Transfer (DSSAT) CERES rice model" and arrived at predicted values of yield under different carbon dioxide concentrations at four different locations in Eastern India out of which three locations were irrigated and one location was rainfed.

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}.

Singh *et al.* (2017) conducted an experiment to forecast rice yield using DSSAT during *kharif* 2015 and 2016 at Faizabad using three rice varieties Sarooj-52, NDR-359, and Swarna. The genetic coefficients for these varieties were determined using DSSAT. Further calibration and validation of the model is done by using these previously determined genetic coefficients. The rice yield was found to decrease due to delay in transplanting.

2.7. STATISTICAL MODELS

Kokate *et al.* (2000) conducted experiments at Ratnagiri, Maharashtra to develop a suitable statistical model for forecasting the yields of rice cultivars Jaya and Ratna based

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on yield characters and weather variables. Results revealed that integrating these two parameters in the same model gives reliable and predictive model for forecasting yield of rice rather than using either of these alone.

Attempts for predicting the yields of rice in Chattisgarh Plain and Bastar plateau and wheat in Vindhyachal Plateau zone of Madhya Pradesh were carried out by Agrawal *et al.* (2001) using agricultural inputs and time series data on weather in different districts within the selected zone. They concluded that when the crops were 12 weeks old, good and reliable crop yield forecasts were obtained using about 15 years' data.

Kandiannan *et al.* (2002) attempted to predict the first season (June- September) rice yield at Coimbatore, Tamil Nadu, India by including solar radiation as one of the predictors. The other selected predictors were percentage of rice area during first season (X_1), number of days with minimum temperature below 22°C in August and September (X_2), average daily maximum temperature for three months (July, August and September; X_3), average daily minimum temperature for three months (July, August and September; X_4), total of average sunshine hours in August and September (X_5), and total rainfall of July, August and September (X_6) total average solar radiation of August and September (X_7). Stepwise regression analysis was performed. They concluded that among the three models fitted, the model that can be used to forecast rice yield of first season was model III with minimum parameters (X_1, X_2, X_4 and X_7).

Patel (2004) attempted to analyze the effect of technological advancement and weather parameters on rice and to develop appropriate pre-harvest models for Kheda district of Gujarat state. Rice yield data of 33 years from 1967-68 to 2001-02 were used for the study. Different approaches used for developing yield forecasting models were week wise approach and crop stage-wise approach using original weather variables, and approaches using generated variables with correlation coefficients and week number as weight. Time trend was also included as an independent variable. It was found that week-wise approach based on original weather variables was best compared to. other approaches. Forecast of rice yield four weeks prior to the expected harvest can be

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provided by this approach. More than 75% of variation in rice yield can be explained by the selected model.

In 2009, Chauhan *et al*. tried to develop suitable agro-meteorological model for rice yield prediction in Bulsar district of Gujarat using six weather variables (bright sunshine hours, rainfall, maximum temperature, minimum temperature, morning relative humidity and afternoon relative humidity). For developing regression models, these weather variables were analyzed to establish crop weather relationship. Week wise, stage wise, period wise, week number as weight and correlation coefficient as weight were the approaches used for fitting the models. Among these, only model fitted with week wise approach gave yield prediction 2 weeks before harvest.

Agnihotri and Sridhara (2014) developed pre-harvest forecast models for rice yield for Dakshin Kannada, Uduppi and Uttar Kannada districts. The forecast models were able to explain the inter annual variation in the rice production to an extent of 86, 95, and 74% for Dakshin Kannada, Uduppi and Uttar Kannada respectively. It was concluded that, these models can be used to forecast rice yield two months before harvest.

Intra seasonal operational yield forecasts are developed by IMD under FASAL project, in association with 46 Agromet Field Units(AMFU) situated at State Agricultural Universities, IITs, ICAR institutes during *kharif* and *rabi* seasons using statistical models. Weekly weather data according to standard meteorological weeks along with long period crop yield data have been used for developing yield forecast models at district level. Models using composite weather variables are being studied for this purpose. Simple and weighted weather indices have been developed for specific variables as well as for interaction of two variables throughout the cropping period. (Ghosh *et al*., 2014)

Post-harvest stage rice yield forecast was worked out for Raipur condition by Jain (2016). Weekly weather data from 22^{nd} to 46^{th} standard meteorological weeks were taken for obtaining weighted and un-weighted indices for carrying out regression analysis. The present validation of regression model using SPSS (Statistical Packages for Social Sciences) showed that its accuracy rate remained 88% for the last ten years where it generally was above 95%. Due to changes in weather variables, MS Excel explained 20% variation in yield.

2.8. COMPARISON OF DIFFERENT WEATHER BASED MODELS

Chauhan (2007) conducted a study in Gujarat, India, to predict the rice yield using crop simulation models DSSAT and WOFOST, and to develop an appropriate agro-meteorological model for the same. The developed agro-meteorological models were adapted in rice yield prediction up to two months before the actual harvest of the crop.

A comparison of two rice growth simulation models ORYZA2000 and CERES-Rice were made by Wikarmpapraharn and Kositsakulchai, in 2010. It was carried out at Central plain in Thailand. Both models forecasted number of days to panicle initiation, days to flowering, grain yields and leaf area satisfactorily. They were evaluated using RMSE index which were within ±12% of the measurements. It was concluded that even though both models were effective in rice growth and development simulation, ORYZA 2000 can be used for assisting field level management in Central Plain of Thailand.

In 2011, Mukherjee *et al.* validated and compared two simulation models WOFOST and ORYZA2000 for predicting growth and productivity of 2 rice varieties PR 116 and PR 118 under central plain regions of Punjab. ORYZA2000 was found to be better than WOFOST model in simulating crop growth parameters and grain yield of rice after statistical evaluation.

Biswas *et al.* (2015) evaluated the applicability of statistical model in predicting rice yields and compared the performance of statistical and WOFOST models. It was observed that the statistical model performs better than the crop growth simulation model WOFOST. Hence, they concluded that, for region specific yield prediction, statistical model can be used as an effective tool, if developed properly and other effects can be incorporated through dummy variable.

Murari (2017) predicted the rice grain yield using statistical and crop simulation models in Chattisgarh plains. The results showed that the statistical model developed using weekly weather data showed an accuracy of 96.7 per cent with 3.3 per cent error during pre-harvest stage. The validation of crop simulation model CERES-Rice yielded an accuracy of 93 percent for which further improvement of genetic coefficients is required.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The study on "Comparison of different weather based models for forecasting rice yield in central zone of Kerala" was carried out during 2017-2018 at the Department of Agricultural Meteorology, College of Horticulture, Vellanikkara.

3.1 DETAILS OF THE EXPERIMENT

3.1.1. Location of experiment

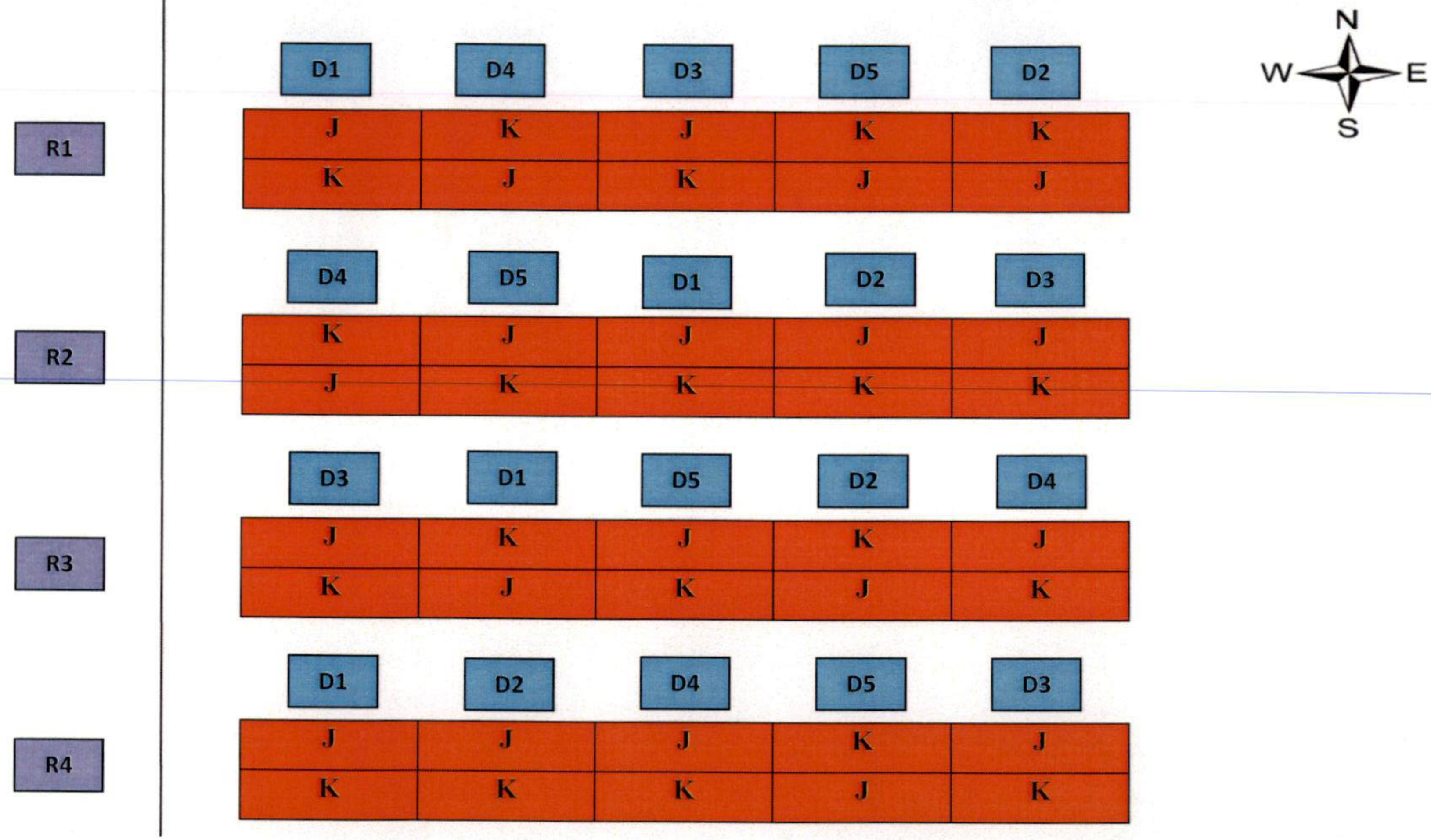
Field experiments were conducted during May 2017 to November 2017 at Agricultural Research Station, Mannuthy, Kerala Agricultural University, Thrissur. The station is located at 10^0 32' N latitude and 76^0 20' E longitudes at an altitude of 22m above mean sea level.

3.1.2. Soil Characters

The soil texture of the experimental field was sandy loam. Table 3.1 shows the physical properties of soil.

Table 3.1. Mechanical composition of soil of the experimental field

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



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

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

3.1.3 **Climate**

The experimental area is a typical warm humid tropical region. Both southwest and northeast monsoons provide rain to the area. The location experienced a mean maximum temperature of 30.9 ^{0}C and a mean minimum temperature of 22.8 ^{0}C during the experimental period. The maximum rainfall was obtained during the month of June which was recorded to be 640.2 mm. the average sunshine received during experiment was 3.7 hrs/ day. The mean forenoon relative humidity was 93.0% and the mean afternoon relative humidity was 73.0%. The average wind speed was 1.1 kmh^{-1}. Table 3.2 represents the details of the weekly weather parameters during the experiment.

3.1.4 **Season of the experiment**

The field experiment was conducted from May 2017 to November 2017 during *kharif* season.

3.2 EXPERIMENTAL MATERIALS AND METHODS

3.2.1 **Variety**

The study was conducted using two most popular varieties among farmers Jyothi and Kanchana. These varieties are categorized as short duration varieties with Jyothi having duration of 110-125 days and Kanchana having duration of 105-110 days.

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

Kanchana is the recommended variety for all the agro-climatic zones of Kerala. It is derived from the cross between IR 36 and Pavizham.

Table 3.2 Weekly weather parameters during the period of experiment 2017

Week No.	Tmax (°C)	Tmin (°C)	RH I (%)	RH II (%)	VPD I (mm Hg)	VPD II (mm Hg)	WS (km hr^{-1})	BSS (hrs)	RF (mm)	RD (days)	EVP (mm)
23	30.4	24.1	92	75	23.1	22.7	0.9	1.3	60.6	5.0	2.3
24	30.7	23.9	97	79	23.6	23.9	0.8	0.9	151.2	5.0	2.2
25	30.7	23.6	94	78	23.2	23.4	4.1	4.1	104.4	6.0	3.0
26	29.7	22.4	96	83	22.8	22.8	1.3	1.3	301.8	7.0	2.5
27	30.2	22.7	96	77	22.3	22.8	1.8	1.8	77.1	7.0	2.8
28	30.3	22.9	94	75	22.3	22.9	1.5	1.5	97.5	4.0	2.5
29	30.8	22.1	95	77	21.9	23.1	2.1	2.1	171.5	6.0	2.5
30	30.3	23.0	90	68	22.7	22.6	1.6	5.2	28.8	4.0	2.7
31	30.2	23.9	94	75	23.4	22.8	1.7	5.1	87.1	2.0	3.0
32	30.6	23.8	95	73	22.9	22.3	1.0	3.5	80.8	4.0	2.8
33	30.5	23.4	96	79	22.9	23.4	0.8	3.5	83.8	3.0	3.6
34	30.1	23.1	97	77	22.7	23.3	0.8	2.1	97.7	3.0	2.3
35	29.4	23.1	95	80	22.7	23.5	1.0	2.9	143.6	6.0	3.1
36	31.4	23.6	94	74	23.3	24.1	0.7	4.4	56.5	5.0	2.8
37	32.5	23.2	96	78	23.1	23.5	0.7	3.9	91.9	5.0	2.8
38	29.9	22.2	95	71	22.4	22.6	1.0	4.2	211.5	5.0	2.9
39	30.7	22.9	94	70	23.1	22.1	0.2	4.1	39.0	2.0	2.2
40	31.2	22.8	95	72	23.1	22.5	0.1	4.1	61.1	2.0	2.3
41	31.7	22.8	93	71	22.4	22.6	0.1	4.5	14.6	2.0	2.2
42	31.0	22.1	95	79	22.4	23.5	0.1	3.9	55.8	3.0	2.2
43	31.2	21.7	91	64	21.4	22.0	0.3	6.0	50.5	2.0	2.4
44	33.2	22.7	83	58	20.7	21.2	1.4	7.3	29.9	2.0	3.2
45	32.1	21.9	85	61	21	20.6	2.2	5.7	3.5	1.0	2.7
46	33.0	20.8	93	57	22.7	20.4	0.6	6.7	0.0	0.0	2.5

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

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3.2.2. Design and Layout

The experimental design used was split plot design with five dates of planting (from 5th June to 5th August) as the main plot treatments and two varieties Jyothi and Kanchana as sub plot treatments. It was replicated four times. Fig. 3.1 shows the field layout. The field was divided into 40 plots of 5x4 m^2size each. A spacing of 15x10 cm was maintained.

3.2.3. Treatments

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

Table 3.3. Treatments used in the experiment

MAIN PLOT	**SUB PLOT**
Date of planting	**Variety**
5th June	Jyothi
	Kanchana
20th June	Jyothi
	Kanchana
5th July	Jyothi
	Kanchana
20th July	Jyothi
	Kanchana
5th August	Jyothi
	Kanchana

3.3 CROP MANAGEMENT

3.3.1. Nursery Management

Nurseries were made eighteen days previous to each date of transplanting. 2-3 seedlings were transplanted per hill in the field. Provision for adequate irrigation and drainage were made. Plant protection measures are also undertaken.

Plate I. General view of the experimental field

Plate II. Nursery preparation

Plate III. Transplanting

Plate IV. Harvesting

Plate V. Threshing

3.3.2. Land Preparation and planting

According to the packages of practices recommended (KAU, 2016) for Jyothi and Kanchana, experimental field was cleared, ploughed well and puddled. As per the layout, plots were prepared.

3.3.3. Application of Manures and Fertilizers

During land preparation, farm yard manure was applied in the field at the rate of 5000 kg ha $^{-1}$. To supply the required nutrients (70N: 35 P_2O_5 : 45 K_2O kg ha $^{-1}$) fertilizers like urea, rajphos and potash were used. The entire dose of P2O5, half dose of N and K2O were applied as basal dose while remaining amount of fertilizers top dressed at 30 days after transplanting.

3.3.4. After Cultivation

For controlling weeds, a pre-emergence herbicide Londax (bensulfuron methyl 0.6% + Pretilachlor 6% GR) was applied at the rate of 1 kg ha $^{-1}$. Hand weeding was done twice, first at 30 days after transplanting and second at 45 days after transplanting. Recommended plant protection measures were implemented to control pests and diseases.

3.4. OBSERVATIONS

Plants were selected randomly for recording observations on growth and yield parameters in each replication for each treatment from a unit area after leaving the border plants. The observations were recorded during different phenological stages of the two rice varieties.

3.4.1. **Biometric characters**

3.4.1.1. Plant height

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

3.4.1.2 Leaf area

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

3.4.1.3. Dry matter production

The observation of biomass production or dry matter accumulation was taken at 15 days' interval after transplanting. Selection of two sample hills were done were randomly and uprooted from the experimental field. First, the samples were dried in sun and thereafter oven dried at a temperature of 80^0C to a constant weight. Then the biomasses were recorded in gram per plant.

3.4.1.4. Number of tillers / unit area

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

3.4.1.5. Number of panicles / unit area

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

3.4.1.6. Number of spikelets / panicle

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

3.4.1.7. Number of filled grains / panicle

Five plants were selected randomly from each experimental plot to count the number of filled grains per panicle at the time of harvest.

3.4.1.8. Thousand grain weight

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

3.4.1.9. Grain yield

The produce from each plot was threshed, properly winnowed and dried to 14 percent moisture, weighed and expressed as kg ha $^{-1}$.

3.4.1.10. Straw yield

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

3.4.2. Phenological observations

3.4.2.1. Number of days for active tillering

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

3.4.2.2. Number of days for panicle initiation

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

3.4.2.3. Number of days for booting

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

3.4.2.4. Number of days for heading

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

3.4.2.5. Number of days for 50% flowering

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

3.4.2.6. Number of days for physiological maturity

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

3.4.3 Physiological observations

3.4.3.1. Leaf Area Index (LAI)

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

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

3.4.3.2 Net Assimilation Rate (NAR)

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

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

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

3.4.3.3. Leaf Area Duration (LAD)

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

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

L_1 = LAI at time t_1

L_2 = LAI at time t_2

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

3.4.3.4. Crop Growth Rate (CGR)

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

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

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

3.4.4. Soil analysis

Before planting, soil samples were collected from the field from 15 cm and 30 cm depths. The collected samples were dried and powdered separately and the respective samples were analyzed for pH, available phosphorous, available potassium and organic carbon content. Table 3.4 shows the results of chemical analysis.

3.4.5. Weather data

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

Table 3.4. Chemical properties of the soil

Sl no.	Parameter	Sampling depth in cm	
		0 - 15	15 - 30
1	Organic carbon (%)	0.8	0.82
2	Soil pH	4.24	4.33
3	Available nitrogen (kg ha^{-1})	0.08	0.08
4	Available phosphorous (kg ha^{-1})	116.81	113.29
5	Available potassium (kg ha^{-1})	291.42	284.26

Table 3.5. Weather parameters used in the experiment

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

3.5 STATISTICAL ANALYSIS

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

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

$$CD_1 = t_1 \times SE_1$$

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

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

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

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

r = number of replications

b = number of sub plot treatments

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

$$CD_2 = t_2 \times SE_2$$

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

SE_2 = Standard error of difference between two sub plot treatments

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

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

r = Number of replications

a = Number of main plot treatments

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

$$CD_3 = t \times SE_3$$

Where,

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

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

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

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

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

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

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

r = Number of replications

b = Number of sub plot treatments

To study the impact of weather parameters on biometric and phenological characters of the crop, correlation analysis was carried out. The experimental data of five years from 2013 - 2017 were used for the study. Critical growth stage wise weather variables were worked out from the daily data of five years and correlated with the important crop growth and yield characters obtained from five years of field experiment.

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

3.6. CROP GROWTH SIMULATION

A crop growth simulation model simulates the processes of crop growth and its development as a function of crop management, weather conditions and soil conditions. Crop simulation models have wider applicability in fields like on-farm and precision management and in assessing the impact of climate change and climate variability on regional basis. Decision support system for agro technology transfer (DSSAT) and its crop simulation models can be used for this purpose. The input required by these crop simulations includes the daily weather data, soil surface and profile information and detailed crop management information. For applications, DSSAT combines crop, soil, and weather database with crop models and application programs to simulate multi-year outcomes of crop management strategies.

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

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DSSAT v. 4.6 includes different application programmes for seasonal, spatial, sequence and crop rotation analysis for the assessment of economic risks, environmental impacts, climate variability, climate change, soil carbon sequestration and precision management.

3.6.1. CERES-Rice model

Crop Estimation through Resource and Environment Synthesis (CERES) model was developed to simulate crop growth, development and yield as a function of weather, soil water, cultivar, planting density and nitrogen. As CERES-Rice model is a part of Decision Support System for Agrotechnology Transfer (DSSAT), it also requires a common input and output data format.

The operation and calibration of the CERES- Rice models can be done by the minimum data set proposed by Hunt and Boote (1994). In the present study, CERES-Rice model was run using the weather, soil, crop management practices and experimental data of past five years' experiment from 2013 – 2017 of two varieties Jyothi and Kanchana The input and output files of CERES-Rice include the following given in Table 3.6 and Table 3.7.

3.6.1.1. Input files and experiment data files

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

3.6.1.2. Output files

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

3.6.2. Running the Crop Model

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

Table 3.6. Input files of CERES-Rice model

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

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

Table 3.7. Output files of CERES-Rice model

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

3.6.3. Model Calibration and Evaluation

Model calibration is the adjusting of parameters to compare simulated values and observed values. Adjusting the relevant coefficients to attain the possible match between simulated and observed number of days taken for the occurrence of phenological events was done to develop genetic coefficients for CERES-Rice. For calibration of genetic coefficients of CERES-Rice model, minimum crop performance data set of planting date, plant density, row spacing, amount of fertilizer application, irrigation data, panicle initiation date, physiological maturity date, harvesting date, harvesting method, grain yield/m^2 and leaf area in 6 crop growth stages were assembled. Statistical parameters such as Normalized Root Mean Square Error (RMSE) and D-stat index are the common tools used to test the goodness-of-fit of simulation models thereby model performance.

3.7. Crop weather models based on Statistical techniques

The weather variables considered for studying the crop weather relationships in two rice varieties are presented in the Table 3.8 given below

Table 3.8. Variables used in crop weather models

Variables	Description
Y	Average yield in tonnes/ha
X_1	Maximum temperature
X_2	Minimum temperature
X_3	Forenoon relative humidity
X_4	Afternoon relative humidity
X_5	Forenoon vapour pressure deficit
X_6	Bright sunshine hours
X_7	Rainfall
X_8	Evaporation
X_9	Number of rainy days

Stepwise regression technique was used for choosing the best regression equation from a number of variables. SPSS computer software aided the study. Mainly four methods were adopted for developing crop yield forecasting model with better-adjusted R^2 and MAPE values.

1. Based on weekly weather variables
2. Based on fortnightly weather variables
3. Based on crop stage wise weather variables
4. Based on composite weather variables

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3.7.1. Crop weather models based on weekly weather variables

In this method, the weekly weather variables are used for fitting regression model, which is arranged according to standard meteorological weeks. The crop period ranged between 23rd to 43rd meteorological weeks. Aiming at developing pre – harvest models, weekly weather variables from 1st to 7th weeks from transplanting were taken to carry out stepwise regression. Using the variables selected from the regression method, models were fitted. Likewise, the regression models were fitted using 1st to 8th, 1st to 9th and 1st to 10th week weather variables. The same procedure was followed for developing models for Jyothi and Kanchana. The details of weather variables taken for the analysis is given in Table 3.9. The general form of the model is

$$Y = A_0 + \sum_{i=1}^{p} \sum_{j=1}^{w} a_{ij} X_{ij}$$

Where

Y = Average yield (tonnes/ha)

A_o = constant

X_{ij} = observed value of i^{th} weather variable in j^{th} week

i = 1, 2,…p=8, the number of weather variables considered.

j = 7,8,9 and 10

a_{ij} = partial regression coefficient associated with each X_{ij}

3.7.2. Crop weather models based on fortnightly weather variables

In this approach, fortnightly averaged weather variables were taken in its original form. Fortnightly weather variables from 1st to 3rd fortnights from transplanting were taken to carry out stepwise regression. Models were fitted using the variables selected from the regression method. Likewise, 1st to 4th fortnights and 1st to 5th fortnights weather variables were also utilized for fitting regression models. Same procedures were followed for both Jyothi and Kanchana. The description of weather variables used for fitting the model is given in the Table. 3.10.

Table 3.9. Weather variables included in crop weather models using weekly weather variables

Crop Week No.	Tmax (X_{1j})	Tmin (X_{2j})	RHI (X_{3j})	RHII (X_{4j})	VPI (X_{5j})	BSS (X_{6j})	RF (X_{7j})	Epan (X_{8j})
1	X_{11}	X_{21}	X_{31}	X_{41}	X_{51}	X_{61}	X_{71}	X_{81}
2	X_{12}	X_{22}	X_{32}	X_{42}	X_{52}	X_{62}	X_{72}	X_{82}
3	X_{13}	X_{23}	X_{33}	X_{43}	X_{53}	X_{63}	X_{73}	X_{83}
4	X_{14}	X_{24}	X_{34}	X_{44}	X_{54}	X_{64}	X_{74}	X_{84}
5	X_{15}	X_{25}	X_{35}	X_{45}	X_{55}	X_{65}	X_{75}	X_{85}
6	X_{16}	X_{26}	X_{36}	X_{46}	X_{56}	X_{66}	X_{76}	X_{86}
7	X_{17}	X_{27}	X_{37}	X_{47}	X_{57}	X_{67}	X_{77}	X_{87}
8	X_{18}	X_{28}	X_{38}	X_{48}	X_{58}	X_{68}	X_{78}	X_{88}
9	X_{19}	X_{29}	X_{39}	X_{49}	X_{59}	X_{69}	X_{79}	X_{89}
10	X_{110}	X_{210}	X_{310}	X_{410}	X_{510}	X_{610}	X_{710}	X_{810}

Table 3.10. Variables used in crop weather models based on fortnightly weather variables

Fortnights	Tmax (X_{1j})	Tmin (X_{2j})	RHI (X_{3j})	RHII (X_{4j})	VPI (X_{5j})	BSS (X_{6j})	RF (X_{7j})	Epan (X_{8j})
1	X_{11}	X_{21}	X_{31}	X_{41}	X_{51}	X_{61}	X_{71}	X_{81}
2	X_{12}	X_{22}	X_{32}	X_{42}	X_{52}	X_{62}	X_{72}	X_{82}
3	X_{13}	X_{23}	X_{33}	X_{43}	X_{53}	X_{63}	X_{73}	X_{83}
4	X_{14}	X_{24}	X_{34}	X_{44}	X_{54}	X_{64}	X_{74}	X_{84}
5	X_{15}	X_{25}	X_{35}	X_{45}	X_{55}	X_{65}	X_{75}	X_{85}

The general form of the model is

$$Y = A_0 + \sum_{i=1}^{p} \sum_{j=1}^{w} a_{ij} X_{ij}$$

Where

Y = average yield (tonnes/ha)

A_o = constant

X_{ij} = Average value of i^{th} weather variable in j^{th} fortnight

i = 1,2,3,…p = 8, j= 1,2, …w = 3,4,5

a_{ij} = partial regression coefficient associated with X_{ij}

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

In this method, the weather variables experienced during different phenophases of rice (transplanting to active tillering, active tillering to panicle initiation, panicle initiation to booting, booting to heading, heading to 50% flowering, and 50% flowering to physiological maturity) were used for developing the crop weather models. Stepwise regression method was carried out to fit the model in each case. The description of variables used in this model is given in Table 3.8. The model takes the general form

$$Y = b_0 + \sum_{i=1}^{p} b_i X_i$$

Where

Y = Average yield (tonnes/ha)

b_o = constant

X_i = observed value of i^{th} weather variable in a crop stage; i = 1, 2,…p

p = no. of weather variables

b_i = partial regression coefficient associated with X_i

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3.7.4. Crop yield forecasting using composite weather parameters

The yield-forecasting model based on partial crop season data given by Agrawal *et al.* (1980) was used for predicting the yield of rice. The forecast model is given by

$$Y = A_0 + \sum_{i=1}^{p}\sum_{j=0}^{1} a_{ij} Z_{ij} + \sum_{i \neq i'=1}^{p} a_{ii'j} Z_{ii'j} + e$$

where

$$Z_{ij} = \sum_{w=1}^{m} r_{iw}^{j} X_{iw}$$

$$Z_{ii'j} = \sum_{w=1}^{m} r_{ii'w}^{j} X_{iw} X_{i'w}$$

Y = average yield (tonnes/ha)

A_O = Constant

r_{iw} = correlation coefficient between yield and i^{th} weather variable X_{iw} in w^{th} week

$r_{ii'w}$ = correlation coefficient between yield and product of i^{th} and i'^{th} weather variable ($X_{iw}X_{i'w}$)

m = week of forecast

p = number of weather variables used

a_{ij} and $a_{ii'j}$ = regression coefficients

e = error term

In this method, two types of weather indices were calculated for each weather variable; unweighted index Z_{i0} (simple sum of weather variables in different weeks) and weighted index Z_{i1} (weighted total) where weights used are the correlation coefficients between yield and weather parameter during respective weeks. Joint effects of weather variables were computed as

$$Z_{ii'0} = \sum_{w=1}^{m} r_{ii'w}^{0} X_{iw} X_{i'w} = \sum_{w=1}^{m} X_{iw} X_{i'w}$$

= Sum of product of two weather variables in different weeks up to week of forecast

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$$Z'_{ii}1 = \sum_{w=1}^{m} r^{1}_{ii'w} X_{iw} X_{ii'w}$$

= sum of product of correlation (between yield and product of two weather variables) and product of two weather variables in different weeks up to week of forecast.

Stepwise regression technique was used to fit the model based on composite weather indices. Generated variables obtained using this method and included in analysis are presented in the Table. 3.11.

Six models were developed using generated weather parameters for 5, 6, 7, 8, 9 and 10 weeks from transplanted stage for each of the varieties Jyothi and Kanchana for pre-harvest yield prediction.

3.8. MODEL ACCURACY MEASURES

Model accuracy measures like adjusted R^2 and Mean Absolute Percentage Error (MAPE) were used to compare the accuracy of the fitted models. These measures are given below.

$$Adjusted\ R^2 = 1 - (1 - R^2)\left(\frac{n-1}{n-p}\right)$$

Where, R^2 = square of correlation between observed and estimated values $0 \leq R^2 \leq 1$

n = Number of observations

p = Number of predictors

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\frac{|Y_i - \widehat{Y_i}|}{O_i} \times 100$$

Where, Y_i = observed yield

$\widehat{Y_i}$ = estimated yield

n = number of observations

Table 3.11. Variables used in crop weather models based on composite weather variables

a) **First order generated variables (Z_{ij})**

Z_{ij}	Z_{1j}	Z_{2j}	Z_{3j}	Z_{4j}	Z_{5j}	Z_{6j}	Z_{7j}	Z_{8j}
Z_{i0}	Z_{10}	Z_{20}	Z_{30}	Z_{40}	Z_{50}	Z_{60}	Z_{70}	Z_{80}
Z_{i1}	Z_{11}	Z_{21}	Z_{31}	Z_{41}	Z_{51}	Z_{61}	Z_{71}	Z_{81}

b) **Second order generated variables ($Z_{ii'j}$)**

$Z_{ii'j}$	$Z_{ii'0}$	$Z_{ii'1}$	$Z_{ii'j}$	$Z_{ii'0}$	$Z_{ii'1}$
Z_{12j}	Z_{120}	Z_{121}	Z_{13j}	Z_{130}	Z_{131}
Z_{14j}	Z_{140}	Z_{141}	Z_{15j}	Z_{150}	Z_{151}
Z_{16j}	Z_{160}	Z_{161}	Z_{17j}	Z_{170}	Z_{171}
Z_{18j}	Z_{180}	Z_{181}	Z_{23j}	Z_{230}	Z_{231}
Z_{24j}	Z_{240}	Z_{241}	Z_{25j}	Z_{250}	Z_{251}
Z_{26j}	Z_{260}	Z_{261}	Z_{27j}	Z_{270}	Z_{271}
Z_{28j}	Z_{280}	Z_{281}	Z_{34j}	Z_{340}	Z_{341}
Z_{35j}	Z_{350}	Z_{351}	Z_{36j}	Z_{360}	Z_{361}
Z_{37j}	Z_{370}	Z_{371}	Z_{38j}	Z_{380}	Z_{381}
Z_{45j}	Z_{450}	Z_{451}	Z_{46j}	Z_{460}	Z_{461}
Z_{47j}	Z_{470}	Z_{471}	Z_{48j}	Z_{480}	Z_{481}
Z_{56j}	Z_{560}	Z_{561}	Z_{57j}	Z_{570}	Z_{571}
Z_{58j}	Z_{580}	Z_{581}	Z_{67j}	Z_{670}	Z_{671}
Z_{68j}	Z_{680}	Z_{681}	Z_{78j}	Z_{780}	Z_{781}

Z_{ij} refers to the generated variable of the i^{th} weather variable where j is the power of correlation coefficient

$j = 0$ or 1

$Z_{ii'j}$ refers to the generated variable of the product of i^{th} and i'^{th} weather variables where j is the power of correlation coefficient

$j = 0$ or 1

1 – Maximum temperature
2 – Minimum temperature
3 – Forenoon relative humidity
4 – Afternoon relative humidity
5 – Forenoon vapour pressure deficit
6 – Bright sunshine hours
7 - Rainfall
8 – Pan Evaporation

RESULTS

4. RESULTS

The results gathered from the study "Comparison of different weather based models for forecasting rice yield in central zone of Kerala" are described here.

4.1. Phenophases

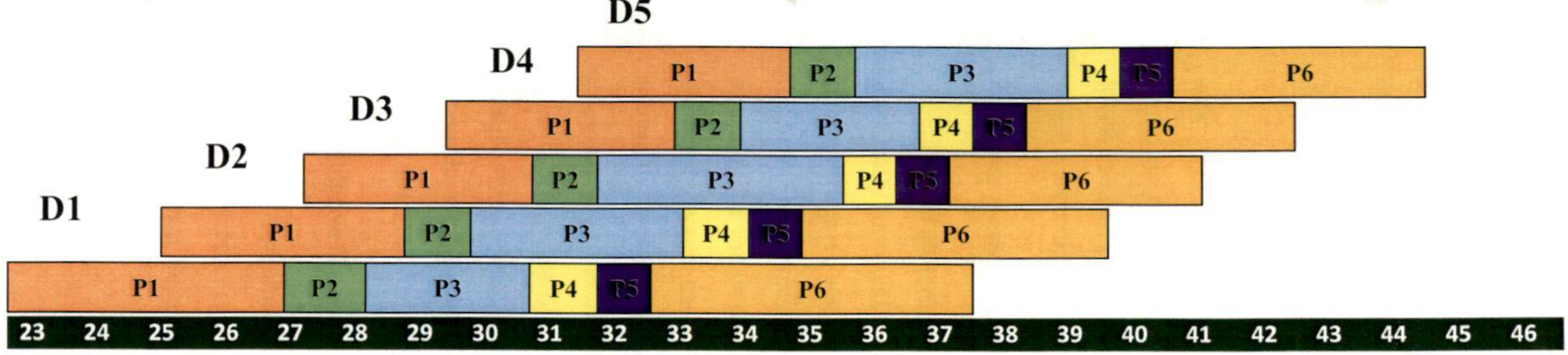
Phenology involves the study of periodic plant cycle events as influenced by the plant environment and climatic conditions. Stable crop yields and quality of produce can be attained by obtaining the knowledge of timing of different phenological events and their variability in a crop by adopting sustainable crop management practices.

The entire life cycle of the rice crop is subdivided into six distinct growth and development phases in this study from transplanting to physiological maturity, which are known as phenophases. These phenophases are:

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

Different periods like vegetative period, reproductive period and ripening period, which are denoted, by P7, P8 and P9 respectively were used to group the above-mentioned phenophases. The phenophases P1 - P2 are added in vegetative period while the phenophases P3 - P4 are included in reproductive period and P5 - P6 are included in ripening period.

The phenological calendar given in Fig. 4.1 (a and b) shows the duration of phenophases P1 - P6 of both Jyothi and Kanchana for different dates of planting used in the experiment (June 5th - August 5th) during *kharif* season 2017. Each phenophases corresponds to the standard week it occurred in the figure. Different dates of planting and varieties showed variation in duration of different phenophases. Jyothi took more days to complete most of the

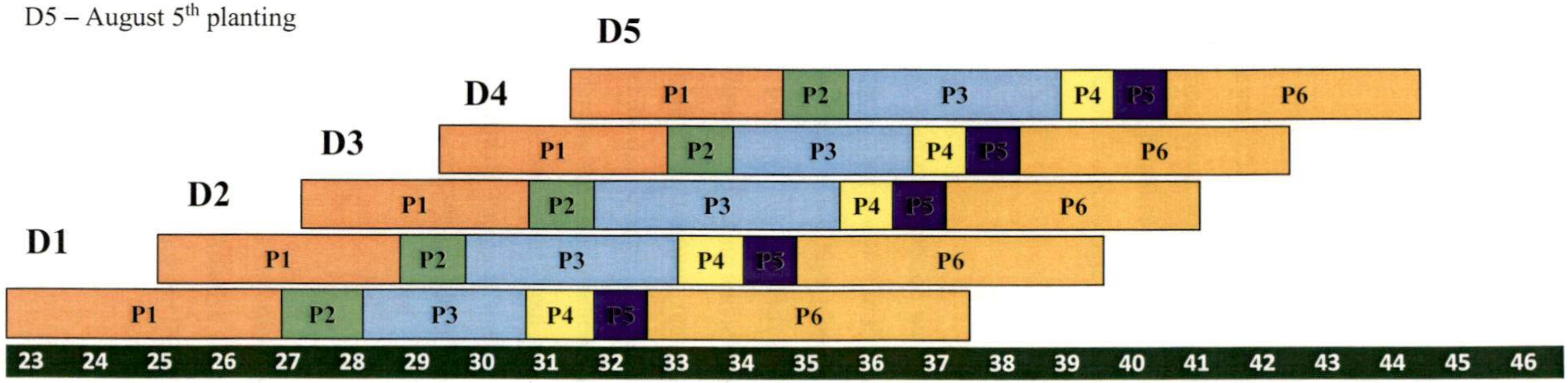


Standard weeks (2017)

Fig. 4.1 (a) Phenological calendar of Jyothi

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

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



Standard weeks (2017)

Fig. 4.1(b) Phenological calendar of Kanchana

phenophases than Kanchana. Delay in date of planting led to the reduction of phenophases duration in both the varieties.

4.2. Weather prevailed during crop growth period

The weather prevailed during the study period of the year 2017 over the crop growing area were recorded in terms of maximum temperature, minimum temperature, relative humidity, vapour pressure deficit, rainfall, number of rainy days, bright sunshine hours, wind speed and pan evaporation. Fig. 4.2 - 4.7 represent the different meteorological parameters, which were averaged over standard meteorological weeks graphically.

4.2.1. Air temperature

The air temperature experienced during the entire crop-growing period was plotted graphically on weekly basis in terms of maximum and minimum temperatures in Fig.4.2. In the same figure, weekly mean temperature and temperature range were also plotted. The maximum and minimum temperature showed a nonlinear progress for different dates of planting. The values were seemingly decreasing towards the June 20th planting and afterwards increases towards the later date of planting. Both the maximum and minimum temperature showed this trend up to a particular stage of growth where after the temperature increased. The maximum temperature was observed during the August 5th planting where it reached a value of 31°C. The value of temperature range (TR) was from 6.8 to 8.0 during different stages of growth where it was stable around 7.5 towards the later stage of growth. The mean temperature during the crop period was continuously varying between 26°C to 27.5°C. Much difference was not observed for both the varieties Jyothi and Kanchana.

4.2.2. Relative Humidity (RH)

The forenoon and afternoon relative humidity (RHI and RHII) were recorded for the entire experimental period. These observations along with calculated mean relative humidity (RHmean) were plotted graphically according to standard meteorological weeks in Fig.4.3.

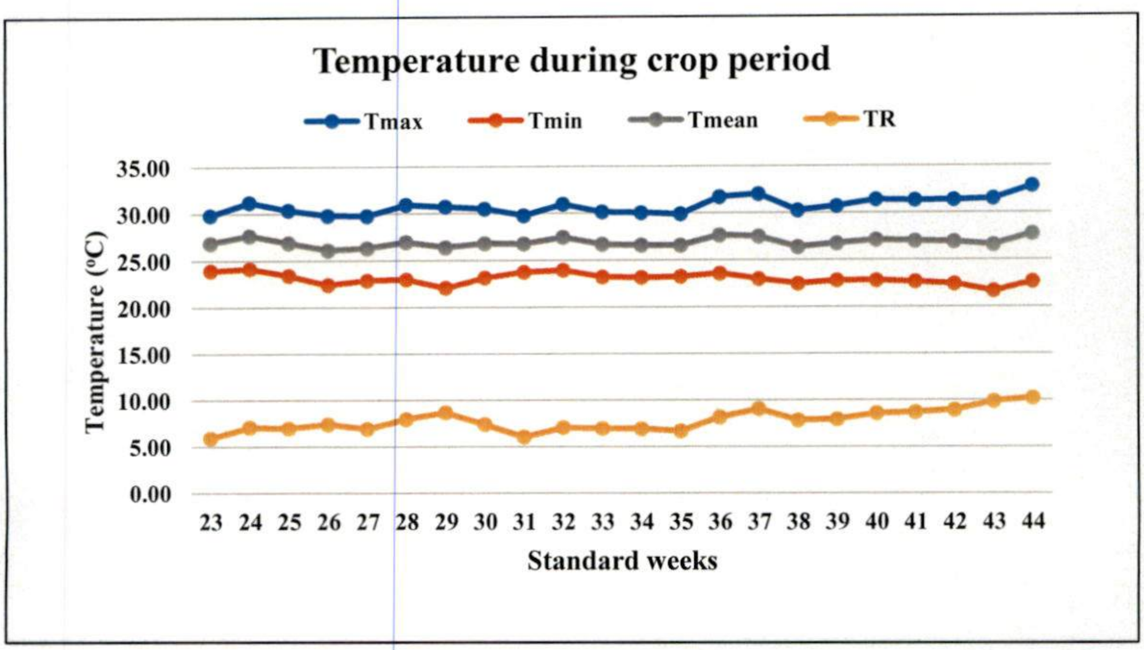


Fig. 4.2. Weekly air temperature during the crop period

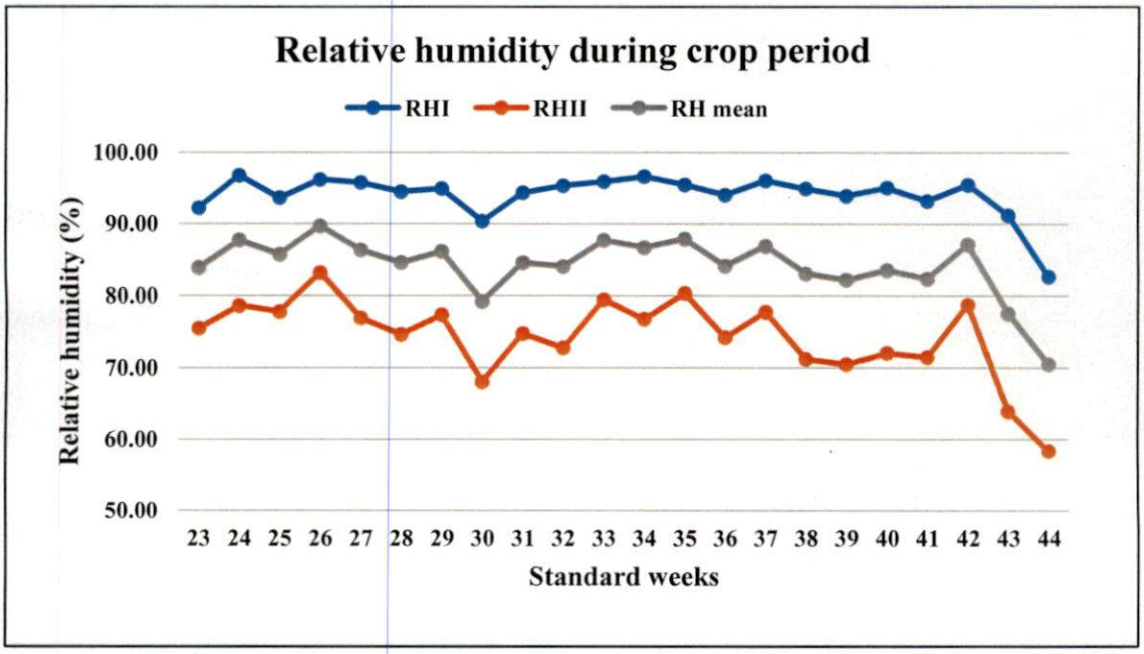


Fig. 4.3. Weekly relative humidity (RH) during crop period

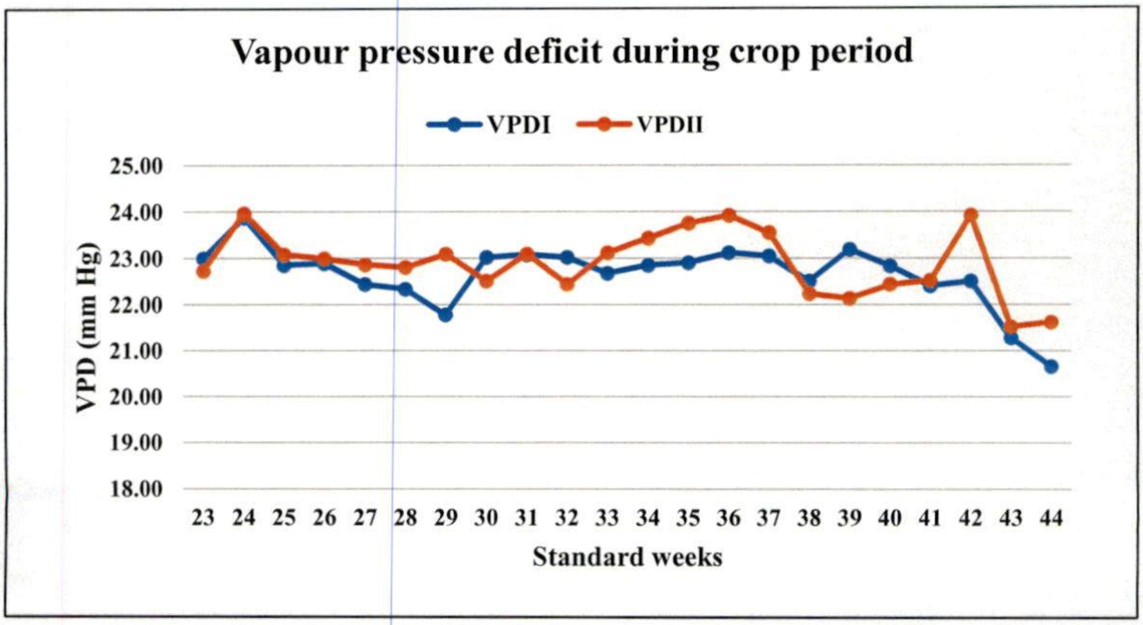


Fig. 4.4. Weekly vapour pressure deficit (VPD) during crop period

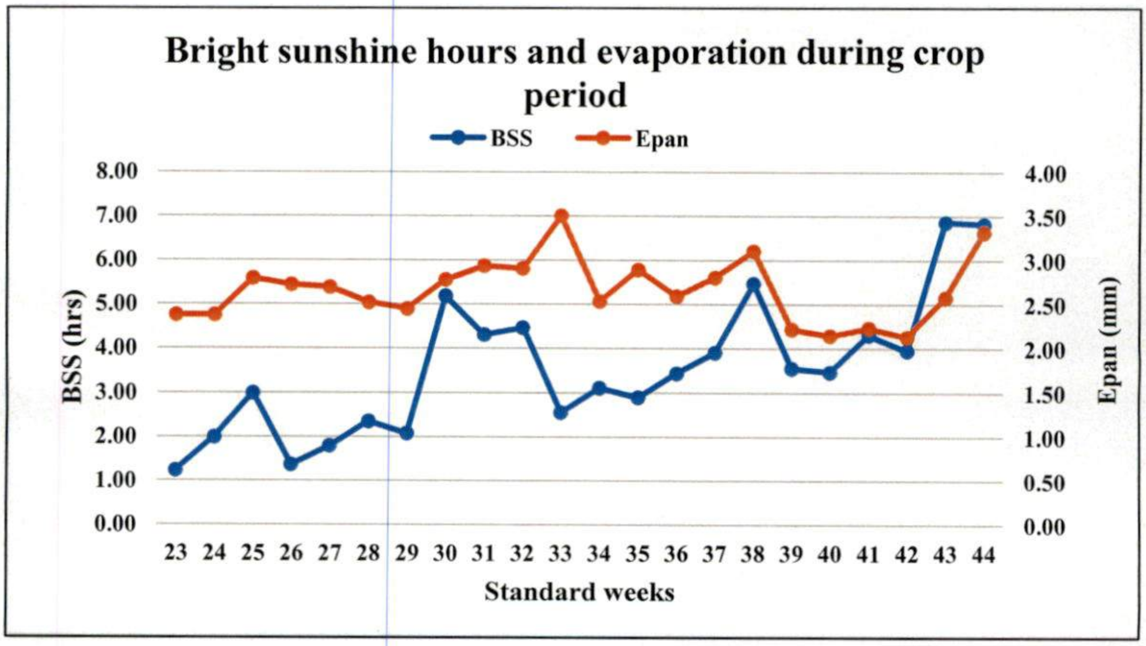


Fig.4.5. Weekly bright sunshine hours (BSS) and evaporation (Epan) during crop period

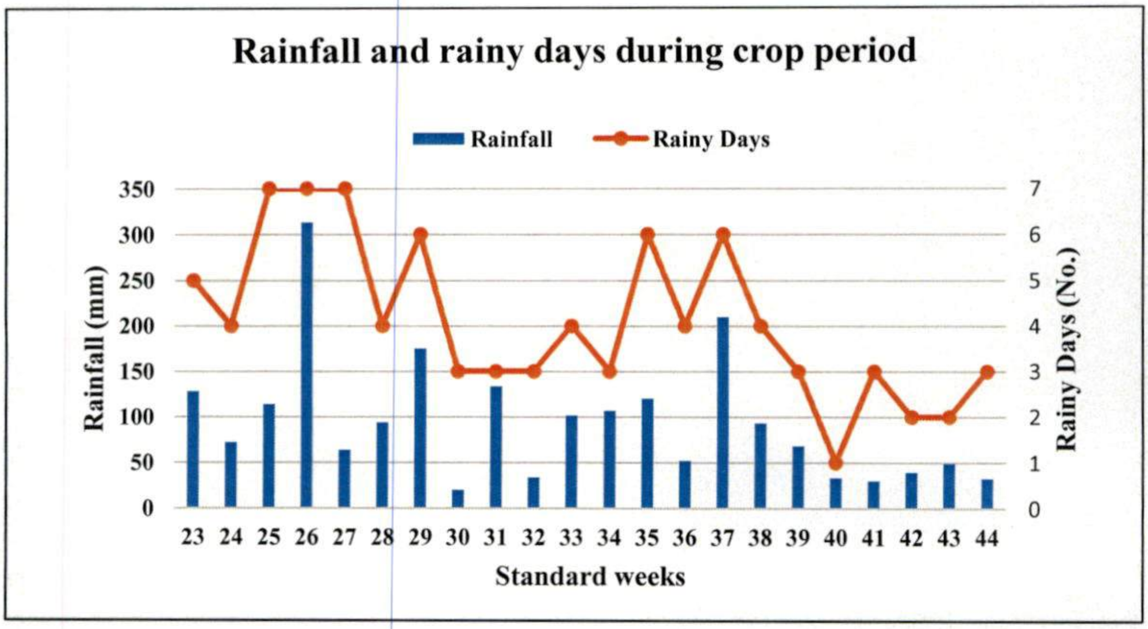


Fig.4.6. Weekly rainfall (RF) and rainy days (RD) during crop period

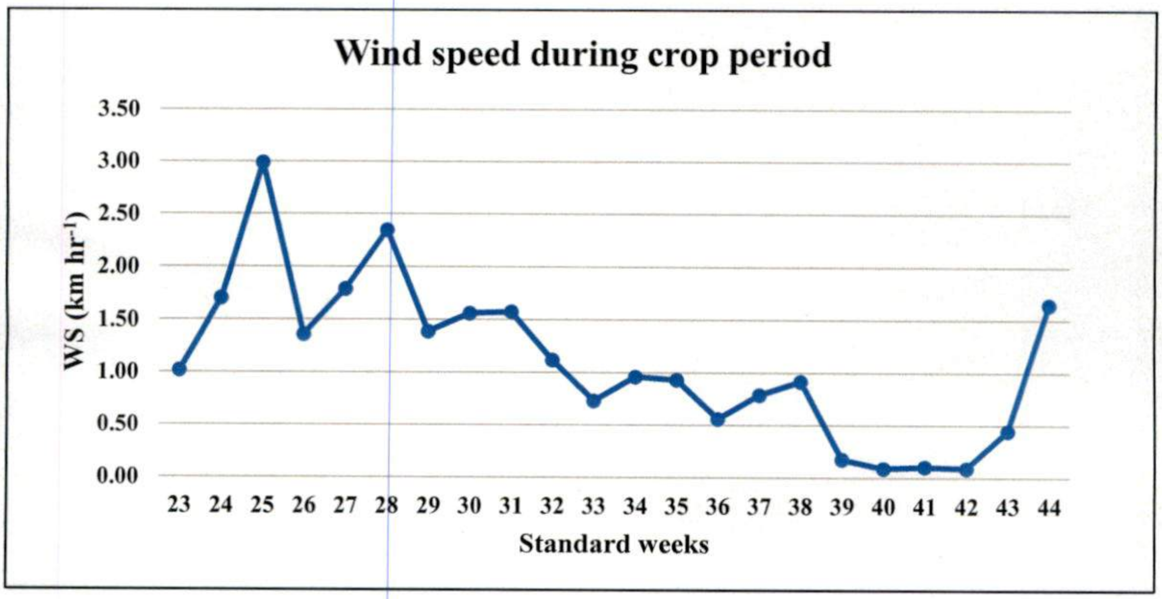


Fig. 4.7. Weekly wind speed during crop period

The forenoon relative humidity did not show any considerable change over different standard meteorological weeks for different dates of planting except a decrease during the last considered week. Afternoon relative humidity and mean relative humidity also showed same trend as forenoon relative humidity. Forenoon relative humidity ranged between 82.6 – 96.7% and afternoon relative humidity ranged between 61.1 – 83.1%. Both the varieties were exposed to same RH conditions.

4.2.3. Vapour Pressure Deficit (VPD)

The forenoon and afternoon vapour pressure deficit were obtained using the dry and wet bulb temperatures recorded throughout the experimental period. The forenoon vapour pressure deficit and afternoon vapour pressure deficit experienced during the crop period averaged according to standard meteorological weeks is plotted graphically and presented in Fig. 4.4.

The forenoon vapour pressure deficit (VPD I) for the period varied between 20.7 to 23.8 mm of Hg and afternoon vapour pressure deficit (VPD II) varied between 21.5 to 23.6 mm Hg. Jyothi and Kanchana experienced similar conditions.

4.2.4. Wind speed (WS)

The wind speed showed higher values during early periods of crop experiment and as the experiment progressed, the values declined. It showed values at a range of 0.1 to 4.1 $kmhr^{-1}$ during this period. The value showed less variation as calculated over a longer period. It is plotted graphically in Fig. 4.7.

4.2.5. Bright Sunshine Hours (BSS)

Fig. 4.5. shows the trend of bright sunshine hours prevailed during the crop period. The bright sunshine duration showed an increasing and then decreasing trend in the early growth stages with progress in date of planting. However, it showed constant values when the maturity phase is approached. It ranged from 0.9 – 7.3 hrs day^{-1}. The accumulated sunshine hours were similar to both varieties.

4.2.6. Rainfall and rainy days (RF and RD)

The rainfall was showing a decreasing trend towards the crop growth period as it progressed with the monsoon which is plotted graphically in Fig. 4.6. The rainfall also showed accumulated values towards the later growth stages. June 20th planting obtained an accumulated rainfall of 1634 mm from transplanting to maturity stage, where August 5th planting obtained less rainfall of 1103 mm. In addition, the number of rainy days were low for August 5th planting as 44 when compared with 69 for June 5th planting.

4.2.7. Pan evaporation (Epan)

The pan evaporation recorded during the entire experimental period was averaged according to standard meteorological weeks from 23 to 44. The value ranged from 2.1 to 3.5 mm. It is plotted graphically and presented in Fig. 4.5.

It showed an increasing trend during the early stages of first two plantings then showed a decreasing trend during the early stages of third and fourth dates of planting. Maximum value of 3.6mm was observed during 33rd week. Thereafter it decreased and showed an increase during last stage of fifth planting.

4.3. Phenological observations of crop growth and development

Number of days taken to attain different phenophases were noted for Jyothi and Kanchana for all dates of planting. Active tillering, panicle initiation, booting, heading, 50% flowering and physiological maturity were the phenophases considered. The observations are presented in Table 4.1.

4.3.1. Number of days for active tillering

From first to the last date of planting, the number of days taken for active tillering showed a decreasing trend. In the case of most of the plantings, Jyothi took more days compared to Kanchana. In August 5th planting, Jyothi and Kanchana took least number of days (23 days) to complete active tillering stage.

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

Crop Stages	Dates of planting									
	June 5th		June 20th		July 5th		July 20th		August 5th	
	J	K	J	K	J	K	J	K	J	K
Active tillering	28	27	26	24	24	24	26	25	23	23
Panicle initiation	36	35	32	30	31	31	32	31	31	30
Booting	57	57	56	55	57	57	51	49	51	51
Heading	62	62	63	62	63	63	56	55	56	56
50% flowering	66	66	63	64	67	66	63	61	62	60
Physiological maturity	102	101	100	99	95	94	93	92	91	90

J – Jyothi K- Kanchana

4.3.2. Number of days for panicle initiation

Jyothi and Kanchana took more number of days to complete panicle initiation in the case of June 5th planting for which Jyothi took more days than Kanchana. Thereafter it showed a decreasing trend and in August 5th planting, Jyothi took 31 days and Kanchana took only 30 days to complete panicle initiation. Except in July 5th planting, Jyothi took more number of days to complete panicle initiation. In July 5th planting, it was the same for both the varieties (31 days).

4.3.3. Number of days for booting

Jyothi and Kanchana took same number of days to complete booting in most of the plantings. In Jyothi, the number of days taken from transplanting to booting ranged from 51 to 57 while in Kanchana it ranged from 49 to 57. With delay in date of planting the number of days taken for booting reduced in both Jyothi and Kanchana.

4.3.4. Number of days for heading

The number of days taken to complete heading ranged from 56 to 63 in both Jyothi and Kanchana. It was more in the case of first three plantings thereafter it reduced and was minimum in the case of August 5th planting. In June 5th planting the number of days taken to complete booting was same for both the varieties (63 days).

4.3.5. Number of days for 50% flowering

50% flowering occurred within one week after heading for all the five plantings. The number of days taken for 50% flowering ranged from 62 to 67 in the case of Jyothi and 60 to 66 in the case of Kanchana where maximum was found for July 5th planting (Jyothi - 67 and Kanchana - 66). Then it decreased and minimum was found in August 5th planting.

4.3.6. Number of days for physiological maturity

Kanchana attained physiological maturity earlier than Jyothi. With delay in planting dates, the number of days taken to attain physiological maturity reduced in both Jyothi and Kanchana. In June 5th planting Jyothi took 102 days to attain physiological maturity while it it reduced to 91 days in the case of August 5th planting. Kanchana took 101 days in the case of June 5th planting and then it reduced to 90 days in August 5th planting.

4.4. WEATHER CONDITIONS PREVAILED DURING DIFFERENT GROWTH STAGES OF VARIETIES

Table 4.2 to Table 4.7 shows the weather conditions experienced by the crop during different growth stages.

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

4.4.1.1. Temperature (Maximum temperature, Minimum Temperature, Mean Temperature and Temperature Range)

The highest maximum temperature during the transplanting to tillering stage was 30.7°C and lowest maximum temperature was 30.0°C for both Jyothi and Kanchana during July 5th and June 20th plantings respectively. The highest minimum temperature was experienced during June 5th planting and lowest minimum temperature was observed during the July 5th plantings. For both Jyothi and Kanchana, during transplanting to active tillering stage of all dates of planting, maximum temperature varied from 30.0°C to 30.7°C whereas minimum temperature varied between 22.7°C to 23.5°C. The mean temperature ranged from 26.4°C to 26.9°C which was lowest during June 20th and highest during July 20th planting. The temperature range increased from June 5th to July 5th and thereafter decreased towards August 5th date of planting. The maximum of 8.0°C was during July 5th planting.

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

The forenoon relative humidity showed a slight decrease with delayed planting for both rice varieties from June 5th to August 5th planting. The maximum relative humidity was found to be 96.0% during August 5th planting in Jyothi and Kanchana and minimum of 93.3% was during July 20th planting. The afternoon relative humidity was showing a reverse trend with decrease towards the July 20th planting and slightly increased towards August 5th

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

Weather variable	Date of transplanting									
	June 5th		June 20th		July 5th		July 20th		August 5th	
	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana
Tmax (^{0}C)	30.28	30.27	30.04	30.02	30.73	30.73	30.47	30.45	30.10	30.10
Tmin (^{0}C)	23.45	23.48	22.82	22.89	22.68	22.68	23.33	23.32	23.35	23.35
Tmean (^{0}C)	26.86	26.88	26.43	26.45	26.70	26.70	26.90	26.88	26.73	26.73
TR (^{0}C)	6.83	6.79	7.23	7.13	8.05	8.05	7.14	7.13	6.76	6.76
VPD I (mm Hg)	23.15	23.19	22.54	22.65	22.33	22.33	22.92	22.92	22.76	22.76
VPD II (mm Hg)	23.18	23.20	22.94	23.01	22.82	22.82	22.68	22.70	23.04	23.04
RH I (%)	95	95	95	95	93.54	94	93	93	96	96
RH II (%)	79	79	79	80	74	74	73	73	78	78
RH mean (%)	87	87	87	87	84	84	83	83	87	87
RF (mm)	627.90	606.40	577.10	530.10	333.50	333.50	245.80	245.80	359.90	359.90
RD	23.00	22.00	23.00	22.00	18.00	18.00	12.00	12.00	12.00	12.00
BSS (h)	1.89	1.94	1.65	1.73	2.71	2.71	4.09	4.26	3.07	3.07
Epan (mm)	2.56	2.53	2.62	2.65	2.56	2.56	2.78	2.82	2.93	2.93
WS (km hr^{-1})	1.76	1.81	1.65	1.73	1.85	1.85	1.37	1.41	0.92	0.92

date of planting. The maximum afternoon relative humidity was experienced as 79.7% during June 20th planting by Kanchana and minimum afternoon relative humidity was experienced as 73.2% during July 20th planting by Jyothi. The mean relative humidity ranged from 83.3% to 87.5% with maximum observed during June 20th planting for Kanchana and minimum was observed during July 20th planting for both rice varieties.

The forenoon vapour pressure deficit was ranging from 22.3 mm to 23.2 mm for both rice varieties. The maximum forenoon vapour pressure deficit was observed for Kanchana during June 5th planting and the minimum was observed for both varieties in July 5th planting. It was showing a general decreasing tendency towards delayed planting date whereas the afternoon vapour pressure deficit showed a decreasing trend towards July 5th and July 20th plantings and then slightly increased towards the August 5th planting. The afternoon vapour pressure deficit was more for both varieties planted on June 5th as 23.2 mm of Hg and the deficit was less during July 20th planting which was 22.7 mm of Hg.

4.4.1.3. Wind Speed (WS)

During transplanting to active tillering stage, the wind speed ranged from 0.9 to 1.85 $kmhr^{-1}$. The wind speed decreased towards delayed date of planting where maximum wind speed was observed for both rice varieties planted during July 5th planting and less wind speed was experienced by August 5th planting.

4.4.1.4. Bright Sunshine Hours(BSS)

Bright sunshine hours varied between 1.73 to 4.26 hrs for both rice varieties during the experimental period. The duration was maximum for July 20th planting whereas less in June 20th planting. The duration varied between 1.65 hrs to 4.1 hrs for Jyothi variety and between 1.7 hrs to 4.26 hrs for Kanchana variety.

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

The quantum of rainfall received decreased steadily from June 5th date of planting to July 20th date of planting and then slightly increased towards August 5th date of planting. The maximum amount was received for Jyothi variety (627.9 mm) during June 5th planting and lowest quantum of 245.8 mm was observed for both rice varieties during July 20th planting.

Rainy days showed a considerable decrease towards the delayed date of planting for both rice varieties. For Jyothi, number of rainy days varied between 12 and 23 whereas it varied between 12 and 22 for Kanchana variety.

4.4.1.6. Pan evaporation (Epan)

The evaporation from the pan evaporimeter was observed to be showing almost a steady trend towards delayed date of planting. The value ranged from 2.53 mm to 2.93 mm for Kanchana and 2.56 to 2.93 mm in Jyothi. The maximum pan evaporation was observed for August 5th planted varieties whereas less evaporation was observed for June 5th planting.

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

4.4.2.1. Temperature (Maximum temperature, Minimum Temperature, Mean Temperature and Temperature Range)

The highest maximum temperature during the transplanting to panicle initiation stage was 31.0°C for both varieties during August 5th planting and lowest maximum temperature was 30.17°C for Jyothi and 30.15°C for Kanchana during June 20th planting. The highest minimum temperature was experienced by Jyothi during August 5th planting (23.34°C) and lowest minimum temperature was experienced by Jyothi (22.67°C) during June 20th planting. For both Jyothi and Kanchana, for all dates of planting from transplanting to panicle initiation stage, maximum temperature varied from 30.15 to 31.0°C whereas minimum temperature varied between 22.67°C to 23.72°C. The mean

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

Weather variable	Date of transplanting									
	June 5th		June 20th		July 5th		July 20th		August 5th	
	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana
Tmax (^{0}C)	30.25	30.17	30.17	30.15	30.50	30.50	30.38	30.45	31.00	31.00
Tmin (^{0}C)	23.31	23.33	22.67	22.77	22.96	23.72	23.29	23.31	23.34	23.32
Tmean (^{0}C)	26.78	26.75	26.42	26.46	26.73	26.73	26.83	26.88	26.74	26.68
TR (^{0}C)	6.94	6.85	7.50	7.38	7.54	7.54	7.08	7.14	6.81	6.73
VPD I (mm Hg)	22.98	23.00	22.42	22.42	22.59	22.59	22.87	22.90	22.84	22.79
VPD II (mm Hg)	23.09	23.12	22.99	22.97	22.80	22.80	22.79	22.81	23.24	23.21
RH I (%)	95	95	95	96	94	94	94	94	96	96
RH II (%)	78	79	79	78	73	73	75	75	78	78
RH mean (%)	87	87	87	87	83	83	84	84	87	87
RF (mm)	724.20	691.80	747.10	699.50	350.60	350.60	347.70	329.60	508.70	480.30
RD	31.00	30.00	29.00	27.00	19.00	19.00	7.00	15.00	19.00	18.00
BSS (h)	1.82	1.87	1.75	1.83	3.49	3.49	3.88	4.00	2.97	3.03
Epan (mm)	2.54	2.56	2.67	2.58	2.80	2.80	2.90	2.95	2.74	2.74
WS (km hr^{-1})	1.72	1.77	1.77	1.78	1.86	1.86	1.26	1.28	0.90	0.92

temperature ranged from 26.42°C to 26.88°C, which was lowest during June 20th and highest during July 20th planting. The temperature range increased from June 5th to July 5th and thereafter decreased towards August 5th date of planting. The maximum of 7.54°C was for July 5th planting.

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

The forenoon relative humidity showed a slight decrease towards July 5th planting and thereafter increased towards August 5th planting for both Jyothi and Kanchana. The maximum relative humidity was found to be 95.7 % for August 5th planting in Kanchana and minimum of 93.6 % was during July 5th planting in both rice varieties. The afternoon relative humidity was showing a similar trend with decrease towards the July 5th planting and then slightly increased towards August 5th date of planting. The maximum afternoon relative humidity was observed as 79% for June 20th date of planting and minimum afternoon relative humidity was 73% for July 5th planted rice varieties. The mean relative humidity ranged from 83% to 87% with maximum observed for June 20th planted Kanchana and minimum observed for July 5th planted Jyothi and Kanchana.

The forenoon vapour pressure deficit ranged from 22.42 mm to 23.00 mm of Hg for both rice varieties. The maximum forenoon vapour pressure deficit was observed for both Jyothi and Kanchana during June 5th planting and the minimum was observed for both varieties in June 20th planting. It was showing a general decreasing tendency towards delayed planting date whereas the afternoon vapour pressure deficit showed a decreasing trend towards July 5th and July 20th planting and then slightly increased towards the August 5th planting. The vapour pressure deficit was more for both varieties planted on August 5th as 23.2 mm of Hg and the deficit was less during July 5th and July 20th planted rice varieties which was 22.8mm of Hg.

4.4.2.3. Wind Speed (WS)

During transplanting to active tillering stage, the wind speed ranged from 0.9 to 1.86 kmhr^{-1}. The wind speed decreased towards delayed date of planting where maximum wind speed was experienced by both rice varieties planted during July 5th and less wind speed was experienced by August 5th planted rice crop.

4.4.2.4. Bright Sunshine Hours (BSS)

Bright sunshine hours varied between 1.75 to 4.0 hrs for both rice varieties during the experimental period. The duration was maximum for July 20th planted Kanchana whereas less in June 20th planted Jyothi. The duration varied between 1.75 hrs and 3.88 hrs for Jyothi variety and between 1.83 hrs and 4.0 hrs for Kanchana variety.

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

The quantum of rainfall received decreased steadily from June 5th date of planting to July 20th date of planting and then then slightly increased towards August 5th planting. The maximum amount was received by Jyothi variety (747.10 mm) during June 20th planting and lowest quantum of 329.6 mm was observed for July 20th planted Kanchana variety.

Rainy days showed a considerable decrease towards the delayed date of planting for both rice varieties. For Jyothi, number of rainy days varied between 7 and 31 whereas it varied between 15 and 30 for Kanchana variety.

4.4.2.6. Pan evaporation (Epan)

The evaporation from the pan evaporimeter was observed to show almost a steady trend towards delayed date of planting. The value ranged from 2.56 mm to 2.95 mm in Kanchana variety and 2.54 to 2.90 mm in Jyothi variety. The maximum pan evaporation was observed for July 20th planting whereas less evaporation was observed for June 5th planting.

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

4.4.3.1. Temperature (Maximum temperature, Minimum Temperature, Mean Temperature and Temperature Range)

The highest maximum temperature during the transplanting to booting stage was 30.56°C and lowest maximum temperature was 30.18°C for both Jyothi and Kanchana during July 5th planting. The highest minimum temperature was experienced for July 20th planting and lowest minimum temperatures were observed during the June 20th planting. For both Jyothi and Kanchana, for all dates of planting from transplanting to booting stage, maximum temperature varied from 30.18°C to 30.56°C whereas minimum temperature varied between 23.0°C to 23.3°C. The mean temperature ranged from 26.6°C to 26.9°C, which was lowest during July 5th and highest during August 5th planting. The temperature range decreased from June 5th to July 20th and thereafter increased towards August 5th date of planting. The maximum of 7.39°C was experienced for August 5th planting.

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

The forenoon relative humidity showed little difference among different plantings for both rice varieties from June 5th to August 5th. The forenoon relative humidity ranged between 95% and 96%. The same trend was followed by afternoon relative humidity also with different dates of planting. It was found to be 76% for both the varieties during all the plantings.

The forenoon vapour pressure deficit was ranging from 22.45 mm to 22.49 mm Hg for both rice varieties. The maximum forenoon vapour pressure deficit was observed for both varieties in July 20th planting and the minimum was observed for Jyothi during July 5th planting and for Kanchana during July 5th planting. It was showing a general decreasing tendency towards July 5th planting and thereafter it increased. The afternoon vapour pressure deficit showed a first decrease then increasing trend towards delayed date of planting. The

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

Weather variable	Date of transplanting									
	June 5th		June 20th		July 5th		July 20th		August 5th	
	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana
Tmax (^{0}C)	30.40	30.40	30.30	30.29	30.18	30.18	30.40	30.33	30.56	30.56
Tmin (^{0}C)	23.11	23.11	23.03	23.02	23.10	23.10	23.29	23.30	23.17	23.17
Tmean (^{0}C)	26.76	26.76	26.67	26.65	26.64	26.64	26.84	26.81	26.87	26.87
TR (^{0}C)	7.28	7.28	7.27	7.27	7.07	7.07	7.11	7.03	7.39	7.39
VPD I (mm Hg)	22.45	22.79	22.65	22.65	22.63	22.63	22.94	22.92	22.83	22.83
VPD II (mm Hg)	22.99	22.99	22.84	22.85	22.93	22.93	23.13	23.10	23.22	23.22
RH I (%)	94	94	95	95	95	95	94	94	95	95
RH II (%)	76	76	76	76	76	76	76	76	76	76
RH mean (%)	85	85	85	85	85	85	85	85	86	86
RF (mm)	981.30	981.30	945.30	945.30	808.80	808.80	623.90	612.50	835.80	835.80
RD	43.00	43.00	39.00	39.00	34.00	34.00	28.00	27.00	32.00	32.00
BSS (h)	2.46	2.46	2.88	4.10	3.14	3.14	3.60	3.64	3.54	3.54
Epan (mm)	2.67	2.67	3.07	3.13	2.96	2.96	2.74	2.77	2.64	2.64
WS (km hr^{-1})	1.77	1.77	1.59	1.61	1.42	1.42	1.11	1.13	0.85	0.85

vapour pressure deficit was more for both varieties planted on August 5th as 23.22 mm and the deficit was less during June 20th planting which was 22.8 mm of Hg.

4.4.3.3. Wind Speed (WS)

During transplanting to active tillering stage, the wind speed ranged from 0.85 to 1.77 $kmhr^{-1}$. The wind speed decreased towards delayed date of planting where maximum wind speed was observed for both rice varieties planted during June 5th and less wind speed was affected for August 5th planted rice crop.

4.4.3.4. Bright Sunshine Hours(BSS)

Bright sunshine hours varied between 2.46 to 4.10 hrs for both rice varieties during the experimental period. The duration was maximum for June 20th planted Kanchana variety whereas less for June 5th planted Jyothi and Kanchana. The duration varied between 2.46 hrs and 3.60 hrs for Jyothi variety and between 2.46 hrs and 4.10 hrs for Kanchana variety.

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

The quantum of rainfall received decreased steadily from June 5th date of planting to July 20th date of planting and then slightly increased towards August 5th date of planting. The maximum amount was received by both varieties (981.3 mm) during June 5th planting and lowest quantum of 612.5 mm was received for July 20th planted Kanchana variety.

Rainy days showed a considerable decrease towards the delayed date of planting for both rice varieties. For Jyothi, number of rainy days varied between 28 and 43 whereas it varied between 27 and 43 for Kanchana variety.

4.4.3.6. Pan evaporation (Epan)

The evaporation from the pan evaporimeter was observed to be showing almost a steady trend towards delayed date of planting. The value ranged from 2.64 mm to 3.07 mm in Jyothi and 2.04mm to 3.07mm in Kanchana. The maximum pan evaporation was observed for June 20th planted crop whereas less evaporation was observed for August 5th planted crop.

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

4.4.4.1. Temperature (Maximum temperature, Minimum Temperature, Mean Temperature and Temperature Range)

The highest maximum temperature during the transplanting to heading stage was 30.85°C and lowest maximum temperature was 30.26°C for Jyothi in July 20th planting and June 20th plantings respectively. For Kanchana, highest maximum temperature (30.71°C) was experienced during August 5th planting and lowest (30.27°C) was experienced during June 20th planting. The highest minimum temperature was experienced for July 20th planting and lowest minimum temperatures were observed during the June 20th plantings. The minimum temperature varied between 23.0°C to 23.3°C. The mean temperature ranged from 26.65°C to 26.97°C, which was lowest during June 20th and highest during July 20th planting. The temperature range increased from June 5th to August 5th date of planting. The maximum of 7.4°C was for August 5th planting.

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

The forenoon relative humidity did not show much variation towards August 5th planting for both rice varieties. The maximum relative humidity was found to be 95% and minimum to be 94% in both Jyothi and Kanchana. The afternoon relative humidity showed a decreasing trend towards July 20th planting and thereafter it increased towards the August 5th planting. The maximum afternoon relative humidity was observed as 76.0% and minimum afternoon relative humidity was 75% for both the varieties. The mean relative humidity ranged from 85% to 86%.

The forenoon vapour pressure deficit was ranging from 22.65 mm to 22.95 mm of Hg for both rice varieties. The maximum forenoon vapour pressure deficit was observed for both Jyothi and Kanchana for July 20th planting and the minimum was

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

Weather variable	Date of transplanting									
	June 5th		June 20th		July 5th		July 20th		August 5th	
	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana
Tmax (^0C)	30.32	30.32	30.26	30.27	30.36	30.36	30.85	30.54	30.55	30.71
Tmin (^0C)	23.16	23.16	23.04	23.04	23.16	23.16	23.31	23.29	23.14	23.14
Tmean (^0C)	26.74	26.74	26.65	26.65	26.76	26.76	26.97	26.92	26.85	26.85
TR (^0C)	7.16	7.16	7.22	7.23	7.20	7.20	7.31	7.25	7.41	7.41
VPD I (mm Hg)	22.80	22.80	22.65	22.65	22.73	22.73	22.95	22.92	22.86	22.86
VPD II (mm Hg)	23.00	23.00	22.88	22.88	23.03	23.03	23.17	23.19	23.14	23.14
RH I (%)	94	94	95	95	95	95	94	94	95	95
RH II (%)	76	76	76	76	75	75	75	75	76	76
RH mean (%)	85	85	86	86	85	85	85	85	86	86
RF (mm)	1068.40	1068.40	1070.80	1047.20	868.10	868.10	651.30	650.30	874.30	874.30
RD	45.00	45.00	44.00	43.00	35.00	35.00	31.00	31.00	34.00	34.00
BSS (h)	2.62	2.62	2.23	2.89	3.25	3.25	3.65	3.61	3.56	3.56
Epan (mm)	3.02	3.06	2.97	2.91	2.80	2.80	2.62	2.67	2.22	2.22
WS (km hr^{-1})	1.77	1.77	1.50	1.51	1.37	1.37	1.05	1.06	0.79	0.79

observed for both varieties in June 20th planting. It was showing a general decreasing tendency towards July 5th planting and then increasing towards delayed planting date whereas the afternoon vapour pressure deficit showed a steadily increasing trend towards delayed date of planting. The afternoon vapour pressure deficit was more for both varieties planted on July 20th as 23.2 mm of Hg and the deficit was less during June 20th planted rice varieties which was 22.8 mm of Hg.

4.4.4.3. Wind Speed (WS)

During transplanting to heading stage, the wind speed ranged from 0.79 to 1.77 $kmhr^{-1}$. The wind speed decreased towards delayed date of planting where maximum wind speed was observed for both rice varieties planted during June 5th and less wind speed was affected for August 5th planted rice crop.

4.4.4.4. Bright Sunshine Hours (BSS)

Bright sunshine hours varied between 2.23 to 3.65 hrs for Jyothi and 2.62 to 3.61 hrs for Kanchana during the experimental period. The duration was maximum for July 20th planted Jyothi whereas less in June 20th planted Jyothi.

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

The quantum of rainfall received decreased steadily from June 5th planting to July 20th planting and then slightly increased towards August 5th planting. The maximum amount was received for June 20th planted Jyothi (1070.8 mm) and lowest quantum of 650.3 mm was observed for July 20th planted Kanchana.

Rainy days showed a considerable decrease towards the delayed date of planting for both rice varieties. For Jyothi and Kanchana, number of rainy days varied between 31 and 65.

4.4.4.6. Pan evaporation (Epan)

The evaporation from the pan evaporimeter was observed to be showing almost a steady trend towards delayed date of planting. The value ranged from 2.6 mm to 3.0 mm in both Jyothi and Kanchana varieties. The maximum pan evaporation was observed for June 5th planting whereas less evaporation was observed for August 5th planting.

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

4.4.5.1. Temperature (Maximum temperature, Minimum Temperature, Mean Temperature and Temperature Range)

The highest maximum temperature during the transplanting to 50% flowering stage was 30.6°C and lowest maximum temperature was 30.3°C for both Jyothi and Kanchana in July 20th and June 20th plantings respectively. The highest minimum temperature was experienced for July 20th planting and lowest minimum temperatures were observed during the June 20th planting. For both Jyothi and Kanchana, for all dates of planting from transplanting to 50% flowering stage, maximum temperature varied from 30.3 to 30.6°C whereas minimum temperature varied between 22.9°C to 23.2°C. The mean temperature ranged from 26.6°C to 27.3°C, which was lowest during June 20th planting for Kanchana and highest during July 5th planting for Jyothi. The temperature range increased from June 5th to August 5th date of planting. The maximum of 7.5°C was for August 5th planting.

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

The forenoon relative humidity showed very little difference from June 5th to August 5th plantings. The forenoon relative humidity was found to be 95% for all dates of planting in both Jyothi and Kanchana. The afternoon relative humidity was showing a similar trend with almost similar values throughout the different dates of planting.

The maximum afternoon relative humidity was observed as 76% and minimum afternoon relative humidity was 75% for July 5th planted Jyothi and Kanchana varieties. The mean relative humidity ranged from 85.0 % to 86% with maximum observed for June 20th planted Kanchana and minimum observed for July 20th planted both rice varieties.

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

Weather variable	**Date of transplanting**									
	June 5th		June 20th		July 5th		July 20th		August 5th	
	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana
Tmax (^{0}C)	30.35	30.35	30.28	30.25	30.39	30.39	30.63	30.61	30.63	30.58
Tmin (^{0}C)	23.20	23.20	22.87	23.02	23.17	23.17	23.22	23.22	23.09	23.11
Tmean (^{0}C)	26.78	26.78	26.65	26.64	27.32	26.78	26.92	26.92	26.86	26.84
TR (^{0}C)	7.15	7.15	7.25	7.23	7.21	7.22	7.41	7.41	7.53	7.48
VPD I (mm Hg)	22.83	22.83	22.64	22.64	22.74	22.75	22.93	22.93	22.88	22.88
VPD II (mm Hg)	22.97	22.97	22.88	22.87	23.08	23.08	23.17	23.06	23.05	23.04
RH I (%)	95	95	95	95	95	95	95	95	95	95
RH II (%)	76	76	76	76	75	75	76	76	75.29	76
RH mean (%)	85	85	86	86	85	85	85	85	85	85
RF (mm)	1140.50	1140.50	1126.80	1125.00	1168.60	879.50	913.00	913.00	934.50	934.50
RD	48.00	48.00	45.00	45.00	41.00	40.00	37.00	37.00	36.00	36.00
BSS (h)	2.63	2.63	2.86	2.82	3.32	3.28	3.58	3.58	3.48	3.47
Epan (mm)	2.98	2.97	2.74	2.80	2.66	2.66	2.31	2.32	2.38	2.38
WS (km hr^{-1})	1.71	1.71	1.47	1.49	1.32	1.34	1.05	1.05	0.72	0.75

The forenoon vapour pressure deficit was ranging from 22.6 mm to 22.9 mm for both rice varieties. The maximum forenoon vapour pressure deficit was observed during July 20th planting and the minimum was observed for June 20th planting for both varieties. Both forenoon and afternoon vapour pressure deficits were showing a general increasing tendency towards delayed planting date. The afternoon vapour pressure deficit was more for both varieties planted on July 20th planting as 23.2 mm of Hg and the deficit was less during June 20th planted Jyothi rice variety which was 22.9 mm of Hg.

4.4.5.3. Wind Speed (WS)

During transplanting to active tillering stage, the wind speed ranged from 0.75 to 1.71 $kmhr^{-1}$. The wind speed decreased towards delayed date of planting where maximum wind speed was observed for both rice varieties planted during June 5th and less wind speed was affected for August 5th planted rice crop.

4.4.5.4. Bright Sunshine Hours(BSS)

Bright sunshine hours varied between 2.6 to 3.6 hrs for both rice varieties during the experimental period. The duration was maximum for July 20th planted Kanchana variety whereas less in June 5th planted varieties.

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

The quantum of rainfall received decreased steadily from June 5th planting to July 20th planting and then slightly increased towards August 5th planting. The maximum amount was received for both varieties (1140.5 mm) and lowest quantum of 879.5 mm was observed for July 5th planted Kanchana variety.

Rainy days showed a considerable decrease towards the delayed date of planting for both rice varieties. For Jyothi and Kanchana, number of rainy days varied between 48 and 36.

4.4.5.6. Pan evaporation (Epan)

The evaporation from the pan evaporimeter was observed to be showing almost a steady trend towards delayed date of planting. The value ranged from 2.3 mm to 2.9 mm in both Jyothi and Kanchana. The maximum pan evaporation was observed for June 5th planted Jyothi and Kanchana whereas less evaporation was observed for July 20th planting.

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

4.4.6.1. Temperature (Maximum temperature, Minimum Temperature, Mean Temperature and Temperature Range)

The highest maximum temperature during the transplanting to maturity stage was 30.97°C for Jyothi during August 5th planting and lowest maximum temperature was 30.46°C for both Jyothi and Kanchana during June 20th planting. The highest minimum temperature was experienced for June 5th planting and lowest minimum temperatures were observed during the August 5th planting. For both Jyothi and Kanchana, for all dates of planting from transplanting to physiological maturity stage, maximum temperature varied from 30.5 to 31.0°C whereas minimum temperature varied between 22.9°C to 23.3°C. The mean temperature ranged from 26.7°C to 26.9°C which was lowest during June 20th planting for Jyothi and highest during July August 5th planting for both Jyothi and Kanchana. The temperature range increased from June 5th to August 5th date of planting. The maximum of 8.1°C was for August 5th planting.

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

The forenoon relative humidity showed a slight decrease with delayed planting for both rice varieties from June 5th to August 5th. The maximum relative humidity was found to be 95% for plantings from June 5th and July 20th in both Jyothi and Kanchana and minimum of 94% was during August 5th planting. The afternoon relative humidity was showing a different trend which decreased through the different dates of planting.

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

Weather variable	Date of transplanting									
	June 5th		June 20th		July 5th		July 20th		August 5th	
	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana	Jyothi	Kanchana
Tmax (^0C)	30.48	30.49	30.46	30.46	30.61	30.59	30.74	30.70	30.97	30.95
Tmin (^0C)	23.25	23.26	23.04	23.05	23.05	23.05	23.01	23.01	22.86	22.86
Tmean (^0C)	26.86	26.87	26.75	26.95	26.83	26.82	26.88	26.85	26.91	26.90
TR (^0C)	7.23	7.23	7.42	7.42	7.56	7.54	7.73	7.68	8.11	8.08
VPD I (mm Hg)	22.87	22.87	22.74	22.75	22.78	22.79	22.84	22.82	22.59	22.62
VPD II (mm Hg)	23.13	23.13	23.03	23.03	22.94	22.96	22.97	22.94	22.85	23.60
RH I (%)	95	95	95	95	95	95	95	95	94	94
RH II (%)	77	76	76	76	75	75	75	75	73	73
RH mean (%)	86	86	85	85	85	85	85	85	80	81
RF (mm)	1604.30	1554.70	1652.10	1630.30	1288.20	1286.50	1101.30	1101.30	1086.70	1083.80
RD	69.00	68.00	67.00	66.00	55.00	65.00	48.00	48.00	45.00	44.00
BSS (h)	2.91	2.89	3.26	3.22	3.52	3.54	3.80	3.72	4.09	4.06
Epan (mm)	2.78	2.77	2.57	2.62	2.18	2.18	2.55	2.49	3.01	3.01
WS ($km\ hr^{-1}$)	0.84	1.40	1.24	1.24	1.07	1.08	1.05	0.79	0.62	0.61

The maximum afternoon relative humidity was recorded as 77% for June 5th planted Jyothi and minimum afternoon relative humidity was 73% for August 5th planted Jyothi and Kanchana. The mean relative humidity ranged from 80% to 86% with maximum observed for June 5th planting and minimum observed for August 5th planted Jyothi.

The forenoon vapour pressure deficit was ranging from 22.6 mm to 22.9 mm for both rice varieties. The maximum forenoon vapour pressure deficit was observed for both varieties during June 5th planting and the minimum was observed for August 5th planted Jyothi. Both forenoon and afternoon vapor pressure deficits were showing a general decreasing tendency towards delayed planting date. The afternoon vapour pressure deficit was more for Kanchana planted on August 5th as 23.6 mm and the deficit was less during July 5th planted Jyothi which was 22.9 mm of Hg.

4.4.6.3. Wind Speed (WS)

During transplanting to physiological maturity stage, the wind speed ranged from 0.6 to 1.4 $kmhr^{-1}$. The wind speed first increased and then decreased towards delayed date of planting where maximum wind speed was observed for Kanchana planted during June 5th and less wind speed was affected for August 5th planted crop.

4.4.6.4. Bright Sunshine Hours(BSS)

Bright sunshine hours varied between 2.9 to 4.1 hrs for both rice varieties during the experimental period. The duration was maximum for August 5th planted Jyothi whereas it was found to be less during June 5th planting of both rice varieties.

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

The quantum of rainfall received decreased steadily from June 5th planting to August 5th planting. The maximum amount was received for Jyothi planted on June 20th (1652.1 mm) and lowest quantum of 1101.3 mm was received by July 20th planted Jyothi and Kanchana.

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Rainy days showed a considerable decrease towards the delayed date of planting for both rice varieties. For Jyothi number of rainy days varied between 45 and 69.and for Kanchana, number of rainy days varied between 44 and 68.

4.4.6.6. Pan evaporation (Epan)

The evaporation from the pan evaporimeter was observed to be showing almost a steady trend towards delayed date of planting. The value ranged from 2.18 mm to 3.01 mm in both Jyothi and Kanchana. The maximum pan evaporation was observed for August 5th planting whereas less evaporation was observed for July 5th planting.

4.5. PLANT CHARACTERS

4.5.1. Weekly plant height

The results of analysis of variance performed for weekly plant height up to harvest stage are represented in Appendix II. Significant difference was noticed between different dates of planting for plant height up to five weeks after transplanting in both Jyothi and Kanchana.

Table 4.8 (a &b) shows the weekly observed plant height for five planting dates with respect to varieties and irrespective of varieties. No significant difference was observed between dates of planting for plant height from 6th to 13th week after transplanting (harvest). No definite pattern was observed in the ranking of plant height in the different dates of planting (week 1 to week 5) from June 5th to August 5th. As observed in Table 4.8(b), during all weeks from 2nd to 13th, Jyothi had more plant height than Kanchana.

4.5.2. Dry matter accumulation at fortnightly intervals

Analysis of variance was performed for dry matter accumulation at fortnightly intervals and are presented in Appendix II. Date of planting showed significant effect on dry matter accumulation. (Table.4.9)

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Table.4.8(a) Effect of date of planting on plant height at weekly intervals

Date of planting	Plant height (cm)														
	Week 1			Week 2			Week 3			Week 4			Week 5		
	J	K	Mean	J	K	Mean	J	K	Mean	J	K	Mean	J	K	Mean
5th June	18.78	19.18	18.98^{c}	29.43	26.97	28.20^{b}	51.49	45.26	48.37^{a}	60.82	52.98	56.90^{a}	66.42^{bc}	57.05^{b}	61.73^{b}
20th June	22.95	22.68	22.81^{a}	33.01	31.40	32.20^{a}	54.64	45.93	50.28^{a}	58.05	51.64	54.84^{ab}	62.42^{c}	59.25^{ab}	60.83^{b}
5th July	22.12	21.66	21.89^{ab}	29.09	28.41	28.75^{b}	42.73	36.65	39.69^{c}	57.48	45.04	51.26^{b}	73.76^{a}	60.30^{ab}	67.03^{a}
20th July	21.08	20.26	20.67^{ab}	29.01	25.83	27.42^{b}	44.97	40.02	42.50^{bc}	53.88	48.41	51.14^{b}	68.02^{bc}	61.68^{ab}	64.85^{ab}
5th August	20.94	17.61	19.27^{bc}	31.83	27.18	29.50^{ab}	48.54	39.44	43.99^{b}	60.26	50.87	55.53^{a}	70.18^{ab}	62.73^{a}	66.46^{a}
CD	NS		2.62	NS		2.86	NS		3.69	NS		4.02	5.63		4.58

Date of planting	Plant height (cm)											
	Week 6			Week 7			Week 8			Week 9		
	J	K	Mean	J	J	J	J	K	Mean	J	K	Mean
5th June	74.66	68.63	71.64	100.10	100.10	100.10	90.82	81.57	86.20	100.10	90.61	95.35
20th June	70.52	67.97	69.24	103.78	103.78	103.78	93.94	86.50	90.22	103.78	101.46	102.62
5th July	77.91	65.27	71.59	107.49	107.49	107.49	92.11	80.09	86.10	107.49	98.75	103.12
20th July	75.48	69.31	72.40	103.91	103.91	103.91	94.33	87.68	91.00	103.91	96.74	100.33
5th August	73.46	68.31	70.88	102.99	102.99	102.99	92.54	87.37	89.95	102.99	97.22	100.10
CD	NS		NS	NS		NS	NS		NS	NS		NS

Date of planting	Plant height (cm)											
	Week 10			Week 11			Week 12			Week 13		
	J	K	Mean	J	K	Mean	J	K	Mean	J	K	Mean
5th June	112.74	99.20	105.97	116.01	102.79	109.40	117.41	104.20	110.80	118.31	105.02	111.66
20th June	112.18	106.56	109.37	117.07	107.78	112.42	119.19	108.39	113.79	120.46	109.65	115.05
5th July	111.93	101.64	106.78	114.42	102.55	108.48	116.84	103.87	110.35	118.88	105.04	111.96
20th July	109.83	99.13	104.48	113.23	100.89	107.06	117.20	101.93	109.56	119.94	103.95	111.94
5th August	107.65	99.45	103.55	109.47	100.37	104.92	111.68	101.87	106.78	113.06	102.41	107.73
CD	NS		NS	NS		NS	NS		NS	NS		NS

J – Jyothi K – Kanchana

Table.4.8(b) Comparison between varieties with respect to plant height at weekly intervals

	Plant height (cm)												
Variety	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
Jyothi	21.17	30.47[a]	48.47[a]	58.10[a]	68.16[a]	74.40[a]	85.70[a]	92.75[a]	103.65[a]	110.86[a]	114.04[a]	116.46[a]	118.13[a]
Kanchana	20.27	27.96[b]	41.46[b]	49.79[b]	60.20[b]	67.90[b]	77.86[b]	84.64[b]	96.95[b]	101.19[b]	102.87[b]	104.05[b]	105.21[b]
CD	NS	1.63	1.84	1.75	2.07	2.31	2.46	2.86	3.31	2.65	2.69	2.30	2.18

Table 4.9(a) Effect of dates of planting on dry matter accumulation at fortnightly intervals

Date of planting	Dry matter accumulation (kg ha^{-1})								
	15 DAP			30 DAP			45 DAP		
	J	K	Mean	J	K	Mean	J	K	Mean
5th June	488.06[a]	526.63[a]	507.35[a]	3,090.62[a]	2,848.65[ab]	2,969.64[a]	6,921.22[a]	6,890.31[ab]	6,905.76[a]
20th June	487.62[a]	547.75[a]	517.68[a]	3,180.70[a]	3,116.77[a]	3,148.74[a]	6,375.91[b]	6,601.17[bc]	6,488.54[c]
5th July	432.41[b]	394.55[c]	413.48[b]	3,170.98[a]	2,951.54[ab]	3,061.26[a]	6,586.93[ab]	7,112.04[a]	6,849.48[ab]
20th July	360.46[c]	431.89[bc]	396.17[b]	3,109.23[a]	2,803.38[b]	2,956.30[a]	6,822.02[a]	6,478.72[c]	6,650.37[bc]
5th August	375.19[c]	451.38[b]	413.29[b]	2,548.62[b]	2,683.78[b]	2,616.20[b]	6,857.35[a]	6,705.47[bc]	6,781.41[ab]
CD	55.06		40.15	305.55		279.21	368.36		245.11

Date of planting	Dry matter accumulation (kg ha^{-1})								
	60 DAP			75 DAP			90 DAP		
	J	K	Mean	J	K	Mean	J	K	Mean
5th June	11,939.50[a]	12,203.77[a]	12,071.63[a]	15,257.53[a]	15,094.84[a]	15,176.18[a]	13,796.09	13,428.23	13,612.16[a]
20th June	10,942.31[b]	12,313.54[a]	11,627.93[ab]	14,541.91[bc]	15,186.57[a]	14,864.24[a]	13,530.35	13,905.51	13,717.93[a]
5th July	11,316.67[ab]	11,507.56[b]	11,412.11[b]	14,737.14[b]	14,245.68[b]	14,491.41[b]	13,369.42	13,094.66	13,232.04[b]
20th July	11,746.44[a]	10,556.26[c]	11,151.35[bc]	14,240.35[c]	13,966.76[b]	14,103.55[c]	12,855.23	12,621.75	12,738.49[c]
5th August	10,642.33[b]	10,835.88[bc]	10,739.10[c]	13,607.14[d]	13,442.65[c]	13,524.90[d]	12,587.10	12,400.76	12,493.93[c]
CD	687.55		488.37	421.60		314.73	NS		370.50

DAP – Days After Planting

Table.4.9(b) Comparison between varieties with respect to dry matter accumulation

Variety	15 DAP	30 DAP	45 DAP	60 DAP	75 DAP	90 DAP
Jyothi	428.75[b]	3020.03[a]	6712.69	11317.45	14476.81	13227.64
Kanchana	470.44[a]	2880.83[b]	6757.54	11483.40	14387.30	13090.18
CD	23.83	78.52	NS	NS	NS	NS

With delay in planting dates, dry matter accumulation was found to be decreasing in both Jyothi and Kanchana. In the case of dry matter accumulation during 15 days after planting, June 5th planting recorded dry matter accumulation which was on par with June 20th planting. During 30 days after planting, August 5th planting showed lower dry matter accumulation than all other plantings. At 45 days after planting, June 20th planting was found to be on par with July 20th planting. July 5th and August 5th plantings were found to be on par and June 5th, July 5th and August 5th plantings were on par. In Jyothi, at 45 days after planting, June 5th, July 5th, July 20th, and August 5th plantings were on par while June 20th and July 5th plantings were on par. In the case of Kanchana, June 20th planting showed more dry matter accumulation which was on par with June 5th and July 5th plantings. In Jyothi, August 5th planting accumulated least amount of dry matter which was on par with June 20th and July 5th plantings at 60 days after planting while in Kanchana, 20th July planting showed dry matter accumulation which was on par with August 5th planting. Maximum dry matter accumulation was noted at 75 days after planting in both the varieties where June 5th planting (15257.53 kg ha^{-1}) was found superior in Jyothi and June 20th planting (15186.57 kg ha^{-1}) was found to be on par with June 5th planting (15094.84 kg ha^{-1}) in Kanchana. At 90 days after planting, significant interaction was absent between different dates of planting and varieties. But due to dates of planting, significant difference was observed in dry matter accumulation for which June 20th and June 5th plantings were on par.

4.5.3. Yield and yield attributes

Analysis of variance (ANOVA) was carried out for yield and different yield attributes and is given in Appendix II.

Mean values for yield, recorded yield attributes for all five dates of planting for both Jyothi, and Kanchana is given in Table 4.10. The interaction was found to be non- significant in all the cases.

Table.4.10(a) Effect of dates of planting on yield and yield attributes

Date of planting	Number of tillers per unit area			Number of panicles per unit area			Number of spikelets per panicle			Number of filled grains per panicle		
	J	K	Mean	J	K	Mean	J	K	Mean	J	K	Mean
5th June	438.50	425.00	431.75	351.75	388.60	370.18^{ab}	104.10	88.80	96.45^{a}	70.00	68.85	69.43^{b}
20th June	366.50	372.25	369.38	355.10	462.30	408.70^{a}	96.20	81.00	88.60^{ab}	58.50	54.70	56.60^{c}
5th July	393.50	406.75	400.13	402.00	442.20	422.10^{a}	104.40	95.90	100.15^{a}	87.20	76.55	81.88^{a}
20th July	376.50	439.50	408.00	348.40	381.90	365.15^{abc}	107.60	85.50	96.55^{a}	79.20	64.25	71.73^{ab}
5th August	368.00	443.50	405.75	301.50	314.90	308.20^{bc}	85.15	70.95	78.05^{b}	52.75	48.95	50.85^{c}
CD	NS		NS	NS		69.02	NS		13.03	NS		10.57

Date of planting	1000 grain weight (g)			Straw yield (kg ha^{-1})			Grain yield (kg ha^{-1})		
	J	K	Mean	J	K	Mean	J	K	Mean
5th June	28.10	27.30	27.70^{a}	3,575.00	3,725.00	3,650.00	5,500.00	6,245.00	5,872.50^{a}
20th June	27.78	26.75	27.26^{a}	5,900.00	4,175.00	5,037.50	5,227.50	6,188.00	5,707.75^{ab}
5th July	24.83	25.58	25.20^{b}	3,725.00	5,440.00	4,582.50	4,837.00	5,878.50	5,357.75^{bc}
20th July	27.50	27.18	27.34^{a}	4,692.50	4,270.00	4,481.25	5,172.50	4,838.25	5,005.38^{cd}
5th August	25.93	26.20	26.06^{b}	5,265.00	5,450.00	5,357.50	4,773.50	4,639.45	4,706.48^{d}
CD	NS		1.01	NS		NS	NS		498.53

Table.4.10. (b) Comparison between varieties and yield attributes

Variety	Tillers per m^2	Panicles per m^2	Spikelets per panicle	Filled grains per panicle	1000 grain weight	Grain Yield (kg ha^{-1})	Straw yield (kg ha^{-1})
Jyothi	388.60	351.75^{b}	99.49^{a}	69.53^{a}	26.83	5102.10^{b}	4631.50
Kanchana	417.40	397.98^{a}	84.43^{b}	62.66^{b}	26.60	5557.84^{a}	4612.00
CD	NS	40.342	6.24	5.13	NS	377.40	NS

J – Jyothi K - Kanchana

4.5.3.1. Number of tillers per m^2

Analysis of variance did not show any significant difference for different dates of planting and the interaction between dates of planting and varieties was also found to be non-significant.

4.5.3.2. Number of panicles per m^2

Panicles per m^2 for the two varieties in the different planting dates are depicted in Table 4.10(a). For Jyothi and Kanchana, interaction between dates of planting and varieties was found to be non-significant. Overall, significant difference was found between different dates of planting. Number of panicles per m^2 recorded for July 5th planting was on par with June 5th, June 20th and July 20th plantings. Lowest number of panicles was obtained for August 5th planting which was on par with July 20th planting.

4.5.3.3. Number of spikelets per panicle

Spikelets per panicle for the two varieties in the different planting dates are depicted in Table 4.10(a). The interaction between five dates of planting and two varieties was non-significant. August 5th planting showed least number of spikelets per panicle which was on par with June 20th planting. Number of spikelets was more for July 5th planting which was on par with June 5th, June 20th, and July 20th planting.

4.5.3.4. Number of filled grains per panicle

The interaction between five dates of planting and varieties was non-significant in the case of number of filled grains per panicle. August 5th planting showed lowest number of filled grains per panicle which was on par with June 20th planting. More number of filled grains was noted for July 5th planting which was on par with July 20th planting.

4.5.3.5. Thousand grain weight

Overall, significant difference was observed between different dates of planting in the case of thousand-grain weight. June 5th planting showed more thousand-grain weight, which was on par with June 20th and July 20th plantings. July 5th planting showed lowest thousand-grain weight which was on par with August 5th planting.

4.5.3.6. Grain yield

Grain yield showed non-significance in the case of interaction between five dates of planting and varieties. Overall, significant difference was observed between different dates of planting. Higher yield was given by June 5th planting and June 20th planting which were on par. Lowest yield was obtained from August 5th planting.

4.5.3.7. Straw yield

Significant difference was not found among interaction between five dates of planting and varieties in the case of straw yield. It was absent between different dates of planting also.

4.6. CROP WEATHER RELATIONSHIPS

Correlation analysis was carried out between different weather variables and phenophases duration, yield and yield attributes for Jyothi and Kanchana separately using the data of five years' experiment conducted at Department of Agricultural Meteorology. The results are presented below.

4.6.1. Influence of weather parameters on crop duration of Jyothi

Table 4.11 & Table 4.12 shows the outcomes of the correlation analysis carried out between weather variables and different phenophases duration of Jyothi and Kanchana respectively.

4.6.1.1. Transplanting to active tillering (P1)

Number of rainy days showed a significant positive correlation with the number of days taken from transplanting to active tillering in Jyothi.

Table.4.11 Correlation between duration of phenophases and weather variables in Jyothi

Stages	Tmax	Tmin	Tmean	TR	RHI	RHII	RHm	VPDI	VPDII	RF	RD	BSS	WS	Epan
P1	-0.140	-0.027	-0.101	-0.111	0.169	0.191	0.204	0.202	0.166	0.302	0.512**	-0.224	0.275	-0.258
P2	-0.342	-0.075	-0.273	-0.311	0.277	0.033	0.077	-0.315	-0.428*	0.377	0.305	-0.145	0.016	-0.381
P3	-0.023	0.202	0.063	-0.140	-0.105	0.185	0.138	0.127	0.268	0.235	0.168	-0.246	-0.305	-0.109
P4	-0.355	-0.474*	-0.442*	-0.149	0.331	-0.001	0.098	-0.588**	-0.395	0.438*	0.559**	-0.184	0.317	-0.123
P5	-0.071	-0.421*	-0.282	0.170	0.082	0.127	0.127	-0.197	-0.042	0.442*	0.541**	0.002	0.175	0.015
P6	0.260	0.672**	0.502*	-0.306	-0.241	-0.303	-0.311	0.266	0.213	-0.155	0.061	0.161	0.271	0.598**

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

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

4.6.1.2. Active tillering to panicle initiation (P2)

Afternoon vapour pressure deficit showed a significant negative correlation with the number of days taken from active tillering to panicle initiation in Jyothi.

4.6.1.3. Booting to heading (P4)

Minimum temperature, mean temperature and forenoon vapour pressure deficit exhibited a negative correlation with number of days taken from booting to heading whereas rainfall and number of rainy days showed a positive correlation in Jyothi.

4.6.1.4. Heading to 50% flowering (P5)

Minimum temperature showed a negative correlation while rainfall and number of rainy days showed a positive correlation with the number of days taken from heading to 50% flowering in Jyothi.

4.6.1.5. 50% flowering to physiological maturity (P6)

Minimum temperature, mean temperature and pan evaporation exhibited a significant positive correlation with the number of days taken from 50% flowering to physiological maturity in Jyothi.

4.6.2. Influence of weather parameters on crop duration of Kanchana

4.6.2.1. Transplanting to active tillering (P1)

No weather variables showed correlation with the number of days taken from transplanting to active tillering in Kanchana.

4.6.2.2. Active tillering to panicle initiation (P2)

Maximum temperature, mean temperature, forenoon vapour pressure deficit and afternoon vapour pressure deficit showed significant negative correlation with number of days taken from active tillering to panicle initiation in Kanchana while rainfall and rainy days exhibited a negative correlation.

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Table 4.12 Correlation between duration of phenophases and weather variables in Kanchana

Stages	Tmax	Tmin	Tmean	TR	RHI	RHII	RHm	VPDI	VPII	RF	RD	BSS	WS	Epan
P1	-0.258	-0.108	-0.220	-0.155	0.305	0.297	0.323	0.113	0.154	0.367	0.169	-0.303	0.225	-0.365
P2	-0.500*	-0.320	-0.483*	-0.324	0.329	0.223	0.256	-0.433*	-0.600**	0.398*	0.421*	-0.278	0.162	-0.441*
P3	0.040	0.260	0.141	-0.108	-0.197	0.149	0.088	0.267	0.265	0.329	0.384	-0.127	-0.287	0.001
P4	-0.313	-0.450*	-0.403*	-0.097	0.236	0.125	0.180	-0.477*	-0.429*	0.339	0.422*	-0.105	0.371	-0.109
P5	-0.179	-0.488*	-0.360	0.137	0.031	0.080	0.075	-0.322	-0.234	0.333	0.513**	0.091	0.304	0.013
P6	0.250	0.669**	0.492*	-0.313	-0.214	-0.314	-0.308	0.256	0.182	-0.190	0.017	0.179	0.180	0.549**

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

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

4.6.2.3. Booting to heading (P4)

Minimum temperature, mean temperature, forenoon vapour pressure deficit and afternoon vapour pressure deficit exhibited a negative correlation with number of days taken from booting to heading and number of rainy days showed a positive correlation in the case of Kanchana.

4.6.2.4. Heading to 50% flowering (P5)

In the case of Kanchana, the number of days taken from heading to 50% flowering has a positive correlation with number of rainy days and negative correlation with minimum temperature.

4.6.2.5. 50% flowering to physiological maturity (P6)

Minimum temperature, mean temperature and pan evaporation exhibited a significant positive correlation with the number of days taken from 50% flowering to physiological maturity in Kanchana.

4.6.3. Correlation between weather and yield of Jyothi

Table 4.13 shows the results of the correlation analysis carried out between weather variables and grain yield of Jyothi.

4.6.3.1. Transplanting to active tillering (P1)

Afternoon relative humidity, mean relative humidity, rainfall and number of rainy days during transplanting to active tillering stage showed a significant positive correlation with yield while maximum temperature and bright sunshine hours showed significant negative correlation in the case of Jyothi.

4.6.3.2. Active tillering to panicle initiation (P2)

Wind speed during active tillering to panicle initiation stage showed a significant positive correlation.

Table 4.13 Correlation between yield and weather variables in Jyothi

Stages	Tmax	Tmin	Tmean	TR	RHI	RHII	RHm	VPI	VPII	RF	RD	BSS	WS	Epan
P1	-0.457*	-0.189	-0.389	-0.274	0.190	0.661**	0.632**	-0.267	0.214	0.527**	0.404*	-0.616**	0.253	-0.378
P2	-0.299	-0.391	-0.395	-0.030	0.200	0.361	0.356	-0.301	0.071	0.254	0.301	-0.215	0.506**	0.033
P3	-0.351	-0.523**	-0.479*	-0.084	0.186	0.421*	0.407*	-0.342	-0.024	0.439*	0.568**	-0.365	0.297	-0.099
P4	-0.474*	-0.555**	-0.562**	-0.244	0.493*	0.296	0.421*	-0.652**	-0.318	0.597**	0.584**	-0.382	0.405*	-0.317
P5	-0.498*	-0.059	-0.443*	-0.395	0.400*	0.460*	0.479*	-0.054	-0.023	0.295	0.460*	-0.377	0.230	-0.158
P6	-0.762**	-0.425*	-0.698**	-0.487*	0.673**	0.479*	0.637**	-0.180	-0.332	0.388	0.461*	-0.370	0.255	-0.100

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

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

4.6.3.3. Panicle initiation to booting (P3)

Afternoon relative humidity, mean relative humidity, rainfall and number of rainy days during panicle initiation to booting stage in Jyothi exhibited a significant positive correlation with yield while minimum temperature and mean temperature showed a significant negative correlation.

4.6.3.4. Booting to heading (P4)

Forenoon relative humidity, mean relative humidity, rainfall, number of rainy days and wind speed during booting to heading stage showed a significant positive correlation with yield while maximum temperature, minimum temperature mean temperature and forenoon vapour pressure showed a significant negative correlation.

4.6.3.5. Heading to 50% flowering (P5)

Forenoon relative humidity, afternoon relative humidity, mean relative humidity and number of rainy days during heading to 50% flowering stage exhibited a positive correlation with yield while maximum and mean temperatures showed a significant negative correlation.

4.6.3.6. 50% flowering to physiological maturity

Forenoon relative humidity, afternoon relative humidity, mean relative humidity, and number of rainy days during 50% flowering to physiological maturity stage exhibited a significant positive correlation whereas maximum temperature, minimum temperature, mean temperature and diurnal temperature range showed a significant negative correlation in Jyothi.

4.6.4. Correlation between weather and yield of Kanchana

Table 4.14 shows the results of the correlation analysis carried out between weather variables and grain yield of Kanchana.

Table.4 14. Correlation between yield and weather variables in Kanchana

Stages	Tmax	Tmin	Tmean	TR	RHI	RHII	RHm	VPI	VPII	RF	RD	BSS	WS	Epan
P1	-0.295	-0.188	-0.288	-0.119	0.000	0.650**	0.582**	-0.076	0.347	0.480*	-0.152	-0.534**	0.071	-0.386
P2	-0.377	-0.471*	-0.471*	-0.057	0.248	0.453*	0.450*	-0.365	0.114	0.459*	0.212	-0.457*	0.354	-0.137
P3	-0.334	-0.330	-0.397*	-0.160	0.093	0.343	0.317	-0.254	0.034	0.334	0.469*	-0.426*	0.191	-0.368
P4	-0.056	-0.112	-0.084	0.002	0.225	0.183	0.228	-0.155	0.089	0.202	0.216	0.035	0.247	0.155
P5	-0.234	-0.002	-0.172	-0.238	0.263	0.284	0.300	-0.033	0.237	0.197	0.375	-0.299	0.070	-0.061
P6	-0.597**	-0.356	-0.557**	-0.368	0.581**	0.685**	0.724**	0.076	-0.002	0.427*	0.444*	-0.635**	-0.021	-0.234

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

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

4.6.4.1. Transplanting to active tillering

Afternoon relative humidity, mean relative humidity and rainfall during transplanting to active tillering stage exhibited a positive correlation with yield whereas bright sunshine hours showed a negative correlation in Kanchana.

4.6.4.2. Active tillering to panicle initiation

Afternoon relative humidity, mean relative humidity, rainfall showed positive correlation and minimum temperature, mean temperature and bright sunshine hours during active tillering to panicle initiation stage showed a significant negative correlation.

4.6.4.3. Panicle initiation to booting

Number of rainy days during panicle initiation to booting stage showed a positive correlation while mean temperature and bright sunshine hours showed a significant negative correlation.

4.6.4.4. 50% flowering to physiological maturity

Forenoon relative humidity, afternoon relative humidity, mean relative humidity, rainfall, and number of rainy days during 50% flowering to physiological maturity stage exhibited positive correlation with yield while maximum temperature, minimum temperature, mean temperature and bright sunshine hours showed a significant negative correlation with yield.

4.6.5. Correlation between weather variables and yield attributes of Jyothi

Correlation analysis was carried out between different yield attributes of rice variety Jyothi viz., thousand grain weight, number of panicles per m^2, number of spikelets per panicle and number of filled grains per panicle with different weather variables. The analysis was carried out using the data obtained from 5 years' field experiments conducted at Department of Agricultural Meteorology from 2013 to 2017. The correlation results are given in the tables from Table 4.15 to Table 4.18.

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

Forenoon and afternoon vapour pressure deficit during transplanting to active tillering stage showed significant positive influence on thousand-grain weight of Jyothi while minimum temperature during the same phenophases showed significant negative influence on it. When temperature range (TR) during active tillering to panicle initiation stage showed significant positive correlation with this yield attribute, minimum temperature during the same phenophases showed significant negative correlation. During panicle initiation to booting stage, afternoon vapour pressure deficit and rainfall had a significant negative influence on thousand-grain weight. Minimum temperature, forenoon vapour pressure deficit and wind speed during booting to heading stage had significant positive influence on thousand grain weight while maximum temperature and diurnal temperature range had significant negative influence. During heading to 50% flowering, wind speed positively influenced thousand-grain weight while afternoon vapour pressure deficit negatively influenced it. Forenoon relative humidity, forenoon vapour pressure deficit and pan evaporation during 50% flowering to physiological maturity stage had a significant positive influence on thousand grain weight while maximum temperature, diurnal temperature range, rainfall and number of rainy days had a significant negative influence.

4.6.5.2. Correlation between weather variables and number of panicles per m^2 in Jyothi

Significant positive correlation was exhibited by forenoon, afternoon and mean relative humidity, rainfall, number of rainy days and wind speed during transplanting to active tillering and panicle initiation to booting stages while significant negative correlation was exhibited by maximum and minimum temperatures, diurnal temperature range and forenoon vapour pressure deficit during panicle initiation to booting and booting to heading stages with number of panicles per m^2. Wind speed during active tillering to panicle initiation, booting to heading, heading to 50% flowering, 50% flowering to physiological maturity was found to be positively correlated with number of

Table.4.15. Correlation between weather and thousand grain weight in Jyothi worked out using 5 years' experimental data

Crop stages	Tmax	Tmin	Tmean	TR	RHI	RHII	RHmean	VPI	VPII	RF	RD	BSS	WS	Epan
P1	-0.024	-0.268**	-0.165	0.166	0.07	0.163	0.156	0.293**	0.331**	-0.071	0.186	-0.16	0.042	-0.136
P2	0.072	-0.267**	-0.078	0.275**	0.033	-0.14	-0.119	-0.008	-0.026	-0.164	-0.071	-0.082	0.104	-0.022
P3	-0.024	0.013	-0.013	-0.033	-0.061	-0.189	-0.176	0.142	-0.214*	-0.198*	-0.025	0.005	0.14	-0.065
P4	-0.211*	0.223*	-0.078	-.374**	0.146	0.108	0.143	0.198*	-0.138	-0.011	-0.118	-0.079	0.214*	0.082
P5	-0.111	0.173	0.00	-0.19	0.07	-0.14	-0.107	0.024	-0.368**	-0.045	-0.059	0.108	0.207*	0.165
P6	-0.216*	0.104	-0.085	-0.339**	0.270**	-0.045	0.106	0.292**	-0.07	-0.377**	-0.206*	-0.042	-0.009	0.282**

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

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

Table. 4.16. Correlation between weather and number of panicles per m^2 in Jyothi worked out using 5 years' experimental data

Crop stages	Tmax	Tmin	Tmean	TR	RHI	RHII	RHmean	VPI	VPII	RF	RD	BSS	WS	Epan
P1	-0.352**	0.027	-0.235*	-0.337**	0.394**	0.426**	0.450**	-0.042	0.055	0.407**	0.355**	-0.441**	0.407**	-0.149
P2	-0.232*	-0.124	-0.220*	-0.157	0.137	0.172	0.177	-0.186	-0.074	0.161	0.153	-0.136	0.479**	0.012
P3	-0.549**	-0.173	-0.491**	-0.486**	0.467**	0.373**	0.427**	-0.378**	-0.189	0.336**	0.321**	-0.405**	0.480**	-0.174
P4	-0.275**	-0.136	-0.258**	-0.247*	0.267**	-0.062	0.023	-0.206*	-0.207*	0.235*	0.215*	-0.086	0.565**	0.066
P5	-0.184	0.101	-0.099	-0.214*	0.197*	0.132	0.154	-0.091	-0.077	-0.095	0.115	0.031	0.462**	0.205*
P6	-0.265**	-0.058	-0.198*	-0.250*	0.273**	0.07	0.18	0.015	-0.114	0.142	0.15	-0.182	0.405**	0.14

*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

panicles while temperature ranges during transplanting to active tillering, heading to 50% flowering and 50% flowering to physiological maturity was negatively correlated. Forenoon relative humidity during booting to heading, heading to 50% flowering, 50% flowering to physiological maturity showed significant positive correlation with number of panicles per m^2 whereas maximum and mean temperatures during transplanting to active tillering, active tillering to panicle initiation and 50% flowering to physiological maturity and afternoon vapour pressure deficit during booting to heading stages exhibited significant negative correlation. Significant positive influence of rainfall and number of rainy days during booting to heading stage on number of filled grains was obtained while significant negative influence of bright sunshine hours during transplanting to active tillering and panicle initiation to booting stage was noticed through correlation analysis.

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

Significant positive influence was exhibited by forenoon, afternoon and mean relative humidity, rainfall and number of rainy days during panicle initiation to booting, booting to heading, heading to 50% flowering and 50% flowering to physiological maturity stages on number of spikelets per panicle whereas maximum, minimum and mean temperatures, and forenoon vapour pressure deficit during active tillering to panicle initiation, panicle initiation to booting, booting to heading and 50% flowering to physiological maturity exhibited significant negative influence on number of spikelets per panicle. Afternoon and mean relative humidity and rainfall during transplanting to active tillering and active tillering to panicle initiation stages showed a significant positive correlation while bright sunshine hours during transplanting to active tillering, panicle initiation to booting, and 50% flowering to physiological maturity and pan evaporation during panicle initiation to booting, and 50% flowering to physiological maturity showed significant negative correlation with number of spikelets per panicle. Wind speed during all phenophases except transplanting to active tillering and 50% flowering to physiological maturity exhibited significant positive correlation with number of spikelets per panicle. Significant negative influence of maximum temperature during transplanting

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Table.4.17. Correlation between weather and number of spikelets per panicle in Jyothi worked out using 5 years' experimental data

Crop stages	Tmax	Tmin	Tmean	TR	RHI	RHII	RHmean	VPI	VPII	RF	RD	BSS	WS	Epan
P1	-0.198*	-0.019	-0.151	-0.166	0.069	0.311**	0.284**	-0.257**	-0.063	0.279**	0.111	-0.218*	0.016	-0.144
P2	-0.285**	-0.220*	-0.303**	-0.142	0.107	0.384**	0.361**	-0.348**	-0.106	0.284**	0.19	-0.163	0.384**	0.125
P3	-0.470**	-0.438**	-0.541**	-0.247*	0.310**	0.550**	0.544**	-0.424**	0.134	0.354**	0.277**	-0.516**	0.244*	-0.435**
P4	-0.239*	-0.577**	-0.391**	0.046	0.382**	0.098	0.205*	-0.402**	-0.154	0.291**	0.342**	-0.176	0.281**	-0.103
P5	-0.239*	-0.158	-0.282**	-0.119	0.300**	0.404**	0.410**	0.102	0.184	0.419**	0.398**	-0.191	0.232*	-0.072
P6	-0.477**	-0.533**	-0.571**	-0.065	0.509**	0.516**	0.578**	-0.277**	-0.12	0.501**	0.392**	-0.441**	0.184	-0.301**

*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

to active tillering and heading to physiological maturity, forenoon vapour pressure deficit during transplanting to active tillering stage, diurnal temperature ranges during panicle initiation to booting, and mean temperature during heading to 50% flowering was observed on number of spikelets per panicle .

4.6.5.4. Correlation between weather variables and filled grains per panicle in Jyothi

Significant positive correlation was observed between forenoon relative humidity, afternoon relative humidity and mean relative humidity of transplanting to active tillering and panicle initiation to booting stage and number of filled grains per panicle while significant negative correlation was obtained for maximum temperature, minimum temperature, mean temperature and forenoon vapour pressure deficit of phenophases transplanting to active tillering, active tillering to panicle initiation, panicle initiation to booting and 50% flowering to physiological maturity with number of filled grains. Wind speed during all of the phenophases except during transplanting to active tillering had a significant positive effect on number of filled grains while afternoon vapour pressure deficit during active tillering to panicle initiation, panicle initiation to booting, booting to heading and 50% flowering to physiological maturity had a significant negative effect on number of filled grains per panicle. Number of rainy days during booting to heading and heading to 50% flowering showed a significant positive correlation with number of filled grains whereas bright sunshine hours and pan evaporation during transplanting to active tillering, panicle initiation to booting and 50% flowering to physiological maturity stages exhibited negative correlation. A significant positive influence of forenoon relative humidity and mean relative humidity was evident from the analysis. Diurnal temperature ranges during transplanting to active tillering and minimum and mean temperatures during booting to heading stage exhibited a negative influence on number of filled grains per panicle in Jyothi.

4.6.6. Correlation between weather variables and yield attributes of Kanchana

Correlation analysis was carried out between different weather variables and different yield attributes at transplanting stage of rice variety Kanchana like thousand

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Table.4.18. Correlation between weather and filled grains per panicle in Jyothi worked out using 5 years' experimental data

Crop stages	Tmax	Tmin	Tmean	TR	RHI	RHII	RHmean	VPI	VPII	RF	RD	BSS	WS	Epan
P1	-0.419**	-0.246*	-0.433**	-0.206*	0.345**	0.375**	0.397**	-0.327**	-0.195	0.218*	0.147	-0.312**	0.176	-0.253*
P2	-0.247*	-0.324**	-0.326**	-0.024	0.139	0.124	0.134	-0.262**	-0.275**	0.069	-0.127	0.01	0.248*	-0.012
P3	-0.419**	-0.439**	-0.502**	-0.193	0.338**	0.248*	0.291**	-0.397**	-0.224*	0.056	0.103	-0.295**	0.207*	-0.231*
P4	-0.083	-0.396**	-0.208*	0.126	0.145	-0.144	-0.089	-0.229*	-0.279**	0.146	0.286**	0.09	0.362**	-0.066
P5	-0.119	-0.112	-0.157	-0.041	0.051	0.147	0.138	-0.123	-0.034	0.182	0.377**	0.045	0.349**	0.115
P6	-0.490**	-0.407**	-0.516**	-0.194	0.374**	0.16	0.287**	-0.374**	-0.487**	0.036	0.000	-0.236*	0.239*	-0.243*

*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

grain weight, number of panicles per m^2, number of spikelets per panicle and number of filled grains per panicle. The analysis was carried out using the data obtained from 5 years' field experiments conducted at Department of Agricultural Meteorology from 2013 to 2017. The Correlation results are presented in the table 4.19 to 4.22.

4.6.6.1. Correlation between weather variables and thousand grain weight in Kanchana

Significant positive correlation was shown by diurnal temperature range, forenoon vapour pressure deficit, afternoon vapour pressure deficit and number of rainy days on thousand-gram weight while significant negative correlation was shown by minimum temperature and pan evaporation during transplanting stage to active tillering stage. Minimum temperature and bright sunshine hours during active tillering to panicle initiation stage was observed to show significant influence on thousand-grain weight. Forenoon vapour pressure deficit during panicle initiation to booting stage showed a significant positive influence while afternoon vapour pressure deficit during the same phenophases showed negative influence. Minimum temperature during booting to heading stage was found to have significant positive correlation whereas diurnal temperature ranges and number of rainy days during same phenophases was found to have significant negative correlation with thousand-grain weight. Significant positive influence of minimum temperature and pan evaporation during heading to 50% flowering stage was observed on this yield at transplanting stage while the negative influence was of afternoon relative humidity and mean relative humidity, rainfall and number of rainy days. Significant positive influence of forenoon vapour pressure deficit and pan evaporation was observed during 50% flowering to physiological maturity stage while significant negative influence of diurnal temperature range, rainfall and number of rainy days was found during the same stage.

Table.4.19. Correlation between weather and thousand grain weight in Kanchana worked out using 5 years' experimental data

Crop stages	Tmax	Tmin	Tmean	TR	RHI	RHII	RHmean	VPI	VPII	RF	RD	BSS	WS	Epan
P1	0.129	-0.322**	-0.103	0.415**	-0.009	-0.004	-0.005	0.358**	0.350**	-0.069	0.460**	0.004	-0.178	-0.233*
P2	-0.095	-0.277**	-0.192	0.115	0.081	0.072	0.078	-0.08	0.006	0.058	0.189	-0.277**	-0.057	-0.127
P3	-0.09	0.082	-0.034	-0.141	0.052	-0.107	-0.082	0.230*	-0.246*	-0.111	0.083	-0.062	0.178	-0.174
P4	-0.102	0.346**	0.056	-0.331**	0.104	-0.11	-0.066	0.186	-0.059	-0.192	-0.247*	0.041	0.175	0.071
P5	0.025	0.290**	0.155	-0.164	-0.132	-0.214*	-0.211*	0.052	-0.184	-0.212*	-0.211*	0.069	0.123	0.218*
P6	-0.193	0.169	-0.039	-0.375**	0.189	-0.126	0.004	0.292**	-0.162	-0.470**	-0.310**	0.069	0.055	0.309**

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

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

4.6.6.2. Correlation between weather variables and number of panicles per m^2 in Kanchana

Panicles per m^2 was positively influenced by forenoon relative humidity, afternoon relative humidity and mean relative humidity and wind speed during active tillering to panicle initiation, panicle initiation to booting, booting to heading and 50% flowering to physiological maturity stages. Significant negative correlation was shown by maximum temperature and mean temperature during all the phenophases. rainfall and number of rainy days during panicle initiation to booting, booting to heading and 50% flowering to physiological maturity with panicles per m^2 while negative correlation was shown by bright sunshine hours during all phenophases except heading to 50% Flowering. Afternoon relative humidity and mean relative humidity, rainfall and wind speed during transplanting stage to active tillering stage exhibited significant positive correlation whereas forenoon vapour pressure deficit during active tillering to panicle initiation, panicle initiation to booting and heading to 50% flowering showed significant negative correlation with panicles per m^2. Forenoon relative humidity, number of rainy days and wind speed during heading to 50% flowering showed a significant positive influence on panicles per m^2. Significant negative influence of minimum temperature during active tillering to panicle initiation and panicle initiation to booting stage and of diurnal temperature range during panicle initiation to booting, booting to heading, 50% flowering to Physiological Maturity was noticed by correlation analysis. Pan evaporation during Transplanting stage to active tillering stage also influenced these yield at transplanting stage negative.

4.6.6.3. Correlation between weather variables and number of spikelets per panicle in Kanchana

A significant positive correlation was shown by forenoon relative humidity, afternoon relative humidity and mean relative humidity, rainfall, number of rainy days and wind speed during panicle initiation to booting, booting to heading, heading to 50% flowering, and 50% flowering to physiological maturity with number of spikelets per panicle. minimum temperature, maximum temperature and mean temperature, forenoon

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Table.4.20. Correlation between weather and number of panicles per m^2 in Kanchana worked out using 5 years' experimental data

Crop stages	Tmax	Tmin	Tmean	TR	RHI	RHII	RHmean	VPI	VPII	RF	RD	BSS	WS	Epan
P1	-0.240*	-0.169	-0.243*	-0.083	0.09	0.413**	0.386**	-0.152	0.08	0.337**	-0.005	-0.399**	0.363**	-0.310**
P2	-0.233*	-0.320**	-0.305**	-0.012	0.245*	0.207*	0.228*	-0.249*	0.024	0.18	0.103	-0.231*	0.468**	-0.143
P3	-0.417**	-0.321**	-0.457**	-0.251*	0.261**	0.358**	0.366**	-0.328**	-0.022	0.275**	0.256*	-0.394**	0.328**	-0.184
P4	-0.256*	-0.105	-0.230*	-0.240*	0.374**	0.259**	0.340**	-0.175	0.006	0.373**	0.364**	-0.218*	0.431**	0.119
P5	-0.266**	-0.140	-0.260**	-0.180	0.198*	0.163	0.182	-0.255*	0.036	-0.007	0.213*	-0.141	0.376**	0.002
P6	-0.387**	-0.136	-0.314**	-0.324**	0.445**	0.365**	0.449**	0.059	-0.023	0.304**	0.319**	-0.384**	0.258**	-0.019

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

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

Table. 4.21. Correlation between weather and number of spikelets per panicle in Kanchana worked out using 5 years' experimental data

Crop stages	Tmax	Tmin	Tmean	TR	RHI	RHII	RHmean	VPI	VPII	RF	RD	BSS	WS	Epan
P1	-0.307**	0.143	-0.107	-0.427**	0.059	0.371**	0.343**	-0.19	-0.084	0.330**	-0.357**	-0.344**	0.557**	-0.006
P2	-0.323**	-0.129	-.276**	-0.272**	0.239*	0.370**	0.374**	-0.261**	-0.087	0.252*	0.152	-0.249*	0.457**	-0.011
P3	-0.432**	-0.313**	-.465**	-0.272**	0.317**	0.531**	0.528**	-0.516**	0.13	0.437**	0.250*	-0.436**	0.404**	-0.207*
P4	-0.220*	-0.369**	-.304**	-0.036	0.348**	0.339**	0.402**	-0.349**	0.151	0.402**	0.401**	-0.342**	0.362**	-0.142
P5	-0.350**	-0.375**	-.432**	-0.114	0.251*	0.416**	0.410**	-0.245*	0.107	0.327**	0.434**	-0.293**	0.367**	-0.022
P6	-0.329**	-0.383**	-.400**	-0.035	0.396**	0.466**	0.493**	-0.203*	0.035	0.519**	0.439**	-0.440**	0.356**	-0.227*

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

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

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vapour pressure deficit and bright sunshine hours during the same phenophases showed significant negative correlation with number of spikelets per panicle. Afternoon relative humidity and mean relative humidity, rainfall and wind speed during transplanting stage to active tillering and active tillering to panicle initiation stages exhibited a significant positive influence on this yield attribute at transplanting stage while maximum temperature, temperature range and bright sunshine hours during the same phenophases exhibited significant negative influence. Forenoon relative humidity during active tillering to panicle initiation had a significant positive correlation with number of spikelets per panicle. Pan evaporation during panicle initiation to booting and 50% flowering to physiological maturity had a significant negative correlation with number of spikelets per panicle. Number of rainy days during transplanting stage to active tillering stage, mean temperature and forenoon vapour pressure deficit during active tillering to panicle initiation and diurnal temperature range during panicle initiation to booting stage also showed a significant influence on number of spikelets per panicle.

4.6.6.4. Correlation between weather variables and filled grains per panicle in Kanchana

Mean relative humidity and wind speed during active tillering to panicle initiation stage, panicle initiation to booting and 50% flowering to physiological maturity exhibited a significant positive correlation with filled grains per panicle while maximum temperature, minimum temperature and mean temperature, forenoon vapour pressure deficit and afternoon vapour pressure deficit during transplanting stage to active tillering, active tillering to panicle initiation, panicle initiation to booting and 50% flowering to physiological maturity showed a significant negative correlation with filled grains per panicle. Forenoon relative humidity during transplanting stage to active tillering, panicle initiation to booting and 50% flowering to physiological maturity had a significant positive influence on this yield at transplanting stage while bright sunshine hours during transplanting stage to active tillering and panicle initiation to booting had a significant negative influence. Rainfall and afternoon relative humidity during transplanting stage to active tillering, active tillering to panicle initiation and number of rainy days and wind

Table.4.22. Correlation between weather and filled grains per panicle in Kanchana worked out using 5 years' experimental data

Crop stages	Tmax	Tmin	Tmean	TR	RHI	RHII	RHmean	VPI	VPII	RF	RD	BSS	WS	Epan
P1	-0.400**	-0.372**	-0.457**	-0.055	0.209*	0.298**	0.306**	-0.374**	-0.202*	0.207*	-0.384**	-0.216*	0.132	-0.414**
P2	-0.329**	-0.361**	-0.388**	-0.091	0.174	0.244*	0.249*	-0.249*	-0.230*	0.207*	0.119	-0.195	0.215*	-0.118
P3	-0.475**	-0.411**	-0.540**	-0.261**	0.372**	0.191	0.245*	-0.429**	-0.339**	0.074	0.129	-0.300**	0.289**	-0.169
P4	-0.236*	-0.232*	-0.263**	-0.139	0.186	0.019	0.072	-0.159	-0.256*	0.165	0.241*	0.052	0.528**	-0.114
P5	-0.063	-0.093	-0.09	-0.004	-0.149	-0.138	-0.15	-0.202*	-0.206*	-0.124	0.229*	0.292**	0.430**	0.241*
P6	-0.465**	-0.332**	-0.461**	-0.237*	0.334**	0.083	0.210*	-0.348**	-0.451**	-0.103	-0.114	-0.181	0.263**	-0.105

*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

speed during booting to heading and heading to 50% flowering exhibited a significant positive correlation with filled grains per panicle. Number of rainy days and pan evaporation during transplanting stage to active tillering and temperature range during panicle initiation to booting stage had a significant negative impact on filled grains per panicle. Mean relative humidity during Transplanting stage to active tillering, bright sunshine hours and pan evaporation during heading to 50% flowering influence the filled grains per panicle positively. Maximum temperature, minimum temperature and mean temperature during booting to heading, afternoon vapour pressure deficit during booting to heading and heading to 50% flowering had significant negative influence on filled grains per panicle. Forenoon vapour pressure deficit during heading to 50% flowering and diurnal temperature range during 50% flowering to physiological maturity. Also influenced filled grains per panicle negatively.

4.7. GROWTH INDICES

Growth indices/physiological observations like leaf area index, leaf area duration, crop growth rate and net assimilation rate were computed from the biometric observations such as leaf area and dry matter accumulation, which were recorded at fortnightly intervals.

4.7.1. Leaf area index at fortnightly intervals

The influence of different dates of planting and varieties on leaf area index at fortnightly interval were assessed by performing analysis of variance for which results are given in Appendix II. The mean values are depicted in the Table.4.23.

Significant influence of dates of planting was evident from the results of the analysis. During all fortnights, leaf area index was significantly different with respect to five dates of planting. At 15 days after planting, June 20th and July 5th plantings were observed to be on par. August 5th planting was found to have lowest LAI at 15 DAP.

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

Date of planting	Leaf area index								
	15 DAP			30 DAP			45 DAP		
	J	K	Mean	J	K	Mean	J	K	Mean
5^{th} June	0.52^{a}	0.51^{c}	0.52^{b}	2.27	2.21	2.24^{a}	4.04	3.94	3.99^{a}
20^{th} June	0.55^{a}	0.66^{a}	0.60^{a}	2.21	2.26	2.24^{a}	3.47	3.53	3.50^{b}
5^{th} July	0.55^{a}	0.58^{b}	0.58^{a}	1.94	2.07	2.00^{b}	3.62	3.50	3.56^{b}
20^{th} July	0.54^{a}	0.51^{c}	0.53^{b}	2.06	2.19	2.13^{a}	3.48	3.19	3.34^{b}
5^{th} August	0.51^{a}	0.47^{c}	0.49^{c}	1.96	2.04	2.00^{b}	3.33	3.39	3.36^{b}
CD	0.06		0.04	NS		0.12	NS		0.29

Date of planting	Leaf area index								
	60 DAP			75 DAP			90 DAP		
	J	K	Mean	J	K	Mean	J	K	Mean
5^{th} June	4.96	4.39	4.68^{a}	5.28^{a}	4.82^{a}	5.05	3.99^{a}	3.29^{a}	3.64^{a}
20^{th} June	4.73	4.84	4.79^{a}	4.94^{b}	4.94^{a}	4.94	3.47^{c}	3.25^{a}	3.36^{c}
5^{th} July	4.71	4.45	4.58^{a}	5.12^{a}	5.01^{a}	5.06	3.27^{d}	2.91^{b}	3.09^{d}
20^{th} July	4.59	4.13	4.36^{b}	5.25^{a}	4.91^{a}	5.08	3.68^{b}	3.38^{a}	3.53^{b}
5^{th} August	4.74	4.45	4.60^{a}	5.21^{a}	4.73^{b}	4.97	3.33^{cd}	3.01^{b}	3.17^{d}
CD	NS		0.23	0.28		NS	0.19		0.10

DAP – Days After Planting

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

Varieties	Leaf area index					
	15 DAP	30 DAP	45 DAP	60 DAP	75 DAP	90 DAP
Jyothi	0.54	2.09	3.59	4.74^{a}	5.16^{a}	3.55^{a}
Kanchana	0.55	2.15	3.51	4.45^{b}	4.88^{b}	3.17^{b}
CD	NS	NS	NS	0.16	0.09	0.10

DAP – Days After Planting

In Jyothi, all planting dates showed similar leaf area index at 15 DAP while in Kanchana, June 20th planting exhibited highest leaf area index compared to other plantings. At 30 DAP, the interaction between five plantings and two varieties was found to have non-significant influence on leaf area index while there was significant difference in LAI between five dates of planting. June 5th and June 20th plantings were found to have higher LAI which was on par with July 20th planting. At 45 DAP, June 5th planting was found to obtain highest LAI compared to other plantings and the interaction was non-significant. July 20th planting was superior in LAI compared all other plantings at 60 DAP. In the case of all five plantings, maximum LAI was observed at 75 DAP. June 20th planting showed lowest LAI in Jyothi whereas August 5th planting showed lowest LAI in Kanchana at 75 DAP. Remaining all plantings were on par. After 75 DAP, LAI showed a decreasing trend towards physiological maturity. LAI showed significant difference between two varieties at 60, 75 and 90 DAP where Jyothi was found to be superior to Kanchana.

4.7.2. Leaf area duration at fortnightly intervals

Table 4.24. shows the mean leaf area duration during different dates of planting for two varieties at fortnightly interval.

Five dates of planting showed significant influence on leaf area duration at fortnightly intervals. During 0-15 DAP, July 5th planting was on par with June 5th, June 20th and July 20th plantings in Jyothi while June 20th planting was superior than other plantings in Kanchana. Irrespective of varieties, with different dates of planting, June 20th and July 5th plantings were on par. Interaction effect of different dates of planting with varieties was non-significant during 15-30, 30-45 and 45-60 DAP where effect of different dates of planting was significant. June 20th planting was observed to be on par with June 5th planting during 15-30 DAP. June 5th planting was significantly different and superior to all other plantings during 30-45 DAP. August 5th planting was found to be on par with July 5th and July 20th plantings. During 45-60 DAP, June 5th planting was found

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

Date of planting	Leaf area duration (days)								
	0 - 15 DAP			15 - 30 DAP			30 - 45 DAP		
	J	K	Mean	J	K	Mean	J	K	Mean
5th June	3.91^{ab}	3.83^{c}	3.87^{b}	20.91	20.38	20.65^{ab}	47.28	46.09	46.69^{a}
20th June	4.10^{ab}	4.90^{a}	4.50^{a}	20.68	21.86	21.27^{a}	42.59	43.41	43.00^{b}
5th July	4.32^{a}	4.32^{b}	4.32^{a}	18.85	19.80	19.32^{cd}	41.71	41.72	41.72^{bc}
20th July	4.07^{ab}	3.80^{c}	3.94^{b}	19.54	20.23	19.88^{bc}	41.53	40.39	40.96^{bc}
5th August	3.83^{b}	3.53^{c}	3.68^{b}	18.55	18.80	18.67^{d}	39.72	40.69	40.20^{c}
CD	0.45		0.33	NS		0.99	NS		2.25

Date of planting	Leaf area duration (days)								
	45 – 60 DAP			60 – 75 DAP			75 – 90 DAP		
	J	K	Mean	J	K	Mean	J	K	Mean
5th June	67.46	62.48	64.97^{a}	76.79^{a}	69.06^{b}	72.93	69.54^{a}	60.80^{ab}	65.17^{a}
20th June	61.46	62.77	62.11^{ab}	72.48^{b}	73.31^{a}	72.90	63.03^{c}	61.34^{ab}	62.19^{b}
5th July	62.46	59.63	61.04^{bc}	73.66^{ab}	70.97^{ab}	72.31	62.90^{c}	59.43^{bc}	61.16^{b}
20th July	60.48	54.89	57.68^{d}	73.76^{ab}	67.75^{b}	70.75	66.94^{b}	62.17^{a}	64.55^{a}
5th August	60.54	58.80	59.67^{bcd}	74.60^{ab}	68.85^{b}	71.73	64.05^{c}	58.02^{c}	61.04^{b}
CD	NS		3.02	3.79		NS	2.51		2.00

DAP – Days After Planting

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

Varieties	Leaf area duration					
	0 - 15 DAP	15 - 30 DAP	30 - 45 DAP	45 - 60 DAP	60 - 75 DAP	75 - 90 DAP
Jyothi	4.04	19.70	42.57	62.48[a]	74.26[a]	65.29[a]
Kanchana	4.08	20.22	42.46	59.71[b]	69.99[b]	60.35[b]
CD	NS	NS	NS	1.70	1.53	0.95

DAP – Days After Planting

to be on par with June 20th planting and July 20th planting was on par with August 5th planting. Overall effect of date of planting was non-significant in the case of 60-75 DAP. The value of leaf area duration was maximum during this period in both Jyothi and Kanchana. Significant superiority in leaf area duration was shown by June 5th planting in Jyothi while June 5th planting was on par with June 20th and July 20th plantings in the case of Kanchana during 75- 90 DAP. Irrespective of varieties, June 5th planting was on par with July 20th planting.

Considering the significant influence of varieties in leaf area duration, it was significantly different among varieties during 45-60, 60-75 and 75-90 DAP. In all these cases, Jyothi was found to be superior over Kanchana.

4.7.3. Crop growth rate at fortnightly intervals

Analysis of variance was carried out for crop growth rate at fortnightly interval to analyze the effect of different dates of planting and varieties. The results are given in the Appendix II. Table 4.25 shows the crop growth rate at fortnightly intervals for different dates of planting.

The overall effect of different dates of planting was significant in almost all observations except during 60-75 DAP. The interaction effect of dates of planting with respect to varieties was found non-significant only during 75-90 DAP.

In both Jyothi and Kanchana, June 5th and June 20th plantings were on par during 0-15 DAP. In the case of effect of planting dates, June 5th and June 20th plantings were found to be on par and superior over other plantings during 0-15 DAP. During 15-30 DAP, August 5th planting was significant and inferior to all other plantings in Jyothi while August 5th planting was on par with July 20th and June 5th plantings in Kanchana. Overall effect of different dates of planting showed that August 5th and June 5th plantings were on par and inferior to all other plantings. Observations recorded during 30-45 DAP reveals that August 5th planting was on par with June 5th planting in Jyothi. June 20th planting was on par with July 20th planting and significantly inferior than all other plantings in

Table. 4.25(a) Effect of date of planting on crop growth rate (CGR) at fortnightly intervals

Date of planting	Crop growth rate (g m^{-2} day^{-1})								
	0 - 15 DAP			15 - 30 DAP			30 - 45 DAP		
	J	K	Mean	J	K	Mean	J	K	Mean
5th June	3.24^{a}	3.49^{a}	3.37^{a}	17.26^{a}	15.40^{ab}	16.33^{ab}	25.41^{ab}	26.81^{a}	26.11^{ab}
20th June	3.24^{a}	3.64^{a}	3.44^{a}	17.87^{a}	17.04^{a}	17.45^{a}	21.20^{c}	23.12^{b}	22.16^{c}
5th July	2.87^{b}	2.62^{c}	2.74^{b}	18.17^{a}	16.96^{a}	17.56^{a}	22.66^{bc}	27.60^{a}	25.13^{ab}
20th July	2.39^{c}	2.87^{bc}	2.63^{b}	18.24^{a}	15.73^{ab}	16.98^{a}	24.63^{b}	24.38^{ab}	24.50^{bc}
5th August	2.49^{c}	2.99^{b}	2.74^{b}	14.42^{b}	14.81^{b}	14.62^{b}	28.58^{a}	26.68^{a}	27.63^{a}
CD	0.37		0.27	1.93		1.78	3.36		2.97

Date of planting	Crop growth rate (g m^{-2} day^{-1})								
	45 - 60 DAP			60 – 75 DAP			75 - 90 DAP		
	J	K	Mean	J	K	Mean	J	K	Mean
5th June	33.29^{a}	35.25^{a}	34.27^{a}	22.01^{ab}	19.18^{a}	20.59	-9.70	-11.06	-10.38^{c}
20th June	30.29^{a}	37.89^{a}	34.09^{a}	23.88^{a}	19.06^{a}	21.47	-6.71	-8.50	-7.60^{ab}
5th July	31.37^{a}	29.16^{b}	30.26^{b}	22.69^{a}	18.17^{a}	20.43	-9.07	-7.64	-8.36^{abc}
20th July	32.67^{a}	27.05^{b}	29.86^{b}	16.55^{b}	22.62^{a}	19.59	-9.19	-8.92	-9.06^{bc}
5th August	25.11^{b}	27.40^{b}	26.25^{c}	19.67^{ab}	17.29^{a}	18.48	-6.77	-6.91	-6.84^{a}
CD	5.11		3.57	5.65		NS	NS		2.17

DAP – Days After Planting

Table.4.25(b) Comparison of crop growth rate (CGR) of varieties at fortnightly intervals

Varieties	Crop growth rate (g m^{-2} day^{-1})					
	0 - 15 DAP	15 - 30 DAP	30 - 45 DAP	45 - 60 DAP	60 - 75 DAP	75 - 90 DAP
Jyothi	2.84^{b}	17.19^{a}	24.50^{b}	30.54	20.96	-8.29
Kanchana	3.12^{a}	15.99^{b}	25.72^{a}	31.35	19.26	-8.61
CD	0.16	0.48	1.00	NS	NS	NS

DAP – Days After Planting

Kanchana. Singular effect of dates of planting during 30-45 DAP shows that August 5th planting, on par with June 5th and July 5th plantings were significantly superior than other plantings. At 45-60 DAP, August 5th planting of Jyothi was found to be significant and inferior than all other plantings. In Kanchana, June 5th and June 20th plantings were found to be on par. They were significant and superior to other plantings. During 60-75 DAP, in Jyothi except July 20th planting, remaining all plantings were on par. In Kanchana, all plantings were on par. During 75–90 DAP, August 5th planting was found to be significant and superior which was on par with June 20th and July 5th plantings.

Considering the significant influence of varieties in crop growth rate, it was significantly different among varieties during 0-15, 15-30 and 30-45 DAP. Jyothi was found to be superior over Kanchana during 15-30 DAP.

4.7.4. Net assimilation rate at fortnightly intervals

Analysis of variance was done for net assimilation rate at fortnightly interval to analyze the effect of dates of planting and varieties on it. The results are given in the Table 4.26.

The overall effect of dates of planting was found to be non-significant for 15-30, 60-75 and 75-90 DAP. The interaction effect between dates of planting and varieties were found to be non-significant for 15-30, 45-60 and 75-90 DAP. During 30-45 DAP, in Jyothi, August 5th planting was found to be significantly superior than all other plantings. In Kanchana, June 20th planting was found to be significantly inferior which was on par with June 5th and July 20th plantings. August 5th was found to be significantly superior to all other plantings when the effect of different dates of planting were considered. During 45-60 DAP August 5th planting was inferior which was on par with July 5th planting. In Jyothi, July 20th planting was found to be on par with June 5th and August 5th plantings and in Kanchana, July 20th planting was found to be on par with June 5th, June 20th and July 5th planting and superior during 60-75 DAP.

Table.4.26(a) Effect of date of planting on net assimilation rate (NAR) at fortnightly intervals

Date of planting	Net assimilation rate (g m^{-2} day^{-1})								
	15 – 30 DAP			30 - 45 DAP			45 – 60 DAP		
	J	K	Mean	J	K	Mean	J	K	Mean
5th June	14.55	13.32	13.94	8.31^{bc}	9.06^{ab}	8.68^{bc}	7.47	8.53	8.00^{a}
20th June	15.07	13.19	14.13	7.59^{c}	8.13^{b}	7.86^{c}	7.46	9.13	8.29^{a}
5th July	16.21	14.59	15.40	8.42^{bc}	10.15^{a}	9.28^{b}	7.58	7.37	7.47^{ab}
20th July	16.06	13.69	14.87	9.11^{b}	9.16^{ab}	9.14^{b}	8.17	7.44	7.81^{a}
5th August	13.38	13.89	13.63	11.07^{a}	10.06^{a}	10.56^{a}	6.29	7.04	6.67^{b}
CD	NS		NS	1.35		1.09	NS		1.00

Date of planting	Net assimilation rate (g m^{-2} day^{-1})					
	60 - 75 DAP			75 – 90 DAP		
	J	K	Mean	J	K	Mean
5th June	4.32^{ab}	4.16^{ab}	4.24	-2.10	-2.76	-2.43
20th June	4.94^{a}	3.91^{ab}	4.43	-1.61	-2.11	-1.86
5th July	4.63^{a}	3.85^{ab}	4.24	-2.20	-1.98	-2.09
20th July	3.37^{b}	5.04^{a}	4.21	-2.08	-2.18	-2.13
5th August	3.96^{ab}	3.77^{b}	3.86	-1.61	-1.83	-1.72
CD	1.22		NS	NS		NS

DAP – Days After Planting

Table.4.26(b) Comparison of net assimilation rate (NAR) of varieties at fortnightly intervals

Varieties	Net assimilation rate (g m^{-2} day^{-1})				
	15 - 30 DAP	30 - 45 DAP	45 - 60 DAP	60 - 75 DAP	75 - 90 DAP
Jyothi	15.05[a]	8.90	7.39	4.24	-1.92
Kanchana	13.73[b]	9.31	7.90	4.15	-2.17
CD	0.71	NS	NS	NS	NS

DAP –Days After Planting

Comparison of net assimilation rate of varieties at fortnightly interval showed that only during 15-30 DAP the effect was significant and Jyothi was superior over Kanchana.

4.8. INCIDENCE OF PESTS AND DISEASES

The incidence of pests and diseases during the experimental period was more in delayed plantings compared to earlier plantings. The major pests and diseases observed in the crop are presented in the table. Major pests observed were Leaf folder (*Cnaphalocrocis medinalis),* Stem borer (*Scirphophaga incertulus*), Brown plant hopper (*Nilaparvata lugens*) and Rice bug (*Leptocorisa acuta*). Disease incidence was very less compared to pests and the important disease found in the crop was Sheath blight (*Rhizoctonia solani*).

Table.4.27. Pests and diseases observed in different plantings

Planting dates	**Pests**				**Diseases**
	Leaf folder	**Stem borer**	**Brown plant hopper**	**Rice bug**	**Sheath blight**
D1	√	√	√	√	√
D2	√	√	√	√	√
D3	√	-	√	√	√
D4	√	√	-	√	√
D5	√	√	-	√	-

4.9. Comparison of different weather based models for forecasting rice yield

The main objective of the present study was to compare the accuracy of different weather based models for rice yield forecasting in central zone of Kerala. For this purpose, four types of crop weather models based on statistical techniques and one crop simulation model (DSSAT- CERES-Rice model) were used. The models were compared by using the model accuracy measures *viz.*, adjusted R^2 and mean absolute percentage error (MAPE).

A model with higher adjusted R^2 value (more than 0.5) and lower MAPE value (less than 10%) can be considered as a good yield-forecasting model.

4.9.1. Crop weather models based on statistical techniques

Possibility of forecasting crop yields well in advance provides sufficient help for the farmers in on-farm decision making and planning the marketing of the produce. It also helps the government in proper resource allocation, marketing and providing storage facilities. Forecasting using crop weather models based on statistical techniques utilizes the crop weather relationship. To compare the accuracy of different weather based models for forecasting rice yield in central zone of Kerala and to validate them with experimental data, the crop yield data and weather data of past four years' experiment (which included five dates of planting each year) were collected from Department of Agricultural Meteorology, Kerala Agricultural University. This data was used to frame crop weather relationship in rice and thereby crop weather models. Mainly four methods were employed:

1. Based on weekly weather variables
2. Based on fortnightly weather variables
3. Based on crop stage wise weather variables
4. Based on composite weather variables

Stepwise regression method was utilized for selecting the variables to be included in the model from five years cropping period weather data (including five dates of planting in each year, total twenty-five crop environments). Different variables were selected in each model fitted.

The results obtained from each model are presented in the following sections.

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The results obtained from each model are presented in the following sections.

4.9.1.1. Crop weather models based on weekly weather variables

Weekly weather variables were used in this method to fit the regression equations. The models obtained by carrying out stepwise regression for Jyothi and Kanchana are represented in tabular form in Table.4.28(a) and Table.4.28(b) respectively. In this method, models were fitted using 7, 8, 9 and 10 weeks' weather variables for both the considered varieties. The crop period was about 14 weeks for both the varieties. Thus, if we use the weather variables from 1^{st} week after transplanting to 7^{th} week after transplanting, yield forecasting can be done 7 weeks prior to harvest. When weather variables from 1^{st} week after transplanting to 8^{th} week after transplanting are used, yield can be forecasted 6 weeks before harvesting. Yield forecast can be provided 5 weeks prior to harvest if weather variables from 1^{st} week after transplanting up to 9^{th} week after transplanting are used. Likewise, when weather variables from 1^{st} week after transplanting up to 10^{th} weeks after transplanting are used, yield can be forecasted 4 weeks before the harvest.

From the results obtained, it is evident that maximum temperature during sixth week (X_{16}), bright sunshine hours during first week (X_{61}) and third week (X_{63}) were the variables entered in the regression model for seven-week crop period. The model could explain about 63.5% of variation in rice yield. It is also evident that the partial regression coefficient corresponding to all the entered variables were significant and negative.

The variables selected in the model for eight-week crop period by stepwise regression are minimum temperature during fifth week (X_{25}), afternoon relative humidity during first week (X_{41}), forenoon vapour pressure deficit during fourth week (X_{54}), forenoon vapour pressure deficit during seventh week (X_{57}), forenoon vapour pressure deficit during eighth week (X_{58}) and bright sunshine hours during third week (X_{63}) which explained about 85.4 % variation in the yield of rice. The partial regression coefficients of afternoon relative humidity during first week (X_{41}) and forenoon vapour pressure deficit during fourth week (X_{54}) were found to be positive and significant while that of minimum temperature during fifth week (X_{25}), forenoon vapour pressure deficit during

Table. 4.28 (a) Crop weather models based on weekly weather variables for Jyothi

Variables in the equation		Weeks			
		7	8	9	10
	Constant A_0	13.925**	20.736**	16.684**	-
X_{16}	Partial regression coefficients	-0.253*	-	-	-
X_{110}			-	-	-0.290*
X_{25}		-	-0.385**	-	-
X_{41}		-	0.045**	0.052**	0.131**
X_{49}		-	-	0.052**	-
X_{54}		-	0.493**	-	-
X_{57}		-	-0.357*	-0.383**	-
X_{58}		-	-0.563**	-0.469*	-
X_{61}		-0.246**	-	-	-
X_{63}		-0.309**	-0.263**	-0.165**	-
X_{71}		-	-	-	-0.004*
X_{73}		-	-	-	0.002*
X_{87}		-	-	-	-0.796**
	Adjusted R^2 (%)	63.5	85.4	81.8	76.1
	MAPE (%)	8.23	5.19	5.62	7.35

Table. 4.28 (b) Crop weather models based on weekly weather variables for Kanchana

Variables in the equation		Weeks			
		7	8	9	10
	Constant A_0	4.138*	4.138*	4.138*	4.138*
X_{43}	Partial regression coefficients	0.047*	0.047*	0.047*	0.047*
X_{61}		-0.269**	-0.269**	-0.269**	-0.269**
X_{87}		-0.839**	-0.839**	-0.839**	-0.839**
	Adjusted R^2(%)	58.1	58.1	58.1	58.1
	MAPE (%)	8.35	8.35	8.35	8.35

X_{16} – maximum temperature during 6th week
X_{25} - minimum temperature during 5th week
X_{41} - afternoon relative humidity during 1st week
X_{43} - afternoon relative humidity during 3rd week
X_{49} - afternoon relative humidity during 9th week
X_{54} –forenoon vapour pressure deficit during 4th week
X_{57} –forenoon vapour pressure deficit during 7th week
X_{58} –forenoon vapour pressure deficit during 8th week
X_{61} - bright sunshine hours during 1st week
X_{63} - bright sunshine hours during 3rd week
X_{87} - pan evaporation during 7th week

seventh (X_{57}) and eighth week (X_{58}) and bright sunshine hours during third week (X_{63}) were found to be significant and negative.

When nine-week weather variables were used to fit model, the variables X_{41}, X_{49}, X_{57}, X_{58} and X_{63} were entered in the equation. 81.8% of variation in rice yield was explained by the model. Among the explanatory variables in the model, the partial regression coefficients of forenoon vapour pressure deficit during seventh week (X_{57}), forenoon vapour pressure deficit during eighth week (X_{58}) and bright sunshine hours during third week (X_{63}) were found to be negative and significant while the partial regression coefficients of afternoon relative humidity during first week (X_{41}) and afternoon relative humidity during ninth week (X_{49}) were found to be positive and significant.

Among the all ten-week variables, the selected variables were afternoon relative humidity during first week (X_{41}) and rainfall during third week (X_{73}) whose partial regression coefficients are positive and significant and maximum temperature during tenth week (X_{110}), pan evaporation during seventh week (X_{87}) and rainfall during first week (X_{71}) whose partial regression coefficients are negative and significant. The model could explain about 76.1 % variation in rice yield.

In the case of Kanchana, the stepwise regression analysis using 7, 8, 9, 10 weeks' weather variables were having the same explanatory variables; afternoon relative humidity during third week (X_{43}), bright sunshine hours during first week (X_{61}) and pan evaporation during seventh week (X_{87}). The model explained rice yield variation of 58.1%. Among these, the partial regression coefficients of afternoon relative humidity during third week (X_{43}) was found to be positive and significant where as that of bright sunshine hours during first week (X_{61}) and pan evaporation during seventh week (X_{87}) were found to be negative and significant.

In Jyothi, the fitted regression models indicate that the coefficient of multiple determination (adjusted R^2) is lowest for seven-week crop period model (63.5%) whereas it is higher for nine-week (81.8 %) and ten-week (76.1%) models. However, it was highest for eight-week model (85.4%). In the case of MAPE value, it was highest for seven-week model (8.23%) and the eight-week model showed lowest MAPE value which can be considered as favorable for a good prediction model. Therefore, eight-week model can be considered as a yield prediction model based on very low MAPE value and very high-adjusted R^2 value.

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

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

It also coincided with the booting stage in Jyothi. So by using this model, yield can be forecasted at booting stage of Jyothi variety.

In Kanchana, the stepwise regression entered same variables in all the four models with same adjusted R^2 (58.1%) and MAPE (8.35%) values which take into account, weather variables up to seventh week.

$$\mathbf{Y = 4.138 + 0.047X_{43} - 0.269X_{61} - 0.839X_{87}}$$

(Adjusted R^2 = 58.1%   MAPE = 8.35%)

Therefore, in Kanchana, using this model, yield prediction can be done at panicle initiation to booting stage.

4.9.1.2. Crop weather models based on fortnightly weather variables

In this method, fortnightly weather variables were used to fit the regression models. The equations were fitted, separately for the rice varieties Jyothi and Kanchana for third, fourth and fifth fortnights. The resulted models along with their coefficients of multiple determinations are presented in tabular form in Table 29(a) and (b) for Jyothi and Kanchana respectively. The total crop duration of 14 weeks was divided into 7 fortnights. If we use fortnightly weather variables from 1st to 3rd fortnight after transplanting, yield forecasting can be done 4 fortnights prior to harvest. Yield forecast can be given 3 fortnights before harvest using fortnightly weather variables from 1st to 4th

Table.4.29(a) Crop weather models based on fortnightly weather variables for Jyothi

Variables in the equation		Fortnights		
		3	4	5
	Constant A_0	-4.711	-3.770	16.774**
X_{15}	Partial regression coefficients	-	-	-0.370**
X_{34}			0.053*	-0.137*
X_{41}		0.125**	0.108**	0.110**
X_{44}		-	-	0.106**
X_{64}		-	-	0.238*
X_{84}		-	-1.226**	-1.605**
	Adjusted R^2 (%)	40.6	73.7	91.2
	MAPE (%)	11.74	8.31	4.00

Table.4.29(b) Crop weather models based on fortnightly weather variables for Kanchana

Variables in the equation		Fortnights		
		3	4	5
	Constant A_0	-2.663	-2.663	-6.143*
X_{42}	Partial regression coefficients	0.099**	0.099**	0.053*
X_{45}		-	-	0.134**
X_{81}		-	-	-0.952*
	Adjusted R^2 (%)	31.7	31.7	65.7
	MAPE (%)	10.15	10.15	7.62

X_{15} – Maximum temperature of 5th fortnight
X_{34} – Forenoon relative humidity of 4th fortnight
X_{41} – Afternoon relative humidity of 1st fortnight
X_{42} - Afternoon relative humidity of 2nd fortnight
X_{44} - Afternoon relative humidity of 4th fortnight
X_{45} - Afternoon relative humidity of 5th fortnight
X_{64} – Bright sunshine hours of 4th fortnight
X_{81} – Pan evaporation of 1st fortnight
X_{84} – Pan evaporation of 4th fortnight

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fortnights. Similarly, by using fortnightly weather variables during 1st to 5th fortnights after transplanting, yield forecasting can be done 2 fortnights prior to harvest.

When three fortnight variables were analyzed using stepwise regression only one variable i.e. afternoon relative humidity during first fortnight (X_{41}) entered in the equation, which could explain about 40.6% variation rice yield. The partial regression coefficient of the entered variable was found to be positive and significant.

Results of stepwise regression analysis using four fortnights showed that fortnightly weather variables; afternoon relative humidity during first fortnight (X_{41}) and fourth fortnight (X_{44}) and pan evaporation during fourth fortnight (X_{84}) were entered in the model. A variation of 73.7% in rice yield was explained by the model. Among these, the partial regression coefficients of forenoon relative humidity of fourth week (X_{34}), afternoon relative humidity during first fortnight (X_{41}) were found to be positive and significant whereas the partial regression coefficient of pan evaporation during fourth fortnight (X_{84}) was negative and significant.

The variables selected in the model for five fortnight's crop period by stepwise regression are maximum temperature during fifth fortnight (X_{15}), forenoon relative humidity during fourth fortnight (X_{34}), afternoon relative humidity during first fortnight (X_{41}), afternoon relative humidity during fourth fortnight (X_{44}), bright sunshine hours during fourth fortnight (X_{64}) and pan evaporation during fourth fortnight (X_{84}). They could explain a variation of 91.2% in the yield of rice. Among these variables, the partial regression coefficients of maximum temperature during fifth fortnight forenoon (X_{15}), forenoon relative humidity during fourth fortnight (X_{34}) and pan evaporation during fourth fortnight (X_{84}) showed a significant negative value while that of remaining variables afternoon relative humidity during first fortnight (X_{41}), afternoon relative humidity during fourth fortnight and bright sunshine hours during fourth fortnight (X_{64}) were found to be positive and significant.

In the case of Kanchana, models fitted using three and four fortnights' weather variables have the same variable (afternoon relative humidity of second fortnight) and the coefficient of multiple determination also were found to be same. Only the variable X_{42} was entered (afternoon relative humidity during second fortnight) and it could explain only 31.7% variation in rice yield.

Compared to the above-mentioned model, the variables entered in the model fitted using five fortnight weather variables in Kanchana could explain 65.7 % of rice yield variation. The selected variables were afternoon relative humidity during second fortnight (X_{42}) and fifth fortnight (X_{45}) and pan evaporation during first fortnight (X_{81}) among which the partial regression coefficient of pan evaporation during first fortnight(X_{81}) was found to be negative and significant. The partial regression coefficients of remaining entered variables; afternoon relative humidity during second fortnight (X_{42}) and fifth fortnight (X_{45}) were positive and significant.

Out of three models fitted, based on fortnightly weather variables in Jyothi, the coefficient of multiple determination (adjusted R^2) is the highest for fifth fortnight crop period model with a value of 91.2%. Remaining two models showed adjusted R^2 values of 40.6% and 73.7%. The MAPE value of five fortnight crop period models also was found to be desirable, which was noted as 4%.

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

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

Thus, this model can be considered as a yield prediction model, which can give yield forecast at the flowering stage of the crop.

In Kanchana also five fortnight crop period model can be considered as yield prediction model due to higher adjusted R^2 value (65.7%) and lower MAPE (7.62%).

$$\mathbf{Y = -6.143 + 0.053X_{42} + 0.134X_{45} - 0.952X_{81}}$$

(Adjusted R^2 = 65.7%   MAPE = 7.62%)

4.9.1.3. Crop weather models based on crop stage wise weather variables

Regression models were fitted using different crop stage wise weather variables (Table 30 a & b). In this method for P_1 stage and P_2 stage, same models were obtained in the case of Jyothi and 41.2% of variation in rice yield was explained. The selected variable was X_4 (afternoon relative humidity) with a partial regression coefficient which was positive and significant.

In regression models using weather variables during P_3 stage, the variable entered in the model was rainy days (X_9) for which partial regression coefficient was positive and significant. However, it could explain only 29.3% of rice yield variation.

Forenoon vapour pressure deficit and rainfall were entered as the explanatory variables in the model using weather variables during P_4 crop stage. The partial regression coefficient of forenoon vapour pressure deficit (X_5) was negative and that of rainfall (X_7) was positive, both being significant. 51.3% of variation in yield of rice was explained by these variables.

Maximum temperature (X_1) during P_5 crop stage was selected in the model as the explanatory variable. However, it could give only 21.5 % variation in rice yield. The partial regression coefficient of this variable was found to be positive and significant.

In models using the weather variables during 50% flowering to physiological maturity (P_6 stage), the variables entered were maximum temperature (X_1) and rainy days (X_9) whose partial regression coefficients were positive and significant. They could explain 65.8% of variation in rice yield.

In the case of Kanchana, the weather variables during P_1, P_2 and P_3 stages only were selected for fitting the model. In the regression model using the weather variables during P_1 growth stage, the variables entered were forenoon relative humidity (X_3) and afternoon relative humidity(X_4). These variables explained 51.7% of rice yield variation. The partial regression coefficient of forenoon relative humidity was found to be

Table 30(a). Crop weather models based on crop stage wise weather variables for Jyothi

Variables in the equation		Crop stages					
		P1	P2	P3	P4	P5	P6
	Constant A_0	-5.406	-5.406	3.765	19.873	20.223**	29.985**
X_1	Partial regression coefficients	-	-	-	-	0.496	0.833**
X_4		0.135**	0.135**	-	-	-	-
X_5		-	-	-	-0.670*	-	-
X_7		-	-	-	0.006	-	-
X_9		-	-	0.118**	-	-	0.069
	Adjusted R^2 (%)	41.2	41.2	29.3	51.3	21.5	65.8
	MAPE (%)	10.87	14.09	11.33	10.49	12.77	7.79

Table 30(b). Crop weather models based on crop stage wise weather variables for Kanchana

Variables in the equation		Crop stages		
		P1	P2	P3
	Constant A_0	29.122	17.090*	3.719**
X_2	Partial regression coefficients	-	-0.528	-
X_3		-0.386	-	-
X_4		0.165**	-	-
X_9		-	-	0.103**
	Adjusted R^2 (%)	51.7	18.8	18.6
	MAPE (%)	10.09	12.32	12.76

X_1 – Maximum temperature
X_2 – Minimum temperature
X_3 – Forenoon relative humidity
X_4 – Afternoon relative humidity
X_5 – Forenoon vapour pressure deficit
X_7 – Rainfall
X_9 – Number of rainy days

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

significant and negative where as that of afternoon relative humidity was significant and positive.

Minimum temperature was entered in the model using P_2 crop stage weather variables for which partial regression coefficient was negative and significant. Only 18.8 % yield variation in rice could be explained by this entered variable.

The third model based on crop stage wise weather variables for Kanchana was fitted using the weather variables during P_3 crop stage. The explanatory variable entered was rainy days in the stepwise regression, which explained only 18.6% rice yield variation. Partial regression coefficient of this variable was found to be positive and significant.

Out of six models fitted for Jyothi, the model developed using weather variables during P_6 stage was found to have and adjusted R^2 value of 65.8% and MAPE of 7.79%. The model fitted using P_4 crop stage weather variables showed an adjusted R^2 value of 51.3% and MAPE of 10.49%. Remaining model showed lesser adjusted R^2 value and higher MAPE value. The crop weather model using weather variables during P_6 stage cannot be considered as a better yield prediction model since would give yield prediction only after physiological maturity, which is not desirable. Thus, crop weather model using P_4 stage weather variables is selected which coincides with booting to heading stage.

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

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

In the case of Kanchana, only the model fitted using weather variables during P_1 stage showed a good adjusted R^2 value of 51.70% and MAPE of 10.09%.

$$\mathbf{Y = 9.122 - 0.386X_3 + 0.165X_4}$$

(Adjusted R^2 = 51.7%   MAPE = 10.09%)

Thus, it can be considered for yield prediction during transplanting to active tillering.

4.9.1.4. Crop weather models based on composite weather parameters

Crop weather models based on composite weather parameters are fitted using the generated variables of individual weather variables and product of variables [Table 4.31.(a)&(b)]. The generated variables are weighted index (weather variable multiplied by the first power of correlation coefficient) and unweighted index (weather variable multiplied by zeroth power of correlation coefficient).

When crop weather models based on this method was fitted by using five-week weather variables, only Z_{41} was entered in the model, which is the weighted index of afternoon relative humidity. Its partial regression coefficient was found to be positive and significant. It explained 44.10% of rice yield variation.

The weighted index of afternoon relative humidity (Z_{41}) was the only variable entered in the crop weather model using six-week weather variables, which explained 46.7% of the yield variation in rice.

For crop weather variables based on seven-week weather variables unweighted and weighted indices of afternoon relative humidity (Z_{40} and Z_{41}) were entered in the model by stepwise regression. They explained 61.4% variation in rice yield, the partial regression coefficient of unweighted index of afternoon relative humidity was found to be negative and significant. While that of weighted index was positive and significant.

Weighted index of afternoon relative humidity (Z_{41}) and weighted index of product of bright sunshine hours and rainfall (Z_{671}) were the variables entered in the crop weather model based on composite weather variables using eight-week weather variables. 74.1% variation in rice yield was explained by these variables. The partial regression coefficients of both variables were found to be positive and significant.

In the crop weather model fitted using 9-week weather variables, the explanatory variables included were unweighted and weighted indices of afternoon relative humidity (Z_{40} and Z_{41}), weighted index of forenoon vapour pressure deficit (Z_{51}) and the

Table 4.31 (a). Crop weather models based on composite weather variables for Jyothi

Variables in the equation		Weeks					
		5	6	7	8	9	10
	Constant A_0	-6.248*	-7.271*	-8.034**	-4.930	40.436**	28.353**
Z_{40}	Partial regression coefficients	-	-	0.71**	-	0.116**	-
Z_{41}		0.068**	0.063**	0.218**	0.158**	0.215**	-
Z_{51}		-	-	-	-	0.917**	-
Z_{140}		-	-	-	-	0.002**	-
Z_{351}		-	-	-	-	-	0.006**
Z_{681}		-	-	-	-	-	0.044**
Z_{671}		-	-	-	0.004**	-	-
	Adjusted R^2 (%)	44.1	46.7	61.4	74.1	87.7	73.4
	MAPE (%)	10.91	10.78	8.93	25.62	61.32	23.94

Table 4.31 (b). Crop weather models based on composite weather variables for Kanchana

Variables in the equation		Weeks					
		5	6	7	8	9	10
	Constant A_0	-5.059*	-6.230**	12.143**	11.397**	11.703**	11.449**
Z_{41}	Partial regression coefficients	0.063**	-	-	-	-	-
Z_{61}		-	0.224**	-	-	-	-
Z_{81}		-	-	1.596**	1.551**	1.395**	1.398**
	Adjusted R^2 (%)	39.7	40.2	58.0	57.5	55.1	55.5
	MAPE (%)	9.87	10.05	8.97	9.01	9.24	9.21

Z_{40} – Un-weighted index of afternoon relative humidity
Z_{41} – Weighted index of afternoon relative humidity
Z_{51} – Weighted index of forenoon vapour pressure deficit
Z_{61} – Weighted index of bright sunshine hours
Z_{81} – Weighted index of pan evaporation
Z_{140} – Un-weighted index of product of maximum temperature and afternoon relative humidity
Z_{351} – Weighted index of product of forenoon relative humidity and forenoon vapour pressure deficit
Z_{681} - Weighted index of product of bright sunshine hours and pan evaporation
Z_{671} - Weighted index of product of bright sunshine hours and rainfall

unweighted index of product of maximum temperature and afternoon relative humidity(Z_{140}). The partial regression coefficients of all the entered variables were significant and positive. 87.7 % of yield variation of rice can be explained through these variables.

Weighted index of the product of forenoon relative humidity and forenoon vapour pressure deficit (Z_{351}) and weighted index of product of bright sunshine hours and pan evaporation (Z_{681}) were the variables entered in the crop weather model using ten-week weather variables. The partial regression coefficients of both the variables were significant and positive and 73.4% variation in rice yield was explained by these variables.

In Kanchana, in the crop weather model based on composite weather variables using five-week weather variables, the variable entered was the weighted index of afternoon relative humidity (Z_{41}) which explained 39.70% of rice yield variation. Its partial regression coefficient was positive and significant.

In the case of model using generated variables of six-week weather variables, the variable entered was the weighted index of bright sunshine hours (Z_{61}) whose partial regression coefficient was positive and significant. 40.20% of variation in the rice yield was explained by this variable.

In crop weather models using generated variables of 7, 8, 9, and 10-week weather variables for Kanchana based on current method, the variable entered was the weighted index of pan evaporation (Z_{81}). The rice yield variation explained by this variable was 58% in the case of seven-week model, 57.5% in the case of eight-week model, 55.1% in the case of nine-week model and 55.5% in the case of ten-week model. In all four models mentioned above, the partial regression coefficients of the selected variable were positive and significant.

Out of six models fitted for Jyothi, the model using generated variables of seven-week weather variables with desirable lower MAPE value of 8.93% and adjusted R^2 value of 61.4% can be considered as the yield prediction model.

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

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

In the case of Kanchana, the model using generated variables of seven-week weather variables with adjusted R^2 of 58% and MAPE of 8.97% can be accepted as the yield prediction model.

$$\mathbf{Y = 12.143 + 1.596Z_{81}}$$

(Adjusted R^2 = 58.00% MAPE = 8.97%)

4.9.2. RESULTS OF CERES-RICE SIMULATION

For running CERES-Rice model, weather file, soil file, crop management file and experimental files (A file and T file) were created for Jyothi and Kanchana for each of the five year experiments from 2013 – 2017. Each year experiment consisted of five dates of planting.

The genetic coefficients calibrated for Jyothi and Kanchana varieties at the Department of Agricultural Meteorology during previous experiment was used to simulate the yield. The genetic coefficients used are:

Table.4.32. Genetic coefficients used in DSSAT-CERES-Rice model

Variety	P1	P2R	P5	P2O	G1	G2	G3	G4	PHINT
Jyothi	557.0	24.3	465.4	10.4	57.0	0.0270	1.1	1.1	81.0
Kanchana	460.7	160.0	445.5	12.4	59.5	0.0230	1.3	1.1	74.0

Simulated vs observed grain yield

The average observed yield of Jyothi for five years was 5144 kg ha^{-1} which was overestimated to be 6297 kg ha^{-1} by the CERES-Rice model. The simulation showed a d-Stat value of 0.406 and MAPE of 29.60% for Jyothi variety.

The average simulated yield obtained from CERES-Rice model for Kanchana was found to be 5716 kg ha^{-1}. The actual mean yield for Kanchana over five years' experiment was 4900 kg ha^{-1}. So, the yield was overestimated by the model. The simulation showed a d-Stat value of 0.413 and MAPE of 23.62%.

Table.4.33. Simulated grain yield from CERES-Rice model

Variety name	Observed	Simulated	RMSE	d-Stat	MAPE(%)
Jyothi	5144	6297	1603.644	0.406	29.60
Kanchana	4900	5716	1234.427	0.413	23.62

4.9. Validation of different weather based models using experimental data

After fitting crop weather models using 4 statistical methods and running DSSAT-CERES-Rice model, the models with better performance were selected from each method for both the varieties Jyothi and Kanchana based on the mean absolute percentage error (MAPE). The selected models for Jyothi for comparison were:

i) 8 weeks' crop period model based on weekly weather variables (MAPE 5.19%)

ii) 5 fortnights crop period model based on fortnightly weather variables (MAPE 4.00%)

iii) P4 stage crop model based on crop stage wise weather variables (MAPE 10.49%)

iv) 7 weeks' crop period model based on composite weather variables (MAPE 8.93%)

Table 4.34. Validation of the selected models for Jyothi using the data of the experimental year 2017

Dates of planting	Model based on 8 weeks weather variables			Model based on 5 fortnights weather variables			Model based on P_4 crop stage weather variables		
	Observed yield	Estimated yield	Error %	Observed yield	Estimated yield	Error %	Observed yield	Estimated yield	Error %
D1	5.50	5.73	4.10	5.50	5.53	0.61	5.50	5.01	8.87
D2	5.23	5.40	3.17	5.23	5.50	5.16	5.23	5.44	3.94
D3	4.84	4.73	2.19	4.84	4.83	0.17	4.84	4.41	8.97
D4	5.17	4.62	10.66	5.17	4.96	4.13	5.17	4.59	11.27
D5	4.77	4.50	5.76	4.77	4.97	4.17	4.77	4.57	4.12

Dates of planting	Model based on 7 weeks composite weather variables			DSSAT		
	Observed yield	Estimated yield	Error %	Observed yield	Estimated yield	Error %
D1	5.50	5.69	3.41	5.5	6.092	-10.76
D2	5.23	5.40	3.22	5.2275	6.175	-18.12
D3	4.84	4.81	0.58	4.837	6.163	-27.41
D4	5.17	4.89	5.50	5.1725	6.21	-20.06
D5	4.77	5.65	18.47	4.7735	6.12	-28.21

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

$$Error\ \%\ for\ DSSAT = \frac{observed\ yield - simulated\ yield}{observed\ yield} \times 100$$

Table 4.35. Validation of the selected models for Kanchana using the data of the experimental year 2017

Dates of planting	Model based on 8 weeks weather variables			Model based on 5 fortnights weather variables			Model based on P_1 crop stage weather variables		
	Observed yield	Estimated yield	Error %	Observed yield	Estimated yield	Error %	Observed yield	Estimated yield	Error %
D1	6.25	6.03	3.49	6.25	6.10	2.26	6.25	5.54	11.32
D2	6.19	5.39	12.93	6.19	5.98	3.36	6.19	5.48	11.37
D3	5.88	5.24	10.91	5.88	5.54	5.84	5.88	5.25	10.65
D4	4.84	4.49	7.19	4.84	4.47	7.68	4.84	5.22	-7.90
D5	4.64	5.02	8.11	4.64	4.92	6.01	4.64	4.89	-5.31

Dates of planting	Model based on 7 weeks composite weather variables			DSSAT		
	Observed yield	Estimated yield	Error %	Observed yield	Estimated yield	Error %
D1	6.25	5.43	13.13	6.25	5.43	13.11
D2	6.19	5.40	12.81	6.19	5.55	10.26
D3	5.88	5.58	5.05	5.88	5.52	6.06
D4	4.84	4.87	0.71	4.84	5.55	14.65
D5	4.64	4.68	0.88	4.64	5.27	13.53

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

$$Error\ \%\ for\ DSSAT = \frac{observed\ yield - simulated\ yield}{observed\ yield} \times 100$$

The selected models for Kanchana for comparison were:

i) 8 weeks' crop period model based on weekly weather variables (MAPE 8.35%)

ii) 5 fortnights crop period model based on fortnightly weather variables (MAPE 7.62%)

iii) P1 stage crop model based on crop stage wise weather variables (MAPE 10.09%)

iv) 7 weeks' crop period model based on composite weather variables (MAPE 8.97%)

These models were compared with the CERES-Rice model for each variety.

The validation using the data of the current experiment and their error per cent is given in Table.4.34 and Table 4.35 for Jyothi and Kanchana respectively. It showed that 5 fortnights crop period model in both Jyothi and Kanchana estimated crop yields which is in good agreement with the observed yields. These models showed higher adjusted R^2 as well as lowest MAPE values. Therefore, these models can be used for rice yield forecasting in central zone of Kerala for Jyothi and Kanchana.

- The model for Jyothi is:

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

(adjusted R^2 – 0.912 and MAPE – 4%)

Stage of yield forecast – Flowering stage

- The model for Kanchana is:

$$\mathbf{Y = -6.143 + 0.053X_{42} + 0.134X_{45} - 0.952X_{81}}$$

(adjusted R^2 – 0.657 and MAPE – 7.62%)

Stage of yield forecast – Flowering stage

DISCUSSION

5. DISCUSSION

The present investigation was done to compare different weather based models for forecasting yield of two popular rice varieties Jyothi and Kanchana in central zone of Kerala and to validate them with experimental data.

5.1. WEATHER CONDITIONS PREVAILED DURING THE CROP PERIOD

Weather conditions prevailed during the entire crop period of 2017 were recorded in terms of maximum temperature, minimum temperature, forenoon and afternoon relative humidity, forenoon and afternoon vapour pressure deficit, rainfall and number of rainy days, bright sunshine hours, wind speed and evaporation. Table 5.1- Table 5.12 represents the maximum values of different weather parameters experienced by the crop during different phenological stages.

In the case of both Jyothi and Kanchana, highest maximum temperature was experienced during transplanting to panicle initiation stage of August 5^{th} (D5) planting. Lowest maximum temperature was experienced during transplanting to active tillering stage of June 20^{th} planting (D2) by both the varieties. In Jyothi, lowest minimum temperature was observed during transplanting to panicle initiation stage in June 20^{th} planting (D2). But in Kanchana, it was observed during transplanting to active tillering stage of July 5^{th} planting (D3). Highest minimum temperature was experienced by both Jyothi and Kanchana during transplanting to active tillering stage of June 5^{th} planting (D1). Forenoon relative humidity experienced by both the varieties ranged between 93% – 96% throughout the crop period while afternoon relative humidity ranged between 73% – 79% in Jyothi and 73% – 80% in Kanchana. In both Jyothi and Kanchana, highest amount of rainfall was received by June 20^{th} planting (1652.10mm and 1630.30mm respectively). Number of rainy days were found to be highest for June 5^{th} planting in both the varieties (69 and 68 respectively). Bright sunshine hours received was the highest during transplanting to physiological maturity stage in Jyothi during August 5^{th} planting. In Kanchana, it was found to be highest during transplanting to active tillering stage of

Table 5.1. Maximum temperature experienced by Jyothi during the crop period

	T - AT	T - PI	T - B	T - H	T - F	T - PM
D1	30.28	30.25	30.40	30.32	30.35	30.48
D2	30.04	30.17	30.30	30.26	30.28	30.46
D3	30.73	30.50	30.18	30.36	30.39	30.61
D4	30.47	30.38	30.40	30.85	30.63	30.74
D5	30.10	31.00	30.56	30.55	30.63	30.97

Table 5.2. Minimum temperature experienced by Jyothi during the crop period

	T - AT	T - PI	T - B	T - H	T - F	T - PM
D1	23.45	23.31	23.11	23.16	23.20	23.25
D2	22.82	22.67	23.03	23.04	22.87	23.04
D3	22.68	22.96	23.10	23.16	23.17	23.05
D4	23.33	23.29	23.29	23.31	23.22	23.01
D5	23.35	23.34	23.17	23.14	23.09	22.86

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

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

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

	T - AT	T - PI	T - B	T - H	T - F	T - PM
D1	79	78	76	76	76	77
D2	79	79	76	76	76	76
D3	74	73	76	75	75	75
D4	73	75	76	75	76	75
D5	78	78	76	76	75	73

Table 5.5. Rainfall experienced by Jyothi during the crop period

	T - AT	T - PI	T - B	T - H	T - F	T - PM
D1	627.90	724.20	981.30	1068.40	1140.50	1604.30
D2	577.10	747.10	945.30	1070.80	1126.80	1652.10
D3	333.50	350.60	808.80	868.10	1168.60	1288.20
D4	245.80	347.70	623.90	651.30	913.00	1101.30
D5	359.90	508.70	835.80	874.30	934.50	1086.70

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

	T - AT	T - PI	T - B	T - H	T - F	T - PM
D1	23	31	43	45	48	69
D2	23	29	39	44	45	67
D3	18	19	34	35	41	55
D4	12	17	28	31	37	48
D5	12	19	32	34	36	45

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

	T - AT	T - PI	T - B	T - H	T - F	T - PM
D1	1.89	1.82	2.46	2.62	2.63	2.91
D2	1.65	1.75	2.88	2.23	2.86	3.26
D3	2.71	3.49	3.14	3.25	3.32	3.52
D4	4.09	3.88	3.60	3.65	3.58	3.80
D5	3.07	2.97	3.54	3.56	3.48	4.09

Table 5.8. Wind speed experienced by Jyothi during the crop period

	T - AT	T - PI	T - B	T - H	T - F	T - PM
D1	1.76	1.72	1.77	1.77	1.71	0.84
D2	1.65	1.77	1.59	1.50	1.47	1.24
D3	1.85	1.86	1.42	1.37	1.32	1.07
D4	1.37	1.26	1.11	1.05	1.05	1.05
D5	0.92	0.90	0.85	0.79	0.72	0.62

Table 5.9. Maximum temperature experienced by Kanchana during the crop period

	T - AT	T - PI	T - B	T - H	T - F	T - PM
D1	30.27	30.17	30.40	30.32	30.35	30.49
D2	30.02	30.15	30.29	30.27	30.25	30.46
D3	30.73	30.50	30.18	30.36	30.39	30.59
D4	30.45	30.45	30.33	30.54	30.61	30.70
D5	30.10	31.00	30.56	30.71	30.58	30.95

Table 5.10. Minimum temperature experienced by Kanchana during the crop period

	T - AT	T - PI	T - B	T - H	T - F	T - PM
D1	23.48	23.33	23.11	23.16	23.20	23.26
D2	22.89	22.77	23.02	23.04	23.02	23.05
D3	22.68	23.72	23.10	23.16	23.17	23.05
D4	23.32	23.31	23.30	23.29	23.22	23.01
D5	23.35	23.32	23.17	23.14	23.11	22.86

Table 5.11. Forenoon relative humidity experienced by Kanchana during the crop period

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

Table 5.12. Afternoon relative humidity experienced by Kanchana during the crop period

	T – AT	T - PI	T – B	T – H	T – F	T – PM
D1	79	79	76	76	76	76
D2	80	78	76	76	76	76
D3	74	73	76	75	75	75
D4	73	75	76	75	76	75
D5	78	78	76	76	76	73

Table 5.13. Rainfall experienced by Kanchana during the crop period

	T - AT	T - PI	T - B	T - H	T - F	T - PM
D1	606.40	691.80	981.30	1068.40	1140.50	1554.70
D2	530.10	699.50	945.30	1047.20	1125.00	1630.30
D3	333.50	350.60	808.80	868.10	879.50	1286.50
D4	245.80	329.60	612.50	650.30	913.00	1101.30
D5	359.90	480.30	835.80	874.30	934.50	1083.80

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

	T - AT	T - PI	T - B	T - H	T - F	T - PM
D1	22	30	43	45	48	68
D2	22	27	39	43	45	66
D3	18	19	34	35	40	55
D4	12	15	27	31	37	48
D5	12	18	32	34	36	44

Table 5.15. Bright sunshine hours experienced by Kanchana during the crop period

	T - AT	T - PI	T - B	T - H	T - F	T - PM
D1	1.94	1.87	2.46	2.62	2.63	2.89
D2	1.73	1.83	4.10	2.89	2.82	3.22
D3	2.71	3.49	3.14	3.25	3.28	3.54
D4	4.26	4.00	3.64	3.61	3.58	3.72
D5	3.07	3.03	3.54	3.56	3.47	4.06

Table 5.16. Wind speed experienced by Kanchana during the crop period

	T - AT	T - PI	T - B	T - H	T - F	T - PM
D1	1.81	1.77	1.77	1.77	1.71	1.40
D2	1.73	1.78	1.61	1.51	1.49	1.24
D3	1.85	1.86	1.42	1.37	1.34	1.08
D4	1.41	1.28	1.13	1.06	1.05	0.79
D5	0.92	0.92	0.85	0.79	0.75	0.61

July 20th planting(D4). Higher wind speed occurred during transplanting to active tillering stage of July 5th planting (D3) in both Jyothi and Kanchana.

5.2. EFFECT OF WEATHER ON GROWTH AND DEVELOPMENT OF RICE

5.2.1. Plant height

The plant height at weekly interval did not show any influence of dates of planting. It was significantly different between two varieties Jyothi and Kanchana during each week except during first week after planting. The results in similar lines were obtained by Vysakh (2015). These results shows that the varieties perform differently under different dates of planting.

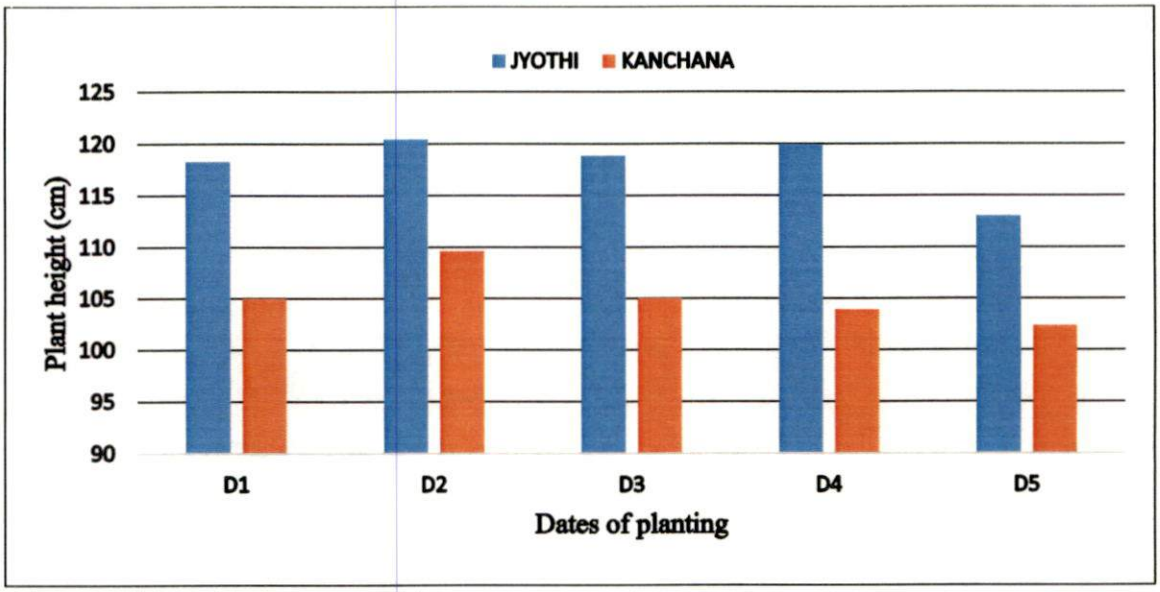

Fig. 5.1. Difference in weekly plant height due to varieties

5.2.2. Dry matter accumulation

With delay in dates of planting, dry matter accumulation was found to be decreasing in both Jyothi and Kanchana. Dry matter accumulation was maximum during 75 days after planting. Maximum temperature was found to influence the dry matter accumulation negatively in both Jyothi and Kanchana while minimum temperature, afternoon relative humidity, rainfall and number of rainy days were found to have positive

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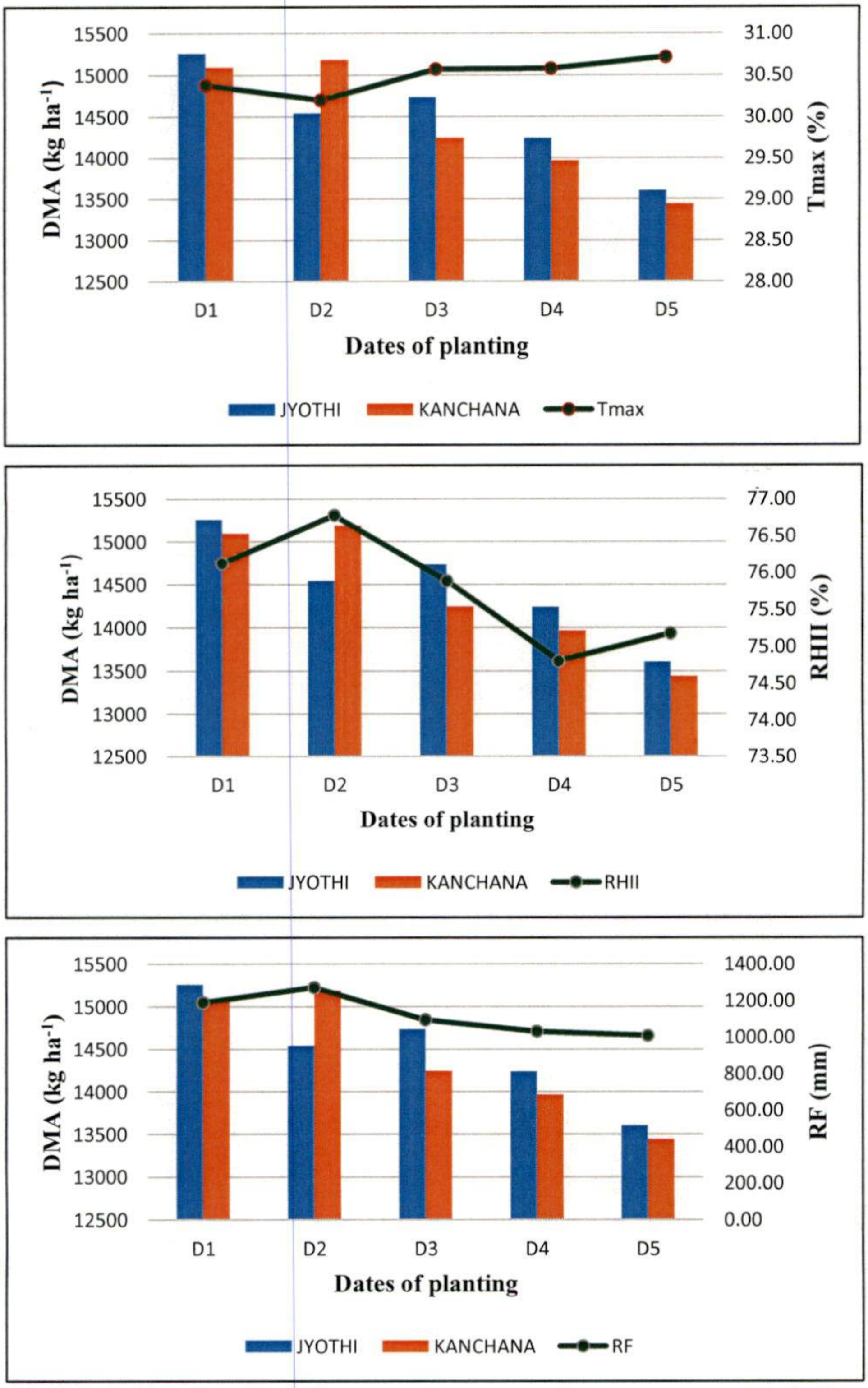

Fig.5.2. Influence of weather parameters on dry matter accumulation with respect to planting date

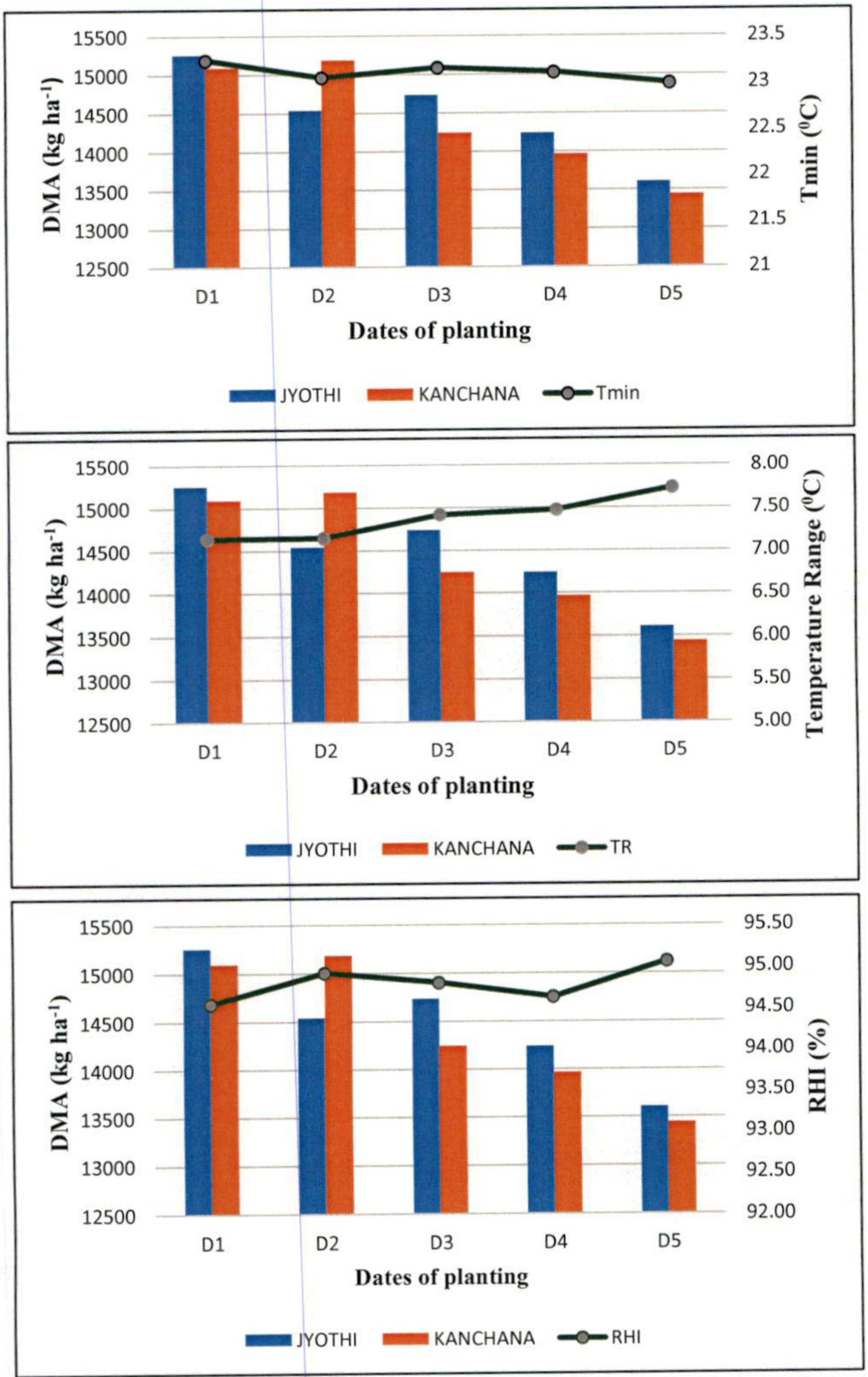

Fig.5.2. Influence of weather parameters on dry matter accumulation with respect to planting date

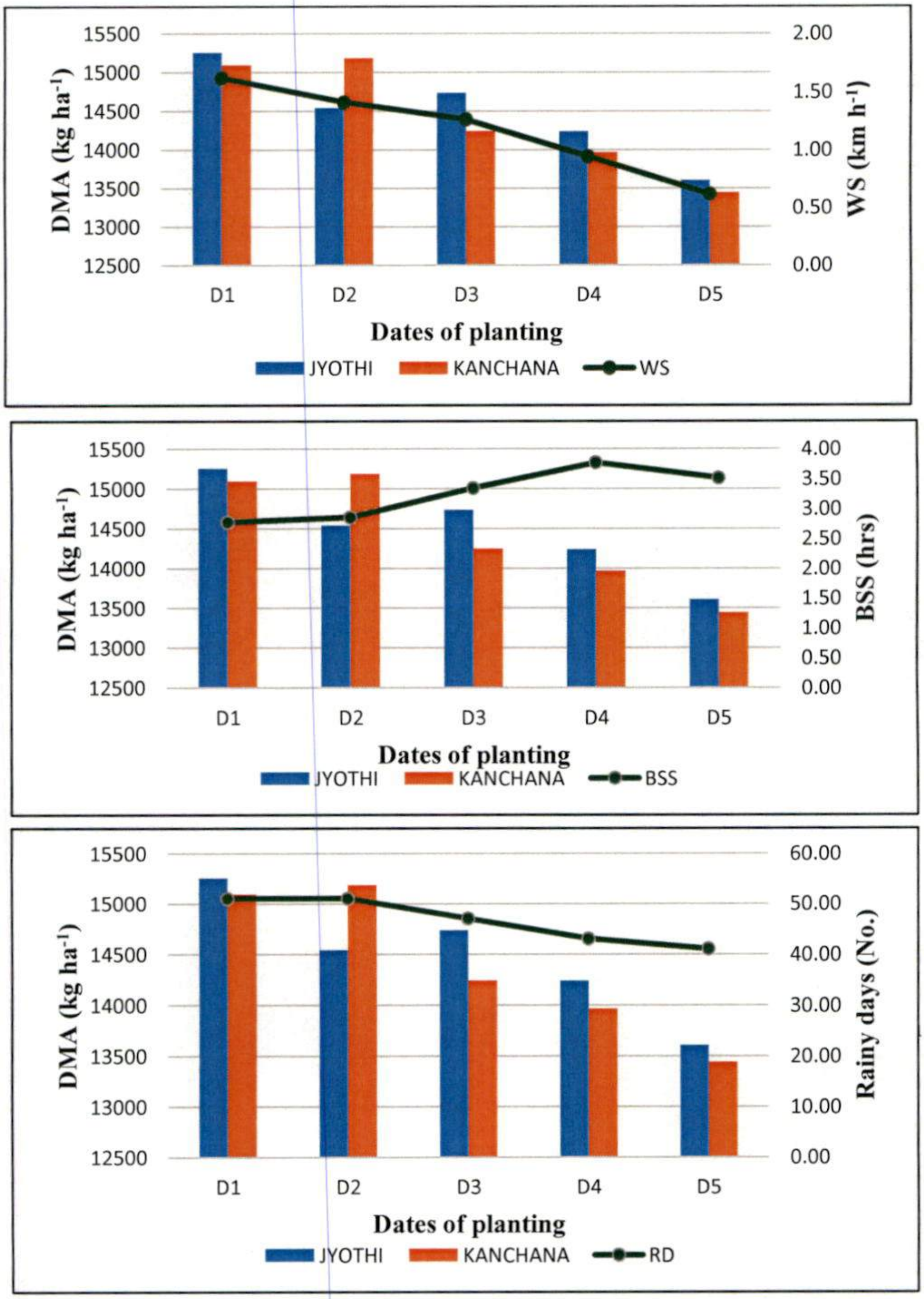

Fig.5.2. Influence of weather parameters on dry matter accumulation with respect to planting date

influence on dry matter accumulation (Table 5.17). Influence of weather parameters on dry matter accumulation is depicted in Fig.5.2. These results were in agreement with the findings of Roy and Biswas (1980), Hirai *et al.*(1993) and Kaladevi *et al.*(1999).

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

	Tmax	Tmin	DTR	RHI	RHII	WS	BSS	RF	RD
J	-0.574**	0.856**	-0.803**	-0.679**	0.545*	0.893**	-0.647**	0.607**	0.799**
K	-0.877**	0.498*	-0.910**	-0.371	0.791**	0.868**	-0.816**	0.883**	0.903**

J – Jyothi K - Kanchana

5.2.3. Number of panicles per m^2

Significant difference in number of panicles per m^2 was observed with different dates of planting. It was found to be decreasing as the planting was delayed. The same results were reported by Reddy and Reddy (1992), Akram *et al.* (2007), Akbar *et al.* (2010) and Faghani *et al.* (2011).

5.2.4. Number of spikelets per panicle

Spikelets per panicle showed a decreasing trend with delaying plantings. August 5th planting had least number of spikelets per panicle. These results have shown similarities with the results obtained by Akram *et al.* (2007), Akbar *et al.* (2010) and Faghani *et al.* (2011).

5.2.5. Number of filled grains per panicle

Number of filled grains per panicle was more during early plantings which showed a decrease with delay in planting dates. This results was in conformity with the research findings of Akbar *et al.* (2010) and Faghani *et al.* (2011).

5.2.6. Thousand grain weight

Thousand grain weight also showed a decreasing trend with delay in planting where Jaune 5th planting showed higher value and August 5th planting showed a lower value. These results were found to be in good agreement with the research findings of Biswas and Salokhe (2001), Akram *et al*. (2007), Akbar *et al*. (2010), Faghani *et al.* (2011), Singh *et al* (2012), and Khalifa *et al*. (2014).

5.2.7. Grain yield

In both Jyothi and Kanchana, planting date significantly influenced the yield. Highest grain yield in Jyothi was obtained for June 5th planting while in Kanchana it was for June 20th planting which was on par with June 20th planting. With delay in dates of planting, grain yield was found to be decreasing. June 5th and June 20th plantings were on par. Grain yield decreases when date of planting is delayed because total sterile spikelet per panicle increases and the 1000 grains weight decreases (Faghani *et al*., 2011). The results obtained in this study were on similar lines with Murthy and Rao (2010), Roy and Biswas (1980), Reddy and Reddy (1986), Mahmood *et al.* (1995), Akram *et al.* (2007), Khalifa *et al.* (2014) and Ali *et al.* (2015).

5.3. RELATIONSHIP BETWEEN WEATHER AND DURATION OF PHENOLOGICAL STAGES

Jyothi and Kanchana showed variation in number of days taken to complete each different growth stages for different dates of planting. The number of days taken to achieve physiological maturity showed a decreasing trend with delay in planting in both Jyothi and Kanchana. The weather conditions experienced by the crop planted on different dates were not the same. This shall be the reason for difference in duration of phenological stages.

Reduction in duration of physiological maturity was due to increased temperature with delayed transplanting. Crops grown under increased temperature conditions showed reduced duration of different phenological stages like active tillering, panicle initiation, booting, heading, 50% flowering and harvest.

After correlation analysis, it was concluded that afternoon vapour pressure deficit during active tillering to panicle initiation, minimum temperature and forenoon vapour pressure deficit during booting to heading, and minimum temperature during heading to 50% flowering resulted in reduction of phenophase duration in Jyothi while number of rainy days during transplanting to active tillering, rainfall and number of rainy days during booting to heading and heading to 50% flowering, and minimum temperature and pan evaporation during 50% flowering to physiological maturity led to increase in phenophases duration in Jyothi. Maximum temperature, forenoon vapour pressure deficit, afternoon vapour pressure deficit and pan evaporation during active tillering to panicle initiation, minimum temperature, forenoon vapour pressure deficit, afternoon vapour pressure deficit during booting to heading and minimum temperature during heading to 50% flowering resulted in reduction in phenophase duration in Kanchana whereas rainfall and number of rainy days during active tillering to panicle initiation, number of rainy days during booting to heading and heading to 50% flowering, and minimum temperature and pan evaporation during 50% flowering to physiological maturity contributed to increase in phenophase duration in Kanchana.

5.4. GROWTH INDICES

5.4.1. Leaf area index (LAI)

Highest value of leaf area index was obtained at 75 days after transplanting in both Jyothi and Kanchana. Among five plantings, early planted crop showed more leaf area index than other plantings in both the varieties. This result was in accordance with the findings of Ahmad *et al.* (2009) and Khalifa *et al.* (2014). Leaf area index gradually increased after transplanting and after attaining its maximum value at 75 days after planting it decreased towards maturity. These results are in similar lines with Azharpour *et al.* (2014) and Medhi *et al.* (2016).

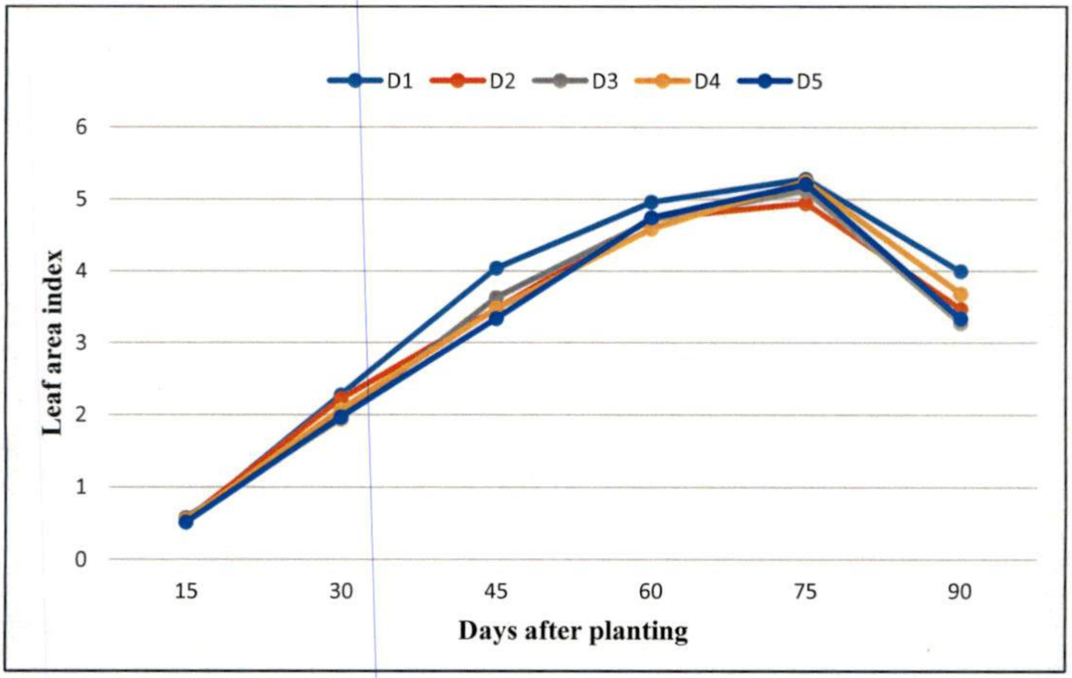

Fig. 5.3.(a)Trend of Leaf area index in different dates of planting in Jyothi

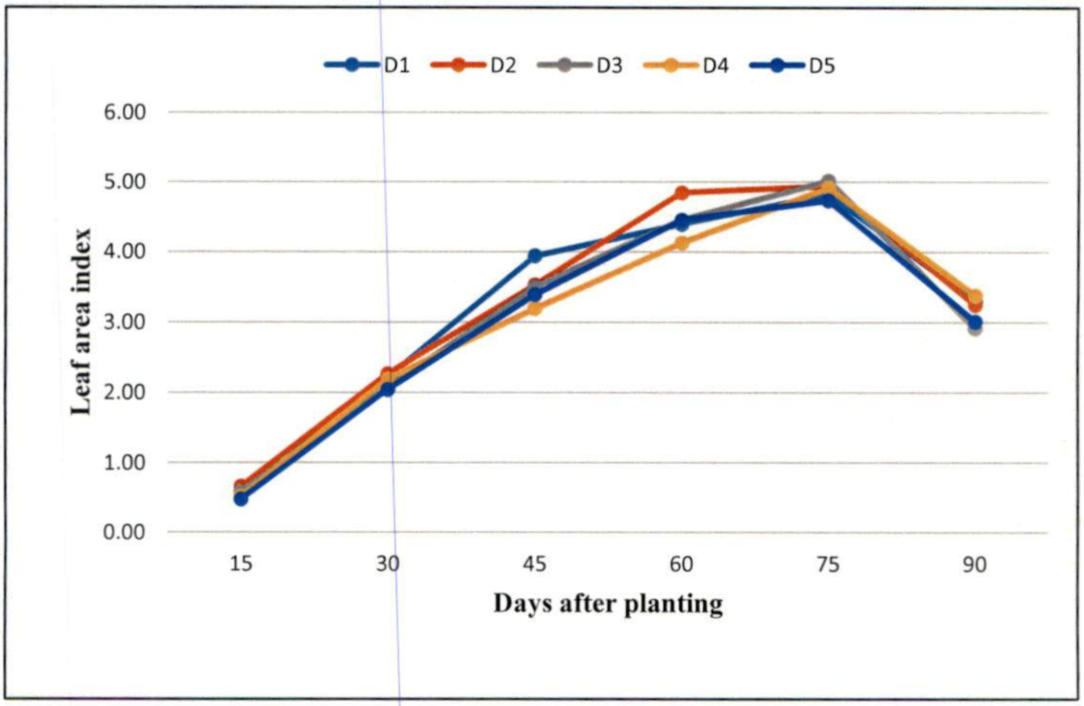

Fig. 5.3. (b) Trend of Leaf area index in different dates of planting in Kanchana

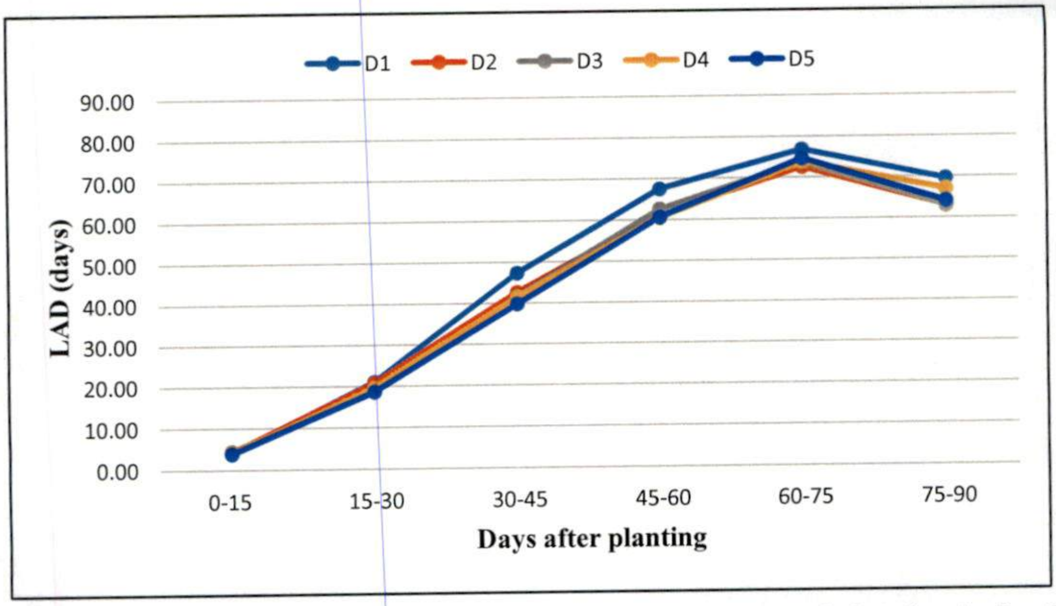

Fig. 5.4. (a) Trend of Leaf area duration in different dates of planting in Jyothi

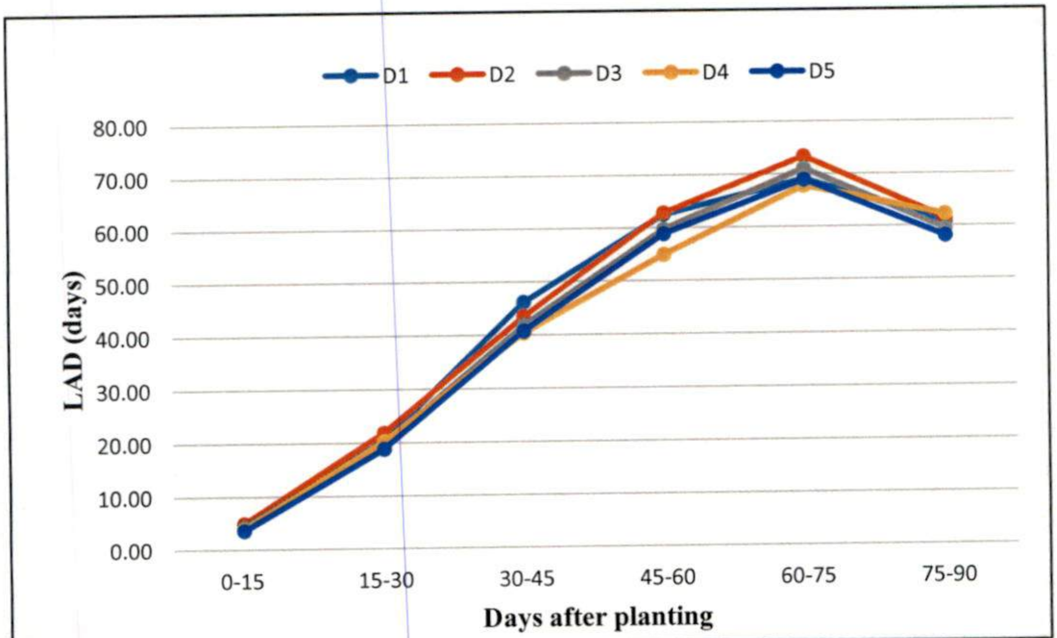

Fig.5.4.(b) Trend of Leaf area duration in different dates of planting in Kanchana

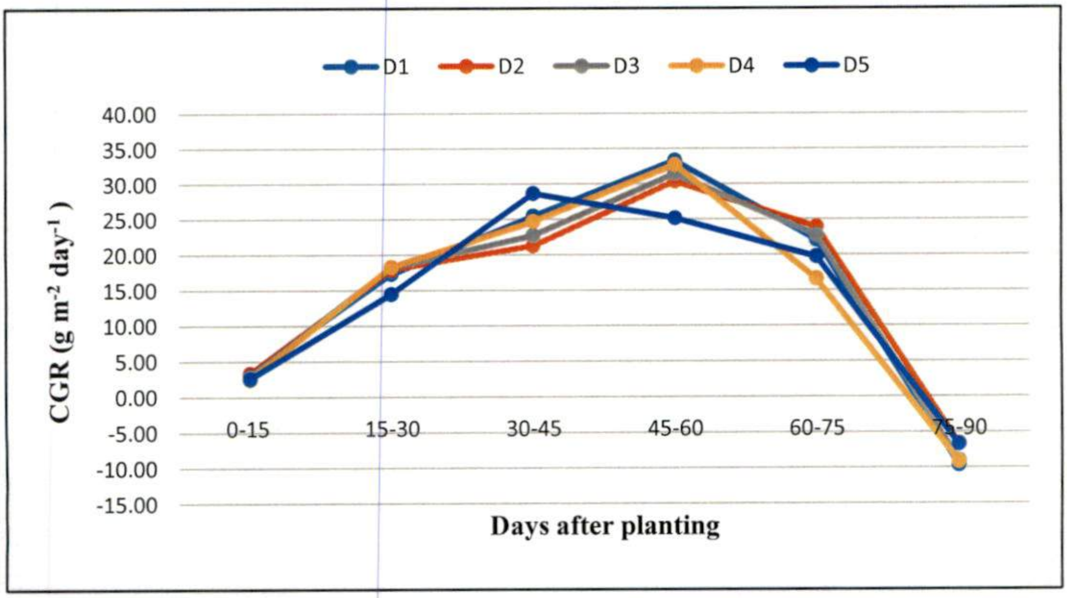

Fig.5.5. (a)Trend of crop growth rate in different dates of planting in Jyothi

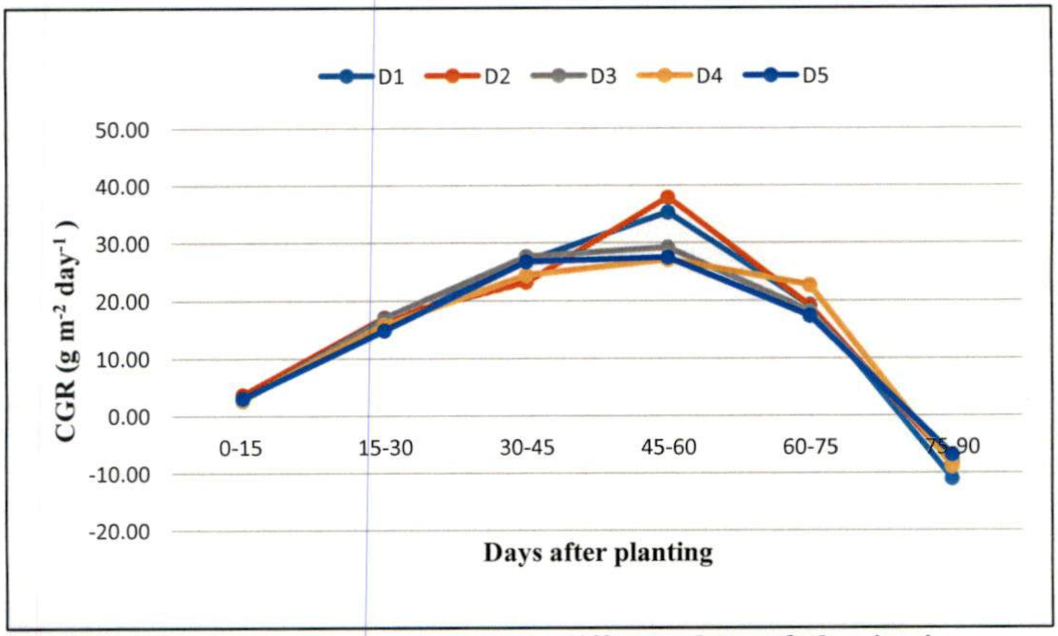

Fig. 5.5. (b)Trend of crop growth rate in different dates of planting in Kanchana

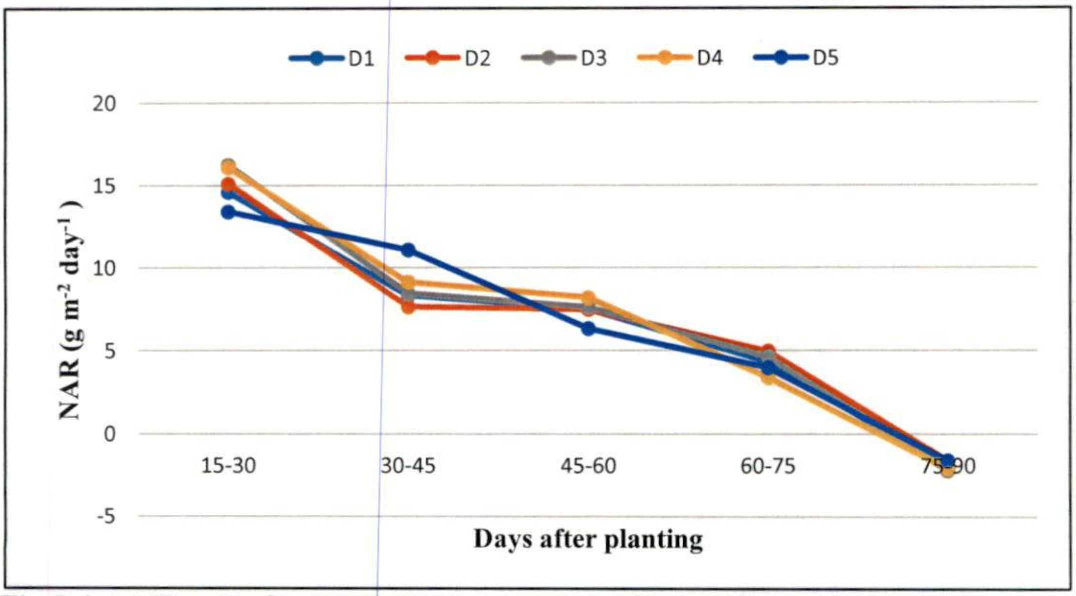

Fig.5.6. (a) Trend of net assimilation rate in different dates of planting in Jyothi

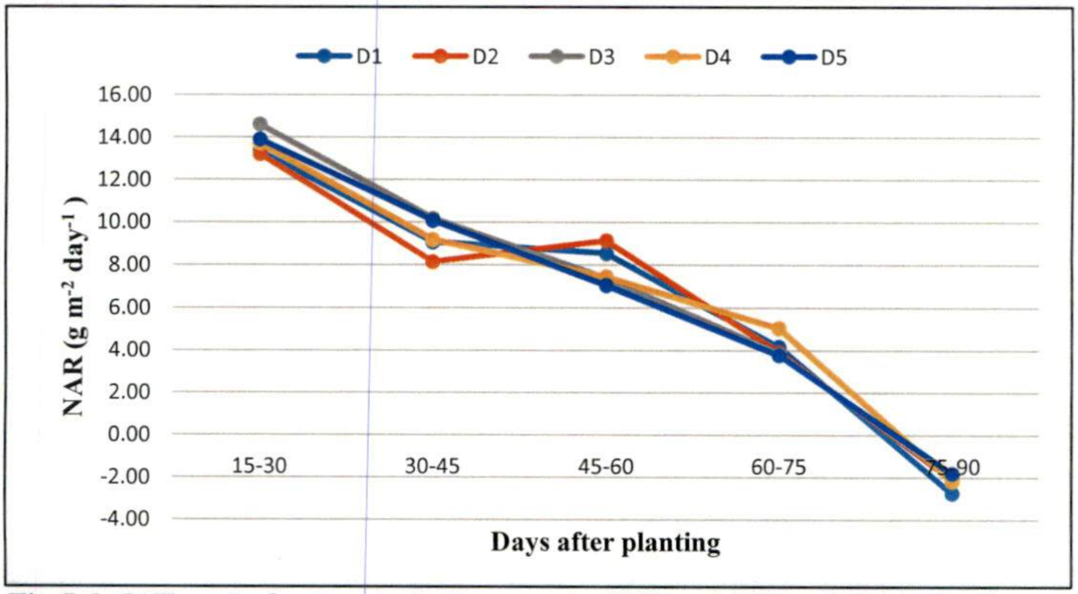

Fig.5.6. (b)Trend of net assimilation rate in different dates of planting in Kanchana

5.4.2. Leaf area duration (LAD)

Like leaf area index, leaf area duration also attained its maximum value at 75 days after planting in all plantings as shown by Sadeghi and Bohrani (2001). Leaf area duration gradually increased after transplanting and after attaining its maximum value at 75 days after planting it decreased towards maturity. It was shown by Devendra *et al.* (1983). Increase in maximum temperature shall be the reason for reducing leaf area duration with delay in plantings.

5.4.3. Crop growth rate (CGR)

In Jyothi and Kanchana, the crop growth rate was found to be maximum during 45-60 days after planting.

Due to under developed plant canopy and low absorption of light, crop growth rates at early stages was found to be reduced. Crop growth rate started increasing as the canopy developed and was maximum at 45 – 60 days after planting. Then due to reduction in the light penetration due to fully developed canopy and interplant competition reduces the activity of photosynthetic organs and movement of assimilates into grains also take place. Mani and Noori (2015) showed the similar findings.

5.4.4. Net assimilation rate (NAR)

In almost all plantings of Jyothi and Kanchana, maximum net assimilation rate occurred during early growth stage of the crop i.e. 15 – 30 days after planting. Net assimilation rate reduced with increasing dry matter accumulation and it acquired a negative value when the crop reached 75 – 90 days' age. Similar trend of changes of this growth index was given by Esfahani *et al*. (2006). Due to increased light penetration into crop canopy and less shadow of leaves at the earlier crop stages, net assimilation rate was found to be more. At later stages, canopy develops and shading is increased thus light penetration also decreased which lead to lower values of net assimilation rate (NAR).

5.5. CROP WEATHER MODELS

Different crop weather models were fitted using the yield and weather data of past five years' field experiment. The models were fitted using weekly weather variables, fortnightly weather variables, crop stage wise weather variables and composite weather variables. Better yield prediction model among the crop weather models using weekly weather variables was crop weather model using eight weeks' weather variables in both Jyothi and Kanchana in terms of higher adjusted R^2 and lower MAPE values which can give yield prediction at booting stage of the rice crop. Crop weather model using five fortnightly weather variables was found to be a good yield prediction model in terms of higher adjusted R^2 and lower MAPE values in both the varieties which can give yield prediction at flowering stage of the crop. In the approach using crop stage wise weather variables, crop weather models using weather variables during booting to heading stage was found to be better for Jyothi and crop weather models using weather variables during transplanting to active tillering stage was found to be better for Kanchana. In the case of crop weather models based on composite weather variables, crop weather model using seven weeks' weather variables was found to be good in both the varieties by which yield prediction can be done during panicle initiation to booting stage.

5.6. COMPARISON OF DIFFERENT WEATHER BASED MODELS FOR FORECASTING RICE YIELD

The importance of forecasting crop yield at an appropriate early stage of the crop has its importance since it can help farmers in proper agricultural planning. Crop weather models were fitted using statistical techniques based on weekly weather variables, fortnightly weather variables, crop stage-wise weather variables and composite weather variables in both the varieties Jyothi and Kanchana. The better models using each method was selected based on adjusted R^2 and MAPE values for both Jyothi and Kanchana separately. These selected models were validated using the experimental data of 2017.

DSSAT-CERES-Rice, which is a crop simulation model was also run by creating the required weather, soil, crop management and experimental files for Jyothi and

Kanchana for five years from 2013 to 2017. The genetic coefficients calibrated by Vysakh (2015) for Jyothi and Kanchana for central zone of Kerala were used for running DSSAT-CERES-Rice. The MAPE value of DSSAT in predicting rice yield were also calculated. The accuracy of yield prediction using the already calibrated genetic coefficients was found to be low as per the mean absolute percentage error which showed higher values. This shows that fine tuning of the model is required for predicting yields (Akinbile, 2013). The observed and simulated yield using DSSAT in Jyothi and Kanchana is given in Fig.5.7 and Fig.5.8 respectively.

The comparison between the four crop weather models fitted using statistical techniques and the crop simulation model DSSAT-CERES-Rice was done based on the comparison between the observed yield and the yield estimated using the model. Fig.5.9 and Fig.5.10 shows the comparison between the observed yield and the estimated yield using different weather based models in Jyothi and Kanchana respectively.

By analyzing the figures, it can be concluded that, in Jyothi, five fortnight crop period model which used variables maximum temperature of 5th fortnight (X_{15}), forenoon relative humidity of 4th fortnight (X_{34}), afternoon relative humidity of 1st fortnight and 4th fortnight (X_{41} and X_{44}), bright sunshine hours of 4th fortnight (X_{64}) and pan evaporation of 4th fortnight (X_{84}) was found to be the best performing model with highest adjusted R^2 value and least MAPE value (4%). In Kanchana also, five fortnight crop period model was found to be performing the best which has afternoon relative humidity of 2nd fortnight (X_{42}), afternoon relative humidity of 5th fortnight (X_{45}), and pan evaporation of 1st fortnight (X_{81}) as the explanatory variables. It has higher adjusted R^2 value compared to the other crop weather models and a lower MAPE value. Biswas et al (2015) also obtained similar results by comparing crop simulation model WOFOST and statistical models in which he had concluded that statistical models are good for region specific yield prediction.

According to Patel (2004), Chauhan *et al.* (2009) and Agnihotri and Sridhara (2014), the crop weather models developed based on weekly weather variables showed better results in forecasting crop yields. But in the present study, the crop weather models developed based on five fortnight crop period weather variables could give better yield prediction in both Jyothi and Kanchana even though, the crop weather models developed based on weekly weather variables also performed well. The selected models can be used to give yield prediction at the flowering stage of both the varieties.

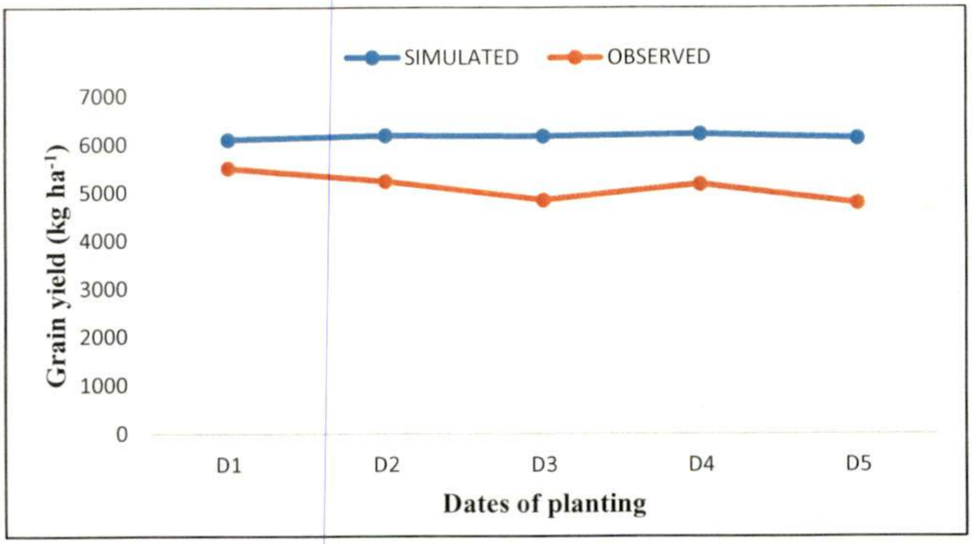

Fig.5.7 (a). Comparison of observed and simulated yield by DSSAT in Jyothi

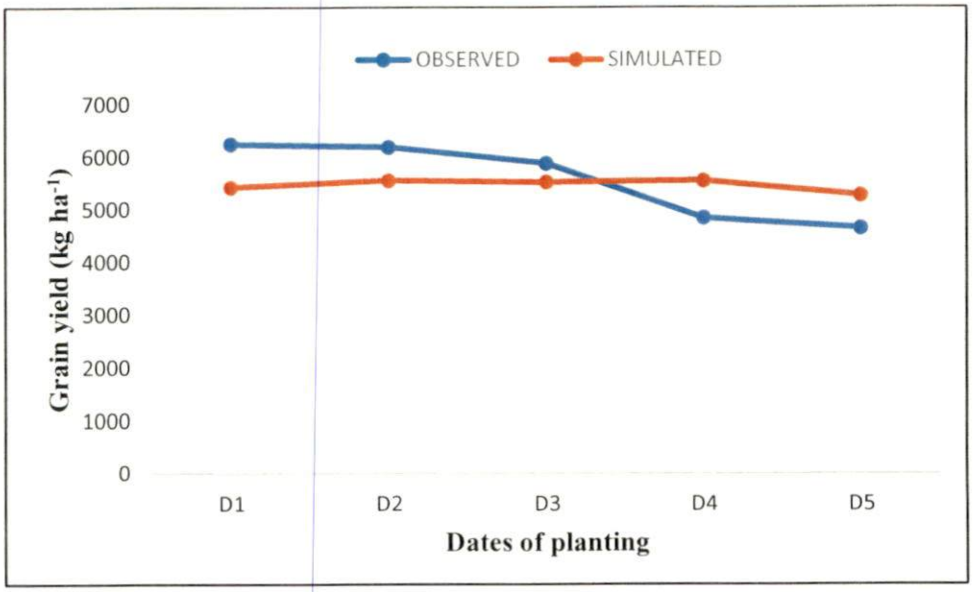

Fig.5.8 (a). Comparison of observed and simulated yield by DSSAT in Kanchana

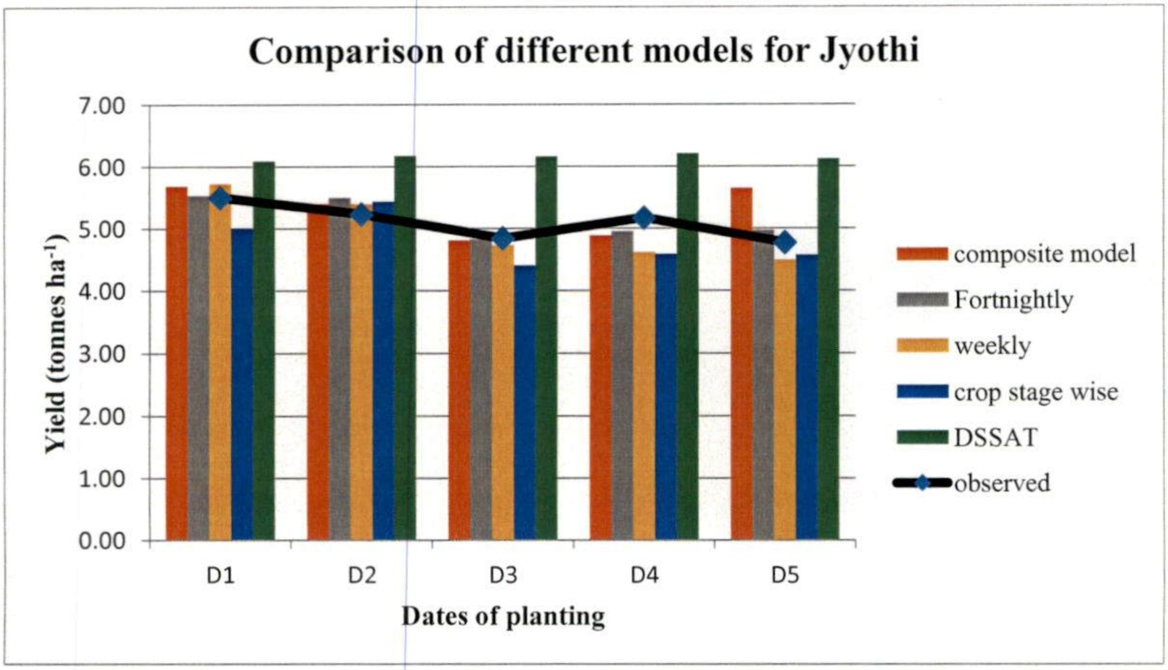

Fig. 5.9. Comparison between the observed yield and the estimated yield using different weather based models in Jyothi

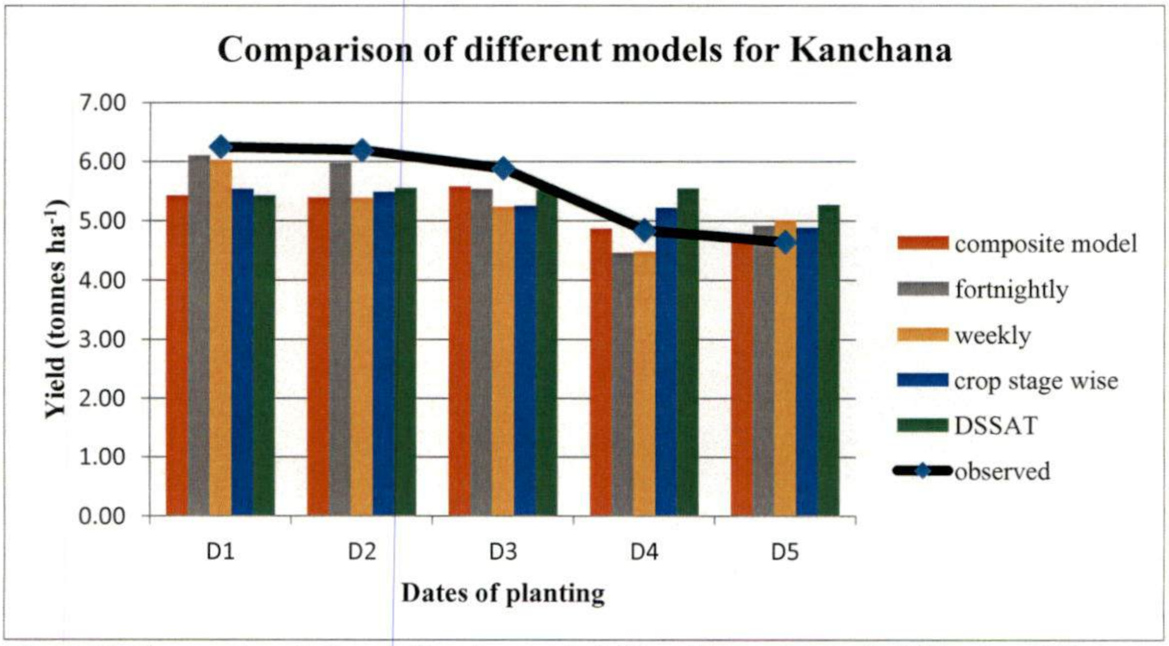

Fig. 5.10. Comparison between the observed yield and the estimated yield using different weather based models in Kanchana

SUMMARY

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6. SUMMARY

The present investigation on "Comparison of different weather based models for forecasting rice yield in central zone of Kerala" was conducted at Department of Agricultural Meteorology, College of Horticulture, Vellanikkara, Thrissur during 2017 - 18. The study was conducted to compare the accuracy of different weather based models for forecasting rice yield and to validate the results with experimental data.

Weather, phenological, biometric and soil data were noted during the study period. Crop weather relationship was analyzed using the experimental data of past 5 years from 2013 – 2017 by correlation studies. Biometric observations viz., leaf area and dry matter accumulation at an interval of 15 days were used to calculate different growth indices such as leaf area index, leaf area duration, crop growth rate, net assimilation rate. Crop simulation model DSSAT-CERES-Rice was run and different crop weather models based on statistical techniques and were fitted using weather and crop yield data collected from the department and validated using the present year experimental data. The results of this study are summarized below:

- Significant influence of date of planting on plant height was observed for both varieties up to 5 weeks after transplanting. After first five weeks, no significant influence of dates of planting was observed for both the varieties. During all weeks, significant difference was observed in plant height due to varieties.
- With delay in planting dates, dry matter accumulation was found to be decreasing in both Jyothi and Kanchana. Maximum dry matter accumulation was noted at 75 days after planting in both the varieties where June 5th planting (15257.53 kg ha^{-1}) was found superior in Jyothi and June 20th planting (15186.57 kg ha^{-1}) was superior in Kanchana which was on par with June 5th planting (15094.84 kg ha^{-1}).
- Analysis of variance did not show any significant difference in the case of number of tillers m^{-2} for different dates of planting and the interaction between dates of planting and varieties was also found non-significant.

- Significant difference was found between different dates of planting in the case of number of panicles. Number of panicles per m^2 were more for July 5th planting which was on par with June 5th, June 20th and July 20th plantings. Lowest number of panicles was obtained for August 5th planting which was on par with July 20th planting.
- August 5th planting showed least number of spikelets per panicle which was on par with June 20th planting. Number of spikelets was more for July 5th planting which was on par with June 5th, June 20th, and July 20th planting.
- August 5th planting showed lowest number of filled grains per panicle which was on par with June 20th planting. More number of filled grains was noted for July 5th planting which was on par with July 20th planting.
- June 5th planting showed more thousand-grain weight, which was on par with June 20th and July 20th plantings. July 5th planting showed lowest thousand-grain weight which was on par with August 5th planting.
- Higher grain yield was given by June 5th planting and June 20th planting which were on par. Lowest yield was obtained from August 5th planting.
- Jyothi and Kanchana took more number of days to complete each phenophase during early plantings and showed reduction in duration with delay in plantings. Low temperature and high relative humidity favoured increased duration in early plantings. Jyothi took more days than Kanchana to complete each phenophases.
- Weather parameters during different phenophases influenced yield and yield attributes such as number of panicles per m^2, number of spikelets per panicle, number of filled grains per panicle and thousand grain weight.
- In the case of all five plantings, maximum LAI was observed at 75 DAP. June 20th planting showed lowest LAI in Jyothi whereas August 5th planting showed lowest LAI in Kanchana at 75 DAP. The value of leaf area duration was maximum during 60 – 75 days in both Jyothi and Kanchana. Crop growth rate was found to be maximum during 45 – 60 DAP in both Jyothi and Kanchana. Net assimilation rate was increasing during initial stages and it decreased towards later stages.

- Crop weather models based on statistical techniques were fitted using weekly, fortnightly, crop stage-wise and composite weather variables of past 5 years' experimental data.
- Crop weather models based on weekly, fortnightly and crop stage wise weather variables used original weather variables for fitting models while the crop weather model based on composite weather variables used the generated variables (Z_{ij}) of individual variables and product of any two weather variables.
- Stepwise regression analysis was used to select the variables in the models.
- One crop weather model fitted using each method having lowest MAPE value was selected for comparison.
- Weather file, soil file, crop management file and experimental file were created for past 5 years from 2013 to 2017 to run DSSAT-CERES-Rice model for Jyothi and Kanchana separately. Their MAPE values were also calculated.
- DSSAT-CERES-Rice model was run using the genetic coefficients calibrated at the Department of Agricultural Meteorology during 2015 for Jyothi and Kanchana.
- The selected models were validated using the present year experimental data. The error % of each model showed that the models using five fortnightly weather variables performed well in both Jyothi and Kanchana.
- It was also concluded that fine tuning is required for the crop simulation model for simulating grain yield in Jyothi and Kanchana.
- Out of all the models fitted for Jyothi, the crop weather model using five fortnights' weather variables was selected which can give yield forecast at flowering stage of the crop. The selected model for Jyothi is:

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

(Adjusted R^2 – 0.912 and MAPE – 4%)

- Out of all the models fitted for Kanchana, the crop weather model using five fortnights' weather variables was selected which can give yield forecast at flowering stage of the crop. The selected model for Kanchana is:

$$\mathbf{Y = -6.143 + 0.053X_{42} + 0.134X_{45} - 0.952X_{81}}$$

(Adjusted R^2 – 0.657 and MAPE – 7.62%)

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APPENDICES

Appendix I

Abbreviations and units used

Weather parameters

Tmax : Maximum temperature

Tmin : Minimum temperature

TR : Temperature range

RH I : Forenoon relative humidity

RH II : Afternoon relative humidity

VPD I : Forenoon vapour pressure deficit

VPD II: Afternoon vapour pressure deficit

RF : Rainfall

RD : Rainydays

WS : Wind speed

Epan : Pan evaporation

BSS : Bright sunshine hours

Phenophases

T – AT : Transplanting – active tillering

T – PI : Transplanting – panicle initiation

T – B : Transplanting – booting

T – H : Transplanting - heading

T – F : Transplanting - flowering

T - PM: Transplanting – Physiological maturity

Varieties

J – Jyothi

K - Kanchana

Units

g : gram

kg : kilogram

km hr^{-1}: kilometre per hour

^0C : degree Celsius

kg ha^{-1} : kilogram per hectare

% : per cent

Growth indices

LAI – Leaf area index

LAD – Leaf area duration

CGR – Crop growth rate

NAR – Net assimilation rate

(ii)

Appendix II

ANOVA of different plant growth characters of 2017 experiment

Plant height at different weeks after planting

Source of variation	DF	Mean sum of squares							
		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
Date of planting	4	21.767*	26.970*	149.556**	54.392*	61.839*	11.395^{NS}	32.968^{NS}	44.388^{NS}
Error(a)	12	5.677	6.723	11.233	13.332	17.315	23.783	30.465	37.009
Variety	1	8.067^{NS}	63.306**	492.097**	690.715**	633.425**	423.428**	615.085**	657.236**
DOP x Variety	4	4.096^{NS}	4.598^{NS}	6.482^{NS}	15.040^{NS}	29.038*	27.740^{NS}	7.875^{NS}	13.896^{NS}
Error(b)	15	3.627	5.766	7.315	6.608	9.239*	11.539	13.048	17.619

Source of variation	DF	Mean sum of squares				
		Week 9	Week 10	Week 11	Week 12	Week 13
Date of planting	4	75.729^{NS}	40.544^{NS}	62.198^{NS}	50.735^{NS}	54.184^{NS}
Error(a)	12	61.703	43.287	34.518	24.273	17.880
Variety	1	448.572**	935.088**	1,246.458**	1,541.518**	1,668.286**
DOP x Variety	4	16.094^{NS}	17.504^{NS}	6.915^{NS}	9.272^{NS}	10.001^{NS}
Error(b)	15	23.623	15.145	15.636	11.419	10.246

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

(iii)

Appendix II (contd.)

Dry matter accumulation at fortnightly intervals

Source of variation	DF	Mean sum of squares					
		15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT
Date of planting	4	26,894.88**	327,433.25**	224,672.60*	2,003,469.92**	3,349,192.04**	2,284,329.33**
Error(a)	12	1,328.61	64,255.21	49,520.58	196,583.24	81,643.43	113,141.28
Variety	1	17,380.06**	193,731.18**	$20,122.23^{NS}$	$275,409.58^{NS}$	$78,320.87^{NS}$	$188,124.07^{NS}$
DOP x Variety	4	4,376.91*	62,868.21**	229,158.79*	1,651,512.95**	373,225.23**	$173,364.25^{NS}$
Error(b)	15	1,227.61	13,327.09	65,389.81	202,567.46	68,059.03	115,128.40

Leaf area index at fortnightly intervals

Source of variation	DF	Mean sum of squares					
		15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT
Date of planting	4	0.016**	0.112**	0.553**	0.199*	0.032^{NS}	0.435**
Error(a)	12	0.002	0.013	0.069	0.044	0.049	0.009
Variety	1	0.000^{NS}	0.042^{NS}	0.063^{NS}	0.838**	0.775**	1.459**
DOP x Variety	4	0.007*	0.012^{NS}	0.040^{NS}	0.135^{NS}	0.093**	0.068*
Error(b)	15	0.001	0.019	0.020	0.052	0.018	0.021

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

Appendix II (Contd.)

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

Source of variation	DF	Mean sum of squares					
		Grain yield	Panicles per m^2	Spikelets per panicle	Number of filled grains per panicle	1000 grain weight	Straw yield
Date of planting	4	1,863,882.54**	15,873.20*	626.18**	1,228.73**	8.76**	3,359,510.00^{NS}
Error(a)	12	204,845.45	3,926.36	139.97	92.14	0.85	1,371,068.33
Variety	1	2,076,988.05*	21,372.500*	2,268.10**	471.99**	0.51^{NS}	3,802.50^{NS}
DOP x Variety	4	826,752.94^{NS}	2,540.66^{NS}	46.69^{NS}	65.57^{NS}	1.09^{NS}	3,075,090.00^{NS}
Error(b)	15	307,878.59	3,517.88	84.24	56.86	0.64	1,939,659.17

Leaf area duration at fortnightly intervals

Source of variation	DF	Mean sum of squares					
		0-15 DAT	15-30 DAT	30-45 DAT	45-60 DAT	60-75 DAT	75-90 DAT
Date of planting	4	0.914**	8.521**	52.079**	59.406**	6.626^{NS}	29.690**
Error(a)	12	0.089	0.799	4.159	7.499	6.990	3.309
Variety	1	0.012^{NS}	2.618^{NS}	0.125^{NS}	76.538**	182.211**	244.299**
DOP x Variety	4	0.404**	0.907^{NS}	2.139^{NS}	15.202^{NS}	22.864*	14.171**
Error(b)	15	0.082	1.153	2.193	6.209	5.062	1.960

Appendix II (Contd.)

Crop growth rate at fortnightly intervals

Source of variation	DF	Mean sum of squares					
		0-15 DAT	15-30 DAT	30-45 DAT	45-60DAT	60-75 DAT	75-90 DAT
Date of planting	4	1.186**	11.633*	32.916*	89.209**	10.229^{NS}	14.787*
Error(a)	12	0.059	2.618	7.248	10.511	15.573	3.873
Variety	1	0.765**	14.391**	14.921*	6.480^{NS}	28.701^{NS}	1.011^{NS}
DOP x Variety	4	0.192*	2.401*	13.137**	50.056*	39.986*	3.341^{NS}
Error(b)	15	0.054	0.491	2.180	11.538	11.308	3.154

Net assimilation rate at fortnightly intervals

Source of variation	DF	Mean sum of squares				
		15-30 DAT	30-45 DAT	45-60DAT	60-75 DAT	75-90 DAT
Date of planting	4	4.205^{NS}	7.748**	3.113*	0.335^{NS}	0.599^{NS}
Error(a)	12	2.112	0.978	0.825	0.747	0.219
Variety	1	17.449**	1.707^{NS}	2.586^{NS}	0.097^{NS}	0.630^{NS}
DOP x Variety	4	2.424^{NS}	2.008*	1.870^{NS}	2.236*	0.243^{NS}
Error(b)	15	1.083	0.544	0.788	0.502	0.176

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

COMPARISON OF DIFFERENT WEATHER BASED MODELS FOR FORECASTING RICE YIELD IN CENTRAL ZONE OF KERALA

By

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ABSTRACT OF THE THESIS

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ABSTRACT

Rice is the staple food and the major field crop cultivated in Kerala. Its production is highly influenced by unfavourable weather events and climatic conditions. Thus it poses a challenge to farmers, crop planners and government owing to varying production of grains. Reliable crop yield forecasts are highly essential to estimate crop production, to assist farmers, exporters and government in decision making for efficient resource allocation, price adjustment and export planning. It also helps to reduce various secondary risks associated with local and national food systems.

The present investigation "Comparison of different weather based models for forecasting rice yield in central zone of Kerala" was carried out at the Department of Agricultural Meteorology, College of Horticulture, Vellanikkara during 2017-18, to compare the accuracy of different weather based models developed using five years' rice crop data collected from previous studies at the department for forecasting rice yields in central zone of Kerala and to validate them using the present experimental data. The field experiment was conducted at Agricultural Research Station, Mannuthy during the *kharif* season of 2017. Split plot design was adopted with five dates of planting *viz.,* 5th June, 20th June, 5th July, 20th July and 5th August as the main plot treatments and two varieties *viz.*, Jyothi and Kanchana as the sub plot treatments. The number of replications for the experiment was four.

Daily observations of weather during the crop period were made which showed an increase in the maximum and minimum temperature and decrease in rainfall and relative humidity towards the end of the crop period. Different growth and yield attributes like plant height, dry matter accumulation, number of tillers, panicles, spikelets, filled grains, grain yield, straw yield and the duration of different phenophases were also noted. Correlation analysis was carried out using the weather, yield and phenological data of 5 years in both the varieties. The various growth indices such as leaf area index, net assimilation rate, leaf area duration and crop growth rate were worked out to analyze the growth and development of the crop.

Plant height was found to be higher for Jyothi compared to Kanchana. Dry matter accumulation, yield attributes except straw yield were found varying between five dates of planting. Yield and yield attributes were influenced by different weather parameters during different dates of planting. With delay in dates of planting the duration of different phenological stages were reduced in both the varieties. Jyothi took more number of days to attain different growth stages compared to Kanchana. The highest yield in Jyothi and Kanchana were obtained for June 5th planting.

Crop weather models using statistical techniques were developed using five years' weather and crop yield data by adopting four different methods for Jyothi and Kanchana separately. The methods were (i) based on weekly weather variables (ii)based on fortnightly weather variables (iii) based on crop stage wise weather variables and (iv) based on composite weather parameters. Each crop weather model was fitted by stepwise regression analysis using SPSS software. CERES-Rice model also was run for Jyothi and Kanchana by creating weather file, soil file, crop management file and experimental files separately for each year.

For comparing the accuracy of the developed crop weather models and simulation model for Jyothi and Kanchana, and for their validation, mean absolute percentage error (MAPE) was calculated for each model using the observed and estimated yield data. The model with least mean absolute percentage error (MAPE) is considered as a better model for yield prediction. In the case of Jyothi, lowest MAPE (4.00%) was obtained for model based on 5 fortnightly weather variables. In Kanchana also, the model developed using 5 fortnightly weather variables was selected with an MAPE value 7.62%.

All the crop weather models are showing very good results out of which crop weather model using 5 fortnightly weather variables which coincide with flowering stage has given a good forecast compared to the other models for both Jyothi and Kanchana.

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