EFFECT OF WEATHER ON SHEATH BLIGHT INCIDENCE IN RICE AND PREDICTING POTENTIAL EPIDEMICS UNDER VARIOUS CLIMATE CHANGE SCENARIOS

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(2011-20-123)

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VELLANIKKARA, THRISSUR – 680656

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THESIS

Submitted in partial fulfillment of the requirement

for the degree of

BSc-MSc (integrated) Climate Change Adaptation

Faculty of Agriculture

Kerala Agricultural University, Thrissur

ACADAMY OF CLIMATE CHANGE EDUCATION AND RESEARCH

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

DECLARATION

I hereby declare that the thesis entitled **"Effect of weather on sheath blight incidence in rice and predicting potential epidemics under various climate change scenarios"** is a bonafide record of research work done by me during the course of research and the thesis has not been previously formed the basis for the award to me any degree, diploma, fellowship or other similar title, of any other University or Society.

Date: 28.03.2017

Vellanikkara

DEVI KRISHNA P

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CERTIFICATE

Certified that this thesis entitled **"Effect of weather on sheath blight incidence in rice and predicting potential epidemics under various climate change scenarios"** is a record of research work done independently by Ms. Devi Krishna, P (2011-20-123) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship with any other person.

Vellanikkara
28.03.2017

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We, the undersigned members of the advisory committee of Ms. Devi Krishna, P a candidate for the degree of **BSc-MSc (Integrated) Climate Change Adaptation** agree that the thesis entitled **'Effect of weather on sheath blight incidence in rice and predicting potential epidemics under various climate change scenarios.'** may be submitted by Devi Krishna, P. (2011-20-123), in partial fulfillment of the requirement for the degree.

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Devi Krishna, P

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ABBREVIATIONS

AR5	Assessment Report 5
AVGRH	Average relative humidity
AVGSM	Average soil moisture
AVGSR	Average solar radiation
AVGT	Average temperature
AVRST	Average soil temperature
BSH	Bright Sunshine Hours
CD	Critical Difference
CERES	Crop Estimation through Resource and Environment Synthesis
FAO	Food and Agriculture Organization
GCM	General Circulation Model
GDD	Growing Degree Days
IBSNAT	International Benchmark Sites Network for Agrotechnology Transfer
IPCC	Inter government panel on Climate Change
IRRI	International Rice Research Institute
KAU	Kerala Agricultural University
LAI	Leaf area index
MAXRH	Maximum relative humidity
MAXSM	Maximum soil moisture
MAXSR	Maximum solar radiation
MAXST	Maximum soil temperature
MAXT	Maximum temperature
MINAT	Minimum temperature
MINRH	Minimum relative humidity

MINST	Minimum soil temperature
POP	Package of practices
RARS	Regional Agricultural Research Station
RCP	Representative Concentration Pathway
RF	Rainfall
RMSE	Root Mean Square error
STR	Soil test results
Tmax	Maximum temperature
Tmin	Minimum temperature

INTRODUCTION

Rice (*Oryza sativa* L.) is the most extensively cultivated food crop and is being cultivated in 114 countries over the world. The majority of the rice (90%) is being produced in Asia with China and India being the major producers (IRRI 2008). The other major rice producing countries includes Indonesia, Bangladesh, Vietnam, Thailand, Myanmar, Philippines, Brazil and Japan. It is one of the most important food crops of India in term of area, production and consumer preference. India is the second largest producer and consumer of rice in the world. Rice production in India crossed the mark of 100 million MT in 2011-12 accounting for 22.81 per cent of global production.

Several pathogenic diseases have been found to occur on the rice crop resulting in extensive damage to the grain and straw yield. The crop is subjected to attack by many diseases caused by fungi, bacteria, viruses and nematodes which cause annual loss to the tune of 12-25 per cent of the total production. Major rice diseases under Kerala conditions are Bacterial leaf blight, Sheath blight and Blast. Among these diseases, the Sheath blight which was earlier considered to be a minor disease is now posing a major threat to the rice cultivation. Sheath blight is an important soil-borne fungal disease which causes 10-30 per cent yield loss (Xie *et al.*, 2008). It may reach up to 50 per cent during favourable years especially when susceptible cultivars are grown (Prasad and Eizenga 2008). The disease manifests initially as water soaked lesions on sheaths of lower leaves near water level.

Sheath blight, caused by *Rhizoctonia solani* Kühnhas become an important disease of rice, especially in intensive production systems. From the epidemiological viewpoint, rice sheath blight shares characteristics with other diseases caused by *Rhizocionia spp.* in that the primary inoculum is mainly soil-borne while secondary inoculum does not consist of spores, but is predominantly in the form of mycelial strands produced by primary lesions that run on the surface of leaves and sheaths to establish new lesions. As a result, epidemics usually exhibit a very strong spatial aggregation (Savary *et al.*, 1995).

Plant diseases may reduce crop yields depending on the diseases involved, the crop species grown, the management practices followed, and various environmental factors. An integrated disease-control program, based on knowledge of pathogen biology and which diseases are most likely to occur in an area, is the most effective and efficient means of controlling diseases in the long run. The integrated disease management is a system that, in the context of the associated environment and the population dynamics of the pathogen species, utilizes all suitable techniques and methods in a manner as compatible as possible and maintains the pathogen population at levels below those causing economic injury. Moreover, integrate plant disease management advocates the use of multiple control measures, including, if possible, a rational system for predicting the risk of disease outbreaks. Therefore, a support system for decision-making can be a valuable tool for farmers and crop advisers aiming for integrated disease management.

With incentives for more sustainable practices in crop protection it is important to decrease the usage of pesticides. This implies that, rather than eliminating pathogens, crop protection lowers damage of pathogen origin to an acceptable level, by combining reduced chemical control with resistant cultivars and environmentally responsible agronomic practices. In turn, a better understanding of pathosystems is required. We use Pathosystems to mean a dynamic ensemble consisting of a host plant population, a parasite population and their biophysical environment. Pathosystems involve multiple levels of interactions that are the source of complex behaviours.

Rice diseases, accountable for considerable yield losses of rice production, are likely to be affected by meteorological changes resulting from global climate change. No critical evaluation has yet been made of the potential impacts of climate change on rice diseases. So, keeping in view the important of sheath blight of rice under Kerala conditions, the present studies were planned with the following objectives:

1. Study the effect of various weather parameters and climate change on incidence and development of sheath blight disease of rice
2. Evaluation of disease forecasting models for sheath blight of rice.

Pest and diseases are one of the major causes of reduction in crop yield and the loss can be minimized by timely application of remedial measures. This requires a prior knowledge of time and severity of the outbreak of pest and diseases. The intensity of sheath blight disease of rice has increased tremendously over the years in India. It is a major production constraint in many of the rice growing areas especially in coastal and high humid regions. Loss in yield may vary between 7-50% depending on the cultivar, environmental condition, stages at which the plants are infected and level of infection. Crop weather simulation models with the help of GCM's can estimate the impact of future climate conditions on sheath blight disease of rice. In this chapter we are going to review the effect of different weather variables on sheath blight incidence and how the climate change is altering weather and its impact on the disease severity is being reviewed.

2.1 Climate change

Climate change influence pathogen populations; in some cases, altered temperatures may favour overwintering of sexual propagules, thus increasing the evolutionary potential of a population. (Pfender *et al.*, 1999). Effect of elevated concentrations of CO_2 has also been evaluated on two important diseases of rice, namely blast (*Pyricularia oryzae*) and sheath blight (*Rhizoctonia solani*) and rice plants were found more susceptible to injury (Kobayashi *et al.*, 2006). Cooling trends have been observed in northwest India and parts of South India. There is no significant trend in rainfall data for the last 100 years at the all-India level. At the regional level, increasing monsoon seasonal rainfall has been found along the west coast, northern Andhra Pradesh and northwestern India, while a trend of decreasing monsoon seasonal rainfall has been observed over eastern Madhya Pradesh, NE India and some parts of Gujarat and Kerala. The possible changes in temperature, precipitation, concentration of CO_2, CH_4, nitrous oxide (N_2O) and O_3 are expected to have significant impact on crop growth. Plant diseases are one of the important factors which have a direct impact on global agricultural productivity and climate change will further aggravate the situation (IPCC, 2007).

A single factor of climate change like temperature can have a terrible effect on crop yield. Temperature increases of 1°C, 2°C and 3°C in Punjab, would reduce the grain yield of rice by 5.4%, 7.4% and 25.1% respectively (Aggarwal *et al.*, 2009).The impacts are more in developing countries, where damage to agricultural production from extreme weather linked to climate change is contributing to deaths from malnutrition, poverty and their associated diseases. (Gautam, 2009).Changing disease scenario due to climate change has highlighted the need for better agricultural practices and use of ecofriendly methods in disease management for sustainable crop production (Boonekamp, 2012)

Climate change is the result of the acceleration in the increase in temperature and CO_2 concentration over the last 100 years. During the period, the global mean temperature has increased by 0.74°C and atmospheric CO_2 concentration has increased from 280 ppm in 1750 to 400 ppm in 2013.Changes in climate are still going unabated and temperature is projected to increase by 3.4°C and CO_2 concentration to1250 ppm by 2095 under the A2 scenario, accompanied by much greater variability in climate and more extreme weather-related events. (Savary *et al.*, 2012)

Such changes will have a drastic effect on the growth and cultivation of the different crops on the Earth. Simultaneously, these changes will also affect the reproduction, spread and severity of many plant pathogens, thus posing a threat to our food security. Rice diseases are affected by meteorological changes resulting from global climate change. Elevated temperature and CO_2 concentration are also causing important rice disease sheath blight (*Rhizoctonia solani*) (Kim *et al.*, 2015)

2.2 Sheath blight disease in rice

The fungus, *Rhizoctonia solani* (Kühn) produces enzymes and toxin that can degrade plant tissue, such as pectic enzymes, cellulolytic enzymes, and proteolytic enzymes (Parmeter and Whitney, 1970).

Sheath blight is a second, only to rice blast in reducing both grain yield and quality (Lee and Rush, 1983; Ou, 1985).

Sheath blight, caused by Rhizoctonia solani Kühn is potentially a devastating disease in intensive production systems. This disease is one of the major constraints to rice production, with yield losses of between 10 and 36%, depending on the growth stage when the disease occurs. *Rhizoctonia solani* (Kühn) has been identified in the subdivision of Deuteromycotina and Class Agonomycetes, and divided in the anastomosis group 1 IA (AG-1 IA) (Sneh *et al.*, 1991).

Tillering to panicle stage was found most favourable for sheath blight development, so the crop age is an important factor for sheath blight development. Early crop stages were less susceptible (Tan *et al.*, 1995)

Dense canopy provides more favorable and conducive environment for sheath blight development because of higher canopy wetness and contact frequency between host tissues (Savary *et al.*, 1995; Castilla *et al.*, 1996; Srinivasachary *et al.*, 2011)

High leaf area index and more tillers facilitate the horizontal spread of sheath blight disease by increasing leaf-to-leaf and leaf to sheath contacts (Castilla *et al.*, 1996; Willocquet *et al.*, 2000).

The incidence and severity of sheath blight in rice-growing regions have increased through intensified rice production systems which are characterized by abundant application of nitrogenous fertilizers, high plant population and adaptation of super high-yielding cultivars (Castilla *et al.,* 1996; Cu *et al.,* 1996; Willocquet *et al.,* 2000; Slaton *et al.,* 2003; Wu *et al.,* 2012).

Sheath blight can damage many parts of rice plant, resulting in significant losses in yield and milling quality. The spread of disease is largely dependent on inoculum density, warm and high humidity conditions and varietal resistance. The disease appears both on sheath and laminar portion of leaf (Swamy *et al.*, 2009).

For suppressing sheath blight development can be recognized as "disease avoidance"; an efficient way to minimize yield loss from sheath blight (Zhong *et al.*, 2006; Willocquet *et al.*, 2000; Savary *et al.*, 2012).

Adaptation of 'healthy' canopy structure resulting from appropriate crop management practices such as rational use of fertilizers, optimum planting density and water management (Yang and Zhang, 2010; Wu *et al.,* 2012) Sheath blight significantly reduced LAI and biomass production. Sheath blight could reduce rice grain yield up to 50% in double-season system (Wu *et al.,* 2012)

The knowledge of critical factors influencing disease development can help in prediction of plant diseases and in taking timely measures for their effective management (Kaur *et al.*, 2015)

2.3 Disease cycle of rice sheath blight disease

The fungus is present in most soils and, once established in a field, remains there indefinitely. The mycelium, which is fast growth, colorless when young, becoming yellowish brown when older, 8-12 μm in diameter, consists of long cells and produces branches that grow at approximately right angles to the main hypha, are slightly constricted at the junction, and have a cross wall near the junction . The mycelium consists of monilioid cells involved in the formation of sclerotia as a hard, weather-resistant structure, and which can remain alive in for several years. Sclerotia are white when young, becoming brown or dark brown. Individual sclerotia measure up to 5 mm but may unite to form a larger mass in culture. *R. solani* has the wide range of hosts, such as cucumbers, tomatoes, potatoes, eggplants, beans, and rice. The rice sheath blight fungus infected 20 species of weeds from 11 families and that the sclerotia or diseased tissues obtained from the weeds produced typical symptoms of rice sheath blight on rice plants (Ou, 1987).

The disease usually infects the plant at late tillering or early internode elongation growth stages. The fungus penetrates through the cuticle or the stomatal slit. Infection pegs are formed from each lobe of the lobate appressorium of infection cushion. The mycelium grows from the outer surface of the sheath going through the sheath edge and finally through the inner surface. Primary lesions are formed while the mycelium grows rapidly on the surface of the plant tissue and inside its tissue. It proceeds upwards and laterally to initiate formation of the secondary lesions. The symptoms are observed on the upper leaf sheath and on the leaf blade. Disease spread both vertically and horizontally from one hill to another through leaf-to-leaf or leaf-to-sheath contacts (Chaudhary, 2002).

2.3.1 Host range

All the weeds / crops *(Zeamays. Pennisetumamericanum. Vignaradiata,* V. *mungo. Solanumtuberosum. Cynodondactylon. Oigitariaadscendus. Echinochloacrusgalli. Panicum crusgalli* and *Cyperusrotundus* artificially inoculated developed blight symptoms except *Sorghum halepens.* However. the colour and shape of lesions appeared on leaves/sheaths varied. Sclerotial inoculum of the fungus in the soil or presence of infected weeds viz. Cynodon*dactylon, Cyperusrotundus. Echinochloacrusgalli, Oigitariaadscendus*etc. in and around the fields and infected seedlings in the nursery may help in perpetuating the disease (Roy, 1977; Kannaiyan and Prasad, 1979).

2.4 Disease control measures

2.4.1 Biological control

Rice sheath blight is one of the plant diseases which have been controlled using a biological control approach (Mew and Rosales, 1986; Vasantha Devi *et al*., 1989; Kanjanamaneesathian *et al*., 1998; Pengnoo *et al*., 2000).

BanShbFPS5 (2) B, BanShb738 (3), BanShb738 (2) and BanShb581 (1), the four antagonistic bacterial isolates could be applied as biological agent to control sheath blight disease of rice and they could control sheath blight disease development and could delay the epidemics of the disease. (Bashar, 2010)

2.4.2 Cultural control

Resistance breeding efforts against sheath blight has been only moderately successful, mainly due to a lack of source for resistance in cultivated rice or in wild related species. (Webster, R K and Gunnell, P S, 1992).

One approach to sustainable disease management without the use of chemicals is to develop disease-resistant cultivars. Benefits from disease-resistant cultivars include reduced disease incidence and increased grain and milling yields. (Groth *et al.*, 1993)Using molecular plant breeding programs, researchers manipulate the identified pathogen resistant genes to develop commercially resistant cultivar. So far, these attempts were ineffective and this may be attributed to the resistance being controlled by multiple genes or quantitative trait loci (QTLs) (Pinson *et al.*, 2005).

Rice cultivars ranging from susceptible to moderately resistant to Sheath blight are available for cultivation. The development of new resistant cultivars was hampered through direct screening of germplasm because the fungal pathogen *R. solani* is plurivorous and semi-saprobiotic (Zuo *et al.*, 2009).

Sheath blight resistance QTLs have been identified in 12 rice chromosomes, only few were mapped and most did not show any effect (Zeng *et al.*, 2011)

2.4.3 Chemical Control

Chemical control, though effective in managing disease, often has a significant impact on humans and the natural environment through the pollution of soils, above and below ground water resources, and the entire food supply chain. Human health and environmental protection regulations are strict. A major goal in developing a new fungicide is to ensure a good balance between potency and safety. (Knight, 1997).

A product that clears all regulations is patented and sold in the market. Patent time varies with the country of application. The success of the product is not guaranteed, as it may have competition from rival products, and it may develop pathogen resistance (Gullino *et al.*, 2000)

Panicle formation stage is more prone to infection by *R. solani* and can cause heavy losses. Weeds plays major role in disease perpetuation. Propiconazole (0.1%), Edifenphos (0.1%), Iprodione(0.3%), Carboxin (0.2%) and Carbendazim (0.1%) effectively controlled sheath blight. (Chahal *et al.*, 2003)

The fungicide is a derivative of β-methoxyacrylate and was the first registered fungicide from this class of chemistry, It is sold as Quadris 2.08 SC. Azoxystrobin is considered one of the best fungicides in the U.S. for sheath blight control (Grichar *et al.*, 2004) Within the strobilurins group, azoxystrobin fungicide is widely used as it works effectively against sheath blight pathogen infestation (Groth and Bond., 2006).

Due to the low inherent level of resistance among cultivated or wild rice, sheath blight management is difficult and broad host range and high genetic diversity of the pathogen (Taheri *et al.,* 2007).Benefits from fungicide control include lower disease incidence, likely reduction of inoculum, and improved grain and milling yields (Groth, 2008).

2.5 Weather on sheath blight

Sheath blight is a typical tropical rice disease favored by high temperature and high relative humidity (Lee and Rush, 1983).

Changes in the amount of rainfall were not predicted to affect the occurrence of epidemics due to having little effect on the leaf wetting period best suitable period for maximum mycelial growth and sclerotial production of *Rhizoctonia solani* is 28°C (Luo *et al.,* 1995). High temperature and humidity favoured lesion enlargement, both lengthwise and breadth wise (Sarkar *et al.*, 2000). No symptoms were recorded at lower temperature that is 15°C and 18°C and at higher temperature that is 35°C and 40°C , maximum disease severity of 65 % was at temperature of 25°C and 27°C. More than 80% relative humidity is more congenial for development of sheath blight of rice (Thind *et al.*, 2008).

Strong relationship between disease and weather variables, which thereby established that rainfall, relative humidity (morning and evening), temperature (maximum and minimum) during the course of disease development contributed more than 97.5 per cent variation in disease with respect to disease incidence and severity. High relative humidity, temperature and rainfall favoured the development of rice sheath blight. High relative humidity, temperature and rainfall favoured the development of rice sheath blight (Dutta *et al.*, 2011). Biswas *et al.*, (2011) observed increased in sheath blight disease with an increase in maximum temperature and minimum temperature whereas, its spread was accompanied with relative humidity (RH) through stepwise regression. Rakhonde *et al.,* 2011 reported that conidial germination of powdery mildew on green gram was influenced by minimum temperature, maximum temperatures, relative humidity and light.

The disease incidence and severity were negatively correlated with maximum temperature, minimum temperature, evening relative humidity and rainfall and positively correlated with morning relative humidity and sunshine hours. Sheath blight incidence can be reduced by 8-9% by bed planting method as compared to conventional planting. The pathogen thrives when the canopy humidity is 96 to 97%. High infection occurs at 100% relative humidity and gradually falls when decreased; the minimum being 85 to 88%. High temperature (28-32°C) was reported to favour infection. Frequent rainfall favours disease development. Therefore, the disease is more common during the rainy than in the dry season in the tropics (Kaur *et al*., 2015)

2.6. Generating forewarning models for pests and diseases of rice

The regression model taking pest/disease variable as dependent and independent variables such as weather variables, crop stages, population of natural enemies/predators etc., is used. These variables are used in original scale or on a suitable transformed scale such as cos, log, exponential etc., (Coakley *et al*., 1985).

Forewarning models of pests and diseases based on time series data on weather variables can be developed using the discriminant function analysis. For this analysis, a series of data for 25-30 years are required. Based on the pest and diseases variables, data can be divided into different groups – low, medium and high etc. and using weather data in these groups, linear or quadratic discriminant functions can be fitted which can be used to find discriminant scores. Considering these discriminant scores as independent variables and diseases/pest as a dependent variable, regression analysis can be performed. (Johnson *et al.*, 1996)

Multiple regression equations were developed by using the most significant weather parameters through stepwise regression technique. These regression equations indicated that red rot infection of sugarcane variability could be explained from 73 to 99 per cent with the use of climatic parameters. Maximum temperature alone explained 74 per cent variation in red rot infection whereas the addition of relative humidity morning to this equation, 5 per cent more variation was explained. Rainfall alone accounted for about 73 to 98 percent variation in disease ignition. By adding both rainfall and relative humidity morning, 9 per cent more variation was explained. By taking maximum temperature with rainfall one percent variation in disease initiation remained unaccounted. Both relative humidity in evening and rainfall explained up to 92 per cent variation in red rot ignition during the August 5 inoculation period. (Anil Kumar *et al.*, 1998)

Prajneshu (1998) developed a nonlinear statistical model for describing the dynamic population growth. Solanki *et al.* (1999) used correlation analysis and regression equation through multiple and stepwise regression technique to know the associations of various biological and meteorological variables with powdery mildew disease of mustard. Reddy *et al.* (2001) developed models for prediction of sheath rot epidemics based on weather parameters for crops planted at different dates. The R^2 value (coefficient of determination) of multiple regression indicated that, weather parameters accounted for 44-81per cent and 46-77 per cent of variation in sheath rot epidemics. Sometimes, past data on pests and diseases are not available but the pests and diseases status at different points of time during the crop season are available for the current season only. In such situations, within years growth model can be used for forewarning maximum disease severity / pest population, provided there are 10-12 data points between time of first appearance of pest / disease and maximum or most damaging stage. The methodology consists in fitting appropriate growth pattern to the pests and diseases data based on partial data and using this growth curve for forecasting the maximum value of variable of interest. A number of growth models such as logistic, Gompertz etc., can be used for this purpose (Agrawal *et al.*, 2004).

Upadhyay *et al.*, (2004) used principal component analysis to find out the factors which play important roles in the population buildup of yellow stem borer. They reported that, rainfall and relative humidity played a significant role in the population buildup of yellow stem borer.

Weather Based Forewarning Models such as epidemic or epidemic/low, medium or high is known. Such a situation arises quite often in pest/disease data. In such cases, the data are classified as 0 and 1(2 categories); 0, 1 and 2 (three categories). The logistic regression is used for obtaining probabilities of different categories.

Agrawal *et al.* (2004); Ramasubramanium *et al.* (2006) developed statistical models for forewarning about infestation of paddy crops using step-wise regression technique and weather indices modeling technique without using transformation of data.

Gururaj *et al.* (2006) used Logistic model for prediction of Groundnut caused by *Pucciniaarchinids*in Northern Eastern dry Zone of Karnataka.

Henderson *et al.*, (2007) used logistic regression analysis for forecasting late blight in potato crops of southern Idaho.

Biswas *et al*. (2011) observed increased in sheath blight disease with an increase in maximum temperature and minimum temperature whereas, its spread was accompanied with RH through stepwise regression. Rakhonde *et al.* (2011) reported that conidial germination of powdery mildew on green gram was influenced by minimum temperature, maximum temperatures, RH and light.

2.7 Simulation Model

Holt *et al*. (1987) described the use of system analysis techniques to investigate the population dynamics of *N. lugens* and outlined the development process of a computer simulation model using field data.

A computer programme LLJET which utilizes an 850 MB weather chart to forecast long distance rice plant hopper migration has also been developed (Watanabe *et al.*, 1990).

RSPM-1 is a simulation model for forecasting rice sheath blight has been developed (Ji *et al.*, 1991).

Nemoto *et al.* (1992) formulated BLASTIL, a forecasting system for rice leaf blast and further BLASTAM- model was developed which predicted favourable conditions for rice blast, using weather data like rainfall, temperature, wind velocity and sunshine.

Graf *et al*. (1992) developed a simulation model for population dynamics of rice leaf folder and its interaction with rice crop. A distributed delay model including attrition was applied to simulate dynamic population changes such as birth, ageing, mortality, migration and growth in terms of numbers and biomass. The host-plant was assumed to affect the leaf folder survival, migration and growth rates while leaf folders, influenced the plant growth and development by feeding and folding of leaves.

Hu and Zhang (1993) formulated ESRICE- an expert system for forecasting and management of *N. lugens and C. medinalis* which involved many factors like immigration, rice variety, plant vigour, natural enemies and local weather conditions for forecasting.

There are number of rice disease simulation models have been developed to understand, predict, and manage rice diseases (Kobayashi *et al*., 1995). EPIRICE is a generic epidemiological model that can be parameterized to address any specific rice disease; it was recently developed as a general model framework for fungal, viral, and bacterial diseases at different levels of hierarchy in a crop canopy (leaves, sheaths, entire plants) depending on the nature of the disease. Thus, its structure was designed to be as simple as possible, involving a few state variables and a limited number of core parameters and weather variables. (Savary *et al.,* 2012).

Field experiments were conducted during 2015-16to study the effect of weather on sheath blight incidence in rice and predicting potential epidemics under various climate change scenarios. The materials used and methods followed are described below:

3.1 DETAILS OF FIELD EXPERIMENT

3.1.1 Location

The field experiments were conducted during May 2016 to October 2016 at the Regional Agricultural Research Station of the Kerala Agricultural University at Pattambi, Palakkad district, Kerala. The station is located at 10° 48' N latitude and 76° 12' E longitude at an altitude of 25.36 m above mean sea level.

3.1.2 Climate

The general climate of the location has studied for 30 years (1983-2012).

3.1.3 Soil

The soil of the experimental field was sandy clay loam in texture. The physical characteristics of the soil are presented in Table 1.

Table1.Physico-chemical properties of soil in the experimental field

Particulars	Value	Method employed
A. Mechanical composition		
Sand (%)	64	Robinson's international Pipette method
Silt (%)	3	(Piper, 1966)
Clay(%)	33	
Bulk density (Kg m^{-3})	1.3	Core sampler method (Piper, 1966)

3.1.4 Season

The experiments were conducted during the first crop season (April-May to September-October)

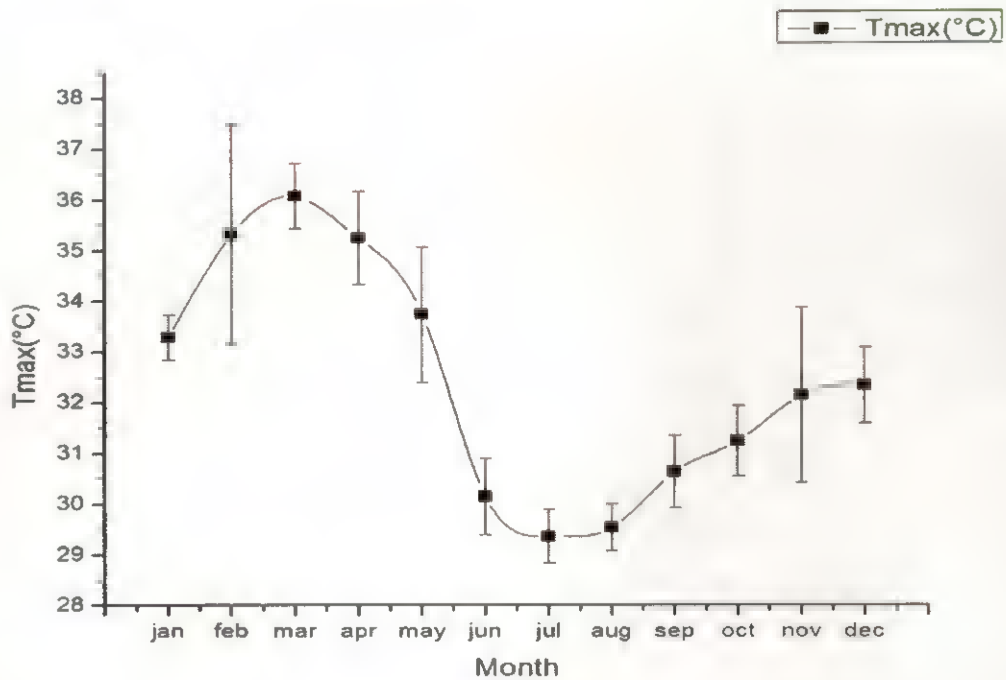

Fig. 1. Monthly maximum temperature (°C) of Pattambi (1983-2012)

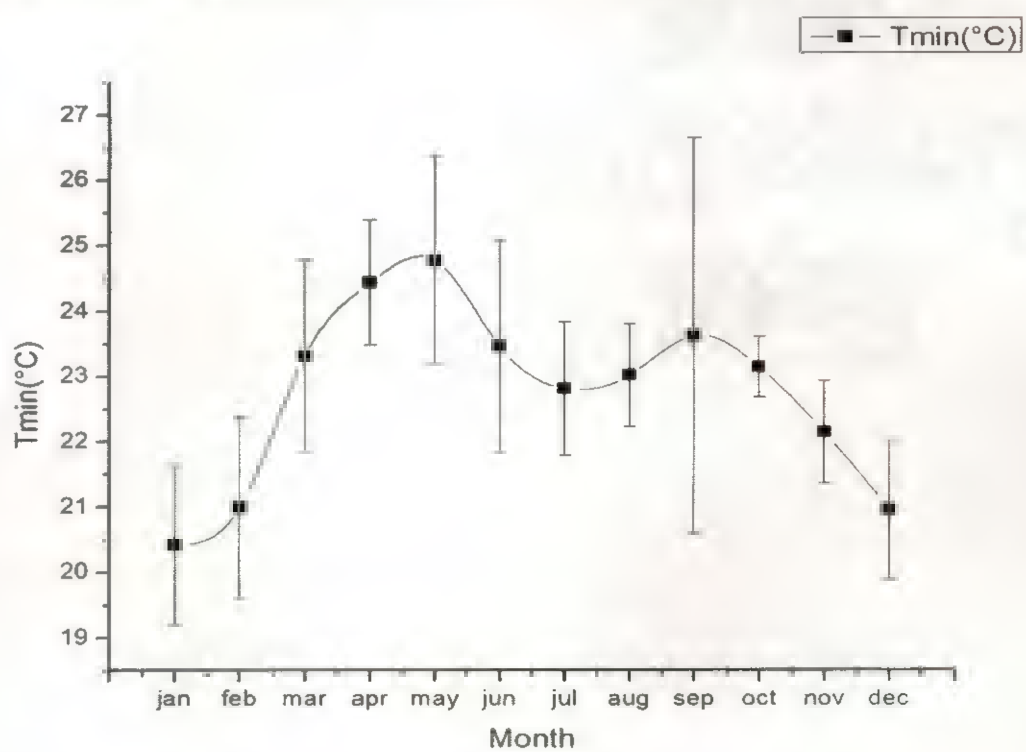

Fig. 2. Monthly minimum temperature (°C) of Pattambi (1983-2012)

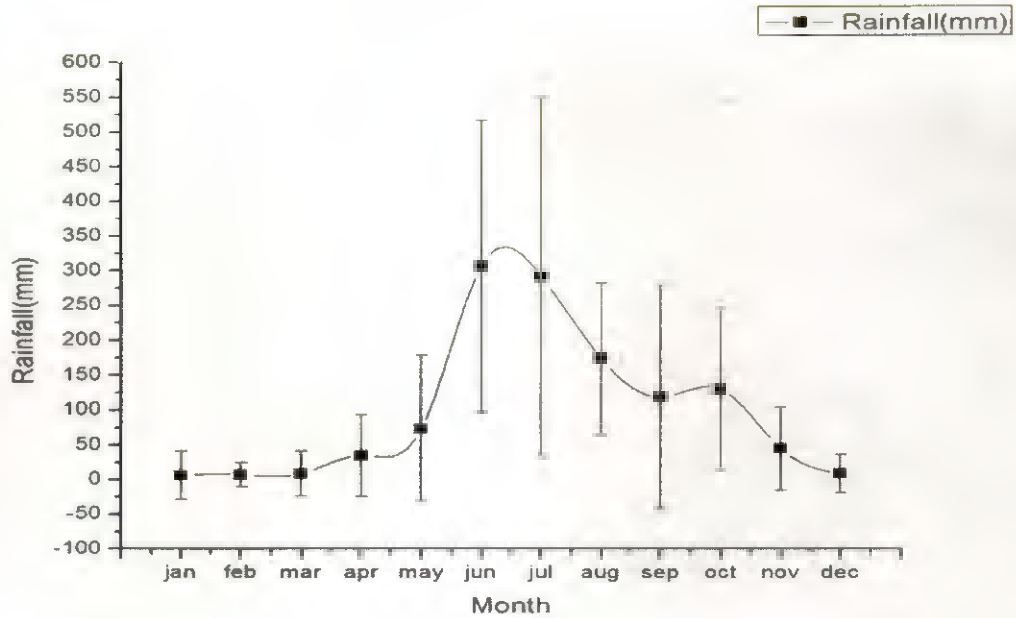

Fig. 3. Monthly rainfall (mm) of Pattambi (1983-2012)

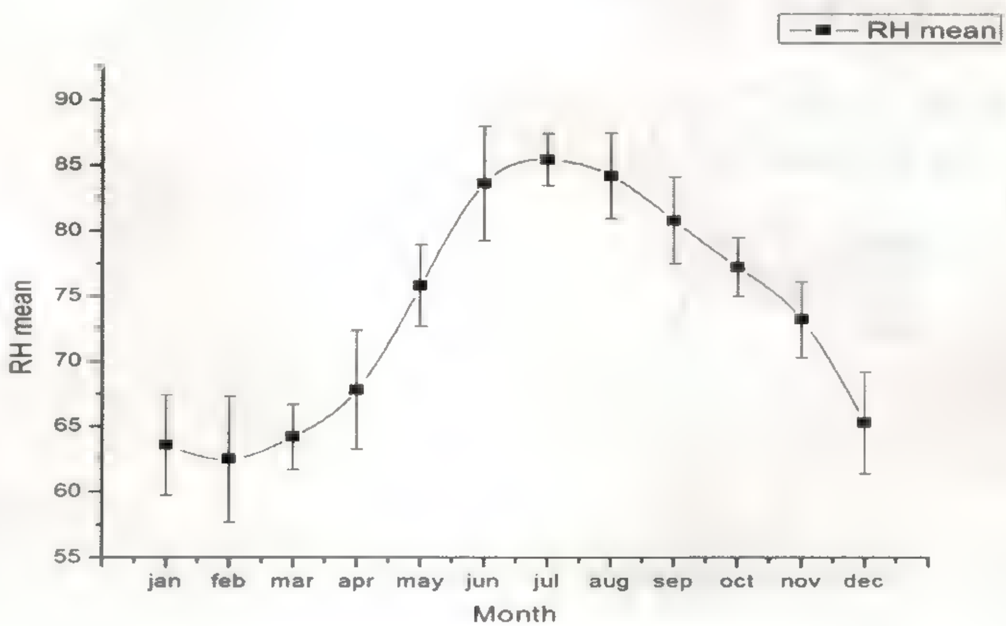

Fig.4. Monthly mean Relative humidity (%) of Pattambi (1983-2012)

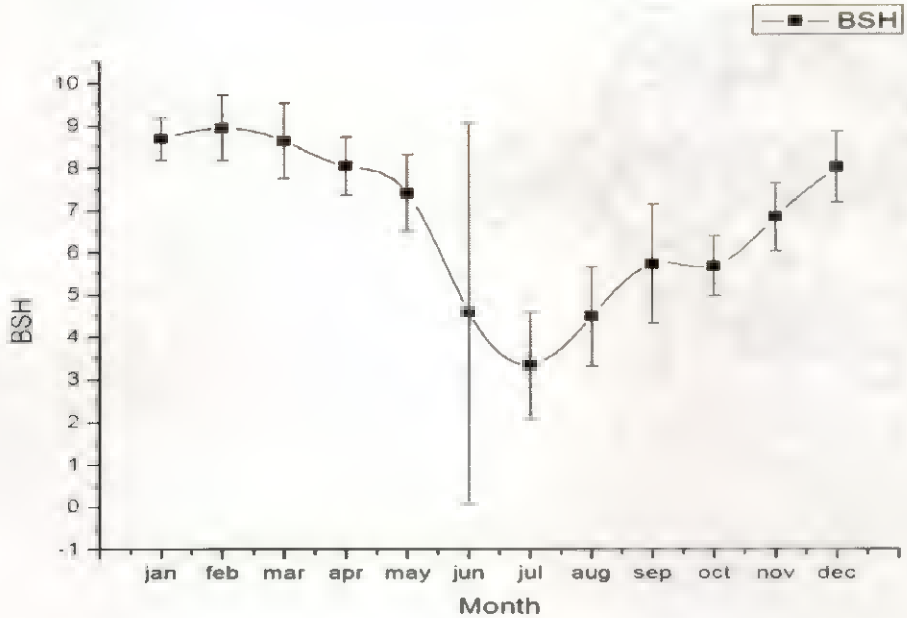

Fig.5. Monthly mean bright sunshine hours of Pattambi (1983-2012)

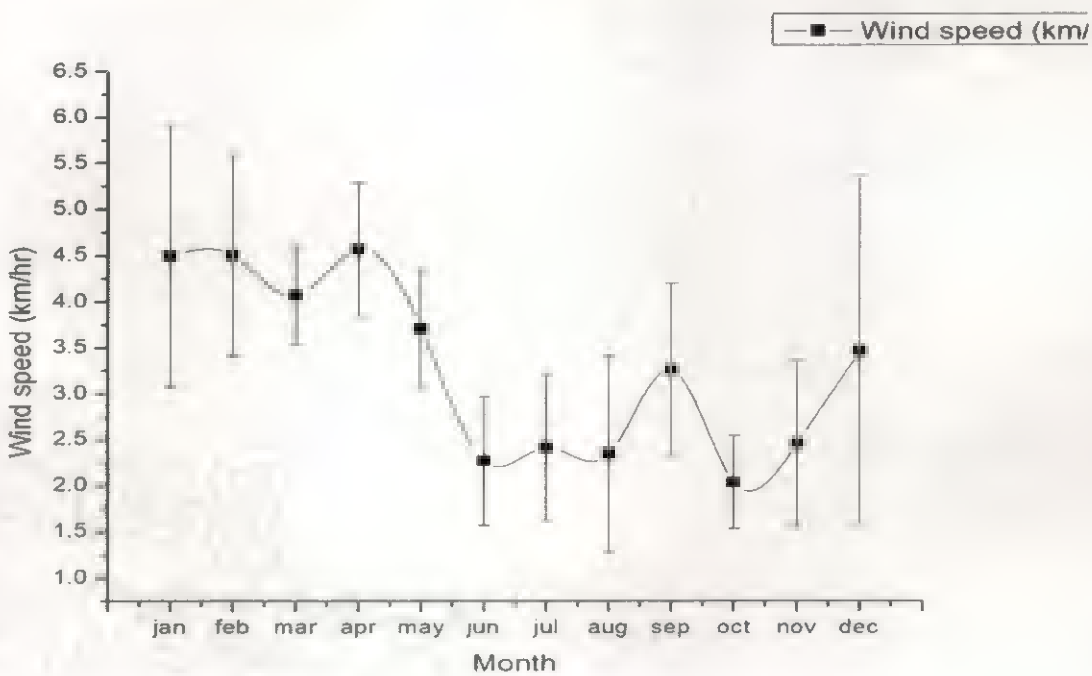

Fig.6. Monthly mean wind speed (km hr^{-1}) of Pattambi (1983-2012)

3.1.5 Varieties

Two popular varieties of Kerala Jyothi and Kanchana were selected for this study. Jyothi and Kanchana are photoperiod insensitive varieties with the duration of 110-115 days and 105-110 days respectively.

3.2 METHODS

The experiment was laid out in Split plot design with three replications. The Main plot treatments were five dates of planting in low land and upland, sub plot treatments were two varieties i.e. Jyothi and Kanchana. The plot size was 10 $m^2$and the spacing adopted was 15 cm × 10 cm.

3.2.1 Cultural operations

3.2.1.1 *Nursery management*

In lowland condition, nurseries were raised prior to each date of transplanting. Twenty one day old seedlings were transplanted . Adequate plant protection measures were also taken. For upland nurseries were raised prior to each date of sowing

3.2.1.2 *Land preparation*

The experimental area was cleared off. The low land was ploughed well and the soil was brought to puddled condition.

Table2.Treatments

No.	Main plot Treatment	Sub plot Treatment
1	June 15	Jyothi
		Kanchana
2	June 26	Jyothi
		Kanchana
3	July 7	Jyothi
		Kanchana
4	July 16	Jyothi
		Kanchana
5	July 26	Jyothi
		Kanchana

3.3 OBSERVATIONS

Observations on growth and yield parameters were recorded on randomly selected plants in each replication for each treatment after leaving the three border rows. Growth observations were taken at weekly intervals. Percentage severity of sheath blight was recorded at five intervals.

3.3.1 Biometric characters

3.3.1.1 *Height of the plant*

The plant height in cm was recorded weekly after transplanting.

3.3.1.2 *Leaf area index (LAI)*

Leaf area index was measured by using Digital Plant Canopy Imager CI-110 at weekly intervals.

3.3.1.4 *Number of panicles per unit area*

Number of panicles per unit area was recorded.

3.3.1.5 *Number of spikelets per panicle*

Number of spikelets per panicles was recorded.

3.3.1.6 *Number of filled grains per panicle*

The number of filled grains per panicle was recorded at harvest.

3.3.1.7 *1000 grain weight*

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

3.3.1.8 *Grain yield*

The grain harvested was dried, weighed and expressed in t ha^{-1}.

3.4 WEATHER OBSERVATIONS

The data on the different weather elements were collected using automatic weather stations installed in the experimental field.

Table 3.Weather parameters used in the experiment

No.	Weather parameter	Unit
1	Maximum temperature (Tmax)	°C
2	Minimum temperature (Tmin)	°C
3	Rainfall (RF)	mm
4	Relative humidity (RH	Per cent (%)
5	Solar radiation	Watts/m-2

3.5. SOIL DATA

The result of soil analysis of experimental site was presented in table.

Table 4. Soil analysis of the experimental site

No	Parameter	Availability
1	Organic carbon (Per cent)	1.00
2	Available Phosphorous (kg ha^{-1})	16.50
3	Exchangeable Potassium (kg ha^{-1})	117.60
4	Available Nitrogen(Per cent)	2.50

3.6. STATISTICAL ANALYSIS

Using Analysis of variance technique, the data recorded from the field experiment was analyzed statistically. Split plot design was used in the analysis of weather and crop data.

Correlation and regression analysis were done between the growth and yield characters with the weekly mean/total values of maximum temperature, minimum temperature, relative humidity, rainfall and sunshine hours to determine the effect of weather elements on the growth and yield of rice. Regression equations were worked out from these observations.

The different statistical software like Microsoft – excel and SPSS were used in the study for various statistical analyses.

3.7. MODELING SHEATH BLIGHT INCIDENCE

The EPIRICE model developed by Savary *et al.* (2012) was used to evaluate the potential importance of plant diseases in rice and their intensity and distribution at a global scale. Three steps were consisted in this part: EPIRICE parameterization and calibration, EPIRICE validation, and application of EPIRICE to climate change scenarios. Because EPIRICE was originally developed to be used regionally or globally to estimate potential epidemics, parameterization, calibration, and validation were needed before applying it directly to the field scale.

3.7.1. Parameterization of the EPIRICE model

The original EPIRICE model translated to the R language (v 2.11.1; http://www.r-project.org) was available on R-Forge:https://r-forge.r-project.org/projects/cropsim/. The model consists of two main modules: a susceptible-exposed-infectious-removed (SEIR) infection module and a host site growth and senescence module. The SEIR model has been widely used to model epidemics of infectious diseases of plants, as well as of animals and humans. A central element of this model is the rate of infection (RI), which is written as:

$$RI = dL/dt = RcICa,$$

where the rate of change in infected-latent sites L with time t (dL/dt) is proportional to (i) the number of infectious sites I, (ii) a power function of the proportion C of sites that are healthy relative to the total number of sites in the system, and (iii)Rc, the basic infection rate corrected for removals (Van Der Plank,1963). The value of the exponential parameter 'a' is ≥1 depending on the level of disease aggregation. Growth and senescence of the host population was added to the model structure in a very simple logistic manner to describe the increase or decrease in the number of healthy sites over time. To describe the effects of host aging and weather variables on the host-pathogen interaction, three modifiers, A, T, and W, that reflect the effects of plant age, temperature, and leaf wetness, respectively, were incorporated into the model as

$$Rc = RcOpt \times A \times T \times W,$$

Where RcOpt refers to a reference potential value of the basic infection rate corrected for removals. For more details, refer to Savary *et al.* (2012).Model parameters for sheath blight diseases were developed from the field experiences.

The source code of EPIRICE is as follows:

```
#################################################################
      EPIRICE Run Created by Kwang-Hyung Kim (15 Jan. 2015)
#################################################################

#REQUIRED PACKAGES
library(cropsim)

# RUN EPIRICE FOR SHEATH BLIGHT AND LEAF BLAST
# Weather data and rice transplanting date are to be provide
seperated following the original EPIRICE coding format (Savary et
al. 2012)
# wth = weather data (same as the original EPIRICE wth format);
tpd = rice transplaning date (yyyy-mm-dd, provided seperately)

AUDPC_SB = Cal.SB.audpc(wth, tpd)
AUDPC_LB = Cal.LB.audpc(wth, tpd)

#################################################################
### Modified FUNCTIONS ###
#################################################################
# EPIRICE SEIR.SB Function -> derived from SEIR function from
original EPIRICE
#################################################################
SEIR.SB <- function (wth, tpd, onset, duration = 100, rhlim = 95,
rainlim = 5, wetness,
initSites, initInfection = 1, ageRc, baseRc, tmpRc, rhRc,
latrans,
inftrans, siteMax, AGGR, RRPhysiolSenesc, RRG, SenescType = 1) {

tpd<- as.Date(tpd)
wth@w<- subset(wth@w, wth@w$date>= tpd - 1)

if (dim(wth@w)[1] < duration) {
stop("Incomplete weather data")
  }
wth@w<- wth@w[1:(duration + 1), ]
if (wetness == 1) {
    W <- leafWet(wth, simple = TRUE)
  }
  COFR <- Rc<- RHCoef<- latency <- infectious <- Severity <-
RSenesced<- RGrowth<- Rtransfer<- Rinfection<- Diseased <-
```

```
Senesced <- Removed <- now_infectious<- now_latent<- Sites <-
TotalSites<- rep(0,
times = duration + 1)
for (day in 0:duration) {
if (day == 0) {
Sites[day + 1] <- initSites
RSenesced[day + 1] <- RRPhysiolSenesc * Sites[day + 1]
    } else {
if (day >inftrans) {
removedToday<- infectious[infday + 2]
      } else {
removedToday<- 0
      }
Sites[day + 1] <- Sites[day] + RGrowth[day] - Rinfection[day] -
RSenesced[day]
RSenesced[day + 1] <- removedToday * SenescType +
RRPhysiolSenesc * Sites[day + 1]
Senesced[day + 1] <- Senesced[day] + RSenesced[day]
latency[day + 1] <- Rinfection[day]
latday<- day - latrans + 1
latday<- max(0, latday)
now_latent[day + 1] <- sum(latency[latday:day + 1])
infectious[day + 1] <- Rtransfer[day]
infday<- day - inftrans + 1
infday<- max(0, infday)
now_infectious[day + 1] <- sum(infectious[infday:day + 1])
    }
if (Sites[day + 1] < 0) {
Sites[day + 1] <- 0
break
    }
if (wetness == 0) {
if (wth@w$rhmax[day + 1] >= rhlim | wth@w$prcp[day + 1] >=
rainlim) {
RHCoef[day + 1] <- 1
      } else {
        W <- leafWet(wth, simple = TRUE)
RHCoef[day + 1] <- AFGen(rhRc, W[day + 1])
      }
    }
Rc[day + 1] <- baseRc * AFGen(ageRc, day) * AFGen(tmpRc,
wth@w$tavg[day + 1]) * RHCoef[day + 1]
Diseased[day + 1] <- sum(infectious) + now_latent[day + 1]+
Removed[day + 1]
Removed[day + 1] <- sum(infectious) - now_infectious[day + 1]
COFR[day + 1] <- 1 - (Diseased[day + 1]/(Sites[day + 1] +
Diseased[day + 1]))
if (day == onset) {
Rinfection[day + 1] <- initInfection
    } else if (day > onset) {
Rinfection[day + 1] <- now_infectious[day + 1] * Rc[day + 1] *
(COFR[day + 1]^AGGR)
```

```
    } else {
Rinfection[day + 1] <- 0
    }
if (day >= latrans) {
Rtransfer[day + 1] <- latency[latday + 1]
    } else {
Rtransfer[day + 1] <- 0
    }
TotalSites[day + 1] <- Diseased[day + 1] + Sites[day + 1]
RGrowth[day + 1] <- AFGen(RRG, day) * Sites[day + 1] * (1 -
(TotalSites[day + 1]/siteMax))
Severity[day + 1] <- (Diseased[day + 1] - Removed[day +
1])/(TotalSites[day + 1] - Removed[day + 1]) * 100
  }
res<- cbind(0:duration, TotalSites, Sites, now_latent,
now_infectious,
               Removed, Senesced, Rinfection, Rtransfer, RGrowth,
RSenesced,
               Diseased, Severity)
  res <- as.data.frame(res[1:(day + 1), ])
dates<- seq(tpd - 1, tpd + duration, 1)
  res <- cbind(dates[1:(day + 1)], res)
colnames(res) <- c("date", "simday", "tsites", "sites", "latent",
"infectious",
                     "removed", "senesced", "rateinf",
"rtransfer", "rgrowth",
                     "rsenesced", "diseased", "severity")
result<- new("SEIR")
result@d<- res
return(result)
}

######################################################################
# EPIRICE-SB Function -> derived from sheathBlight function from
original EPIRICE
######################################################################

sheathBlight.EPIRICE<- function (wth, tpd, ...) {
AgeCoefRc<- cbind(0:12 * 10, c(0.43, 0.5, 0.73, 0.81, 0.94,
                                  1, 1, 1, 1, 0.01, 0.8, 0.7,
0.5))
RHCoefRc<- cbind(c(0:10), c(0, 0.24, 0.41, 0.68, 0.94,
                               0.97, 1,1,1,1,1))
TempCoefRc<- cbind(4:13 * 3, c(0, 0.1, 0.8, 1, 1, 1, 0.2,
                                  0.01, 0.01, 0))
RRPhysiolGrowth<- cbind(0:12 * 10, c(0.15, 0.21, 0.11, 0.0001,
0.0001, 0.001,
                                        0.005,
0.005,0.005,0.005,0.005,0.005,0.005))
return(SEIR.SB(wth = wth, tpd = tpd, onset = 30, ageRc =
AgeCoefRc,
tmpRc = TempCoefRc, rhRc = RHCoefRc, baseRc = 0.58, latrans = 4,
```

```
inftrans = 65, siteMax = 800, AGGR = 2.8, initSites = 90,
RRPhysiolSenesc = 0.005, RRG = RRPhysiolGrowth, wetness = 0))
}

###################################################################
# EPIRICE-SB audpc calculation Function
###################################################################
Cal.SB.audpc<- function(wth, tpd) {

shblight<- sheathBlight.EPIRICE(wth, tpd)

if(class(shblight) != "try-error"){
shblgtout<- sum(shblight@d$severity[1:100])
  } else {
shblgtout<- -999
  }
names(shblgtout) <- "SB_audpc"
return(shblgtout)
}
```

3.8CLIMATE CHANGE SCENARIOS

Impacts of climate change will depend not only on the response of the Earth system but also on how humankind responds. These responses are uncertain, so future scenarios are used to explore the consequences of different options. The scenarios provide a range of options for the world's governments and other institutions for decision making. Policy decisions based on risk and values will help determine the pathway to be followed.

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) has introduced a new way of developing scenarios. These scenarios span the range of plausible radiative forcing scenarios, and are called representative concentration pathways (RCPs).

RCPs are concentration pathways used in the IPCC Assessment Report5 (AR5). They are prescribed pathways for greenhouse gas and aerosol concentrations, together with land use change, that are consistent with a set of broad climate outcomes used by the climate modeling community. The pathways are characterized by the radiative forcing produced by the end of the 21st century. Radiative forcing is the extra heat the lower atmosphere will retain as a result of additional greenhouse gases, measured in Watts per square meter.

Climate change data projected by GCM's on daily basis is used for the present study. Daily data of following variables has taken

1. Rainfall
2. Maximum Temperature
3. Minimum Temperature
4. Solar radiation

The regional climate scenarios including radiation, Maximum temperature (T_{max}), Minimum temperature (T_{min}) and precipitation as inputs of the CERES-Rice model to simulate the impacts of climate change on rice yields in Kerala.

Table 5. Description of representative concentration pathway (RCP) scenarios (Moss, 2010)

RCP	Description
RCP2.6	Its radiative forcing level first reaches a value around 3.1 Wm^{-2} mid-century, returning to 2.6 Wm^{-2} by 2100. Under this scenario greenhouse gas (GHG) emissions and emissions of air pollutants are reduced substantially over time.
RCP4.5	It is a stabilization scenario where total radiative forcing is stabilized before 2100 by employing a range of technologies and strategies for reducing GHG emissions.
RCP6.0	It is a stabilization scenario where total radiative forcing is stabilized after 2100 without overshoot by employing a range of technologies and strategies for reducing GHG emissions.
RCP8.5	It is characterized by increasing GHG emissions over time representative of scenarios in the literature leading to high GHG concentration levels.

3.9 GENERAL CIRCULATION MODELS (GCM's) USED

The Ensembled mean data of seventeen models has been used for the years 2030, 2050 and 2080.

Table 6. General Circulation Models used for the study

S.No	Model	Institution
1	BCC-CSM 1.1	Beijing Climate Center, China Meteorological Administration
2	BCC-CSM 1.1(m)	Beijing Climate Center, China Meteorological Administration
3	CSIRO-Mk3.6.0	Commonwealth Scientific and Industrial Research Organisation and the Queensland Climate Change Centre of Excellence
4	FIO-ESM	The First Institute of Oceanography, SOA, China
5	GFDL-CM3	Geophysical Fluid Dynamics Laboratory
6	GFDL-ESM2G	Geophysical Fluid Dynamics Laboratory
7	GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory
8	GISS-E2-H	NASA Goddard Institute for Space Studies
9	GISS-E2-R	NASA Goddard Institute for Space Studies
10	HadGEM2-ES	Met Office Hadley Centre
11	IPSL-CM5A-LR	Institut Pierre-Simon Laplace
12	IPSL-CM5A-MR	Institut Pierre-Simon Laplace
13	MIROC-ESM	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
14	MIROC-ESM-CHEM	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
15	MIROC5	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
16	MRI-CGCM3	Meteorological Research Institute
17	NorESM1-M	Norwegian Climate Centre

The results of the experiment entitled "Effect of weather on sheath blight incidence in rice and predicting potential epidemics under various climate change scenarios" are presented in this chapter. The effect of different weather parameters on sheath blight incidence of two important varieties i.e. Jyothi and Kanchana were studied.

4.1. WEATHER DURING THE STUDY PERIOD

The daily weather parameters viz., maximum solar radiation, average solar radiation, maximum temperature, minimum temperature, average temperature, maximum relative humidity, minimum relative humidity, average relative humidity, maximum soil temperature, minimum soil temperature, average soil temperature, maximum soil moisture, minimum soil moisture , average soil moisture and rainfall were recorded using automatic weather station installed in Regional Agricultural Research Station, Pattambi .

Maximum solar radiation in which maximum value recorded was 782W/$m^2$and minimum value recorded was 170W/m^2. The height daily average solar radiation was 460.6W/m^2 and minimum was 84.5W/m^2. The maximum temperature, the highest value recorded was 35.1°C and lowest value recorded was 23.1°C. Minimum temperature, lowest value 15.0°C and highest value 26.6°C. The maximum relative humidity in which maximum value recorded was 100% and minimum value recorded was 52%. Minimum relative humidity, maximum value recorded was 81% and minimum value recorded was 54%. The average relative humidity, maximum value recorded was 87.1% and minimum value recorded was 34.1%. The maximum soil temperature in which maximum value recorded was 41.5°C and minimum value recorded was 31°C. The minimum soil temperature, maximum value recorded was29.5°C and minimum value recorded was 28.7°C. The average soil temperature, maximum value recorded was 35.2°C and minimum value recorded was 22.5°C.Themaximum soil moisture in which maximum value recorded was 43% and minimum value recorded was 22.6%.The minimum soil moisture, maximum value recorded was 39.9% and minimum value recorded was 14.6%. The average soil moisture, maximum value recorded was 40.2% and minimum value recorded was

20.1%. Maximum rainfall was recorded 40.2mm (Figures7, 8, 9, 10, 11, 12, 13, 14, 15 and 16)

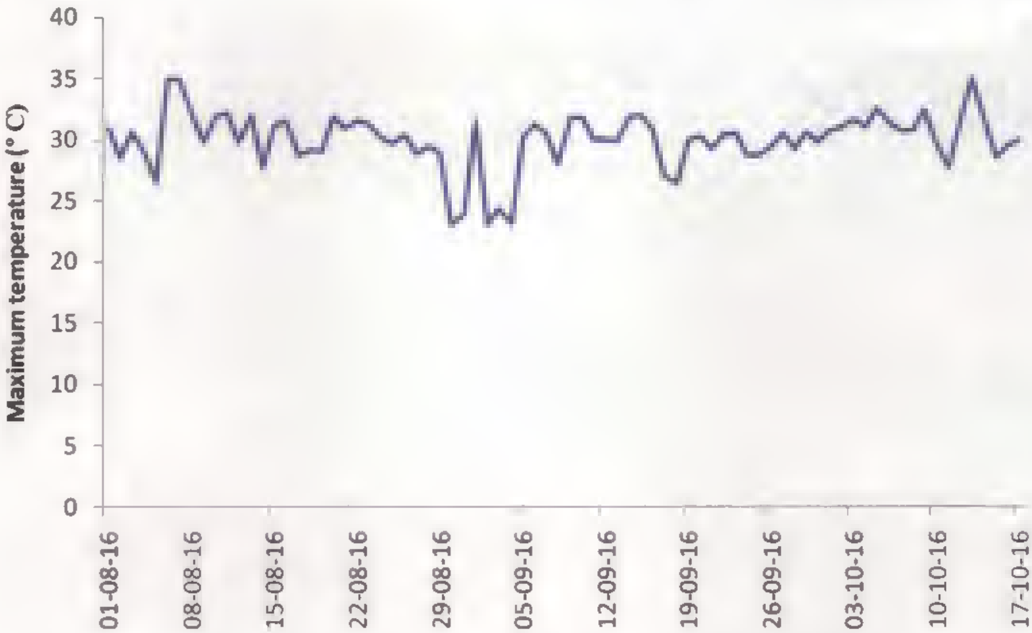

Fig 7. Daily maximum temperature after inoculation

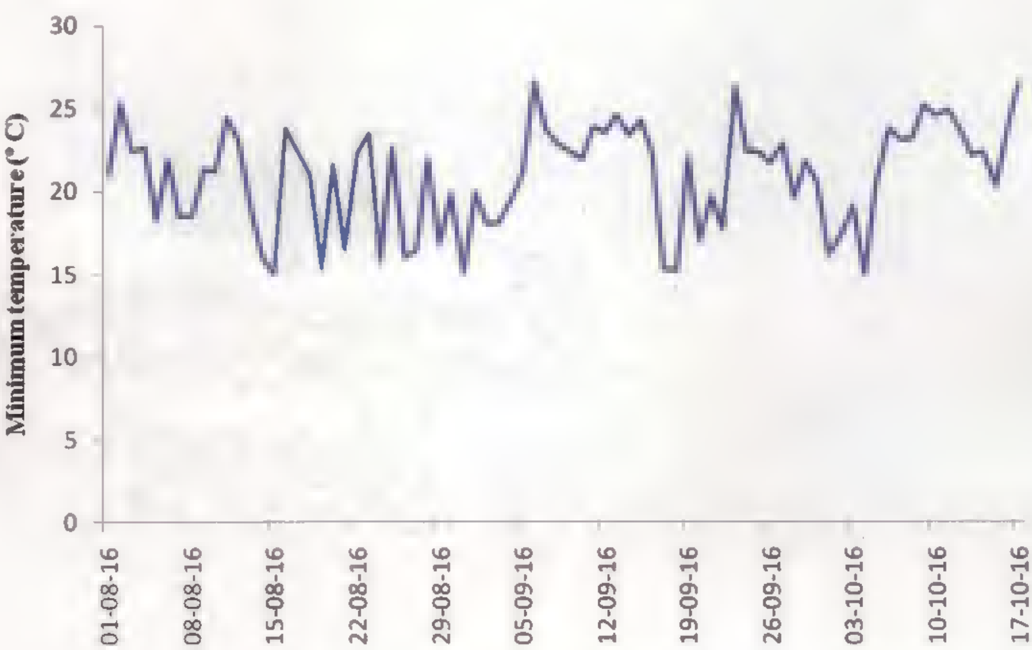

Fig 8. Daily minimum temperature after inoculation

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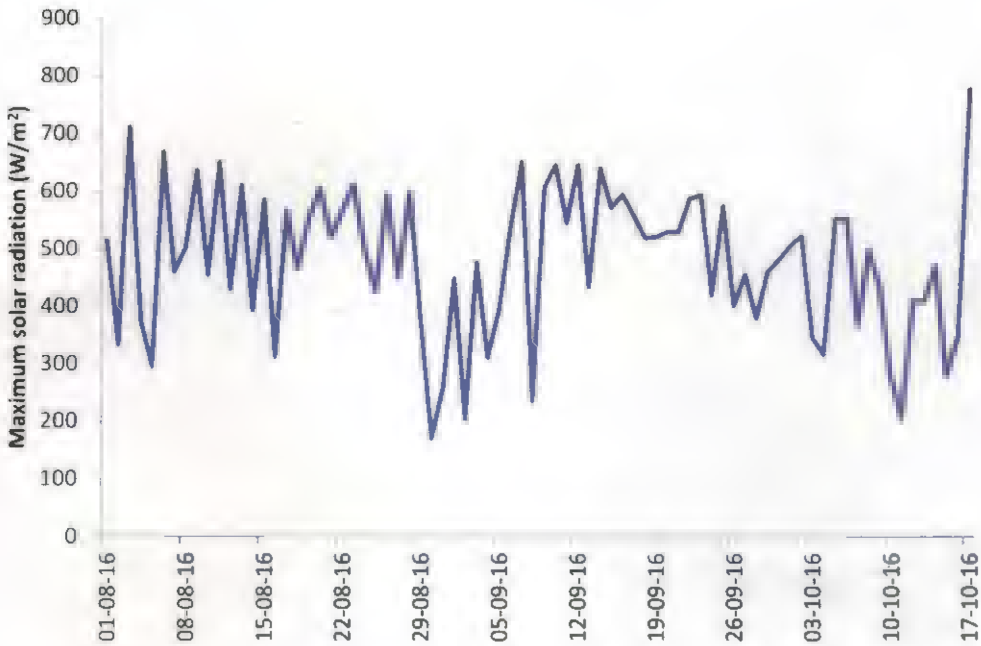

Fig 9. Daily maximum solar radiation after inoculation

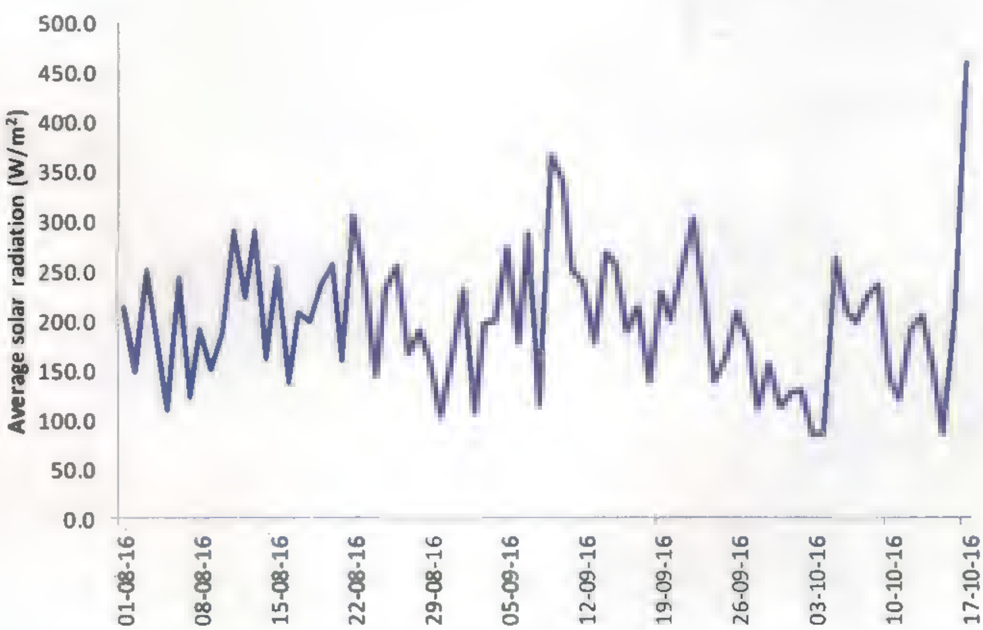

Fig 10. Daily average solar radiation after inoculation

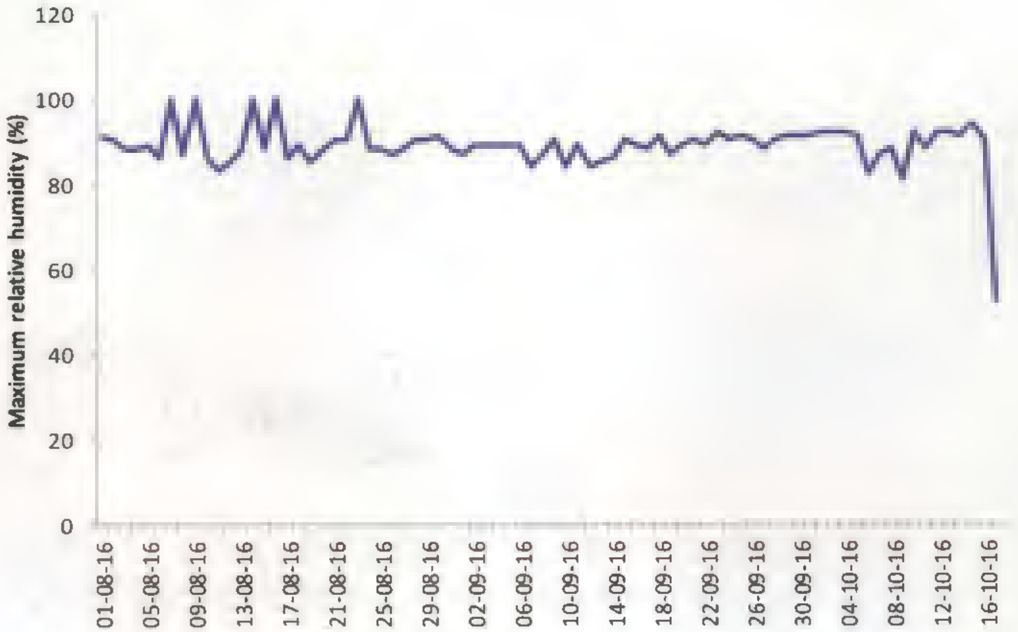

Fig 11. Daily maximum relative humidity after inoculation

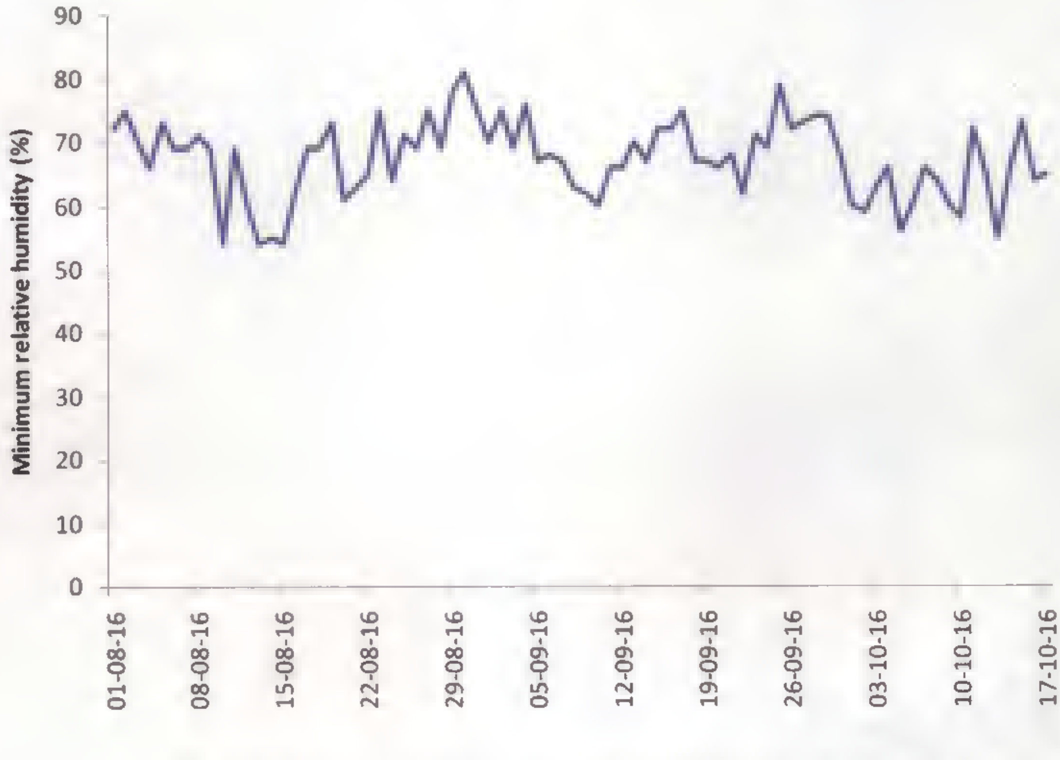

Fig 12. Daily minimum relative humidity after inoculation

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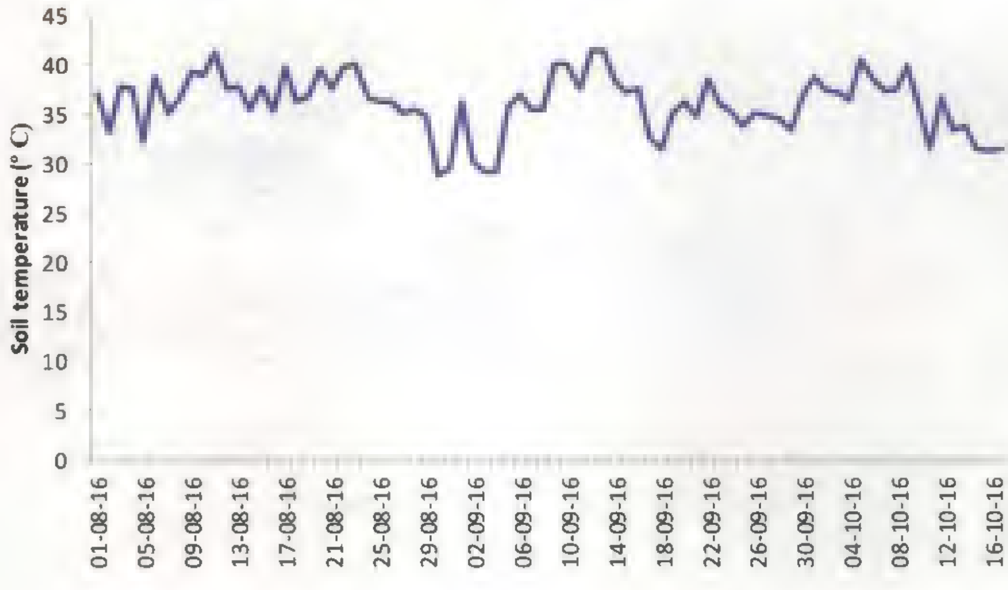

Fig 13. Daily maximum soil temperature after inoculation

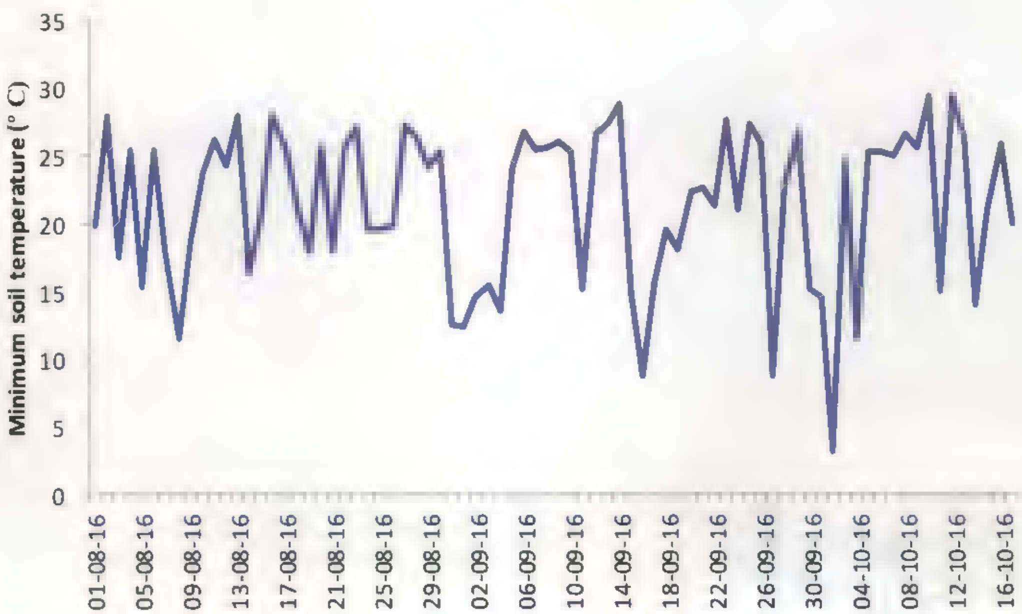

Fig 14. Daily minimum soil temperature after inoculation

47

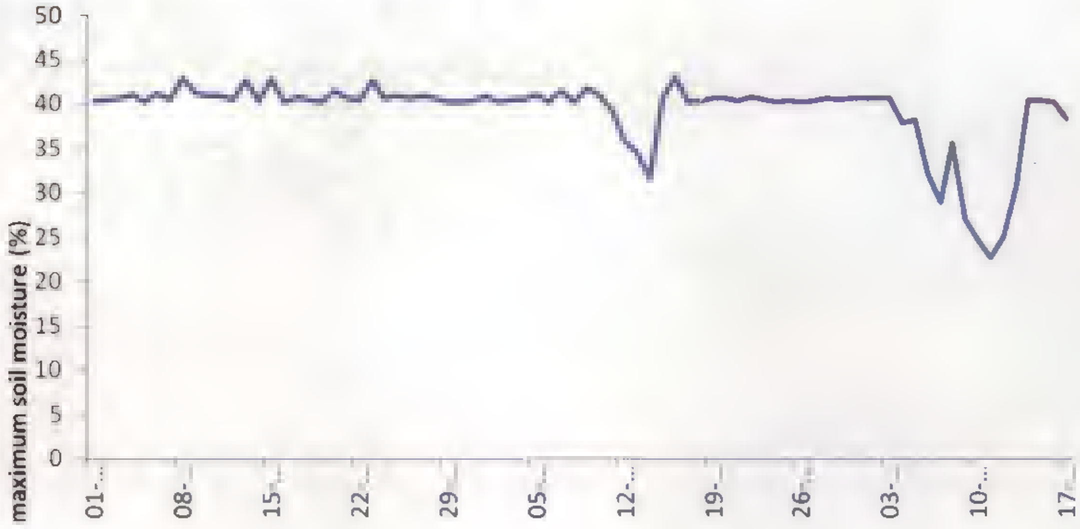

Fig 15. Daily maximum soil moisture after inoculation

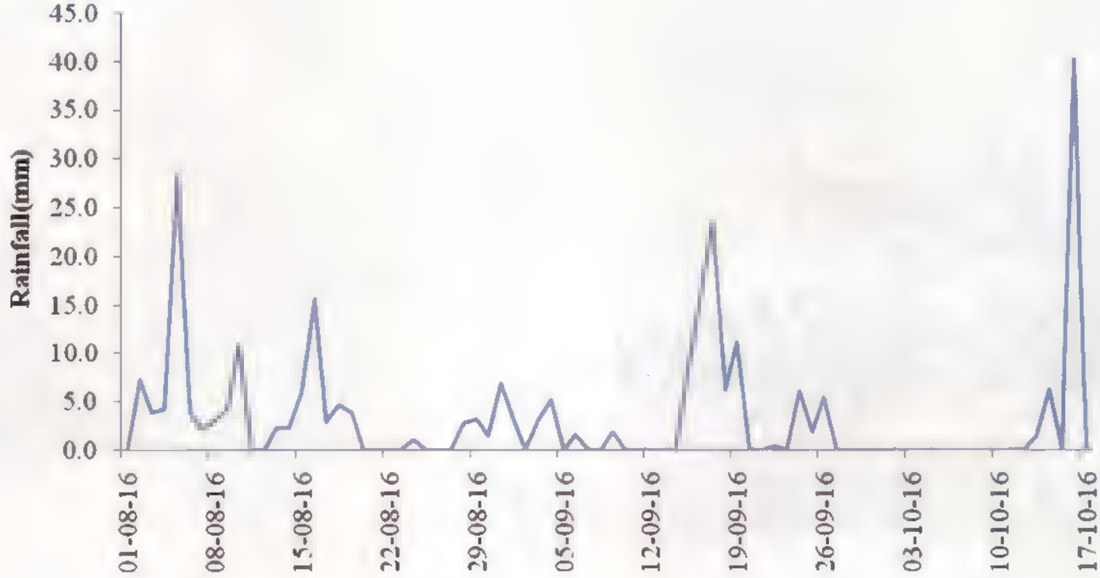

Fig.16. Daily rainfall after inoculation

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4.2 IMPACT OF WEATHER ON SHEATH BLIGHT INCIDENCE

4.2.1 Sheath blight incidence in Jyothi

The effect of dates of planting and varieties on initial sheath blight incidence and its development was studied and is presented in table 7. It can be clearly observed from the table that the crops transplanted June showed a higher disease incidence compared to other dates of planting. It was also noticed that variety Jyothi is more susceptible to sheath blight incidence compared to Kanchana. The crops planted on June 15th recorded the highest disease incidence of 45.77% in Jyothi and 34.43% in Kanchana. The least disease incidence was observed (32.33% for Jyothi and 23.37% for Kanchana) in crops planted on July 26th. The disease development also followed the same trend and is mainly influenced by the initial severity of incidence. Irrespective of varieties the maximum disease severity was observed 4 weeks after the disease incidence. The maximum severity recorded for Jyothi and Kanchana was 78.43% and 54.17% respectively. Moreover the progression of sheath blight incidence follows a linear trend.

Table 7. Sheath blight incidence in Jyothi and Kanchana

DOP	Incidence	Disease development			
		1 Week	2 Week	3 Week	4 Week
		Jyothi			
June 15	45.77	54.47	62.53	71.10	78.43
June 26	36.60	48.83	60.17	69.27	78.17
July 7	40.90	49.43	60.00	68.93	80.93
July 16	34.03	37.17	40.83	48.73	56.00
July 26	32.33	35.37	38.57	44.80	50.67
		Kanchana			
June 15	34.43	38.70	43.03	48.40	54.17
June 26	28.73	34.63	41.07	44.27	47.83
July 7	23.80	31.97	39.23	47.60	52.67
July 16	23.87	27.13	30.40	36.23	42.93
July 26	23.37	25.73	28.50	34.37	40.60

Simple linear correlations between sheath blight incidence daily weather parameters like air temperature, relative humidity, solar radiation, Rainfall, soil temperature and soil moisture were carried out.

Table 8 showed that the correlation between the daily weather parameters and disease incidence percentage in variety Jyothi. The disease incidence was observed 11 days after inoculation. From the table it can be seen that minimum air temperature, average solar radiation, maximum soil temperature and average soil moisture were negatively correlated with sheath blight incidence on Jyothi whereas maximum relative humidity, average relative humidity, rain fall and maximum soil moisture were positively correlated with sheath blight incidence. It is interesting to notice that weather parameters on the day of inoculation are having more profound influence on disease incidence. Except relative humidity all other weather parameters showed a significant negative correlation with disease incidence. It can be also noticed that the disease incidence in the consecutive days after the day of inoculation is mainly influenced by air temperature and soil moisture.

Table 8.Correlation of weather on Sheath blight incidence on Jyothi

Weather	Day1	Day2	Day3	Day4	Day5	Day6	Day7	Day8	Day9	Day10	Day11
MAXT	-0.65*	0.11	-0.18	-0.38	0.43	0.38	0.32	0.34	0.53*	0.34	-0.26
MINAT	-0.61*	-0.43	-0.63*	-0.64	-0.50*	-0.54*	-0.38	-0.55*	-0.33	-0.52*	-0.68*
AVGT	-0.41	-0.01	-0.65*	-0.11	-0.55*	-0.37	-0.69*	-0.06	0.61*	0.75*	0.53*
MAXSR	-0.63*	0.39	-0.40	-0.33	0.22	-0.36	-0.15	0.02	0.15	0.23	-0.15
AVGSR	-0.65*	-0.25	-0.74*	-0.03	-0.62*	-0.41	0.21	-0.35	-0.13	0.48*	0.53*
MAXRH	0.67*	-0.28	0.68*	0.59	0.29	0.66*	-0.28	0.46	-0.31	-0.34	-0.37
MINRH	0.57*	-0.42	0.15	-0.22	-0.26	0.20	0.23	0.21	-0.35	0.38	-0.45
AVGRH	0.51*	0.09	0.65*	0.52	-0.59*	0.08	0.18	-0.02	-0.19	-0.50*	-0.27
MAXST	-0.62*	-0.23	-0.55*	-0.59	0.44	-0.14	-0.15	0.53*	0.64*	0.32	0.29
MINST	0.26	0.34	-0.08	-0.67	-0.40	0.10	0.24	0.40	0.03	0.59*	0.53*
AVRST	-0.42	0.04	-0.02	-0.63	-0.36	0.07	0.38	0.43	0.45*	0.48*	0.60*
MAXSM	-0.35	0.36	0.57*	0.52	0.57*	-0.03	0.03	0.00	0.58*	0.66*	-0.25
AVGSM	-0.37	0.56*	0.50*	0.54*	0.32	-0.74*	-0.57*	-0.71*	-0.51*	-0.30	-0.35
RF	0.56*	0.57*	0.60*	0.53*	0.53*	-0.37	-0.48*	-0.42	0.63*	-0.50*	0.06

4.2.2 Sheath blight incidence in Kanchana

Table 9 showed that the correlation between the daily weather parameters and disease incidence in percentage in variety Kanchana.

Table 9. Correlation of weather on Sheath blight incidence on Kanchana

Weather	Day1	Day2	Day3	Day4	Day5	Day6	Day7	Day8	Day9	Day10	Day11
MAXT	-0.66*	0.69*	-0.70*	-0.79*	0.78*	0.83*	0.61*	0.18	0.51*	0.80*	0.07
MINAT	-0.67*	-0.12	-0.47*	-0.48*	-0.49*	-0.43	-0.18	-0.38	-0.26	-0.32	-0.54*
AVGT	0.05	0.41	-0.44	-0.56*	-0.61*	-0.78*	-0.25	-0.21	0.15	0.70*	0.67*
MAXSR	-0.74*	0.77*	-0.71*	-0.72*	0.54*	-0.82*	0.01	0.59*	-0.10	0.74*	-0.65*
AVGSR	-0.59*	0.39	-0.55*	-0.62*	-0.33	-0.82*	0.53*	-0.80*	0.12	0.75*	0.81*
MAXRH	0.63*	-0.32	0.54*	0.47*	-0.22	0.63*	-0.36	0.84*	-0.38	-0.80*	-0.83*
MINRH	0.65*	-0.84*	0.47*	0.37	-0.57*	0.10	0.36	0.28	-0.79*	-0.18	-0.84*
AVGRH	0.41	-0.52*	0.81*	0.81*	-0.84*	0.49*	-0.14	0.59*	-0.70*	-0.62*	-0.77*
MAXST	-0.74*	0.00	-0.70*	-0.80*	0.15	-0.71*	0.04	0.64*	0.71*	0.69*	0.80*
MINST	0.56*	0.10	0.02	-0.68*	-0.24	-0.40	-0.33	0.13	0.18	0.36	0.25
AVRST	-0.21	0.52*	-0.52*	-0.64*	0.06	-0.50*	0.54*	0.13	0.31	0.67*	0.28
MAXSM	-0.40	0.32	0.35	0.31	0.44	-0.56*	0.53*	-0.06	0.74*	0.50*	-0.57*
AVGSM	0.03	-0.68*	0.50*	-0.57*	-0.25	-0.15	-0.55*	-0.67*	-0.58*	-0.61*	-0.76*
RF	0.73*	0.34	0.07	0.84*	0.84*	-0.24	-0.28	-0.32	0.28	-0.48*	-0.51*

From the table it can be seen that Minimum air temperature, average air temperature, average soil temperature, minimum soil moisture was negatively correlated with sheath blight incidence. Average solar radiation and maximum soil temperature were initially negatively correlated and then showed positive correlation. Maximum temperature, maximum relative humidity, minimum relative humidity, average relative humidity, rain fall and maximum soil moisture were positively correlated with sheath blight incidence in Kanchana. In case of variety Kanchana also weather parameters on the day of inoculation are having more profound influence on disease incidence. All the weather parameters except relative humidity had a significant negative correlation with disease incidence.

4.3 IMPACT OF WEATHER ON SHEATH BLIGHT DEVELOPMENT

4.3.1 Sheath blight progression in Jyothi

Table 10 showed that the correlation between weather parameter and sheath blight development 7 days after incidence. Average temperature, maximum solar radiation, average solar radiation, maximum soil temperature, minimum soil temperature, average soil temperature, rainfall and maximum soil moisture were positively correlated disease incidence. Maximum relative humidity and minimum relative humidity were negatively correlated with disease incidence.

Table 10. Correlation of weather on Sheath blight progression in Jyothi one week after incidence

Weather	Day 1	Day 2	Day3	Day4	Day5	Day6	Day7
MAXT	0.31	0.39	0.61*	0.26	0.46	-0.62*	0.26
MINAT	-0.46*	-0.22	-0.41	0.07	0.34	-0.11	0.33
AVGT	-0.14	-0.42	0.50*	0.53*	0.58*	-0.76*	0.44
MAXSR	0.34	0.49*	0.16	0.73*	0.72*	0.68*	0.41
AVGSR	0.39	0.53*	-0.02	0.14	0.46	0.25	0.65*
MAXRH	0.64*	-0.17	0.77*	-0.67*	-0.40	-0.75*	-0.65*
MINRH	-0.77*	-0.67*	-0.58*	0.47*	-0.76*	0.24	-0.33
AVGRH	0.09	-0.68*	0.57*	0.41	-0.41	-0.39	-0.22
MAXST	0.48*	0.61*	0.41	0.68*	0.59*	0.63*	0.40
MINST	-0.03	0.10	0.55*	0.73*	0.30	-0.77*	0.42
AVRST	-0.18	0.45	0.54*	0.63*	0.62*	-0.58*	0.57*
MAXSM	0.40	0.61*	0.15	0.77*	0.05	-0.54*	0.73*
AVGSM	0.05	-0.34	-0.46	0.66*	0.28	-0.43	0.54*
RF	-0.67*	0.40	0.54*	0.31	0.20	0.63*	-0.46

The impact of weather parameters on sheath blight development two weeks after incidence is presented in table 11. Maximum temperature and maximum soil temperature are negatively correlated with disease incidence. Minimum air temperature, minimum relative humidity, average relative humidity, maximum soil temperature, minimum soil temperature, average soil temperature, rainfall and maximum soil moisture were positively correlated with disease progression.

Table 11.Correlation of weather on Sheath blight progression in Jyothi two week after incidence

Weather	Day 1	Day 2	Day3	Day4	Day5	Day6
MAXT	0.48*	-0.40	-0.79*	-0.59*	-0.46	-0.40
MINAT	0.77*	0.51*	0.11	0.03	0.87*	-0.17
AVGT	0.69*	0.41	-0.02	-0.17	-0.39	-0.70*
MAXSR	0.56*	0.58*	-0.68*	-0.42	-0.04	-0.48*
AVGSR	0.69*	-0.10	-0.44	0.10	0.40	-0.36
MAXRH	0.02	0.51*	0.10	-0.38	-0.14	-0.13
MINRH	0.53*	0.82*	-0.39	0.78*	0.74*	0.66*
AVGRH	0.08	0.47*	-0.15	0.35	0.36	0.73*
MAXST	0.36	-0.28	-0.74*	-0.56*	-0.62*	-0.88*
MINST	0.63*	0.62*	0.44	0.21	-0.14	-0.39
AVRST	0.78*	0.50*	-0.21	-0.30	-0.29	-0.82*
MAXSM	0.46*	0.30	-0.46	0.47*	0.84*	0.79*
AVGSM	0.82*	-0.91*	0.25	0.91*	0.91*	0.88*
RF	-	0.09	0.72*	0.45	0.45	0.45

Table 12 showed that the correlation between weather parameter and sheath blight progression three weeks after incidence. Maximum temperature and average temperature were negatively correlated with disease incidence. Maximum relative humidity, minimum relative humidity, average relative humidity was positively correlated with disease incidence.

Table 12.Correlation of weather on Sheath blight progression in Jyothi three week after incidence

Weather	Day 1	Day 2	Day3	Day4	Day5	Day6	Day7
MAXT	-0.51*	-0.35	0.14	-0.32	-0.48*	-0.22	0.50*
MINAT	-0.17	0.07	0.23	0.18	-0.48*	-0.09	-0.04
AVGT	-0.48*	-0.36	-0.04	-0.29	-0.49*	-0.32	0.30
MAXSR	-0.43	-0.43	0.37	-0.18	-0.14	0.19	0.36
AVGSR	-0.45	-0.03	0.14	-0.18	-0.38	0.33	0.49*
MAXRH	-0.12	0.53*	0.04	-0.09	0.48*	-0.52*	-0.11
MINRH	0.54*	0.51*	0.46	-0.14	0.26	0.38	-0.36
AVGRH	0.52*	0.49*	0.08	0.06	0.43	0.38	-0.25
MAXST	-0.52*	-0.40	-0.02	-0.40	-0.45	-0.15	0.40
MINST	-0.08	-0.31	-0.26	-0.32	-0.31	-0.38	0.56*
AVRST	-0.50*	-0.23	-0.04	-0.33	-0.46	-0.32	0.45
MAXSM	0.24	0.53*	0.52*	0.52*	0.52*	0.53*	0.52*
AVGSM	0.54*	0.53*	0.53*	0.51*	0.52*	0.53*	0.51*
RF	0.04	0.04	0.02	-0.06	0.30	0.40	-0.06

Table 13 presented the correlation between sheath blight development weather parameter four weeks after incidence. Maximum temperature was negatively correlated with disease incidence. Maximum solar radiation, average solar radiation, rainfall and maximum soil temperature were positively correlated with disease incidence.

Table 13.Correlation of weather on Sheath blight progression in Jyothi four week after incidence

Weather	Day 1	Day 2	Day3	Day4	Day5	Day6	Day7
MAXT	0.30	-0.18	-0.15	0.21	0.50*	-0.54*	-0.47*
MINAT	-0.39	-0.09	-0.40	0.33	0.58*	-0.34	-0.28
AVGT	0.03	-0.23	0.14	0.40	0.30	-0.47*	-0.57*
MAXSR	0.41	0.01	0.44	0.43	0.40	0.65*	-0.35
AVGSR	0.40	-0.03	0.21	0.48*	0.28	0.23	-0.46
MAXRH	-0.46	-0.64*	-0.35	-0.18	-0.16	-0.17	0.41
MINRH	0.00	0.29	0.15	0.36	0.17	0.41	0.36
AVGRH	-0.34	0.06	-0.25	0.00	0.10	0.38	0.40
MAXST	0.63*	0.50*	0.35	0.42	0.27	-0.02	-0.08
MINST	0.38	0.04	0.40	-0.12	-0.28	-0.52*	-0.17
AVRST	0.38	0.35	0.35	0.18	-0.10	-0.35	-0.12
MAXSM	0.24	0.15	-0.13	0.14	0.25	0.04	0.12
AVGSM	0.14	0.03	-0.19	0.21	0.16	0.05	0.03
RF	-	-0.19	-0.41	0.20	0.59*	-0.03	0.59*

It can be noticed from the correlation matrix that the disease incidence was more influenced by the prevailing weather conditions than the development.

4.3.2 Sheath blight progression in Kanchana

Table 14 showed that the correlation between weather parameter and sheath blight development 7 days after incidence. Maximum temperature, minimum air temperature, maximum solar radiation, average solar radiation, maximum soil temperature, maximum soil moisture and average soil moisture were positively correlated with sheath blight incidence on Kanchana. Maximum relative humidity, minimum relative humidity and average relative humidity were negatively correlated with sheath blight incidence on Kanchana.

The impact of weather parameters on sheath blight development two weeks after incidence is presented in table 15. Maximum temperature, maximum solar radiation and maximum soil temperature were negatively correlated with sheath blight incidence on Kanchana. Minimum air temperature, minimum relative humidity, minimum soil temperature, maximum soil moisture, rainfall and average soil moisture were positively correlated with sheath blight incidence on Kanchana.

Table 14.Correlation of weather on Sheath blight progression in Kanchana one week after incidence

Weather	Day 1	Day 2	Day3	Day4	Day5	Day6	Day7
MAXT	0.50*	0.51*	0.43	0.27	0.35	-0.12	-0.28
MINAT	-0.31	0.35	-0.20	0.61*	-0.12	0.38	0.76*
AVGT	-0.09	0.19	0.37	0.29	0.53*	-0.41	0.06
MAXSR	0.55*	0.26	0.57*	0.32	0.43	0.67*	-0.16
AVGSR	0.40	0.76*	0.37	-0.44	0.65*	0.41	0.24
MAXRH	0.14	0.05	0.65*	-0.18	-0.75*	-0.48*	-0.61*
MINRH	-0.65*	-0.18	0.00	0.45	-0.47*	-0.20	0.30
AVGRH	-0.42	-0.59*	0.70*	0.35	-0.76*	-0.37	0.16
MAXST	0.51*	0.76*	0.63*	0.36	0.44	0.52*	-0.23
MINST	0.00	0.20	0.36	0.46	0.06	-0.56*	0.52*
AVRST	-0.04	0.39	0.45	0.20	0.42	-0.09	0.26
MAXSM	0.75*	0.07	0.68*	0.55*	0.58*	-0.10	0.32
AVGSM	-0.03	0.24	0.13	0.77*	-0.22	-0.01	0.79*
RF	-0.75*	-0.18	0.04	0.02	-0.17	0.09	-0.31

Table 15.Correlation of weather on Sheath blight progression in Kanchana two week after incidence

Weather	Day 1	Day 2	Day3	Day4	Day5	Day6
MAXT	0.19	-0.54*	-0.78*	-0.72*	-0.63*	-0.17
MINAT	0.51*	0.30	-0.14	0.23	0.65*	0.10
AVGT	0.44	0.33	-0.08	-0.32	-0.51*	-0.43
MAXSR	0.34	0.48*	-0.69*	-0.53*	-0.21	-0.44
AVGSR	0.41	-0.11	-0.30	-0.07	0.23	-0.16
MAXRH	-0.16	0.23	0.11	-0.15	-0.12	-0.21
MINRH	0.44	0.58*	-0.58*	0.81*	0.79*	0.50*
AVGRH	0.19	0.18	-0.33	0.44	0.37	0.56*
MAXST	0.05	-0.48*	-0.69*	-0.69*	-0.66*	-0.68*
MINST	0.59*	0.53*	0.46	0.29	-0.21	-0.58*
AVRST	0.70*	0.38	-0.07	-0.43	-0.44	-0.82*
MAXSM	0.56*	0.04	-0.56*	0.25	0.65*	0.63*
AVGSM	0.58*	-0.77*	-0.06	0.74*	0.79*	0.73*
RF	-	0.33	0.78*	0.62*	0.62*	0.62*

Table 16 showed that the correlation between weather parameter and sheath blight progression three weeks after incidence. Maximum relative humidity, minimum relative humidity and average relative humidity were negatively correlated with sheath blight incidence on Kanchana. Maximum temperature, average temperature, maximum solar radiation, maximum soli temperature minimum soil temperature and average soil temperature were positively correlated with sheath blight incidence on Kanchana.

Table 16.Correlation of weather on Sheath blight progression in Kanchana three week after incidence

Weather	Day 1	Day 2	Day3	Day4	Day5	Day6	Day7
MAXT	0.05	0.56*	-0.07	0.57*	0.33	0.65*	0.26
MINAT	0.62*	-0.51*	-0.59*	0.64*	0.05	-0.59*	0.48*
AVGT	-0.20	0.52*	0.17	0.62*	0.32	0.59*	0.50*
MAXSR	0.25	0.31	0.37	0.66*	-0.60*	0.57*	0.40
AVGSR	0.45	0.71*	-0.42	0.67*	-0.51*	0.55*	0.20
MAXRH	-0.54*	0.07	0.34	-0.70*	-0.20	0.28	-0.66*
MINRH	-0.18	-0.10	-0.37	-0.67*	-0.55*	-0.53*	-0.41
AVGRH	-0.26	-0.22	-0.47*	-0.71*	-0.33	-0.53*	-0.63*
MAXST	0.07	0.49*	0.09	0.50*	0.43	0.69*	0.36
MINST	-0.44	0.56*	0.64*	0.57*	0.60*	0.53*	0.03
AVRST	-0.32	0.63*	0.43	0.57*	0.42	0.58*	0.40
MAXSM	0.05	0.02	-0.07	0.12	-0.04	0.02	-0.04
AVGSM	0.05	-0.10	-0.14	0.04	-0.04	-0.05	-0.08
RF	0.18	-0.19	-0.17	0.02	-0.56*	-0.40	0.02

Table 17 presented the correlation between sheath blight development weather parameter four weeks after incidence. It is interesting to notice that none of the weather parameters had a significant correlation with disease incidence at this stage.

Table 17.Correlation of weather on Sheath blight progression in Kanchana four week after incidence

Weather	Day 1	Day 2	Day3	Day4	Day5	Day6	Day7
MAXT	0.17	-0.24	-0.06	-0.02	-0.08	0.01	-0.03
MINAT	0.18	0.07	-0.10	0.18	-0.03	-0.17	0.35
AVGT	0.33	-0.17	-0.36	-0.38	-0.24	-0.07	0.01
MAXSR	0.12	-0.32	-0.27	-0.36	-0.33	-0.23	-0.05
AVGSR	0.14	-0.32	-0.38	-0.30	-0.28	-0.19	0.05
MAXRH	0.29	0.14	0.38	0.29	0.26	0.36	-0.14
MINRH	0.32	0.21	0.19	0.16	-0.26	-0.16	-0.14
AVGRH	0.38	0.31	0.39	0.33	0.10	-0.13	-0.11
MAXST	-0.14	-0.36	-0.38	-0.35	-0.34	-0.27	-0.26
MINST	-0.12	-0.14	0.14	0.26	-0.22	-0.04	-0.13
AVRST	0.07	-0.35	-0.38	-0.12	-0.27	-0.17	-0.19
MAXSM	-0.16	-0.17	-0.09	0.25	0.21	0.31	0.29
AVGSM	-0.16	-0.17	-0.06	0.21	0.27	0.30	0.31
RF	-	0.18	0.38	0.22	-0.09	0.12	-0.09

4.4 EFFECT OF DATES OF PLANTING ON BIOMETRIC OBSERVATIONS

4.4.1 Wet land

4.4.1.1 Plant height

The mean Plant height (cm) in weekly intervals is presented in the table 18. The plant height was significantly influenced by both planting time and variety. All the treatments recorded the maximum height at 10^{th} week. The crops planted on July 16^{th} and 26^{th} recorded the maximum plant height for both the varieties and are on par.

4.4.1.2 Number of tillers per plant

Crops transplanted during 16^{th} July and 26^{th} July recorded the highest number of tillers per plant (25.6) for Jyothi and Kanchana respectively (Table 19). The number of tillers was significantly affected by both dates of planting and variety.

4.4.1.3 Leaf Area Index (LAI)

The effect of weather on LAI significantly varied with the variety. Kanchana was recorded maximum leaf area index (0.93) when on planted 26^{th} July and minimum LAI was recorded 0.79 by the crops planted on 26^{th}June (Table 20).

4.4.2 Upland

4.4.2.1 Plant height

In all the dates of sowing variety Kanchana recorded highest plant height (62.6cm) compared to Jyothi. The effect of weather on plant height varied significantly with the varieties. (Table 21)

4.4.2.2 Number of tillers

Crops transplanted during 6^{th} June recorded the highest number of tillers per plant for variety Kanchana (11) and the minimum was recorded by variety Jyothi (2.3) when planted on 6^{th} July (Table 22).

4.4.2.3 Leaf area index (LAI)

The effect of weather on LAI significantly varied with the variety. Kanchana was recorded maximum leaf area index (0.82) when on planted 26^{th}June and minimum leaf area index was recorded 0.68 by the crops planted on June $16^{th}$and May 26^{th}respectively for Kanchana and Jyothi respectively(Table 23).

EFFECT OF DATES OF PLANTING ON BIOMETRIC OBSERVATIONS ON RICE

Table 18. Plant height in wet land

Varieties	Dates of planting	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9	Week10
Jyothi	June 15	39.6	43	46.3	51.3	55.1	63	72.3	75.9	78.6	82.6
Kanchana	June 15	42	47.3	51.6	55.3	59.3	66.3	69	71.43	89.16	94.6
Jyothi	June 26	33.3	35.8	39.5	45.6	52.6	56	62	66.3	73	80
Kanchana	June 26	35	37.5	41.1	50.3	57	60.9	67.6	76.6	82.6	91.1
Jyothi	July 7	31	32.6	35.3	37.6	39.6	50.0	53.3	57.6	62	68.6
Kanchana	July 7	28.6	31.3	34.6	38	41.9	53.5	57.6	65	76.3	82.6
Jyothi	July 16	32.3	40.5	46.8	54.3	62	68	73.3	80.3	86.5	95.8
Kanchana	July 16	34	38.6	42.7	48.7	55.1	61	65.6	74.3	85.6	95.6
Jyothi	July 26	29.3	34.6	41.4	46.8	52.6	61	68	79.3	89	95.1
Kanchana	July 26	29.2	34.3	42	49.6	54.6	62.6	71	78	88.6	95.3
CD 5%	Main plot Treatments	4.9	5.2	6.4	6.0	6.7	10.2	11.7	12.7	12.8	15.8
	Sub plot Treatments	1.9	2.8	3.1	3.2	4.6	4.8	5.1	3.97	2.9	6.18
	Main x Sub	4.3	6.3	7.0	7.3	10.3	10.7	11.4	8.87	6.6	13.8

Table 19.Number of tillers in wet land

Varieties	Dates of planting	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9	Week10
Jyothi	June 15	4	4.66	5.33	6.33	9.66	10.66	11.66	10.33	10	9.33
Kanchana	June 15	4.33	5	5.66	7	10	9	11.33	11.33	11	9
Jyothi	June 26	3.66	4	6.33	8.66	9.33	12	15	15	14.33	14.33
Kanchana	June 26	3.66	6	8.66	14.33	15.33	17	19	19.66	18.33	17.33
Jyothi	July 7	4	4	6	9	11	13	12.66	16	18.66	19.66
Kanchana	July 7	4	3.66	7	9.33	11	15.33	15.33	16.66	17.66	18.66
Jyothi	July 16	6.66	13	17.33	19.33	21.66	23.66	25.66	23.66	22.33	20.66
Kanchana	July 16	5	8	11.66	15	17.66	19	22.33	21.66	19.66	19.66
Jyothi	July 26	4.33	5.33	7	8.33	8.66	12.33	11.66	9.33	8	8
Kanchana	July 26	8	10.66	14	16.33	18.33	22	22.66	24	25.66	21.66
CD 5%	Main Treatments	2.65	5.14	7.17	8.01	9.02	9.44	9	10.62	11.57	11.71
	Sub Treatments	1.12	1.85	2.62	2.94	2.94	3.69	3.65	3.41	3.09	3.15
	Main x Sub	2.5	4.14	5.86	6.59	6.57	8.26	8.17	7.63	6.91	7.06

Table 20.Leaf Area Index (LAI) in wet land

Varieties	Dates of planting	Week1	Week2	Week3	Week4	Week5	Week6
Jyothi	June 15	0.32	0.36	0.70	0.84	0.52	0.50
Kanchana	June 15	0.34	0.36	0.69	0.86	0.58	0.51
Jyothi	June 26	0.29	0.31	0.68	0.81	0.54	0.54
Kanchana	June 26	0.27	0.29	0.65	0.79	0.57	0.58
Jyothi	July 7	0.31	0.34	0.62	0.84	0.54	0.49
Kanchana	July 7	0.32	0.33	0.64	0.83	0.59	0.52
Jyothi	July 16	0.31	0.35	0.65	0.85	0.73	0.68
Kanchana	July 16	0.31	0.35	0.62	0.85	0.75	0.7
Jyothi	July 26	0.37	0.38	0.68	0.88	0.74	0.67
Kanchana	July 26	0.41	0.43	0.69	0.93	0.74	0.69
CD 5%	Main Treatments	0.05	0.07	0.04	0.07	0.04	0.02
	Sub Treatments	0.04	0.04	0.04	0.04	0.015	0.01
	Main x Sub	0.10	0.10	0.10	0.10	0.033	0.03

Table 21.Plant height in upland

Varieties	Dates of sowing	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9	Week10
Jyothi	May 26	27.66	32.33	36.66	40.5	49.5	52	55.46	58.5	56.33	54.5
Kanchana	May 26	31	31.33	34.33	38.43	43.33	45.66	48.66	52.43	56	61.66
Jyothi	June 6	22.66	26.33	27.9	32.66	37.7	41.66	42.66	45.33	46.83	52.66
Kanchana	June 6	28.76	30.73	33.8	37.13	41.96	48.5	51.46	53.5	57.96	61.46
Jyothi	June 16	22.4	25.83	27.16	28.9	38.16	45.76	48.43	49.5	54.3	52
Kanchana	June 16	24.93	28.4	30.4	32.2	38.33	42.73	48.33	50.2	54.16	54.33
Jyothi	June 26	31.63	37.5	41.13	43.3	45.33	46.03	48.5	49.13	50	51.63
Kanchana	June 26	34.2	38.33	44.3	47.53	50.93	53.03	54.1	58.66	60	62.66
Jyothi	July 6	23.1	24.66	27.23	31.16	33	34.5	35.53	37	39.13	40.66
Kanchana	July 6	22.16	23.93	26.93	29.03	29.5	31.9	33.36	35.4	40.8	43.7
CD 5%	Main Treatments	7.71	8.49	7.82	8.26	8.63	7.93	6.43	7.08	8.21	9.68
	Sub Treatments	2.86	2.45	2.36	3.66	5.21	5.19	5.98	6.22	6.69	6.85
	Main x Sub	6.41	5.48	5.28	8.19	11.66	11.62	13.37	13.91	14.96	15.33

Table 22. Number of tillers in upland

Varieties	Dates of sowing	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9	Week10
Jyothi	May 26	2	3	4	4	4.66	4.66	5	6.33	7	7.33
Kanchana	May 26	2	3	4	4.66	5.33	5.33	6	5	5	5.33
Jyothi	June 6	1	1	1	1.66	2.33	3.66	4	5	4.33	5.33
Kanchana	June 6	1	1	1.33	2.33	4.33	9	9.66	11	10	8.66
Jyothi	June 16	1	1	1.33	1.66	4.33	5	6	6	4	3.66
Kanchana	June 16	1.33	1.66	1.66	2	5.66	7	7	7	4.33	4.66
Jyothi	June 26	3.33	5	3.66	4	5.33	3.66	3.33	3	2	2
Kanchana	June 26	4	4.33	4	5.33	6.33	5.66	3.66	3.66	3	3
Jyothi	July 6	1	2	1.66	2	2.66	3.33	1.66	2.33	2.33	2.33
Kanchana	July 6	1.66	1.66	4.33	5.33	5.66	4	3	3.33	3.33	3.33
CD 5%	Main Treatments	0.74	1.12	0.97	1.55	2.26	3.67	4.09	3.64	3.03	2.89
	Sub Treatments	0.44	0.51	0.39	0.71	0.84	0.96	1.28	1.37	1.27	0.97
	Main x Sub	0.99	1.15	0.87	1.59	1.87	2.15	2.87	3.08	2.85	2.17

Table 23.Leaf area index in upland

Varieties	Dates of sowing	Week1	Week2	Week3	Week4	Week5	Week6
Jyothi	May 26	0.23	0.21	0.71	0.68	0.34	0.35
Kanchana	May 26	0.21	0.28	0.58	0.78	0.48	0.43
Jyothi	June 6	0.36	0.27	0.57	0.77	0.47	0.42
Kanchana	June 6	0.24	0.21	0.51	0.71	0.41	0.36
Jyothi	June 16	0.37	0.24	0.54	0.74	0.44	0.39
Kanchana	June 16	0.26	0.18	0.48	0.68	0.38	0.33
Jyothi	June 26	0.38	0.23	0.53	0.73	0.43	0.38
Kanchana	June 26	0.27	0.32	0.62	0.82	0.52	0.47
Jyothi	July 6	0.23	0.27	0.57	0.77	0.47	0.42
Kanchana	July 6	0.25	0.23	0.53	0.73	0.43	0.38
CD 5%	Main Treatments	0.18	0.06	0.11	0.07	0.10	0.06
	Sub Treatments	0.10	0.04	0.11	0.03	0.03	0.04
	Main x Sub	0.22	0.09	0.26	0.08	0.08	0.08

4.5 YIELD ATTRIBUTES

4.5.1 Wet land

4.5.1.1Number of panicles

Among all dates of planting Variety Kanchana transplanted on 26th June recorded significantly highest number of panicles (16) (Table 24) but interaction between the treatments is not significant.

4.5.1.2Number of spikelets

The number of spikelets per plant is presented in the Table 24. The variety Jyothi was recorded maximum number of spikelets (9) when planted on 26th June and 16th July.The number of spikelets per plant was significantly varied with varieties.

4.5.1.3Grains per panicle

The variety Jyothi recorded highest number of grains per panicle (103) and minimum was recorded by the variety Kanchana (74.7) in 26th June transplanted crop (Table 24). The number of grains per panicle was significantly varied with varieties.

Table 24.Effect of sheath blight on yield and yield attributes

Varieties	Dates of planting	Number of panicles	Number of spikelets	Grains per panicle	1000 grain weight (gm)	Grain yield(kg)
Jyothi	June 15	9.66	8.33	93	30.4	1945.4
Kanchana	June 15	13.33	6.66	75.33	30.9	2055.4
Jyothi	June 26	10.66	9	103	30.7	2171.1
Kanchana	June 26	16	6.66	74.66	31.1	2438.4
Jyothi	July 7	7.66	8.33	94	29.6	1399.1
Kanchana	July 7	10	8.33	92.66	30.5	1915.2
Jyothi	July 16	14.33	9	100.33	29.1	2782.4
Kanchana	July 16	14	7	78.33	29.4	2174.8
Jyothi	July 26	10	8.66	97.33	28.3	1830.3
Kanchana	July 26	10.33	8.66	97.66	29.0	1905.3
CD 5%	Main Treatments	2.34	1.86	19.81	0.5	549.7
	Sub Treatments	1.42	0.87	10.50	0.2	458.4
	Main x Sub	3.18	1.96	23.49	0.65	1025.1

4.5.1.41000 grain weight

The maximum 1000 grain weight (31.13gm)was recorded by variety Kanchana transplanted on26th June and the minimum 1000 grain weight (28.36gm) was recorded by variety Jyothi transplanted on 26th July (Table 24). The effects of weather and varieties on number of panicles per plant were significant, but interaction between the treatments is not significant.

4.5.1 5 Grain yield

The maximum grain yield (2782.4 kg/ha) was recorded by the variety Jyothi transplanted on 16th July and it also recorded minimum grain yield (1399.2 kg/ha) in7th July transplanted crop (Table 24). The effect weather on grain yield was significant.

4.5.2 Upland

Under dry land condition the sheath blight disease incidence was not observed even after artificial inoculation. But due to heavy blast infestation the crop perished prematurely.

4.6 Incubation period

The effects of weather and varieties on sheath blight incubation period were significant, but interaction between the treatments is not significant. Minimum duration of incubation was recorded in Jyothi in the 26th June planted crop and maximum incubation period was recorded by Kanchana in the 26th July crop (Table 25).

Table 25. Sheath blight Incubation period in rice

Varieties	Dates of planting	Incubation period
Jyothi	June 15	2.66
Kanchana	June 15	3.33
Jyothi	June 26	2.66
Kanchana	June 26	3.33
Jyothi	July 7	4.66
Kanchana	July 7	5.30
Jyothi	July 16	7.00
Kanchana	July 16	7.33
Jyothi	July 26	7.66
Kanchana	July 26	8.33
CD 5%	Main Treatments	0.70
	Sub Treatments	0.33
	Main x Sub	0.74

4.7 Sheath blight severity

The maximum sheath blight severity of Jyothi (80.9%) was recorded in 16th July transplanted crop and the minimum (56%) was observed when planted on 26th July (Table 26).

Table 26. Sheath blight severity of Jyothi

Varieties	Dates of planting	Changes in severity after disease incidence				
		1st week	2nd week	3rd week	4th week	5th week
Jyothi	June 15	45.767	54.467	62.533	71.100	78.433
Jyothi	June 26	36.600	48.833	60.167	69.267	78.167
Jyothi	July 7	36.600	48.833	60.167	69.267	78.167
Jyothi	July 16	40.900	49.433	60.000	68.933	80.933
Jyothi	July 26	34.033	37.167	40.833	48.733	56.000
CD 5%		2.09	5.42	4.97	5.69	5.71

Table 27. Sheath blight severity of Kanchana

Varieties	Dates of planting	Changes in severity after disease incidence				
		1st week	2nd week	3rd week	4th week	5th week
Kanchana	June 15	34.433	38.700	43.033	48.400	54.167
Kanchana	June 26	28.733	34.633	41.067	44.267	47.833
Kanchana	July 7	28.733	34.633	41.067	44.267	47.833
Kanchana	July 16	23.800	31.967	39.233	47.600	52.667
Kanchana	July 26	23.867	27.133	30.400	36.233	42.933
CD 5%		4.08	3.80	4.27	4.65	3.19

The maximum sheath blight severity of Kanchana (54.16%) was recorded in 15th June transplanted crop and the minimum (42.9%) was observed when planted on 26th July (Table 27). The study shows that variety Kanchana was more tolerant to sheath blight incidence.

4.8 REGRESSION MODELS FOR PREDICTION OF SHEATH BLIGHT INCIDENCE

Stepwise regression analysis was carried out to select the critical variables, which contributed to Sheath blight incidence in rice

4.8.1 Regression models for Jyothi,

Disease Incidence=320.061-11AAVT+0.011MAXSR$_{11}$-0.041MINRH$_9$+0.096HRF$_2$ R^2=0.741

Where, AAVT=Mean average temperature

$MAXSR_{11}$=Maximum solar radiation at 11^{th} day

$MINRH_9$=Minimum relative humidity at 9^{th} day

HRF_2=Average rainfall of 7 to 12 days after inoculation

4.8.2 Regression models for Kanchana,

Disease incidence=160.52-5.85AAVT+0.028$MAXSR_{11}$+0.056$MINRH_9$-0.098HRF_2 R^2=0.759

Where, AAVT=Mean average temperature

$MAXSR_{11}$=Maximum solar radiation at 11^{th} day

$MINRH_9$=Minimum relative humidity at 9^{th} day

HRF_2=Average rainfall of 7 to 12 days after inoculation

4.9 EPIRICE MODEL

EPIRICE model developed by Savary *et al.,* (2012) was used to forecast the disease severity of sheath blight disease in rice after transplanting. The model works on daily weather parameters particularly rainfall, maximum and minimum temperature, morning and afternoon relative humidity.

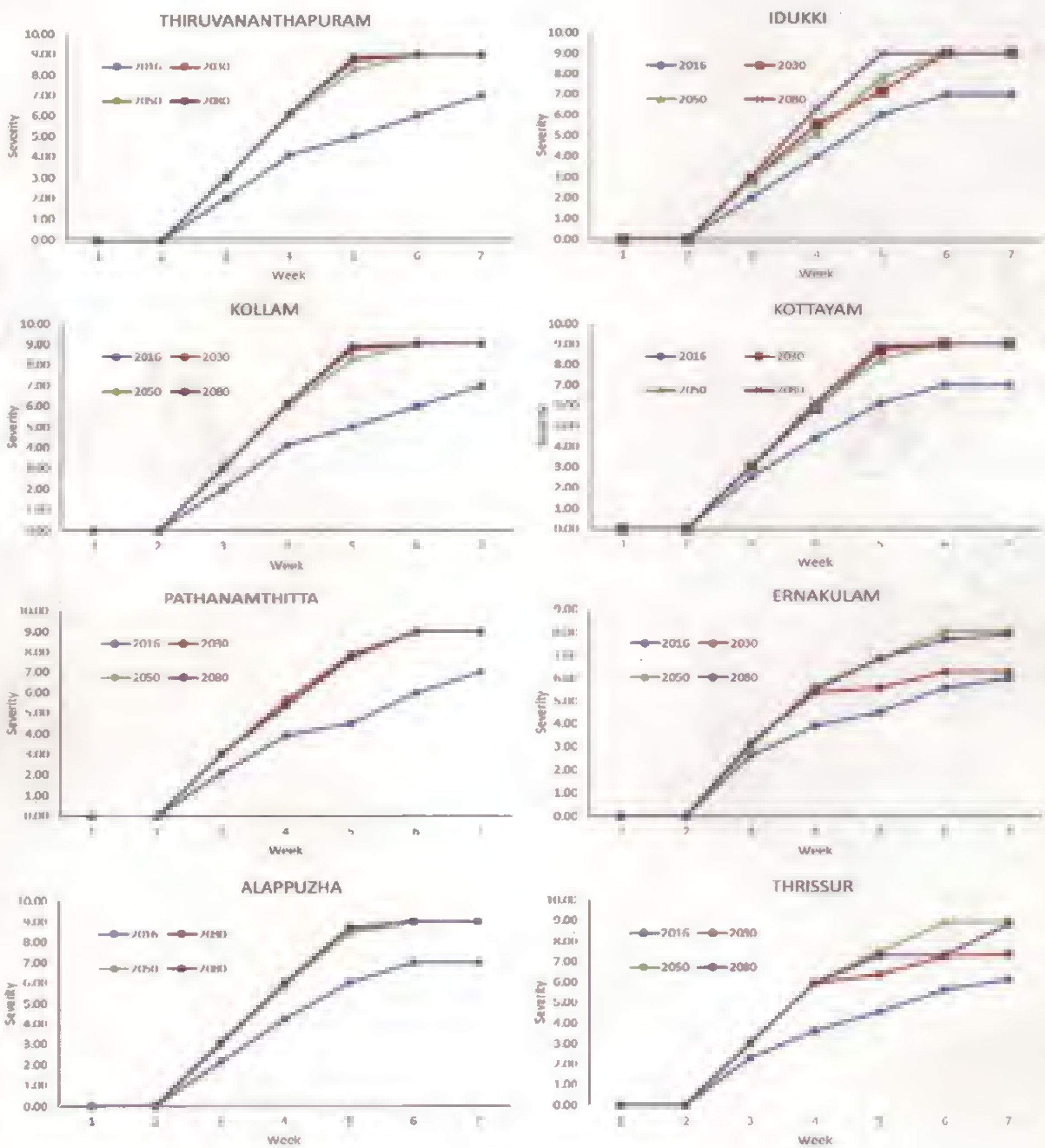
The observed and simulated sheath blight disease severity of variety Jyothi has presented in the Table 28. RMSE for Jyothi prediction is 0.248.This shows that the predicted sheath blight severity was in good agreement with the observed values. So this model can be used for forecasting the rice sheath blight severity under Kerala conditions.

Table 28. Observed and simulated sheath blight disease severity of variety Jyothi

Week after planting	OBSERVED	PREDICTED	RMSE
Week1	0	0.00	
Week2	0	0.00	
Week3	3	2.84	
Week4	4	4.00	0.248
Week 5	5	4.52	
Week 6	6	5.88	
Week 7	6	6.40	

4.10 IMPACT OF CLIMATE CHANGE ON SHEATH BLIGHT INCIDENCE

The future climatic projections have taken from Ensemble of 17 General Circulation Models (GCMs). The future climate data has been incorporated into disease simulation model-EPIRICE and predicted the future disease incidence possibility of sheath blight for the years 2030, 2050 and 2080 in all the 14 districts of Kerala has been presented in the figure 17. The climate data for the years 2030, 2050 and 2080 under different RCPs has been presented in the Figures 19 to 30. The impact of climate change on sheath blight severity in the various districts of Kerala showed an increasing trend.



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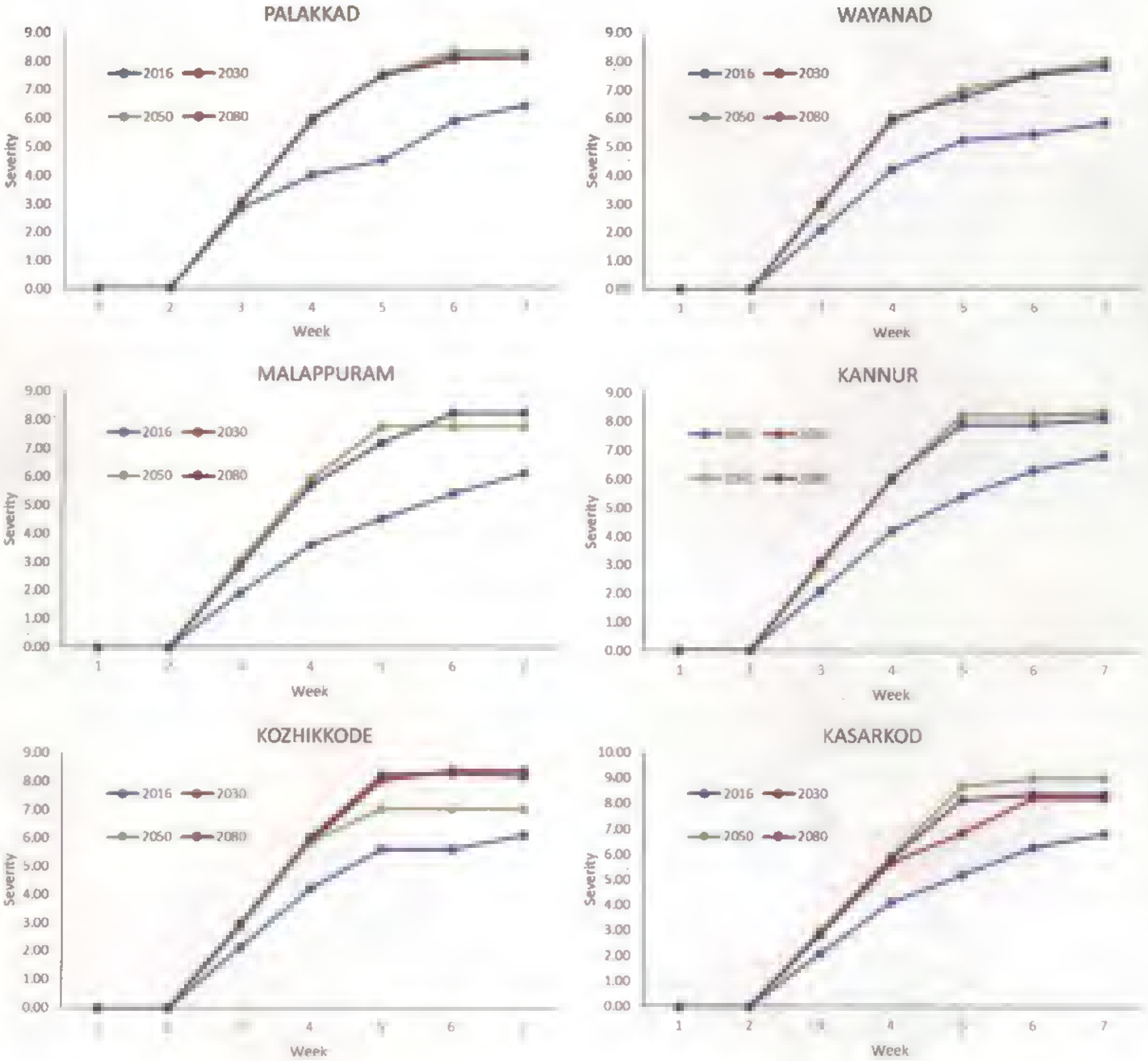

Fig.17 Impact of projected climate on Sheath Blight Disease

It can be observed from the above figures that the southern districts are highly prone to sheath blight disease as compared to northern districts. Considering the major rice growing tracts of Kerala Alappuzha will be more prone to sheath blight than Palakkad and Thrissur.

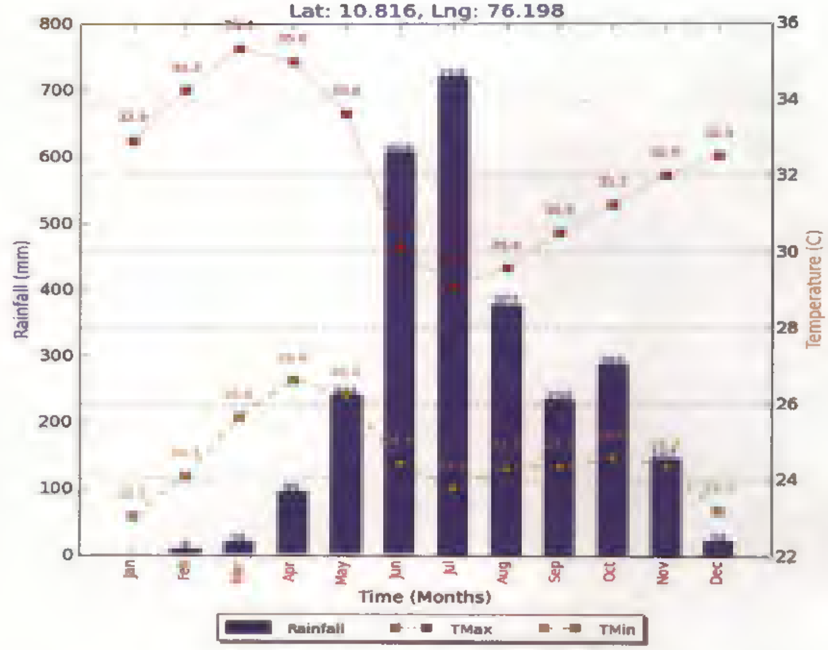

Fig 18. Climate of Pattambi in 2030s under RCP 2.6

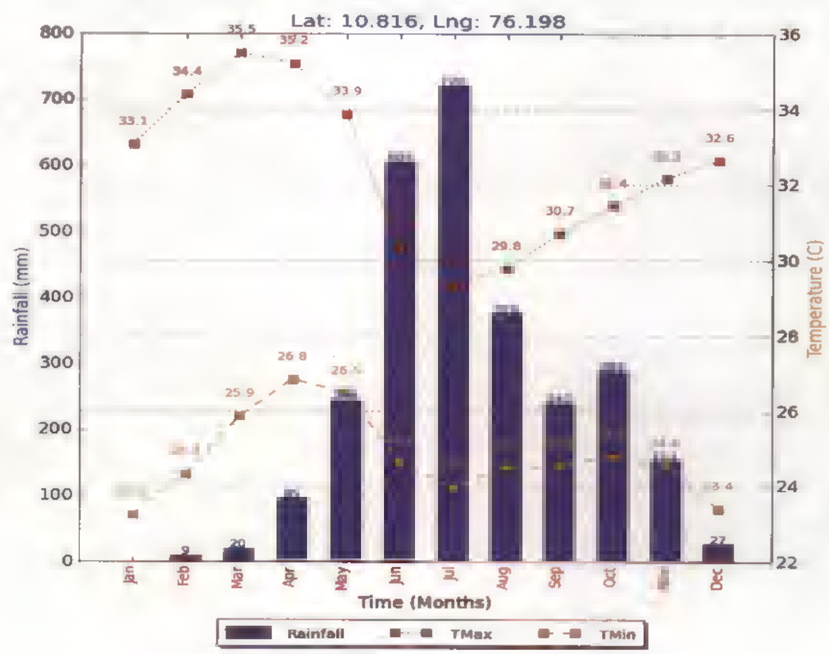

Fig 19. Climate of Pattambi in 2050s under RCP 2.6

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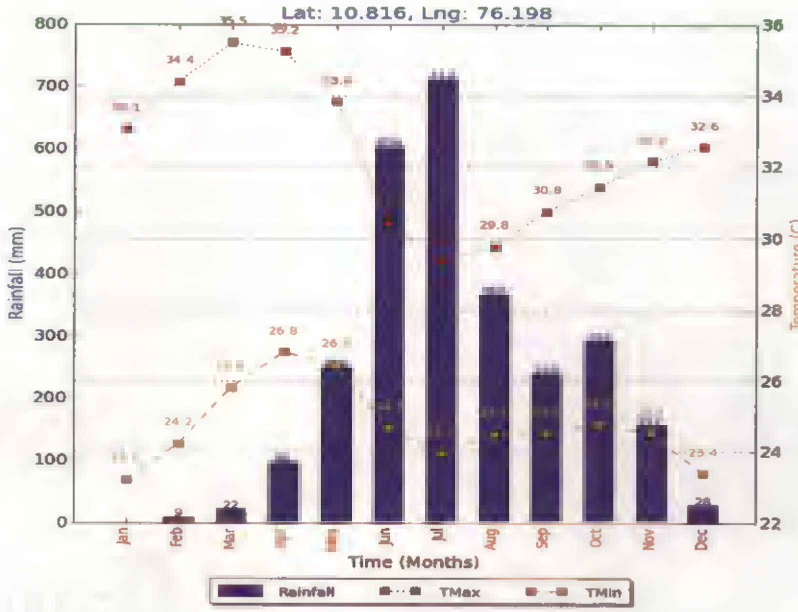

Fig 20. Climate of Pattambi in 2080s under RCP 2.6

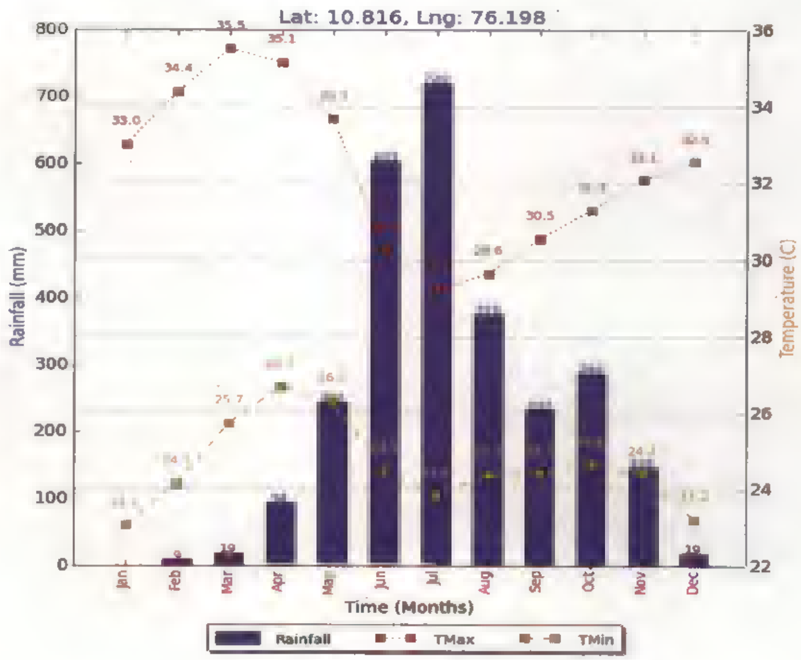

Fig 21. Climate of Pattambi in 2030s under RCP 4.5

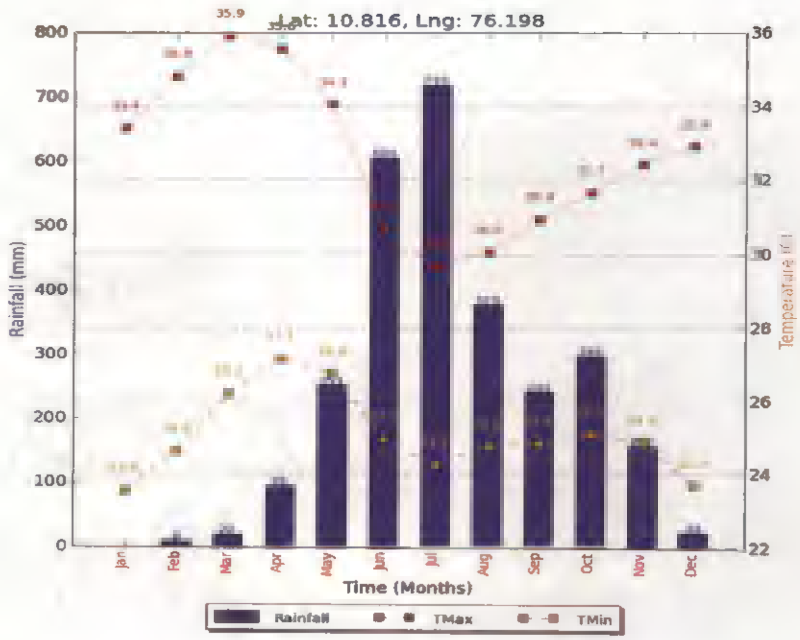

Fig 22. Climate of Pattambi in 2050s under RCP 4.5

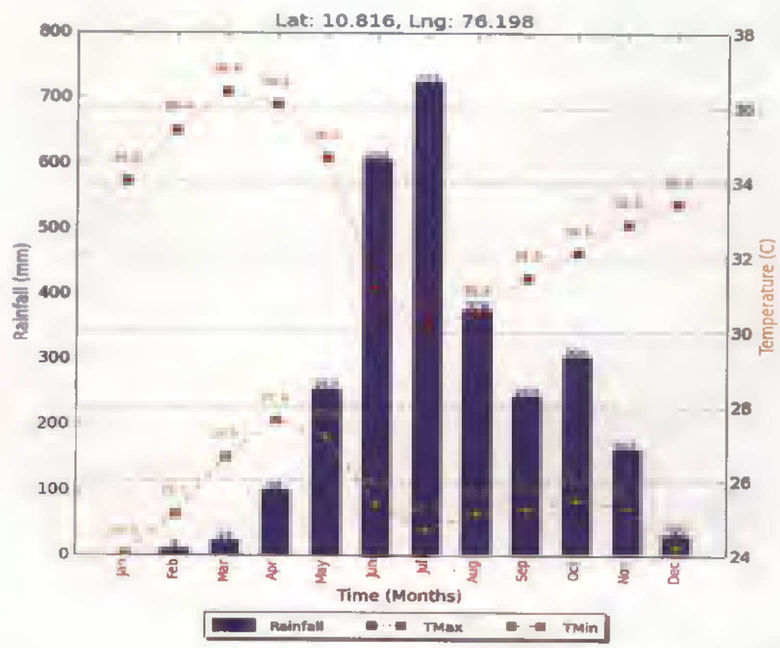

Fig 23. Climate of Pattambi in 2080s under RCP 4.5

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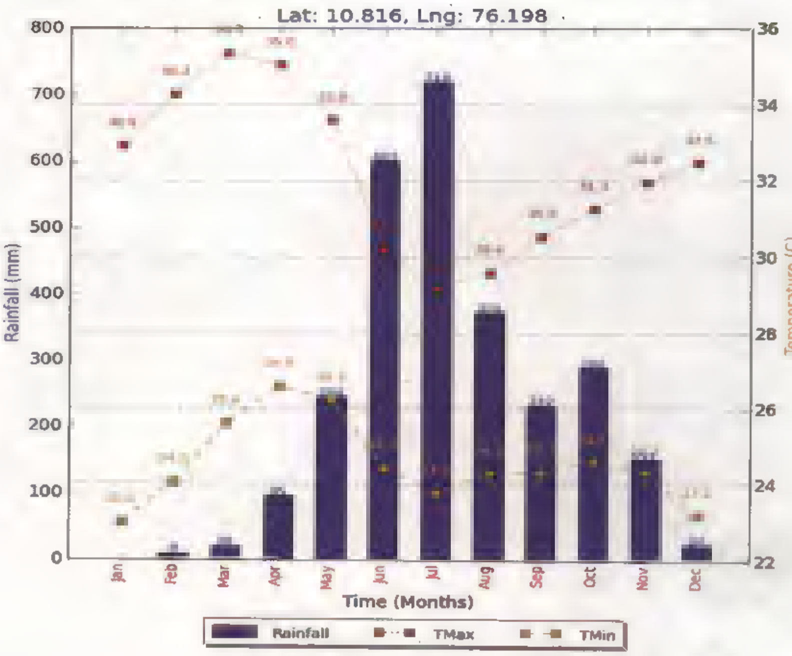

Fig 24. Climate of Pattambi in 2030 under RCP 6.0

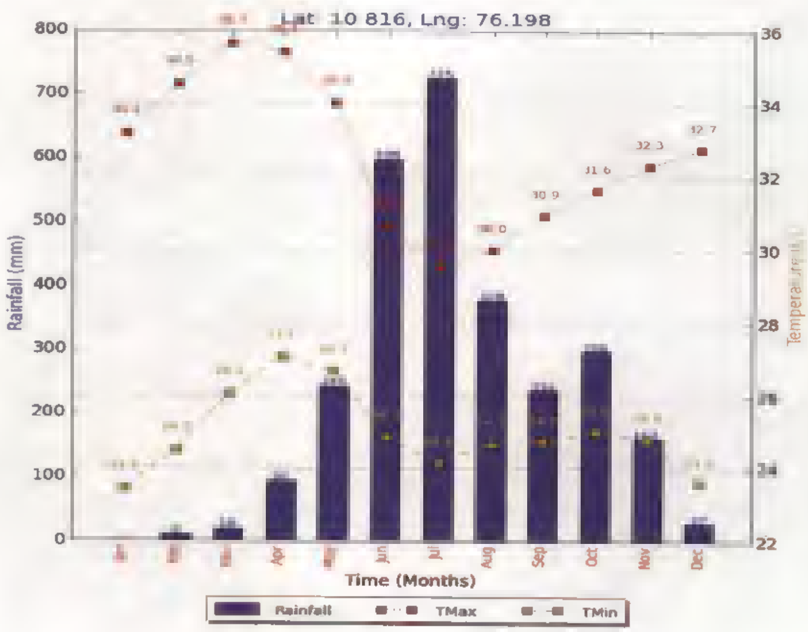

Fig 25. Climate of Pattambi in 2050s under RCP 6.0

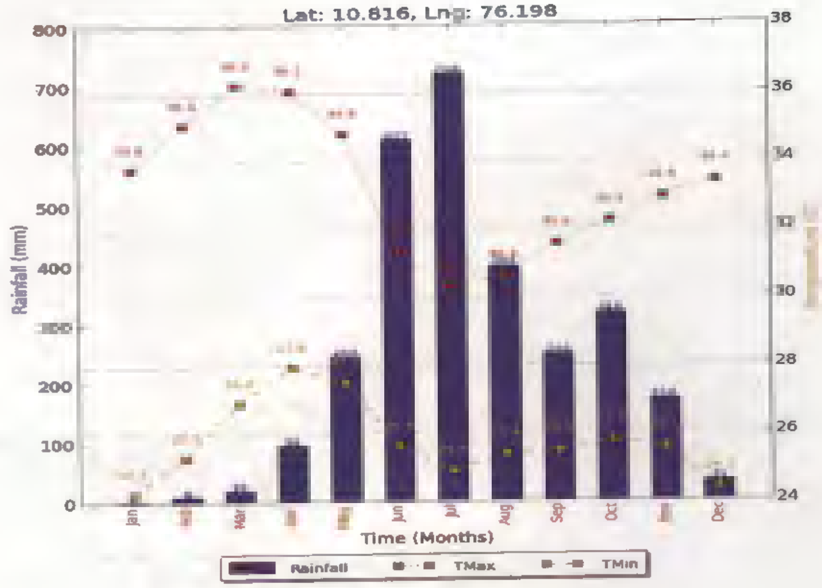

Fig 26. Climate of Pattambi in 2080s under RCP 6.0

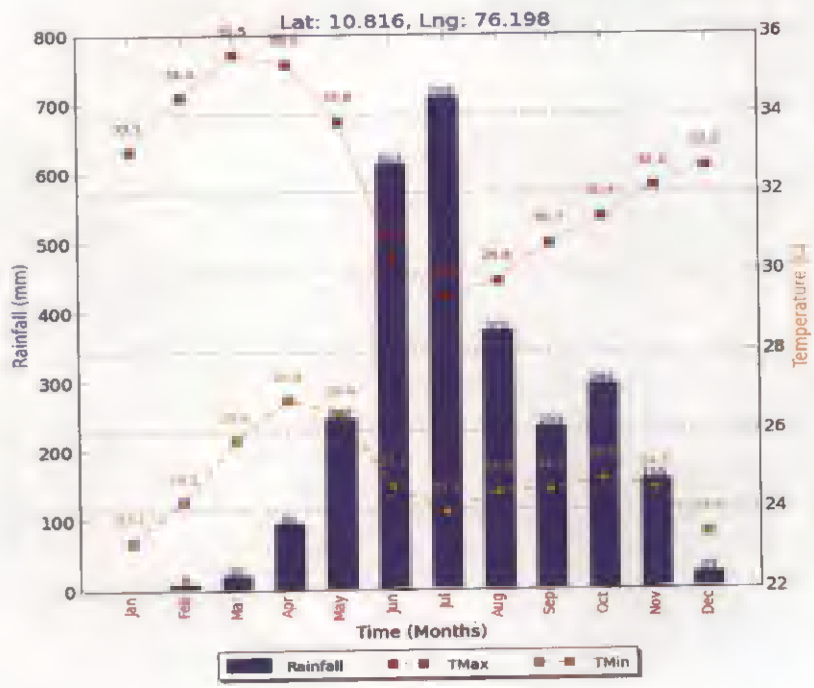

Fig 27. Climate of Pattambi in 2030s under RCP 8.5

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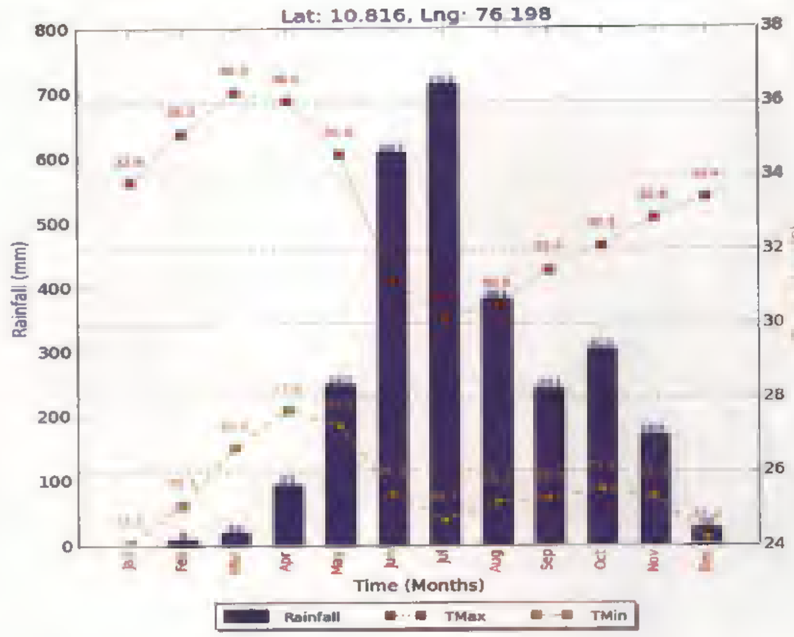

Fig 28. Climate of Pattambi in 2050s under RCP 8.5

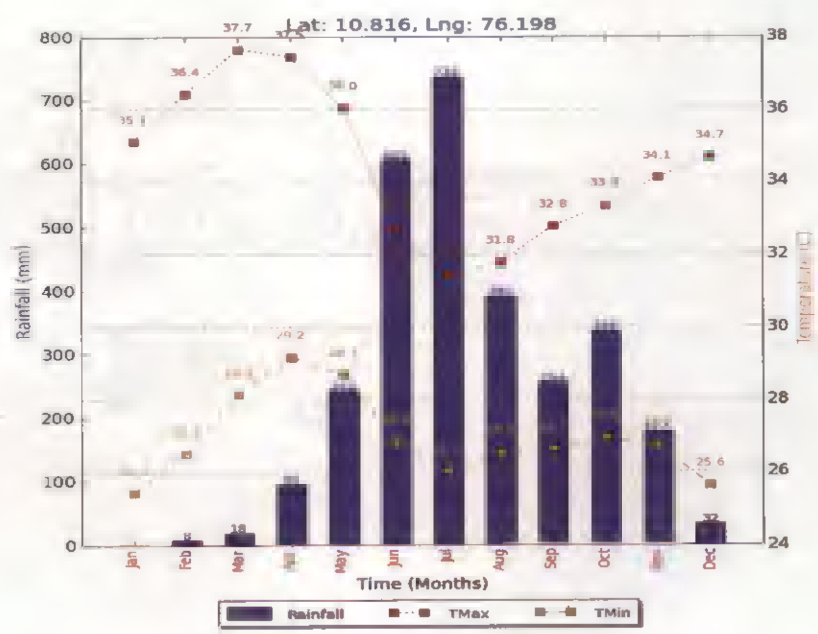

Fig 29. Climate of Pattambi in 2080s under RCP 8.5

This study was taken up to understand the effect of weather on sheath blight incidence in rice and predicting potential epidemics under various climate change scenarios. The results presented in the previous chapter are discussed here under.

5.1. WEATHER DURING THE STUDY PERIOD

The distribution of important weather parameters throughout the crop growing period is depicted in figure

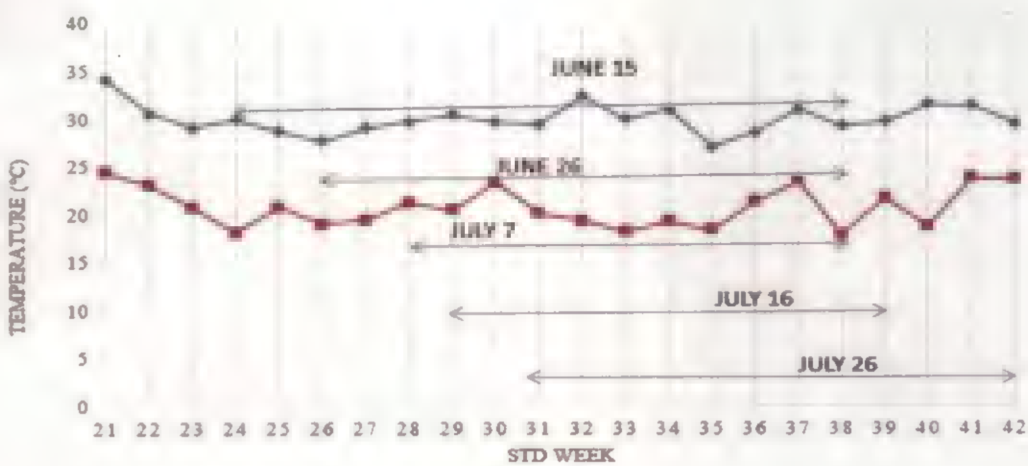

Fig 30. Weekly Temperature

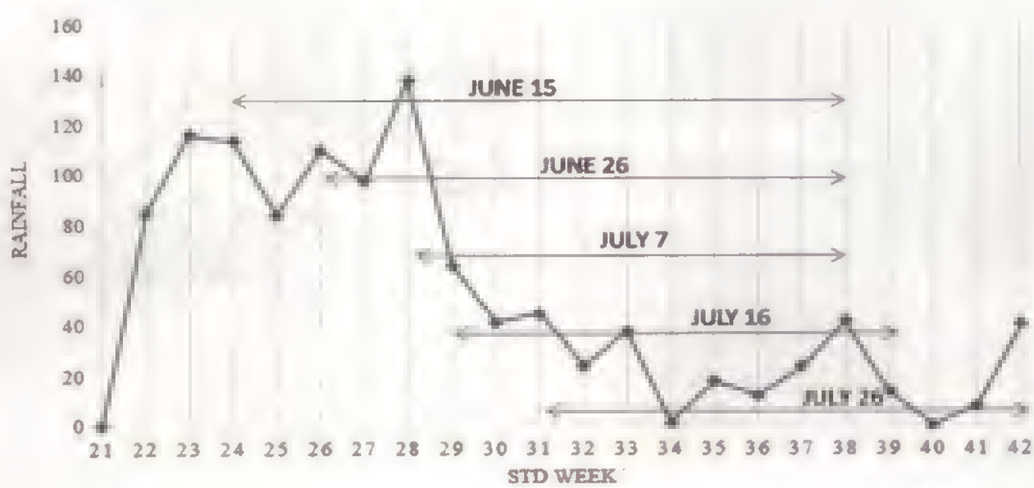

Fig 31. Weekly Rainfall

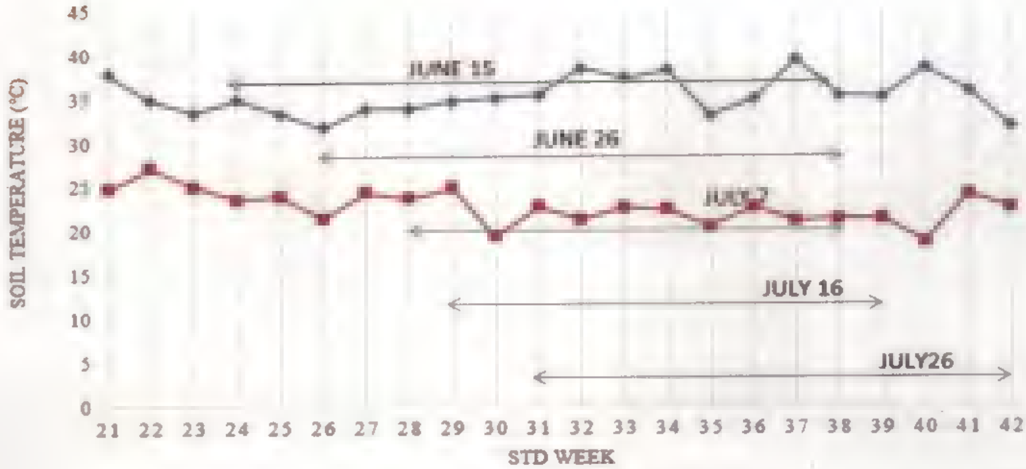

Fig 32.Weekly Soil Temperature

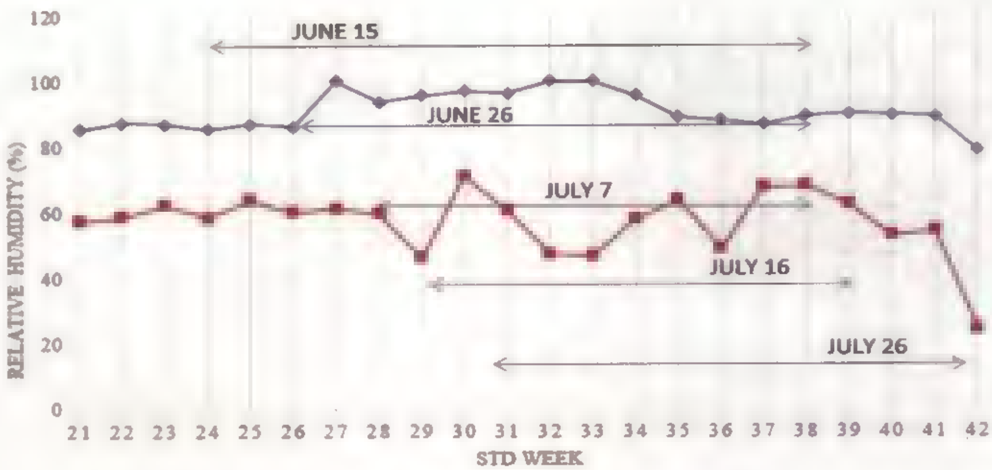

Fig 33. Weekly Relative Humidity

5.2 IMPACT OF WEATHER ON SHEATH BLIGHT INCIDENCE

5.2.1 Sheath blight incidence in Jyothi and Kanchana

The results have showed that the incidence of sheath blight is significantly influenced by the weather parameters and variety. It can be clearly observed from the figure that the early transplanted crops showed a higher disease incidence compared to other dates of planting. It was also noticed that variety Jyothi is more susceptible to sheath blight incidence compared to Kanchana. This is in agreement with package of practice recommendations (POP, 2015). It is interesting to notice that weather parameters on the day of inoculation are having more profound influence on disease incidence. Except relative humidity and rainfall all other weather parameters showed a significant negative correlation with disease incidence. It can be also noticed that the disease incidence in the consecutive days after the day of inoculation is mainly influenced by air temperature and soil moisture. The above results were in agreement with findings of Dutta and Kalha (2011)

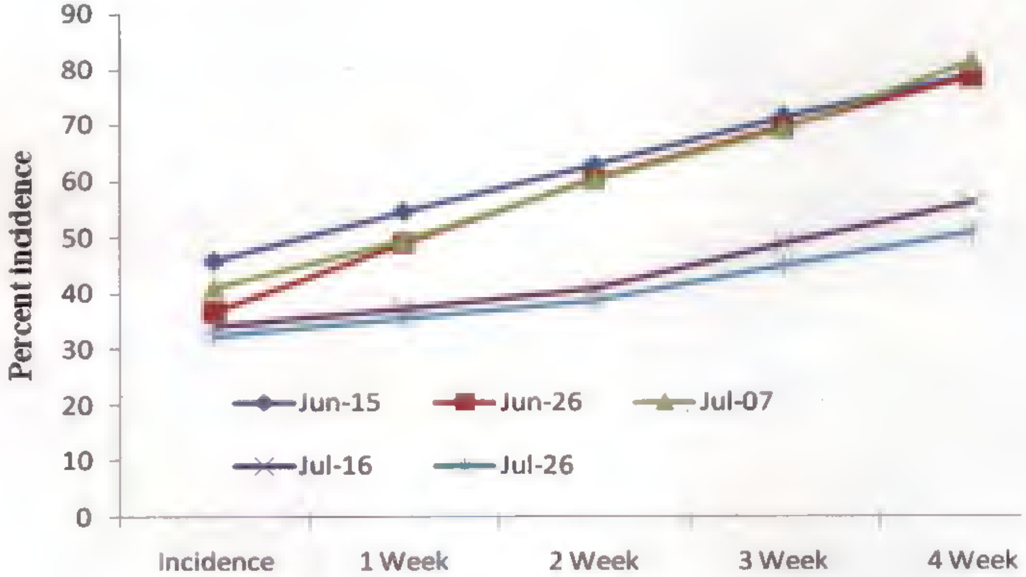

Fig 34. Sheath blight incidence in Jyothi

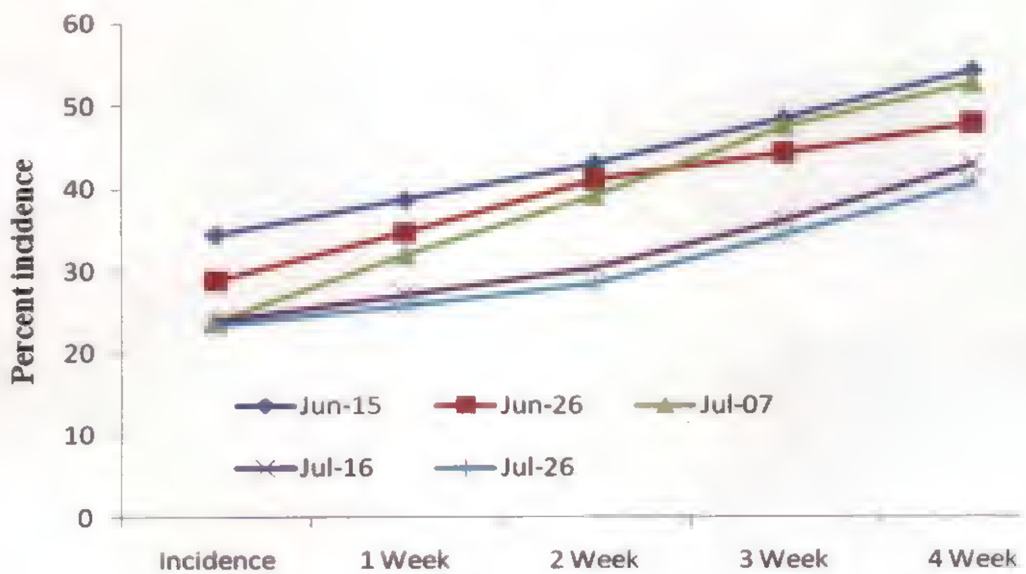

Fig 35. Sheath blight incidence in Kanchana

5.3 EFFECT OF DATES OF PLANTING ON BIOMETRIC OBSERVATIONS

5.3.1 Wet land

5.3.1.1 Plant height

The mean Plant height (cm) in weekly intervals is presented in the figure. The plant height was significantly influenced by both planting time and variety. The crops planted on July 16th and 26th recorded the maximum plant height for both the varieties and are on par.

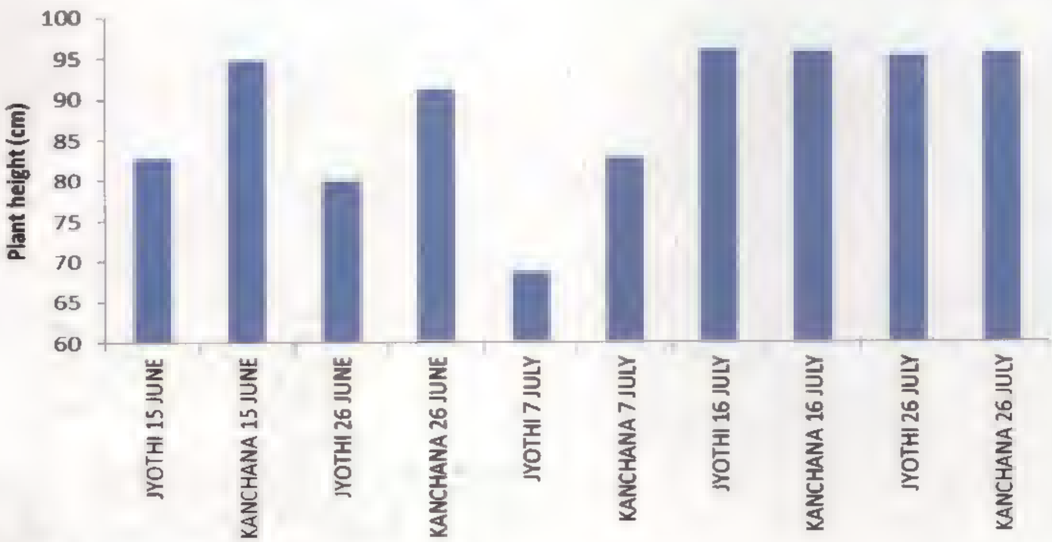

Fig 36. Plant height in wet land

The increase in height is mainly attributed by the high evening relative humidity. This is in agreement with the findings of Hirai *et al.,* 1989. This is also because of the less disease incidence in the crops planted on July 16th and 26th.

5.3.1.2 Number of tillers

Crops transplanted during 16th July and 26th July recorded the highest number of tillers per plant (25.6) for Jyothi and Kanchana respectively. The number of tillers per plant was significantly affected by both dates of planting and variety. This is mainly due to low light intensity up to flowering in kharif, imposed a ceiling on tillering and dry matter production (Venkateswarlu *et al.,* 1977).

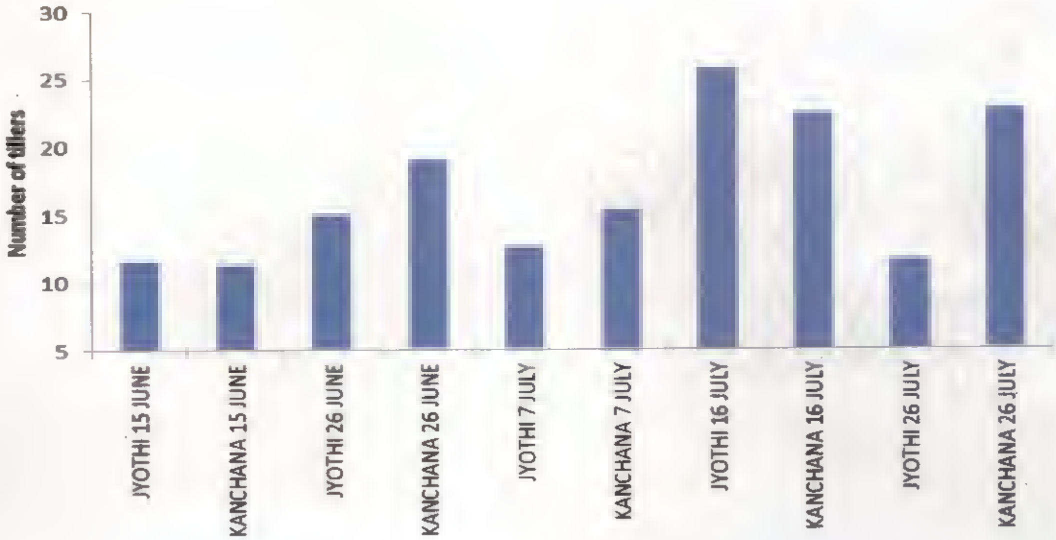

Fig 37. Number of tillers in wet land

5.3.1.3 Leaf Area Index (LAI)

The effect of weather on LAI significantly varied with the variety. Kanchana was recorded maximum leaf area index (0.93) when on planted 26th July and minimum leaf area index was recorded 0.79 by the crops planted on 26th June . This is mainly because of more optimum weather conditions particularly solar radiation, relative humidity and temperature obtained by the crop planted on 26th July. This is on par with the findings of Hirai *et al.,* 1989.

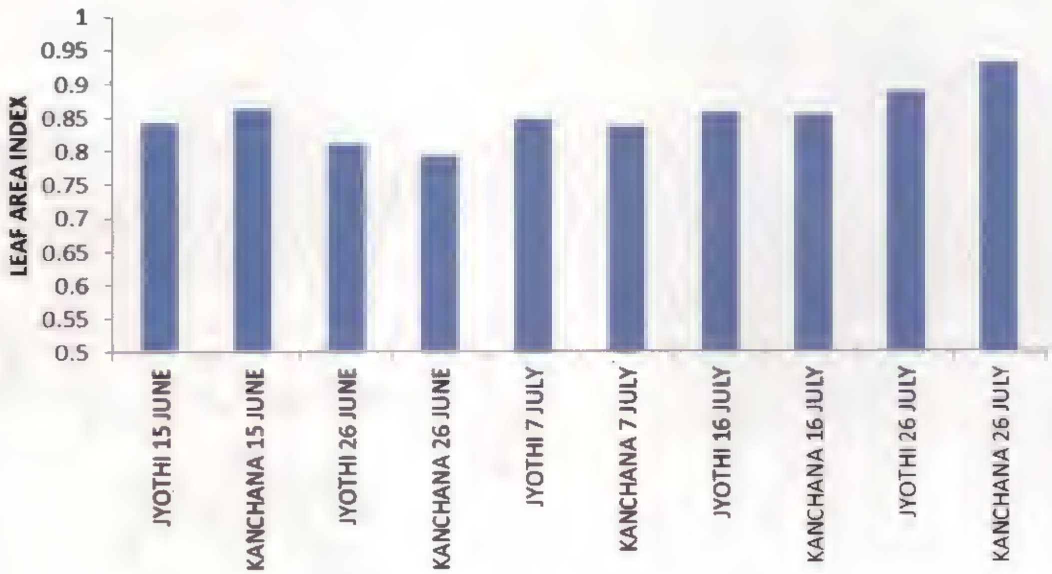

Fig 38. Leaf Area Index in wet land

5.3.2 Upland

5.3.2.1 Plant height

In all the dates of sowing variety Kanchana recorded highest plant height (62.6cm) compared to Jyothi. The effect of weather on plant height varied significantly with the varieties.

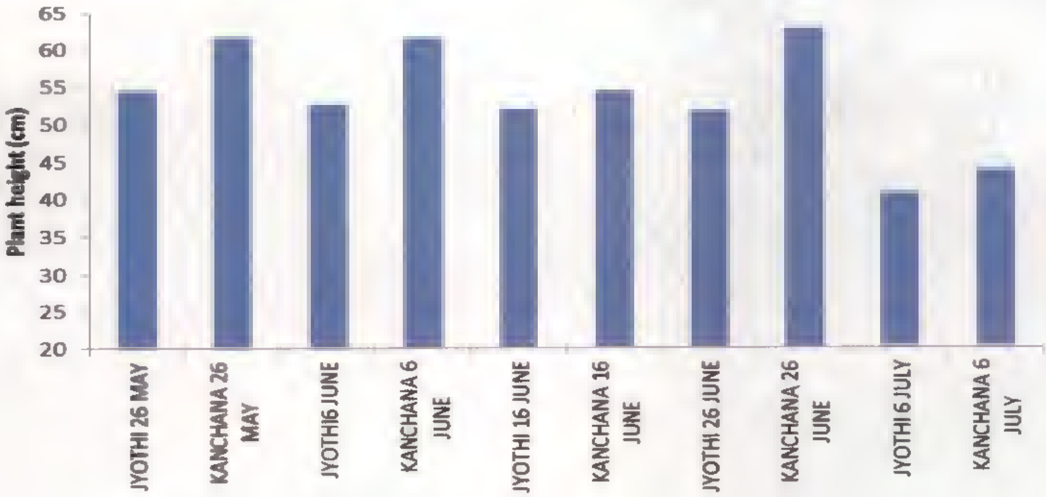

Fig 39. Plant height in upland

5.3.2.2 Number of tillers

Crops sowing during 6th June recorded the highest number of tillers per plant for variety Kanchana (11) and the minimum was recorded by variety Jyothi (2.3) when sowing on 6th July.

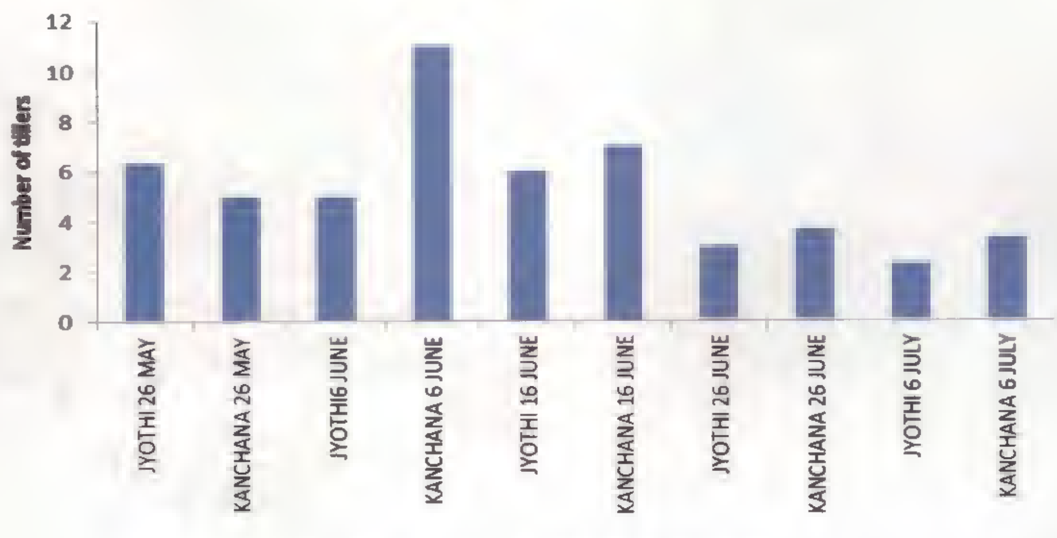

Fig 40. Number of tillers in upland

5.3.2.3 Leaf area index (LAI)

The effect of weather on LAI significantly varied with the variety. Kanchana was recorded maximum leaf area index (0.82) when on sowing 26th June and minimum leaf area index was recorded 0.68 by the crops sowing on June 16th and May 26th respectively for Kanchana and Jyothi respectively.

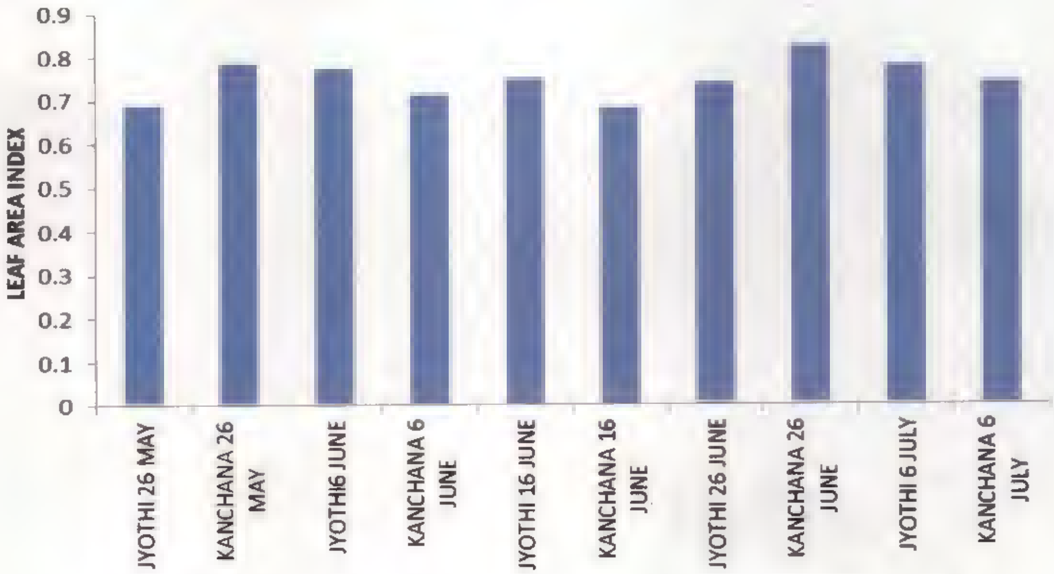

Fig 41. Leaf area index in upland

In general it can be noticed that late transplanted crops showed a high growth and development status compared to early crop. This is mainly due to high temperature that provides more tiller buds and thereby increases tiller count. The optimum temperature for vegetative growth in rice is 25-31.0°C. The rate of tillering and increase in height in rice tends to increase as the temperature increases. When light is adequate, higher temperature increases tiller number. In High rainfall during the active growth period resulted in taller plants and rice requires a fairly high degree of humidity for proper growth. RH of 80-85 per cent is ideal for shoot growth. All these above results were on par with the finding of Sreenivasan (1985), Kamalam *et al.* (1988) and Hirai *et al.*, 1989.

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5.4 YIELD ATTRIBUTES

5.4.1 Wet land

5.4.1.1 Number of panicles

Among all dates of planting Variety Kanchana transplanted on 26th June recorded significantly highest number of panicles (16) but interaction between the treatments is not significant. Reduction in panicle number is mainly attributed by high temperature (Ghosh et al., 1983)

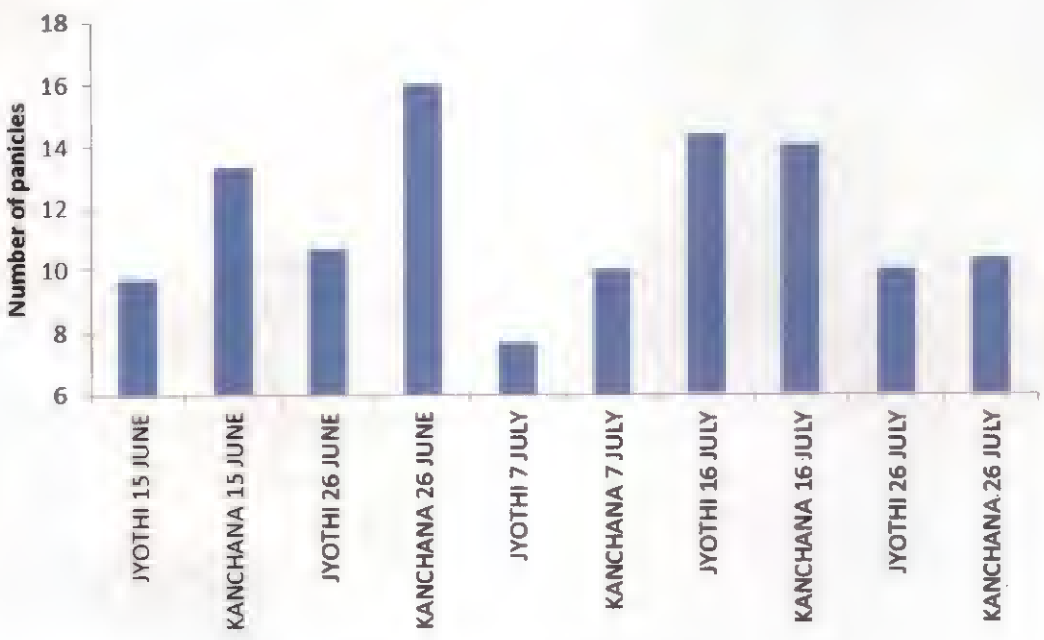

Fig 42. Number of panicles

5.4.1.2 Number of spikelets

. The variety Jyothi was recorded maximum number of spikelets (9) when planted on 26th June and 16th July.The number of spikelets per plant was significantly varied with varieties. High temperature and low humidity during the heading stage is mainly responsible for the variations in spikelet number. This finding is on par with the findings of Osada *et al.,* 1973.

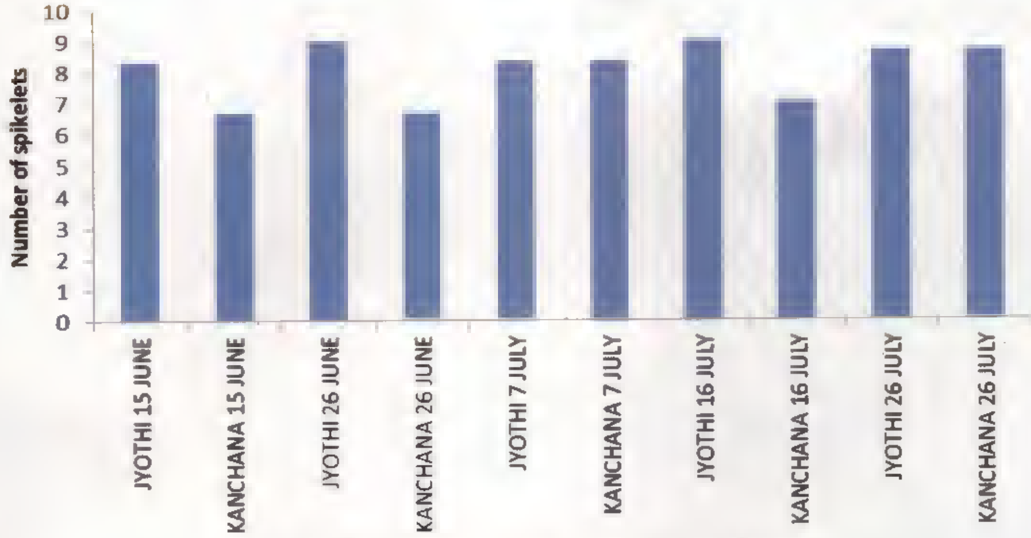

Fig 43. Number of spikelets per panicle

5.4.1.3 Number of grains per panicle

The variety Jyothi recorded highest number of grains per panicle (103) and minimum was recorded by the variety Kanchana (74.7) in 26th June transplanted crop. The number of grains per panicle was significantly varied with varieties. High maximum temperature during the reproductive period might be the reason for lesser number of filled grains. This is in agreement with the findings of Yoshida (1978) and Kovi *et al.*, (2011).

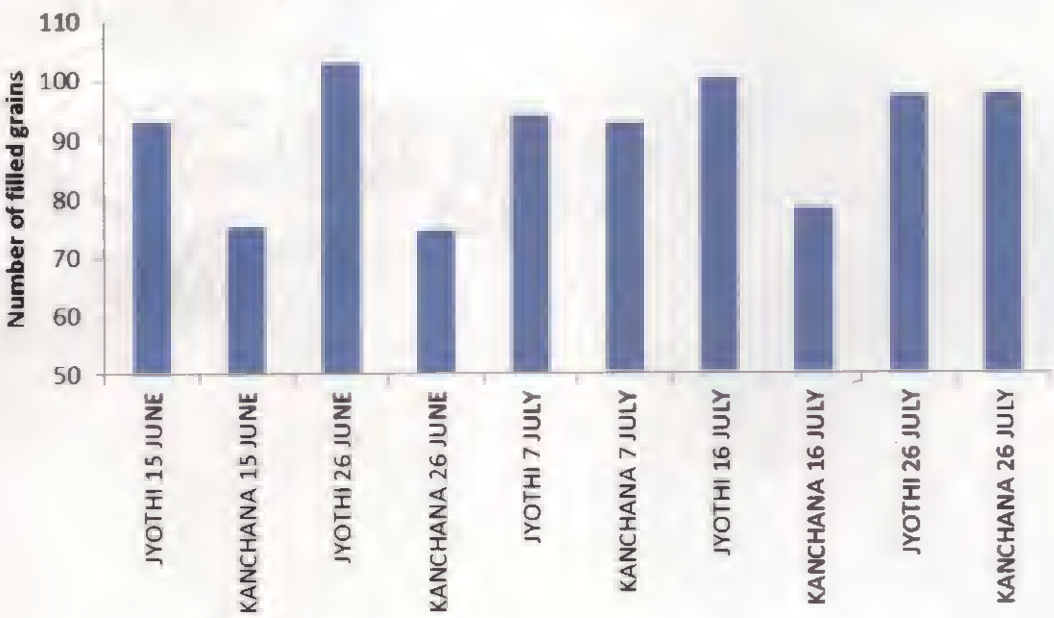

Fig 44. Number of grains per panicle

5.4.1.4 1000 grain weight

The maximum 1000 grain weight (31.13gm) was recorded by variety Kanchana transplanted on 26th June and the minimum 1000 grain weight (28.36gm) was recorded by variety Jyothi transplanted on 26th July.

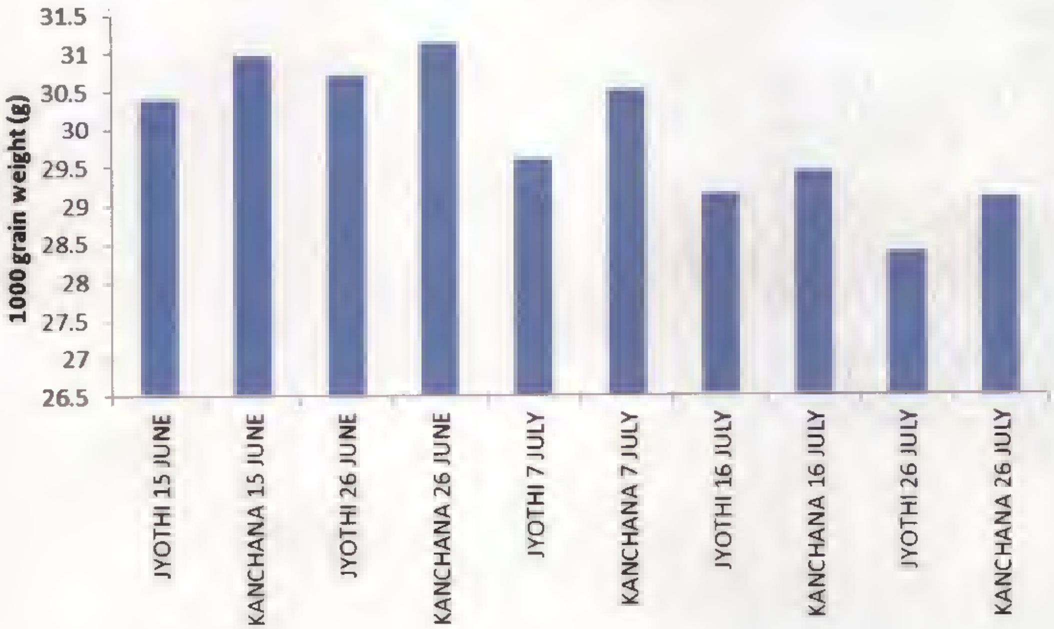

Fig 45. 1000 Grain weight (g)

5.4.1.5 Grain yield

The maximum grain yield (2782.4 kg/ha) was recorded by the variety Jyothi transplanted on 16th July and it also recorded minimum grain yield (1399.2 kg/ha) in 7th July transplanted crop. The effect weather on grain yield was significant.

This mainly due to the fact that when temperature during ripening stage was relatively low the grain yield will be higher, an effect attributed to a more favourable balance between photosynthesis and respiration. Temperature influenced the ripening of rice in two ways-first, low temperature favoured an increase in grain weight and second, low daily mean temperature increased the length of ripening period. This is in confirmation with the findings of Tashiro and Wardlaw, 1989

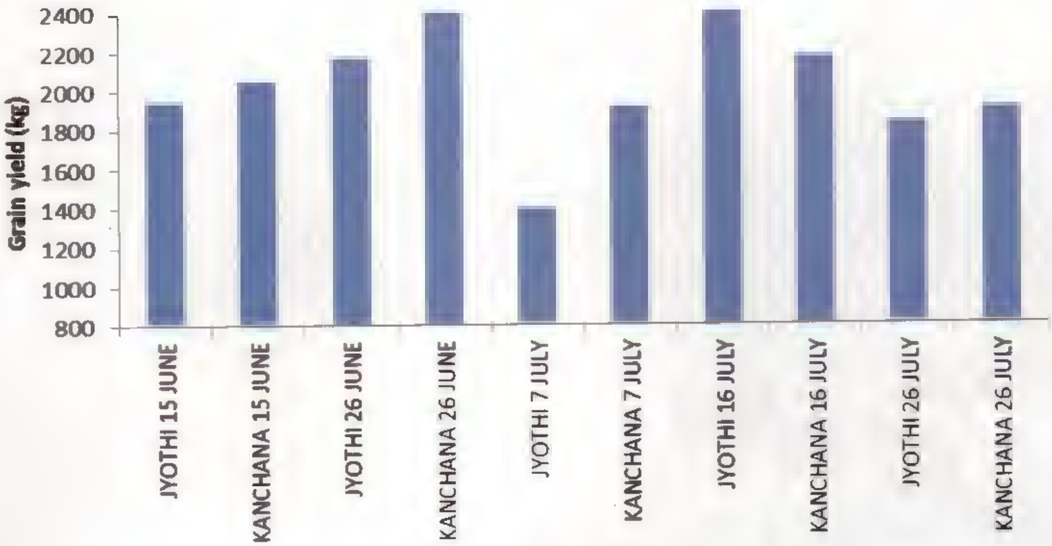

Fig 46. Grain yield (kg per hectare)

The above findings are mainly due to fact that rice is most sensitive to high temperatures at heading. The high sterility may be attributable to failure of fertilization caused by the imperfect splitting of anther or wilting of stigma induced by high temperature and low humidity. It can be observed that the reduced yield was a result of poor pollen shedding as well as inadequate pollen growth in temperature above about 34 °C. The day time temperature of above 32° caused sterility. Generally grain yield was higher when temperature during ripening stage was relatively low, an effect attributed to a more favourable balance between photosynthesis and respiration. Temperature less than 28 °C during grain filling increased its duration and seed size the above observations are on par with the findings of Osada *et al.,* (1973), Mackill *et al.,* (1982) and Tashiro and Wardlaw, (1989). High temperature decreased the grain yield significantly due to the reduction of percentage of ripened grains. It shows that 1000 grain weight is less affected by high temperature rather than percentage of ripened grains. The solar radiation and temperature during reproductive stage (before flowering) had the greatest influence on rice yield because they determine the number of spikelets m^{-2} these findings are in agreement with findings of Yoshida and Parao (1976). It was also noticed that the most critical sunlight requiring period was around the heading stage. Reduced solar radiation during this stage inhibited panicle heading. Low grain yield under reduced light intensity is attributed to the cumulative influence of fewer panicles m^{-2} and grain number $panicle^{-1}$ and lower test weight and higher percentage of spikelet sterility.

Variability in rainfall is associated with an untimely cessation at this stage, the yield reduction is severe. The study observed a positive significant correlation between grain yield and total rainfall. Among the rice growth stages, panicle initiation stage is more sensitive to moisture stress.

Relative humidity plays a major role in altering the days to first flowering. The increased transpiration may influence the physiological process affecting the yield. It was the most significant meteorological factor affecting spikelet fertility in rice followed by mean temperature.

5.4.2 Upland

Under upland condition the sheath blight disease incidence was not observed even after artificial inoculation. But due to heavy blast infestation the crop perished prematurely.

5.5 Incubation period

The effects of weather and varieties on sheath blight incubation period were significant, but interaction between the treatments is not significant. Minimum duration of incubation was recorded in Jyothi in the 26th June planted crop and maximum incubation period was recorded by Kanchana in the 26th July crop.

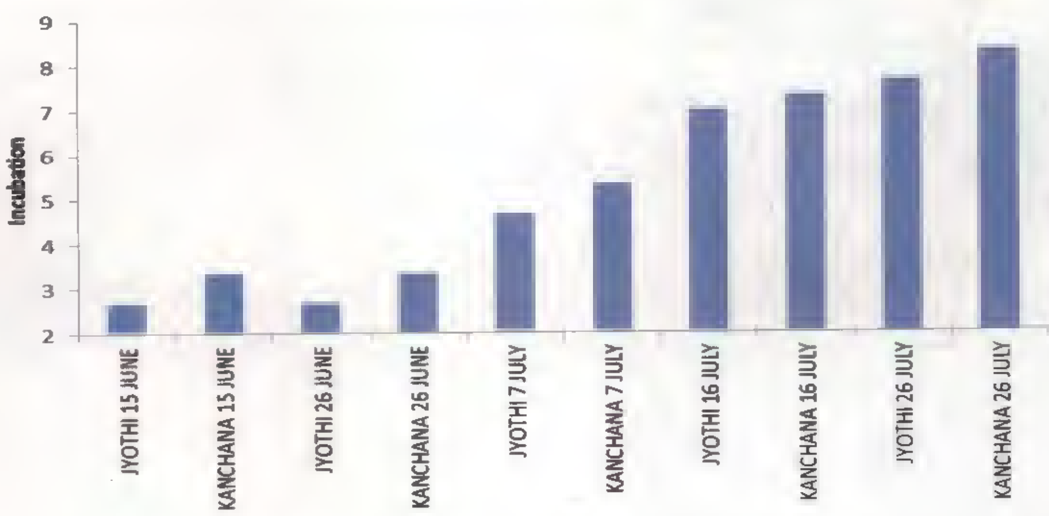

Fig 47. Incubation Period (days) of Sheath blight disease in rice

5.6 Sheath blight severity

The maximum sheath blight severity of jyothi (80.9%) was recorded in 16th July transplanted crop and the minimum (56%) was observed when planted on 26th July. The maximum sheath blight severity of Kanchana (54.16%) was recorded in 15th June transplanted crop and the minimum (42.9%) was observed when planted on 26th July . The study shows that variety Kanchana was more tolerant to sheath blight incidence.

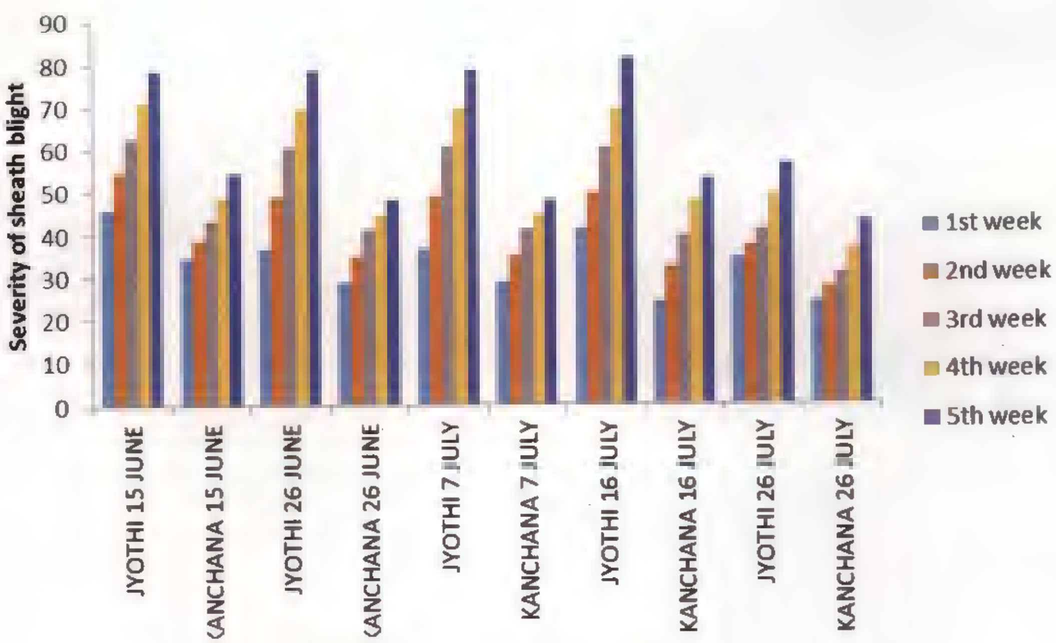

Fig 48. Sheath blight severity

5.7 REGRESSION MODELS FOR PREDICTION OF SHEATH BLIGHT INCIDENCE

The incidence of sheath blight disease in rice results from favourable interaction between weather, host and pathogen. The major weather parameters determining the incidence are temperature, solar radiation, relative humidity and rainfall. Multiple regression equations were developed for the forewarning the sheath blight incidence in rice. As the susceptibility to sheath blight incidence vary with variety separate equations were developed for the two important ruling varieties in Kerala ie., Jyothi (susceptible) and Kanchana (tolerant).

Regression models for Jyothi

Disease Incidence = 320.061 – 11 AAVT + 0.011 $MAXSR_{11}$ - 0.041 $MINRH_9$ + 0.096 HRF_2 R^2=0.741

Where, AAVT=Mean average temperature, $MAXSR_{11}$=Maximum solar radiation at 11th day, $MINRH_9$=Minimum relative humidity at 9th day and HRF_2=Average rainfall of 7 to 12 days after inoculation

Regression models for Kanchana,

Disease incidence = 160.52 - 5.85 AAVT + 0.028 $MAXSR_{11}$ + 0.056 $MINRH_9$-0.098 HRF_2 R^2=0.759

Where, AAVT=Mean average temperature, $MAXSR_{11}$=Maximum solar radiation at 11th day, $MINRH_9$=Minimum relative humidity at 9th day and HRF_2=Average rainfall of 7 to 12 days after inoculation

EPIRICE MODEL VALIDATION

EPIRICE is a generic epidemiological model that can be parameterized to address any specific rice disease (Savary *et al.,* 2012). It was recently developed as a general model framework for fungal, viral, and bacterial diseases at different levels of hierarchy in a crop canopy (leaves, sheaths, entire plants) depending on the nature of the disease. Thus, its structure was designed to be as simple as possible, involving a few state variables and a limited number of core parameters and weather variables. Due to its generality and structural simplicity, EPIRICE can be used to address different biological interactions of rice plants caused by various pathogens.

The observed and simulated sheath blight disease severity of variety Jyothi has presented in the Fig 49. RMSE for Jyothi prediction is 0.248.This shows that the predicted sheath blight severity was in good agreement with the observed values. So this model can be used for forecasting the rice sheath blight severity under Kerala conditions.

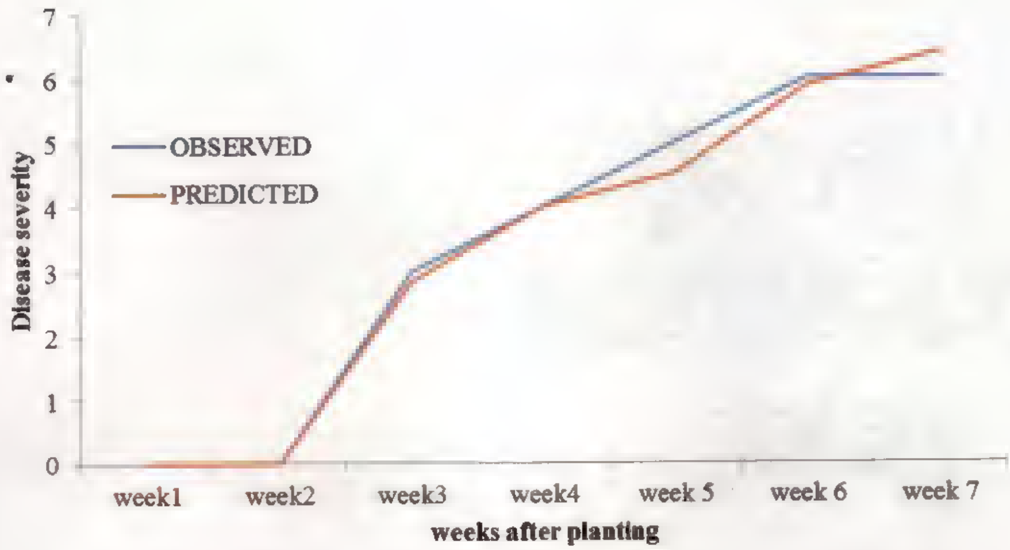

Fig 49. Observed and simulated sheath blight disease severity of variety Jyothi

5.8 IMPACT OF CLIMATE CHANGE ON SHEATH BLIGHT INCIDENCE

The future climatic projections have taken from Ensemble of 17 General Circulation Models (GCMs). The future climate data has been incorporated into disease simulation model-EPIRICE and predicted the future disease incidence possibility of sheath blight for the years 2030, 2050 and 2080 as per RCP 4.5. It can be observed from the study that the severity of sheath blight is going to increase in future and the southern districts will be more disease prone. This is mainly because of increased projected rainfall activity during the future climatic conditions.

Climate change will certainly affect the development of rice diseases. Because the magnitude and range of these changes is very uncertain, however, prediction of climate change effects on these pathosystems is difficult and speculative. Although speculative, published data has suggested potential problems that may occur under a modified climate. Experimental research on a diverse range of disease systems has improved our comprehension of potential climate change impacts. Modeling approaches have been adopted more frequently for impact assessment, given the multitude of atmospheric and climatic factors, the possible changes in scenarios, and the number of disease systems.

SUMMARY

An experiment was conducted at Regional Agricultural Research Station, Pattambi to study the effect of weather on sheath blight incidence in rice and predicting potential epidemics under various climate change scenarios, with two varieties, Jyothi and Kanchana.

The salient findings are summarized as follows:

1. Crops transplanted June showed a higher disease incidence compared to other dates of planting
2. Variety Jyothi is more susceptible to sheath blight incidence compared to Kanchana.
3. The crops planted on June 15th recorded the highest disease incidence of 45.77% in Jyothi and 34.43% in Kanchana.
4. The least disease incidence was observed (32.33% for Jyothi and 23.37% for Kanchana) incrops planted on July 26th
5. The maximum severity recorded for Jyothi and Kanchana was 78.43% and 54.17% respectively.
6. Variety Jyothi recorded the highest plant height compared to Kanchana. The crops planted on July 16th and 26th recorded the maximum plant height for both the varieties and are on par.
7. Crops transplanted during 16th July and 26th July recorded the highest number of tillers per plant (25.6) for Jyothi and Kanchana
8. The effect of weather on LAI significantly varied with the variety. Kanchana was recorded maximum leaf area index (0.93) when on planted 26th July and minimum leaf area index was recorded 0.79 by the crops planted on 26thJune
9. Among all dates of planting Variety Kanchana transplanted on 26th June recorded significantly highest number of panicles (16)
10. The variety Jyothi was recorded maximum number of spikelets (9) when planted on 26th June and 16th July.The number of spikelets per plant was significantly varied with varieties.

11. The variety Jyothi recorded highest number of grains per panicle (103) and minimum was recorded by the variety Kanchana (74.7) in 26th June transplanted crop. The number of grains per panicle was significantly varied with varieties.
12. The maximum 1000 grain weight (31.13gm) was recorded by variety Kanchana transplanted on 26th June and the minimum 1000 grain weight (28.36gm) was recorded by variety Jyothi transplanted on 26th July
13. The maximum grain yield (2782.4 kg/ha) was recorded by the variety Jyothi transplanted on 16th July and it also recorded minimum grain yield (1399.2 kg/ha)in7th July transplanted crop. The effect weather on grain yield was significant.
14. Under upland condition the sheath blight disease incidence was not observed even after artificial inoculation. But due to heavy blast infestation the crop perished prematurely.
15. The effects of weather and varieties on sheath blight incubation period were significant
16. Minimum duration of incubation was recorded in Jyothi in the 26th June planted crop and maximum incubation period was recorded by Kanchana in the 26th July crop
17. The maximum sheath blight severity (80.9%) was recorded by Jyothi in 16th July transplanted crop and the minimum (42.9%) was observed in Kanchana when planted on 26th July.
18. Multiple regression equations was predicted the disease incidence with good accuracy in both the varieties.
19. EPRICE model was validated and RMSE for Jyothi prediction is 0.248.This shows that the predicted sheath blight severity was in good agreement with the observed values. So this model can be used for forecasting the rice sheath blight severity under Kerala conditions.
20. The future carbon dioxide concentrations and climate data has been incorporated into disease simulation model-EPIRICE and predicted the future

disease incidence possibility of sheath blight for the years 2030, 2050 and 2080 in all the 14 districts of Kerala.

21. The impact of climate change on sheath blight severity in the various *districts* of Kerala showed an increasing trend. Southern districts are highly prone to sheath blight disease as compared to northern districts. Considering the major rice growing tracts of Kerala Alappuzha will be more prone to sheath blight than Palakkad and Thrissur.

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EFFECT OF WEATHER ON SHEATH BLIGHT INCIDENCE IN RICE AND PREDICTING POTENTIAL EPIDEMICS UNDER VARIOUS CLIMATE CHANGE SCENARIOS

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ABSTRACT OF THE THESIS

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Several pathogenic diseases have been found to occur on the rice crop resulting in extensive damage to the grain yield and straw yield. The crop subjected to attack by many diseases caused by fungi, bacteria, viruses and nematodes which cause annual loss to the tune of 12-15 per cent of the total production. Major rice diseases under Kerala conditions are bacterial leaf blight, sheath blight and blast. Among these diseases, the sheath blight which was earlier considered to be a minor disease is now causing a major threat to the rice cultivation. Sheath blight is an important soil-borne fungal disease which causes 10-30 per cent yield loss (Xie *et al.,* 2008). It may reach up to 50 per cent during favorable years especially when susceptible cultivars are grown (Prasad and Eizenga 2008). The disease manifests initially as water soaked lesions on sheaths of lower near water level.

Sheath blight, caused by *Rhizoctonia solani* Kuhn has become an important disease of rice, especially in intensive production systems. From the epidemiological viewpoint, rice sheath blight shares characteristics with other diseases caused by *Rhizocionia spp.* In that the primary inoculums is mainly soil-borne while secondary inoculums does not consist of spores, but is predominantly in the form of mycelia strands produced by primary lesions that run on the surface of leaves and sheaths to establish new lesions. As a result, epidemics usually exhibit a very strong spatial aggregation (Savary *et al.,* 1995).

Objectives of the study were to Study the effect of various weather parameters and climate change on incidence and development of sheath blight disease of rice and evaluation of disease forecasting models for sheath blight of rice. The field experiments were conducted during May 2016 to October 2016 at the Regional Agricultural Research Station of the Kerala Agricultural University at Pattambi, Palakkad district, Kerala.

Crops transplanted June showed a higher disease incidence compared to other dates of planting. Variety Jyothi is more susceptible to sheath blight incidence compared to Kanchana. The effect of weather on LAI significantly varied with the variety. The number of grains per panicle was significantly varied with varieties. The effect weather on grain yield was significant. Under dry land condition the sheath blight disease incidence was not observed even after artificial inoculation. The effects of weather and varieties on sheath blight incubation period were significant.

EPRICE model developed by Savary *et al.*, (2012) was used to forecast the disease severity of sheath blight disease in rice after transplanting. The model works on daily weather parameters particularly rainfall, maximum and minimum temperature, morning and afternoon relative humidity. RMSE for Jyothi prediction is 0.248.This shows that the predicted sheath blight severity was in good agreement with the observed values. So this model can be used for forecasting the rice sheath blight severity under Kerala conditions.

The future climatic projections have taken from Ensemble of 17 General Circulation Models (GCMs). The future carbon dioxide concentrations and climate data has been incorporated into disease simulation model-EPIRICE and predicted the future disease incidence possibility of sheath blight for the years 2030, 2050 and 2080 in all the 14 districts of Kerala. The impact of climate change on sheath blight severity in the various districts of Kerala showed an increasing trend. Southern districts are highly prone to sheath blight disease as compared to northern districts. Considering the major rice growing tracts of Kerala Alappuzha will be more prone to sheath blight than Palakkad and Thrissur.