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

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(2011-20-125)

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VELLANIKKARA, THRISSUR – 680656

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THESIS

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ACADAMY OF CLIMATE CHANGE EDUCATION AND RESEARCH

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

DECLARATION

I hereby declare that the thesis entitled **"Effect of weather on leaf blast 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

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CERTIFICATE

Certified that this thesis entitled **"Effect of weather on leaf blast incidence in rice and predicting potential epidemics under various climate change scenarios"** is a record of research work done independently by Ms. Aswathi, N.R (2011-20-125) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associate ship with any other person.

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We, the undersigned members of the advisory committee of Ms. Aswathi, N.R a candidate for the degree of **BSc-MSc (Integrated) Climate Change Adaptation** agree that the thesis entitled **'Effect of weather on leaf blast incidence in rice and predicting potential epidemics under various climate change scenarios.'** may be submitted by Ms. Aswathi, N.R (2011-20-125), in partial fulfillment of the requirement for the degree.

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Aswathi, N.R

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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

Agriculture is always susceptible to vagaries of weather events and climate conditions. Despite technological advances such as improved crop varieties and irrigation systems, weather and climate are important factors, which play a significant role to agricultural productivity. The impacts of climate change on agriculture are global concerns and for that matter India, where agriculture sector alone represents 23 per cent of India's Gross National Product (GNP) and the livelihood of nearly 70 per cent of the population is exposed to a great danger, as the country is one of the most vulnerable countries due to climate change. One of the most remarkable characteristics of climate change is the increase in temperature, so it has been mainly recognized as 'global warming'. This warming has been attributed to the enhanced greenhouse effect produced, among others, by the increased amounts of carbon dioxide from the burning of fossil fuel since the Industrial Revolution (Houghton, 2004).

The rate of global warming is expected to continue increasing if no mitigation efforts take place to reduce the carbon intensity of the world economy and the consequent emission of green-house gases (Raupach *et al.*, 2007). Agricultural production, and thus global food security, is directly affected by global warming (Ainsworth and Ort, 2010).

Rice production plays an essential role in feeding the world's population and will continue to be in the future, because rice is the most important global staple food in many countries. The production of rice, along with other agricultural crops, will be impacted by climate change. There is still great uncertainty about how climatic and atmospheric changes will affect the future productivity of food crops. Major future impacts of climate change are expected on food security and agricultural incomes, including shifts in production areas across the world.

In addition to affecting rice production, climate change may alter pathogen dissemination and development rates, and modify the resistance, growth and metabolism of host plants. The geographical distributions of pathogens are very likely to change, and losses can be expected, in part due to altered effectiveness of control strategies. Thus climate change is a serious threat to agriculture because it can lead to significant changes in the occurrence and severity of plant diseases. All phases of the disease cycle, from the germination of spores to the development of lesions, are considerably influenced by climatic factors. The most important climatic factors are temperature and precipitation. These factors may be modified by the coming climate changes. Recent research indicates that the monsoon has changed in two significant ways during the past half-century: it has weakened (less total rainfall during June–September; Ramanathan *et al.* 2005; Dash *et al.* 2007), and the distribution of rainfall within the monsoon season has become more extreme (Goswami *et al.* 2006; Dash *et al.* 2009).

Rice blast caused by *Pyricularia oryzae* an important disease of rice worldwide is known to cause severe yield losses in rice production area where high inputs of nitrogen fertilizer and favourable climatic conditions occur. Sometimes the yield losses reach as high as 50% in upland cultivations.

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 blast disease of rice
2. Evaluation of disease forecasting models for blast of rice.

2.1 RICE

Rice (*Oryza sativa* L.) is one of the important staple foods of the world and is consumed by 50% of the world population (Luo *et al.,* 1998).

Historically rice was cultivated 10000 years ago in the river valleys of south and south East Asia. Since it is served as the most important foods for people. Since rice provide 21% of energy and 50% of protein for human Zibaee (2013).

2.2 CLIMATE CHANGE

The effects of elevated CO_2 concentration on plant diseases either positive or negative, although in a majority of the cases disease severity increased (Manning *et al.,* 1995). Kobayashi *et al.,* 2006 observed the effect of increased concentrations of CO_2 has also been evaluated on two important diseases of rice, namely blast (*Pyricularia oryzae*) and sheath blight (*Rhizoctoniasolani*) and rice plants were found more susceptible to injury. Due to climate change, variation of the temperature and precipitation pattern will alter the growth stage, development rate and pathogenicity of infectious agents, and the physiology and resistance of the host plant (Chakraborty *et al.,* 2006).

Weather has a very important role to play in the appearance, multiplication and spread of the blast fungus (Rakesh Kaundal, 2006). Bevitori (2014) stated that climate change is a serious disaster to agriculture it will cause significant changes in the occurrence and severity of plant diseases .climate change may alter pathogen dissemination and development rates, and modify the resistance, growth and metabolism of host plants.

2.3 DISEASES

Diseases are liable for losses of at least 10% of global food production, representing a danger to food security (Strange & Scott, 2005). The close relationship between the environment and diseases advises that climate change will cause modifications in the current phytosanitary scenario. The impacts can be positive, negative or neutral, since there can be a decrease, an increase or no effect on the different pathosystems, in each region.

2.4 DISEASE CYCLE

The standard disease triangle establishes the conditions for disease development, i.e. the interaction of a susceptible host, a virulent pathogen and a favorable environment. This relationship is evidenced in the definition of plant disease itself. A plant disease is a dynamic process in which a host and a pathogen intimately related to the environment are mutually influenced, resulting in morphological and physiological changes (Gaumann, 1950).

The classic disease triangle identifies the role of physical environment in plant disease as no virulent pathogen can induce disease on a highly susceptible host if weather conditions are not favorable. Weather influences all stages of host and pathogen life cycles as well as the development of disease. Relationships between weather and disease are normally used for forecasting and managing epidemics, and disease severity over a number of years can fluctuate according to climatic variation (Coakley, 1979; Scherm and Yang, 1995).

2.5 RICE- BLAST DISEASE

Magnaporthe oryzae infects and produces lesions on the following parts of the rice plant: leaf (leaf blast), leaf collar (collar blast), culm (culm nodes), panicle neck node (neck rot) and panicle (panicle blast). In leaf blast initial lesions/spots are white to gray-green with darker borders. Older lesions are white-grey, surrounded with a red-brown margin and are diamond shaped (wide Centre and pointed toward either end). Lesion size is commonly 1-1.5 cm long and 0.3-0.5 cm wide. During favorable conditions, lesions can coalesce and kill the entire leaf. In collar rot, lesions are located at the junction of the leaf blade and leaf sheath and can kill the entire leaf (Padmanabhan, 1974; Bhatt and Singh, 1992; Manibhushanrao, 1994).

According to Yoshida1983; Koutroubas and Ntanos (2003) Rice grain yield is the final product of a combination of different yield components, which varies with the location, season, crop duration, and cultural system. Both yield components evaluated in our study (productive tillers per plant and grain weight) contributed to the differences in grain yield obtained between the disease treatments. Inoculation caused a reduction in grain weight compared to the non-inoculated plants. The negative effect of the disease on grain weight was also confirmed by the negative correlations detected between this trait and leaf and neck blast. These results could be explained taking into account the specific nature of blast disease in rice. Infection of plants during the generative growth stages mainly results in panicle or neck infections that may cause necrosis of the plant neck and incomplete grain filling. Leaf blast lesions reduce the net photosynthetic rate (Bastiaans, 1991).

The pathogen can be widely seen on leaves, causing leaf blast during the vegetative stage of growth, or on neck nodes and panicle branches during the reproductive stage, causing neck blast (Bonman, 1992).

Leaf blast that cause the death of young plants up to the tillering stage, is characterized by the appearance of diamond shaped lesions on the leaves. The significant impact on yield is registered when the pathogen attacks the junction of the leaf blade and sheath, causing the typical brown "collar rot" symptom. Finally, infections just below the panicle ("panicle blast") can be very injurious to the crop and cause incomplete grain filling and poor milling quality (Webster and Gunnel, 1992).

According to Torres and Teng (1993) the larger disease level of the inoculated plants was found to have a shortening effect, causing a mean plant height reduction of 5.5% in 2002 and 8% in 2003 compared to the non-inoculated plants. That is a negative effect of blast disease on plant height proportional to disease level.

The disease leads to a reduction in canopy photosynthesis mainly due to an adverse effect of lesions on leaf photosynthetic rate and also to shading by dead leaf area resulting from disease induced senescence (Bastiaans and Kropff, 1993).

Torres and Teng (1993) reported that neck blast infection was directly related to yield Loss, while it was less reduced by collar infections.

Rice blast, caused by *Magnoporthe oryzae* is one of the most destructive diseases in cultivated rice, which is the staple food for one half of the world's population (Ford *et al.*, 1994; Talbot and Foster, 2001).

Rice blast is a major disease which is caused by the fungus, *Pyricularia grisea* (Cooke) Sacc. This affects the leaf, neck, collar, grain and nodal regions (Webster, 2000).

Candole *et al.*, (2000) reported that rough rice from blast-infected panicles be present drier and thinner than on blast-free panicles. Inoculation was also found to reduce the number of productive tillers per plant in both years. The reduction was proportional to the disease level such as the negative correlation found between leaf blast and number of productive tillers per plant.

2.6 OCCURANCE AND DISTRIBUTION

Dissemination of P. *grisea* by air is considered the most important means of long-distance transport in triggering outbreaks. Once spores are air-borne, temperature and relative humidity influence survival. In temperate regions, blast conidia survive in low temperature regimes (Abe, 1935; Ito and Kuribayashi, 1931).

Nitrogen fertilization and soil silica content have been shown to influence blast occurrence. Higher nitrogen increases susceptibility of rice to leaf and panicle infections (Beier *et al.*, 1959; Paik, 1975; El Refaei, 1977) but silica in soil inhibits blast incidence (Paik, 1975; Datnoff *et al.*, 1991; Teng *et al.*, 1991).

Several studies show that liberation of conidia over field and nursery plots have peaks during late night to early morning hours (Barksdale and Asai, 1961; Kato, 1974; Kingsolver *et al.*,. 1984; Ou *et al.*, 1974; Suzuki, 1975).

A study also demonstrated that release of conidia is possible even during noon time under controlled environments (personal communication, Henry Klein-Gebbinck, University of Alberta, Edmonton). Patterns of spore liberation are affected by several environmental factors. Among these factors, darkness, high relative humidity, wind speed above 3.4 m/s, and rainfall over 83 mm/day are most favorable for release (Kato, 1974; Kim, 1987; Kim and Kim, 1991; Kim and Yoshino, 1987; Kingsolver *et al.*, 1984; Nakamura, 1971; Ou *et al.*, 1974; Suzuki, 1975). Temperature, on the other hand, has

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both direct and indirect effects on liberation due to its contribution to dew formation.

Successful spore dispersal aided by wind and water (in the form of rainfall or irrigation) has a major impact on the potential of epidemics. Gradients of dispersion for blast conidia are influenced by dominant wind directions and speed (Kato, 1974; Suzuki, 1975).

The high rate of silica accumulation in lowland fields is the primary reason why blast was first reported a problem in upland rice cultivars. Reports have shown that lowland fields contain ample amounts of silica due to standing water in the paddy (Tschen and Yein, 1984).

In some blast-prone tropical and subtropical areas where continuous rainfall is experienced, heavy downpour may reduce the chance of a disease outbreak (Bhatt and Chauhan, 1985; Padmanabhan *et al.*, 1971; Surin *et al.*, 1991; Tsai, 1986; Venkatarao and Muralidharan, 1982). This may be due to washing-off of spores from leaves or to deposition of air-borne spores from rain scrubbing.

Wind direction and speed are important in blast epidemics because of their direct effect on the pattern of spore distribution across crop canopies and across rice fields (Koizumi and Kato, 1991; Suzuki, 1975). A logical representation of a spore profile along the canopy is a skewed probability density function curve rotated 90 degrees clockwise. The asymptote or the maximum number of spores is observed a few centimeters above ground and tapers-off with increasing canopy height (Koizumi and Kato, 1991; Suzuki, 1975).

. In Korea (Kim and Kim, 1991) and Japan (Suzuki, 1975), the peak of spore dispersion is observed immediately after heavy rainfall.

The physiological mechanism of blast inhibition by silica has been documented (Datnoff *et al.*, 1991; Volk *et al.*, 1958), but its inclusion in blast simulation models has not been done (Teng *et al.*, 1991).

In tropical regions, high temperature during the dry season does not affect P. *grisea* spores because of their ability to withstand temperature beyond 50-60° C (Kapoor and Singh, 1977).

The beginning of epidemics depends on the viability of initial inoculum. Blast conidia survive in plant residues, in living tissues, or in seeds (Jeyanandarajah and Seveviratne, 1991; Ou, 1985).

A logical representation of a spore profile along the canopy is a skewed probability density function curve rotated 90 degrees clockwise. The asymptote or the maximum number of spores is observed a few centimeters above ground and tapers-off with increasing canopy height (Koizumi and Kato, 1991).Similarly, few spores are observed just above the canopy because of wind turbulence.

Rice blast disease is distributed in about 85 countries in all continents where the rice plant is cultivated, in either paddy or upland conditions. The occurrence of rice blast can be seen wherever rice is cultivated, but the disease occurs with highly variable intensities depending on climate and cropping system. Environments with frequent and elongated dew periods and with cool temperature in daytime are more favorable to blast (Chiba *et al.,* 1996; Liu *et al.*, 2004).

2.7 FAVORABLE FACTORS FOR DISEASE DEVELOPMENT

In cool temperate rice areas in Japan, conidia and hyphae may survive on nodes of culms of a rice plant for more than a year; under dry indoor conditions, survival may exceed 1,000 days. Whereas, viability is lost under moist conditions in soil or compost (Ito and Kuribayashi, 1931).

Rate of lesion expansion is influenced by crop age (Kahn and Libby, 1954; Torres, 1986), lesion age (Calvero *et al.*, 1994; El Refaei, 1977; Kato, 1974), and three environmental factors: temperature, relative humidity, and dew period (Chiba *et al.*, 1972; El Refaei, 1977; Kato, 1974; Kato and Kozaka, 1974).

Another means of spore liberation is by strong winds and heavy rainfall. Both the immature and mature conidia are released by the shaking of infected leaves and panicles caused by wind velocities of over 3 or 4 m/s or rainfall of more than 83 mm/day (Kato, 1974; Kim, 1987; Kim and Kim, 1991; Kim and Yoshino, 1987; Nakamura, 1971; Ou *et al.*, 1974; Suzuki, 1975).

During epidemic development, temperature, relative humidity, and light influence the sporulation potential of lesions on both leaves and panicles. However, large numbers of spores are produced by 10- to 15-day old leaf blast lesions on plants at seedling stage regardless of environmental conditions (Asaga *et al*., 1971; El Refaei, 1977; Kato, 1974; Suzuki, 1975; Torres, 1986).

Latency of infection is affected by the age and degree of susceptibility of the cultivar, temperature, dew duration, and soil moisture. Linear (Yoshino, 1971, 1972) functions have been generated to show the negative effects of mean temperature on latent period.

Chiba *et al*.(1972) examined lesion growth at different temperatures and found out that exposure of plants to constant temperature of 25° C and 32° C and variable temperature of 32/20° C or 32/25° C in a 12-hour thermal period caused lesions to expand rapidly for the first 8 days and level off shortly thereafter. At 16° C and 20/16° C, the rate of lesion expansion was observed to be slow and constant over the 20-day period (Kato, 1974). Lesions expanded more slowly at 20° C and 25/16° C than at higher temperature regimes (Kato, 1974). Such a mode of liberation is observed even below the optimum microclimatic conditions if spores are mature (Yoshino, 1972).

Kato (1974) reported that a mean temperature of 19° C triggers spore release but Ono and Suzuki (1959) believed that release is not temperature-dependent. Other studies have shown that water deposits from dew formation affect spore detachment from conidiophores.

Kato (1974) and Suzuki (1975) reported that although heavy rainfall causes a decrease in blast occurrence, its contribution to dispersion and to providing moisture for infection significantly influence subsequent epidemic development.

Yoshino and Yamaguchi (1974) s reported that shaded plants have a tendency to undergo 'temporary susceptibility' and become infected. Unpublished laboratory studies at the Division of Entomology and Plant Pathology at the International Rice Research Institute (IRRI), however, revealed that sporulation among P. *grisea* isolates grown *in vitro* is enhanced by exposing cultures to continuous fluorescent light for 5-7 days. This practice of enhancing spore production should be explored further to unravel the real effects of solar radiation and sunshine duration on blast incidence.

Suzuki (1975) reported also that sporulation does not occur below 9° C or over 35° C and that, the optimum is 25-28° C. Likewise, production is rapid and occurs in shorter periods at 28° C than at 20-25° C (Suzuki, 1975).

Not much attention has been given to the effect of light on conidial formation. Suzuki (1975) reviewed the effect of light intensity on sporulation. From the review, light indirectly affects sporulation by directly affecting plant resistance. During cloudy days, assimilation of carbon decreases while soluble nitrogen accumulation in tissues increases. When this occurs, physiological activity and resistance of the host are reduced, making plants more vulnerable to pathogen attack.

.*In vivo,* conidia detach readily when water attaches to the junction between spores and conidiophores (El Refaei, 1977).

High relative humidity favors sporulation (El Refaei, 1977; Kato, 1974; Kato *et al.*, 1970; Suzuki, 1975). The most favorable humidity level is over 93%, but ample spore production is also possible at 85% (El Refaei, 1977). In panicle blast, sporulation of lesions is not as affected by relative humidity and spores are produced at 65% (El Refaei, 1977).

High sporulation potential is possible at 20° C (El Refaei, 1977; Kato, 1974; Kato and Kozaka, 1974; Kato *et al.*, 1970).

A subsequent decrease in spore production is seen with increasing temperature; at 15° C and above 29° C, the amount of spores produced by lesions is the same (El Refaei, 1977). Optimum sporulation was found at maximum- minimum temperature combinations of 25/20° C (El Refaei, 1977) and 25/16° C (Kato and Kozaka, 1974).

Physical and micro-climatic factors influence the life cycle of the pathogen, including spore liberation, transport, deposition, infection, latency, and sporulation (Hashimoto, 1981). Ou, (1985) suggested that the environmental conditions, especially relative humidity, are one of the most important factors affecting sporulation, release, and germination of blast.

Excessive nitrogen fertilizer will favor the disease development. Even though water stress also favors the sporulation of the pathogen. Blast is a major disease of both lowland and upland rice, under favorable conditions—for example, extended duration of leaf wetness, a high amount of nitrogen, and cool temperature. The severity of leaf blast epidemics is dependent on two phases of the disease cycle: infection (a deposited pathogen spore infects a healthy leaf site) and sporulation (the amount of spores produced by a blast lesion over an infectious period). Another important factor that determines the likelihood of a blast epidemic is related to the genotype of the rice variety that is cultivated, to the diversity of the pathogen that is present, and their interaction and also recorded that the optimum temperature for conidial germination of *Pyricularia oryzae* on a glass slide was 26-30 degrees C, at this temperature at least 4 h of leaf wetness was required Choi *et al.*, (1987).

The outbreak of blast disease is unpredictable, however, low temperature (about 22-25° C) and long dew appearance are considered as two important factors recognized to induce blast epidemic and environmental conditions have an effect on the incidence of rice blast (Singh, 1988; Chaudhary and Vishwadhar, 1988; Kim and Kim, 1991; Vijaya, 2003; Fukuda *et al.,* 2004; Monma et al., 2004; Iwadate *et al.*, 2004).

The optimum temperature for the mycelial growth of *P. grisea* is said to be 25 to 30° C (Awoderu *et al.,* 1991; Okeke *et al.,*1992; Arunkumar and Singh, 1995) while minimum temperature for the growth of the species is 80 – 90° C and thermal death point is 51 – 52° C (Nishikado, 1927; Yang *et al.,* 2011).

Teng *et al.*,(1991) also reported a decrease in latency of 10 days when temperature increases from 16° C to 27° C. Latency of blast lesions on rice spikelet's appears shorter than those present on panicle axes and neck nodes. At a temperature range of 13-33° C, latent periods are 5, 10, and 13 days, respectively for spikelet, panicle axes, and neck node lesions (Teng, 1993).

Levy *et al.,* 1993; Shen *et al.,* 1993; Zeng *et al.*, 2002; Mian *et al.*, 2003; Sonia and Gopalakrishna, 2005; Yang *et al.,* 2011)Genetic diversity of the rice blast fungus has also been reported by several workers.

For each phase of the life cycle, an optimum of environmental factors often exists for blast. Thus, subtropical or temperate environments, where canopy wetness is frequent along with moderate temperature, are particularly inducive to blast (Teng, 1994).

The occurrence of blast disease is increases with the decrease of temperature. But in the case of humidity, it was positively correlated with Paddy blast i.e. 0.95, 0.90, 0.99, 0.89, 0.93 respectively indicating an increase in disease incidence as humidity increased. Rainfall is also positively correlated with incidence of disease i.e. 0.80, 0.90, 0.88, 0.93 and 0.84 respectively (Shafaullah *et al.*, 2011).

2.8 DISEASE CYCLE

Appressorial formation occurs 6 hours after spores are incubated in moist conditions. Studies have shown a variation in range of temperatures required for formation of appressoria (Ito and Kuribayashi, 1931; Kato, 1974; Rahnema, 1978; Suzuki, 1969; Yoshino, 1972). Penetration and colonization of *P. grisea* in host tissues are influenced by both environment and the genetic relationship between host and pathogen. An incompatible relationship can be expressed even under optimum environmental conditions for disease. With P. *grisea* infecting both leaves and panicles, there is some evidence to suggest that a cultivar could be susceptible to leaf infection but not to panicle infection or vice-versa (personal communication, Bienvenido Estrada, International Rice Research Institute (IRRI)). In most production systems, such incompatibility is broken down as new pathogen races occur among pathogen populations. The impact of environment on infection is obvious once incompatibility is overcome.

Epidemics of blast disease result from favorable interaction between components of the pathosystem. Given a compatible host-pathogen relationship, crop growth and disease severity rely primarily on the existing ambient and edaphic environmental conditions. As in most air-borne pathogens, the life cycle of P. *grisea* is a series of overlapping monocycles that make up a polycyclic process during the growing season (Kato, 1974; Kingsolver *et al.*, 1984).

At 18-38° C, spore germination starts within three hours after spore deposition if host tissues are wet (Kato, 1974).

Each stage in the monocycle is affected by weather conditions, either directly (El Refaei, 1977; Kato, 1974; Kato and Kozaka, 1974; Suzuki, 1975; Yoshino, 1972) or indirectly through plant predisposition (Beier *et al.*, 1959; Gill and Bonman, .1988; Kahn and Libby, 1954), either immediately or with some time lag (Teng and Calvero, 1991).

Refaei (1977) examined appressorial formation *in vitro* along with varying relative humidity. He found that humidity has no direct relationship to appressorial formation, but a temperature range of 21-30° C is most favorable.

In *in vitro* studies, germination occurs 4-6 hours after deposition at 12° C; no germination occurs below 5° C (El Refaei, 1977). An increase in percent germination is also observed at an optimum temperature range of 20-25° C when spores are incubated in water. Spores that are subjected to dry periods prior to incubation in water have reduced viability (El Refaei, 1977; Kato, 1974; Suzuki, 1975).

The most probable source of perrenation and initiation of the disease look to be the grass hosts and early sown paddy crop. The disease cycle is short and most damage is caused by secondary infections. Air can carry the conidia for long distances. The conidia from these sources are carried by air currents to cause secondary spread. Most conidia are released at night in the presence of dew or rain. In the canopy of rice plants, newly developed leaves act as receptors for the spores (Du *et al.*, 1997).

2.9 CORRELATION AMONG CLIMATE FACTORS AND DISEASE PARAMETERS

Padmanabhan (1965) concluded that several meteorological factors such as minimum temperature, relative humidity and rainfall recorded at the Central Rice Research Institute CRRI Cuttack were related with the intensity of occurrence of blast each year. It was found that blast had occurred whenever there was as coincidence of low minimum temperature of 26° C or below along with the relative humidity of 90 per cent. Infection was higher when the minimum temperature was 24° C, 22° C or 20° C. It was suggested that, the occurrence of blast disease of rice could be forecast on the basis of meteorological factors viz., minimum temperature and relative humidity prevailing during the susceptible stages of the crop growth.

Bhatt (1992) reported that, the friendly factors for blast development include minimum temperature between 15-20° C with average temperature between 22-25° C, number of days with relative humidity > 90% with an average of > 50%, higher rainfall and more number of rainy days.

The correlation analysis of Disease Index with weather parameters showed that disease index of inoculated plants had a significant positive correlation with Maximum and Minimum relative humidity in all plantings. Maximum and Minimum temperatures were negatively correlated with Disease Index while the influence of Minimum temperature was insignificant on all plantings. Sunshine was also negatively correlated with Disease Index Reddy *et al.*,(2001).

Kapoor *et al.*, (2004) reported that, the rainfall and distribution varied significantly within growing seasons during 1979-1999. The average monthly temperature (18-28 °C) and RH (>90%) for more than 9 hours was within the optimum range for disease development. The overall rice blast development occurs from the second fortnight of August to first fortnight of September.

Henderson *et al.*, (2007) determined that, of the 12 weather variables examined from potato producing regions across Southern Idaho, two were significant in predicting disease occurrence in the logistic model. This model identified the hours of combined occurrence of positive temperature and humidity from April to May as significant predictors of disease occurrence.

The disease severity almost produced high correlation coefficients with monthly average relative humidity and total precipitation both of which dictate leaf wetness duration. Determination coefficient (R^2) values for each model were calculated and no value below 0.90 was observed which a good indicator is for forecast models Umer jamshed *et al.*, (2008).

Studies conducted at Rice Research & Regional Station, Khudwani,Anantnag on the effect of temperature (Sheikh Gulzar Ahmad *et al.*,(2011) revealed that, there was an important increase in dry weight of mycelia from 35.5 mg to 150.7 mg with an increase of temperature from 5° C to 30° C in case of rice blast. At 35° C, there was an important decrease of mycelia growth from 150.7 mg at 30° C to 94.5 mg at 35° C.

2.10 GENERATING FOREWARNING MODELS FOR PESTS ANDDISEASES OF RICE

Ou, (1980) stated that Forecasting techniques could be used to identify which years are conducive and whether fungicide application would be cost-effective or risky under those conditions. Rice farmers in most developing countries demand immediate results once disease problems are encountered. For this reason, fungicides are still the preferred control measure against diseases like blast and to counter this, better forecasting schemes for tropical conditions are solely needed.

WINDOW PANE was first applied in wheat-Puccinia stripe rust pathosystem in the Pacific Northwest in the United States (Coakley *et al.*, 1982, 1988). Using over 10-12 years of weather and disease data, various meteorological averages were generated and their correlation to disease examined using a time sequence search done at different segments of the growing season.

The regression model taking pest or 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).

WINDOW PANE also used in wheat-Septoria blotch pathosystem to generate models to be used in forecasting that disease (Coakley *et al.*, 1985). The Institute of Plant Protection at the Zhejiang Academy of Science developed a computerized forecasting system for rice blast in China (Zhejiang Research Group, 1986). Meteorological and biological factors affecting P. *grisea* and disease severity were related to field management, growing area, and cultivars to establish a data base. Models developed using stepwise regression analysis, were used to predict blast disease indices based on 20 meteorological, biological, and cultural factors. Predictive models also exist in Taiwan (Tsai, 1986).

Regression equations relating meteorological variables to leaf blast severity on the susceptible cultivar Training 67 were the basis for an early disease warning system in Taiwan. The models showed that average relative humidity, hours of relative humidity over 90%, and rainfall were important to predict blast severity (Tsai, 1986).

In Korea, Kim *et al*., (1987, 1988) developed a computerized forecasting system based on microclimatic events and then tested it in upland and lowland rice fields. A two-battery-operated microcomputer unit regularly monitored air temperature, leaf wetness, and relative humidity, which were used to predict blast development from estimates of blast units of severity (BUS). BUS was calculated based on algorithms employing logical functions that correlate disease to meteorological variables. The cumulative BUS was then used to predict disease progression.

In Japan, a computer model was developed by Uehara and co-workers (1988) to forecast the occurrence of P. *grisea* in relation to prevailing weather (meteorological) conditions. The model named BLASTAM, estimated leaf blast occurrence and development at the Hiroshima Prefecture from daily weather data supplied by the Automated Meteorological Data Acquisition System (AMeDAS). Leaf blast predictions were found to be nearly accurate but further improvements to estimate panicle blast development are needed.

Innovative approaches to rice blast forecasting that consider several meteorological factors occurring during or ' before the growing season can be explored to predict disease outbreaks with accuracy. Methodologies developed from other pathosystems offer new insights for predictive models for blast in tropical and subtropical rice areas. One area of interest is the use of the WINDOW program (Coakley, 1988; Coakley *et al*., 1982, 1985, 1988).

Bowers and Mitchell,(1988); Bowers *et al*., (1990) using the technique to forecast blast, path analysis can identify the kind of influence (direct or indirect) weather factors may exert on disease, in a way revoking or supporting previously reported relationships. As an example, precipitation frequency and degree-day periods were previously reported to be important weather factors in pepper-Phytophthora blight pathosystem. With the use of path analysis, however, these factors were found not to exert any influence at all on disease progression). They found total rainfall (which was also observed to be indirectly influencing other unrelated weather factors such as temperature) to be the most important weather factor influencing blight epidemics.

Lee *et al*., (1989) used spore traps to investigate blast outbreaks at Icheon and

Suweon, South Korea in relation to temperature, relative humidity, rainfall, sunshine hours, and leaf wetness duration in the field. The amount of spores trapped in samplers was used to predict leaf severity and panicle blast incidence. Differences in disease trends were found between the two sites and were attributed to differences in leaf wetness periods at the sites.

A cost- benefit analysis was incorporated to determine if controlling the disease would bring benefits to farmers.

Rice blast outbreaks in the Middle East also resulted in the development of forecasting tools. In Iran, Izadyar and Baradaran (1990) made a 6-year study of blast infection on five local cultivars sown four times a year. At every sowing date, minimum temperature and the number of days after transplanting (NDAT) until the appearance of leaf blast lesions were recorded. Regression models were then generated to establish relationships between NDAT and maximum leaf blast severity, and between NDAT and minimum temperature. Model predictions showed increases in leaf blast severity due to decreases in NDAT and increases in minimum temperature. In Egypt, a forecasting system was developed following a 1984 epidemic.

Models were developed through regression analysis with factors highly correlated to disease as predictor variables. As this technique provides an excellent way of characterizing the environment as a few meaningful factors (Campbell and Madden, 1990).

The model named EPIBLA (Epidemiology of BLAst) simulated incidence of blast and made 7-day forecasts of disease progression in tropical rice areas in India (Manibhushanrao and Krishnan, 1991). EPIBLA was developed following the multiple regression equation

$$Y = O' + S\mathrm{J}X\mathrm{J} + \&2^{X}2 + \cdots + \pounds_{n}X_{n}$$

Where Y is either the number of spores/m^3 of air or disease incidence, *a* the intercept, S the partial regression coefficients, and X the predictor variables. In predicting the number of spores in the air, daily values of maximum temperature and maximum relative humidity served as predictors in the equations. The predicted spore amount, and the minimum temperature and amount of dew, summed and averaged, respectively over a 7-day period preceding disease onset were used to estimate disease incidence.

Empirical models were also found useful for forecasting blast in Thailand (Surin *et al.*, 1991). Microscope slides were placed 80 cm above the ground to monitor spore population in different farmers' fields. The correlation between the number of spores over susceptible canopies and severity of disease, together with measurements of environmental conditions were the basis for developing the models. Occurrence of blast was predicted within 7 to 15 days in the field when the number of spores trapped per slide was five or more. Leaf several statistical techniques can be used to look into weather influences on blast. Although useful, path coefficient analysis (or structural equation analysis) has not been extensively applied to this type of research.

Multivariate statistical procedures are seldom used in disease forecasting primarily because of their computational difficulty. The exploratory nature of these analyses, however, still warrants usage in blast forecasting research. The work on lettuce-downy mildew pathosystem is probably the most recent study that used multivariate analysis in forecasting the disease (personal communication, Harald Scherm, University of California at Davis; Scherm and Van Bruggen, 1991). The framework of this study used discriminant analysis procedures to determine infection periods of the pathogen, *Bremia lactucae,* based on three weather variables: temperature, relative humidity, and leaf wetness. The goal is to identify which of these weather variables are most important in separating days with infection occurring from days with no infection occurring. The researchers used stepwise discriminant to initially identify these variables and then the canonical discriminant procedure to pick out the final weather variables that had direct influence on infection period.

The goal of the analysis is to provide explanations of observed correlations by constructing models of cause-and- effect relations among variables (Johnson and Wichern, 1992).

Several statistical techniques can be used to look into weather influences on blast. Although useful, path coefficient analysis (or structural equation analysis) has not been extensively applied to this type of research. The goal of the analysis is to provide explanations of observed correlations by constructing models of cause-and- effect relations among variables (Johnson and Wichern, 1992).

Simulation studies using data from tropical and subtropical areas have shown that temperature changes may bring about years that are blast conducive (Teng, 1993; Teng and Yuen, 1990).

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) used discriminant analysis for forecasting potato late blight.

The multiple regression equations were developed by using the most significant weather parameters through stepwise regression technique. These regression equations showed 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 per cent 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 relating 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.

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.

Overall for the years 2003 to 2013, the results revealed that there is positive association between the blast infestation and relative humidity and negative association with other climate factors. The results of ANOVA for blast established that there was significant difference between the varieties, between the standard weeks and no significant difference between dates of planting under study.

Field experiments were conducted during 2015-16 to study the effect of weather on leaf blast 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 been 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 (Piper, 1966)
Silt (%)	3	
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)

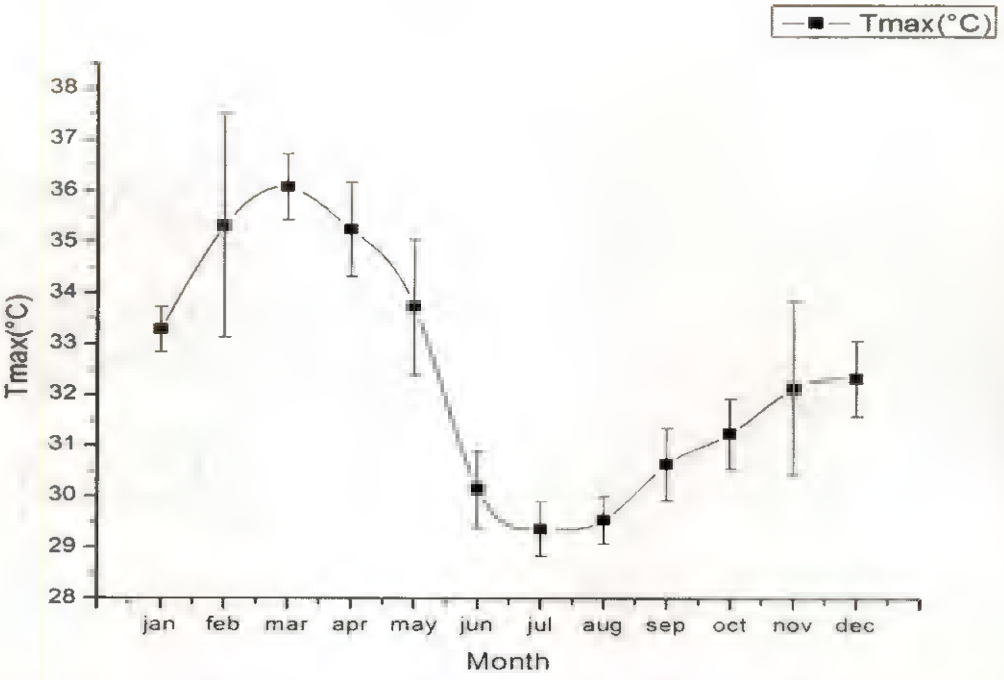

Fig. 1. Monthly maximum temperature (°C) of Pattambi (1983-2012)

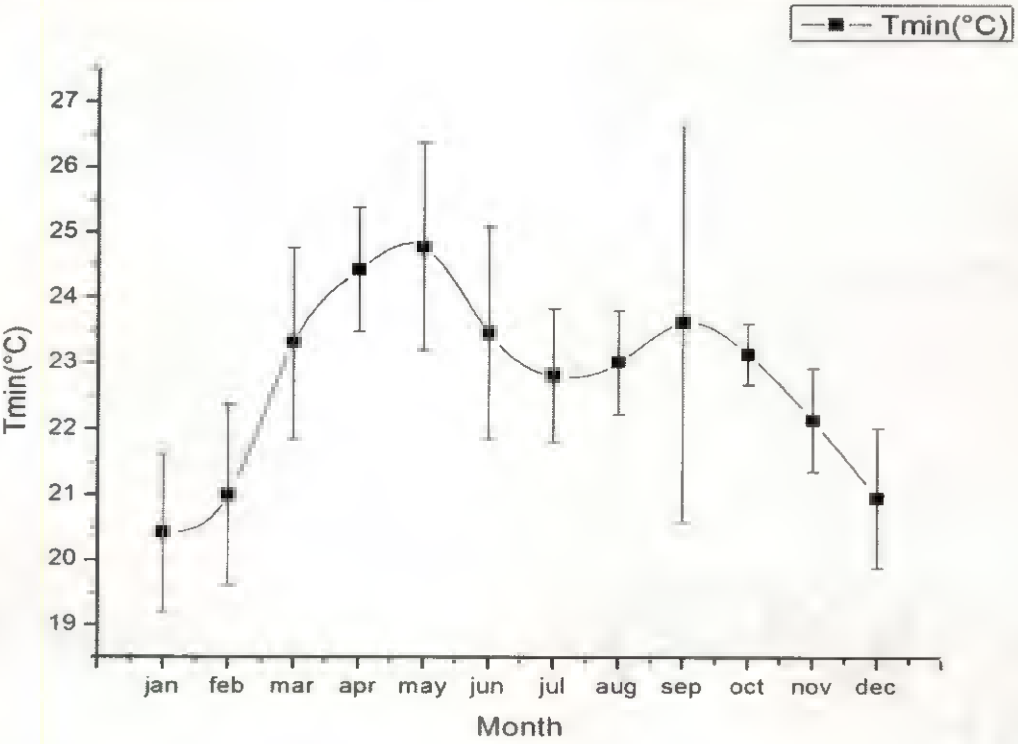

Fig. 2. Monthly minimum temperature (°C) of Pattambi (1983-2012)

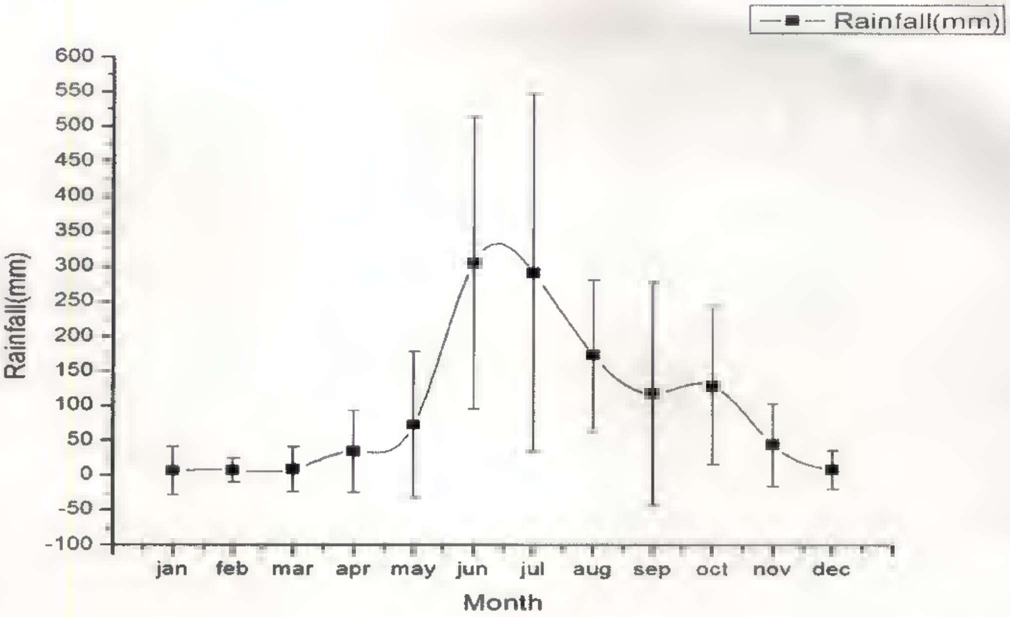

Fig. 3. Monthly rainfall (mm) of Pattambi (1983-2012)

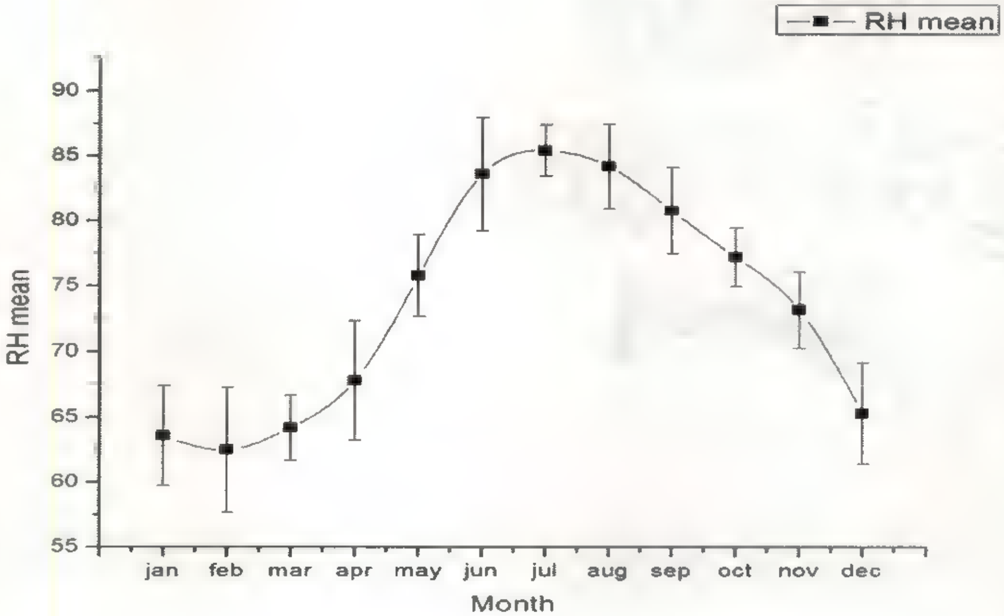

Fig.4. Monthly mean Relative humidity (%) of Pattambi (1983-2012)

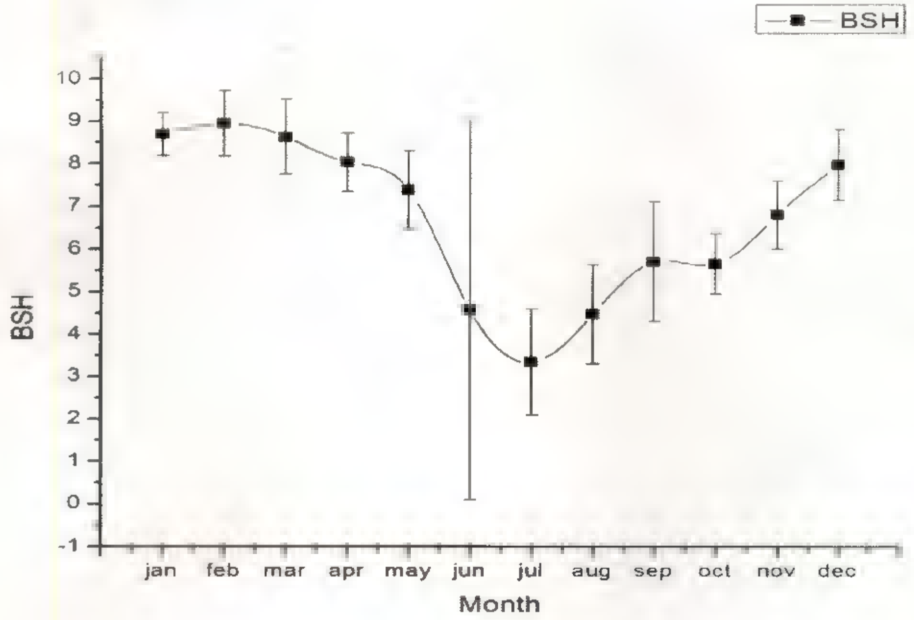

Fig.5. Monthly bright sun shine hours of Pattambi (1983-2012)

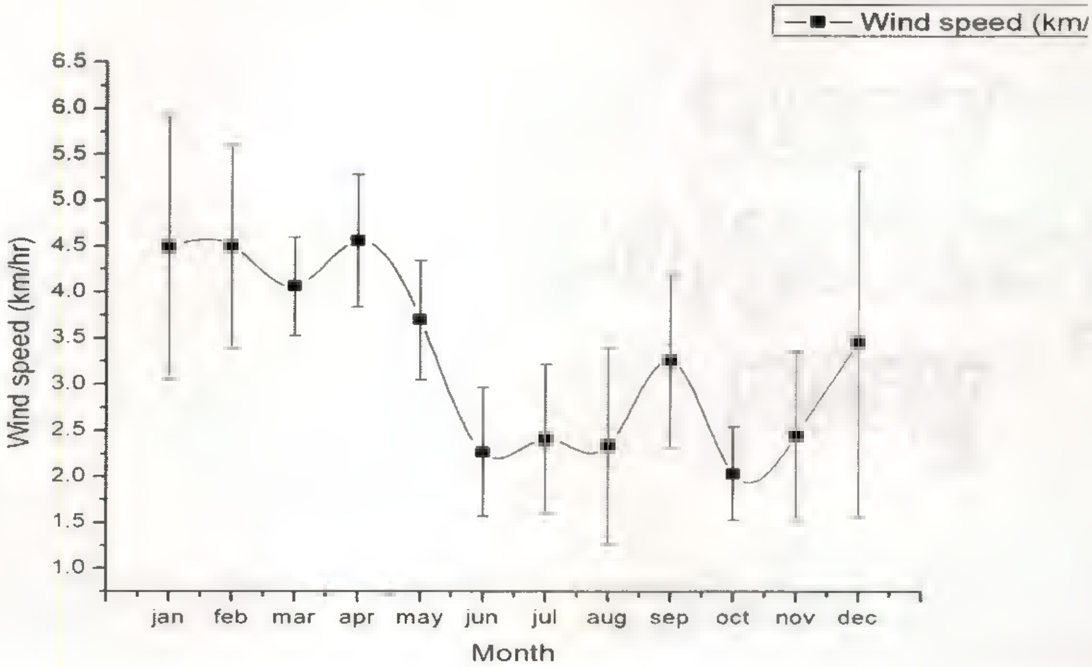

Fig.6. Monthly wind speed (km hr^{-1}) of Pattambi (1983-2012)

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3.1.5 Varieties

Two popular varieties of Kerala viz., 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 consists of five dates of sowing i.e., May 26, June 6, June 16, June 26 and July 6 and two varieties i.e. Jyothi and Kanchana as subplot treatments. Treatments and notations were given in the Table 2. The plot size was 10 $m^2$and the spacing adopted was 15 cm × 10 cm. The experiment was replicated three times with total experimental plots of 54.

3.2.1 Cultural operations

3.2.1.1 *Nursery management*-Dried seedling

For upland condition nurseries were raised prior to five date of sowing. The wet land condition, twenty one old seedlings were transplanted with five dates.

3.2.1.2 *Land preparation*

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

3.2.1.3 *Application of manures and fertilizers*

Farm yard manure at the rate of 5000 kg ha^{-1} was incorporated into the field at the time of land preparation. Urea, Phosphate and Muriate of Potash were used as fertilizers to supply the required amount of nutrients (90 N: 45 P_2O_5: 45 K_2O kg ha^{-1}). The entire dose of P_2O_5, half dose of N and K_2O were applied as basal and the remaining fertilizers were top dressed at 30 days after transplanting.

Table2.Treatments

S.No.	Main plot Treatment	Sub plot Treatment
1	May 26	Jyothi
		Kanchana
2	June 6	Jyothi
		Kanchana
3	June 16	Jyothi
		Kanchana
4	June 26	Jyothi
		Kanchana
5	July 6	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. Observations were taken as per standard procedure (IRRI, 1980).

3.3.1 Biometric characters

3.3.1.1 *Height of the plant*

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

3.3.1.2 *Leaf area index (LAI)*

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

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 (T max)	°C
2	Minimum temperature (T min)	°C
3	Rainfall (RF)	mm
4	Relative humidity (RH	Per cent (%)
5	Solar radiation	Watts/m-2
6	Soil temperature	°C

3.5. SOIL DATA

The result of soil analysis of experimental site was presented in table 4.

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

The data recorded from the field experiment was analyzed statistically using Analysis of variance technique. 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 rainfall, maximum temperature, minimum temperature, relative humidity 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 LEAF BLAST 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.

This part consisted of three steps: 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 at 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:

$$RI = dL/dt = RcIC^a,$$

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 leaf blast diseases were developed from the field experiences.

The source code of EPIRICE is as follows:

```
#######################################################################
# EPIRICE SEIR.LB Function -> derived from SEIR function from
original EPIRICE
#######################################################################
SEIR.LB <- function (wth, tpd, onset, duration = 100, rhlim = 90,
rainlim = 5, wetness,
```

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```
                     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-LB Function -> derived from leaf Blast function from
original EPIRICE
##################################################################


leafBlast.EPIRICE <- function (wth, tpd, ...) {


  AgeCoefRc <- cbind(0:24 * 5, c(1, 1, 1, 1, 1, 1, 1, 1, 1, 0.4,
0.3,
                                   0.1, 0.1, 0.05, 0.03, 0.03,
0.02, 0.02, 0.02,
```

```
                                 0.01, 0.01, 0.01, 0.01, 0.01,
0.01))
  TempCoefRc <- cbind(3:13 * 3, c(0, 0.4, 0.72, 0.88, 1, 0.9,
0.45,
                                  0.2, 0.05, 0.01, 0))
  RHCoefRc <- cbind(c(0:10), c(0, 0.24, 0.41, 0.68, 0.94,
                               0.97, 1,1,1,1,1))
  RRPhysiolGrowth <- cbind(0:12 * 10, c(0.12, 0.12, 0.11, 0.11,
0.09, 0.09,
                                        0.09, 0.09, 0.09, 0.09,
0.05, 0.01, 0.0001))
  return(SEIR.LB(wth = wth, tpd = tpd, onset = 15, ageRc =
AgeCoefRc,
                 tmpRc = TempCoefRc, rhRc = RHCoefRc, baseRc =
0.86, latrans = 4,
                 inftrans = 20, initSites = 600, AGGR = 1,
siteMax = 90000,
                 RRPhysiolSenesc = 0.005, RRG = RRPhysiolGrowth,
wetness = 0,...))
}
#################################################################
# EPIRICE-LB audpc calculation Function
#################################################################
Cal.LB.audpc <- function(wth, tpd) {

  lfblast <- leafBlast.EPIRICE(wth, tpd)

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

3.8 CLIMATE 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 modelling 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 6. 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 7. 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 "The Effect of weather on leaf blast incidence in rice and predicting potential epidemics under various climate change scenarios" are presented in this chapter. The effect of different weather parameters on growth and yield of different 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 and average soil moisture and rainfall were recorded using automatic weather station installed in Regional Agricultural Research Station, Pattambi .

The maximum solar radiation maximum was 782W/m^2 and the maximum solar radiation minimum was 170W/m^2. The minimum solar radiation maximum was 195 W/m^2.The maximum average solar radiation was 460.6 W/m^2 and minimum was 84.5 W/m^2. The temperature maximum was 35.1° C and the minimum was 23.1° C. The maximum value of minimum temperature was 26.6° C and minimum value was 15° C. The maximum value of average temperature was 29.8° C and minimum average temperature was 18.5° C. The maximum relative humidity maximum was 100% and minimum was 52%. The minimum relative humidity maximum was 54% and minimum was 54%. The maximum value of average relative humidity was 87.1% and minimum was 34.1%. The maximum soil temperature maximum was 41.5° C and minimum was 28.7° C. The minimum soil temperature maximum was 29.5° C and minimum was 31° C. The maximum value of average soil temperature was 35.2° C and minimum was 22.5° C. The maximum soil moisture maximum was 43% and minimum was 22.6%. The maximum value of minimum soil moisture was 39.9% and minimum was 14.6%.The average soil moisture maximum was 40.2% and minimum was 20.1%.The rainfall maximum was 40. mm. Figures (7, 8, 9, 10, 11, 12, 13, 14, 15 and 16).

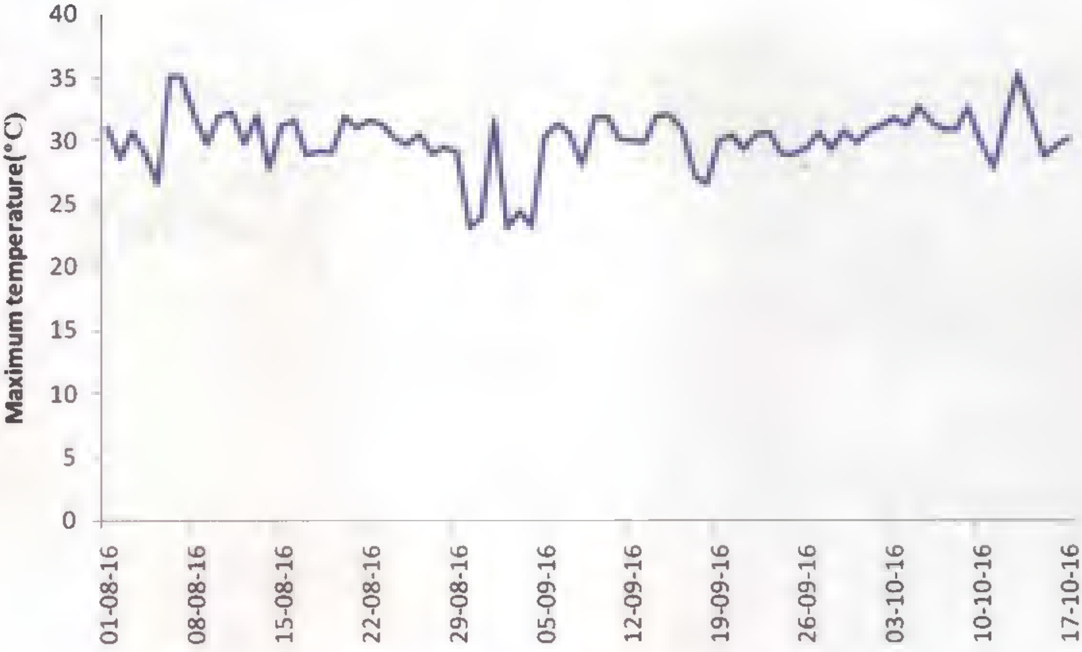

Fig. 7. Daily maximum temperature after inoculation

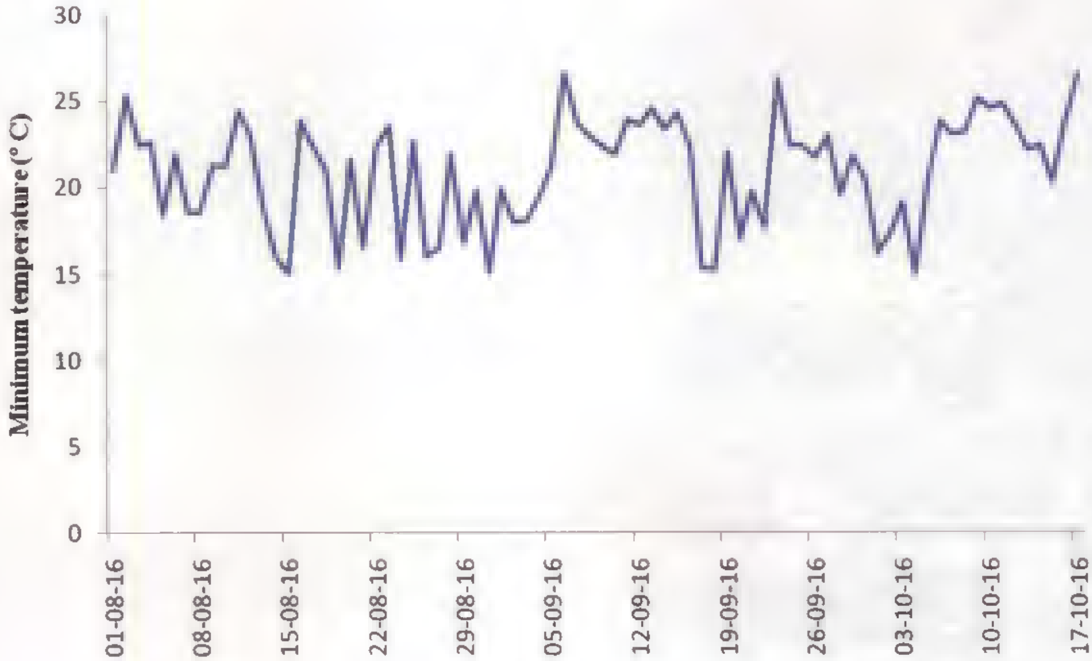

Fig.8. Daily minimum temperature after inoculation

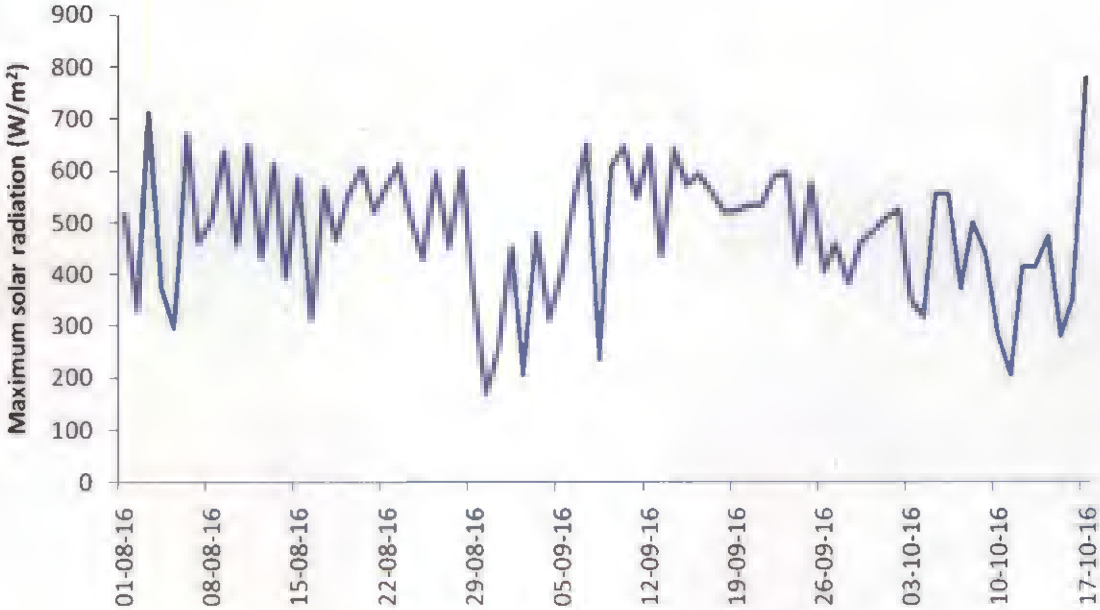

Fig.9. Daily maximum solar radiation after inoculation

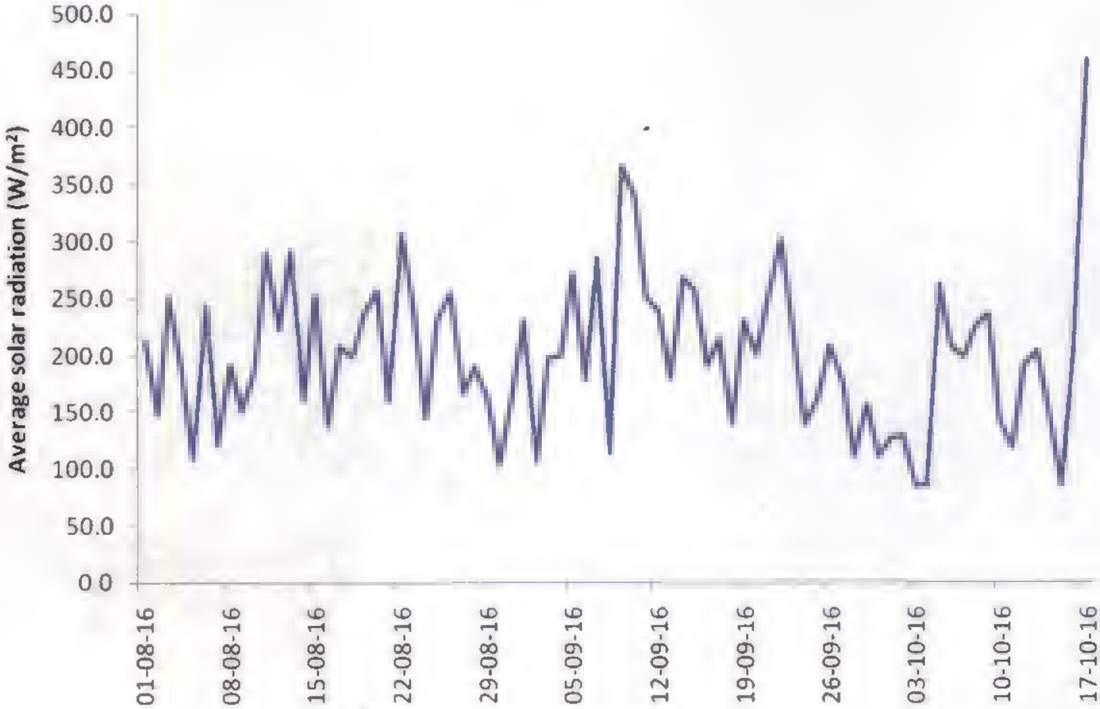

Fig.10. Daily average solar radiation after inoculation

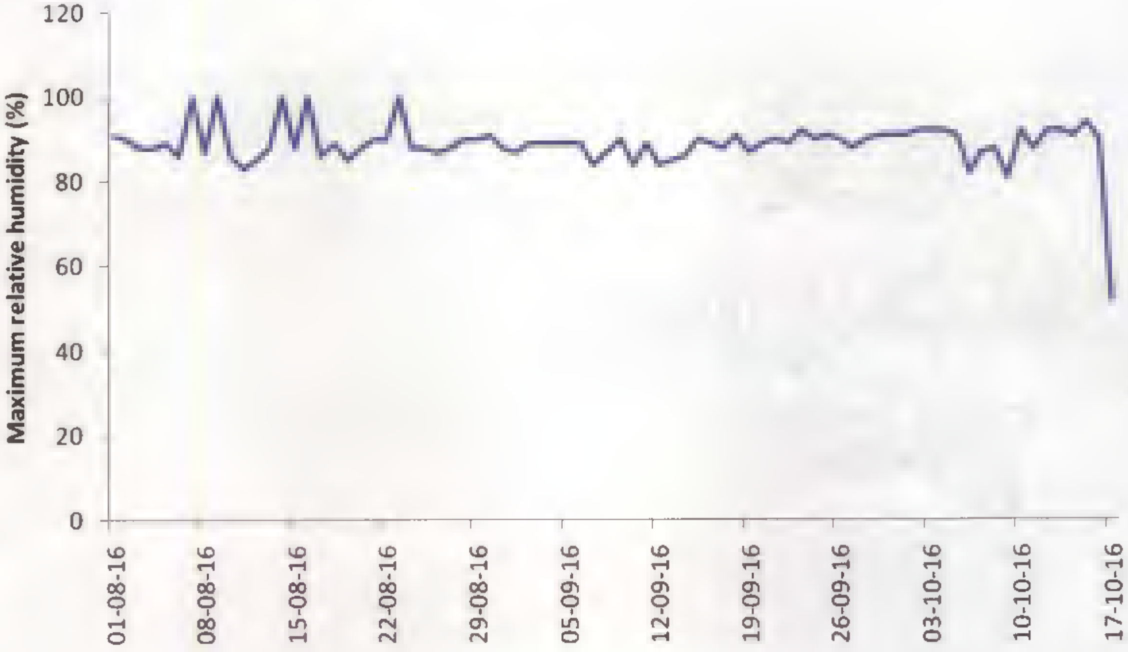

Fig.11.Daily maximum relative humidity after inoculation

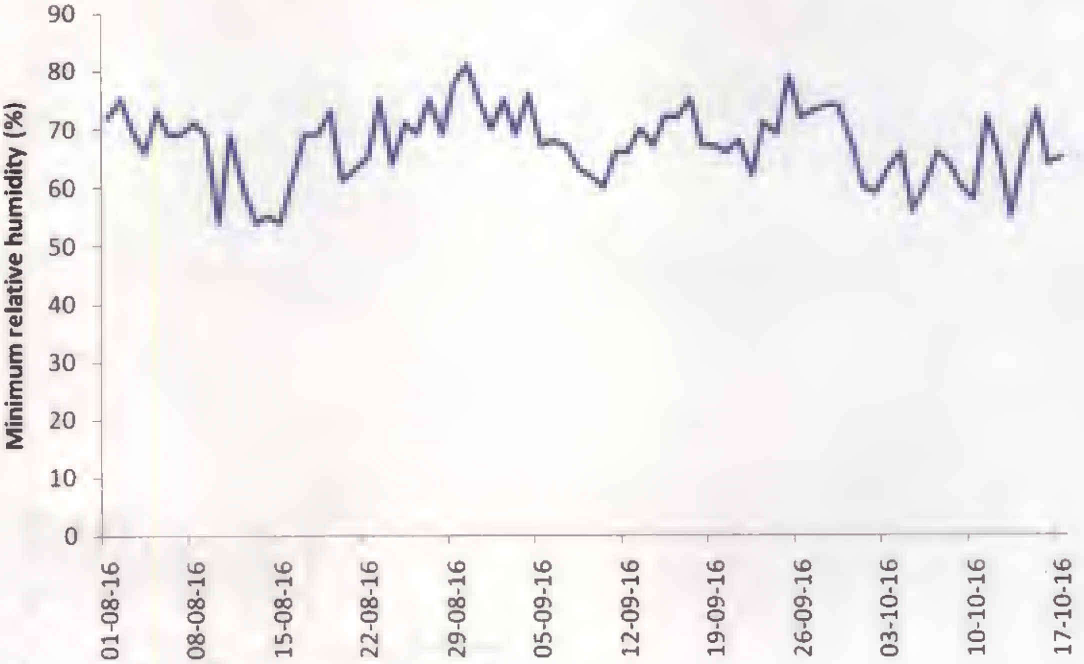

Fig.12. Daily minimum relative humidity after inoculation

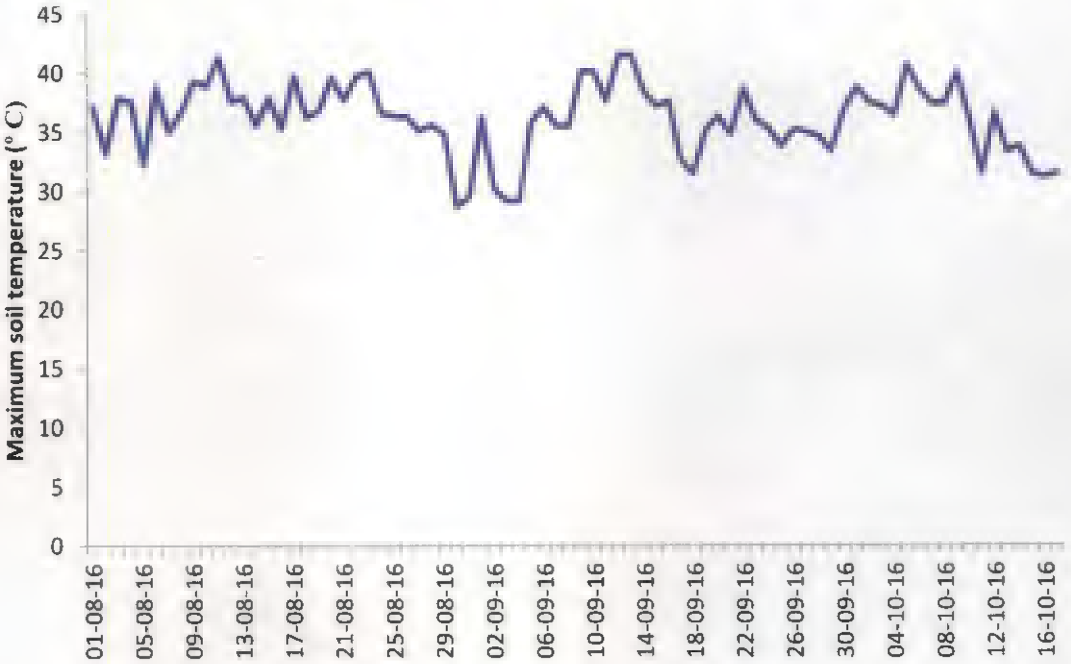

Fig.13. Daily maximum soil temperature after inoculation

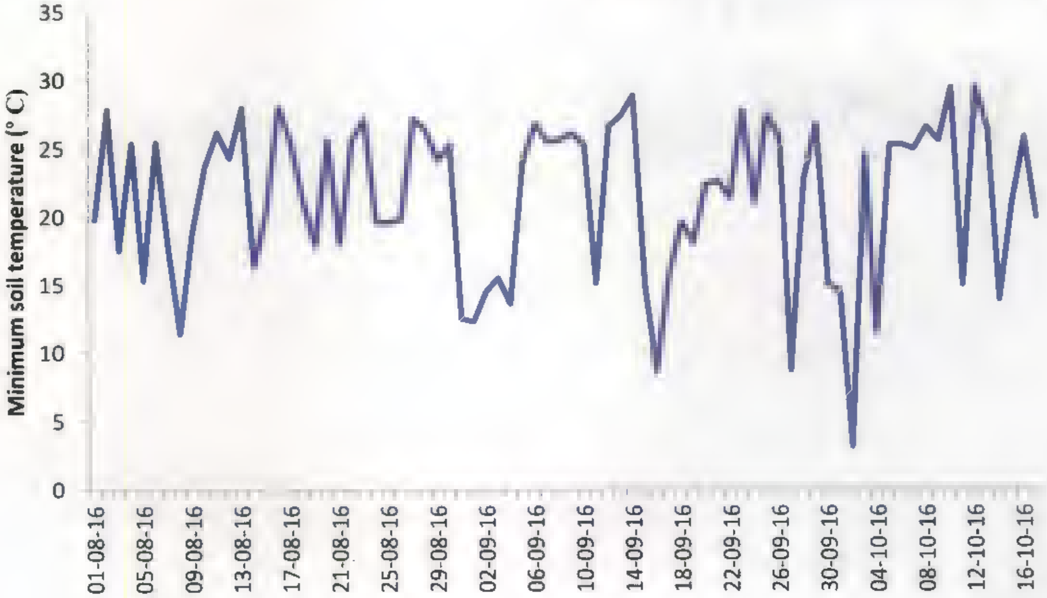

Fig.14.Daily minimum soil temperature after inoculation

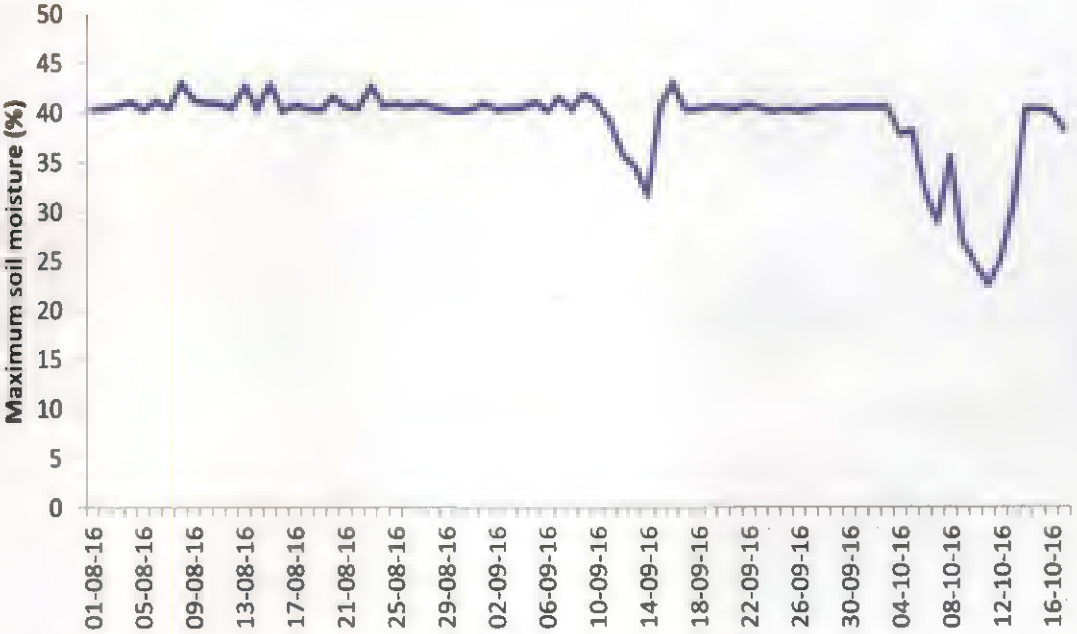

Fig.15.Daily maximum soil moisture after inoculation

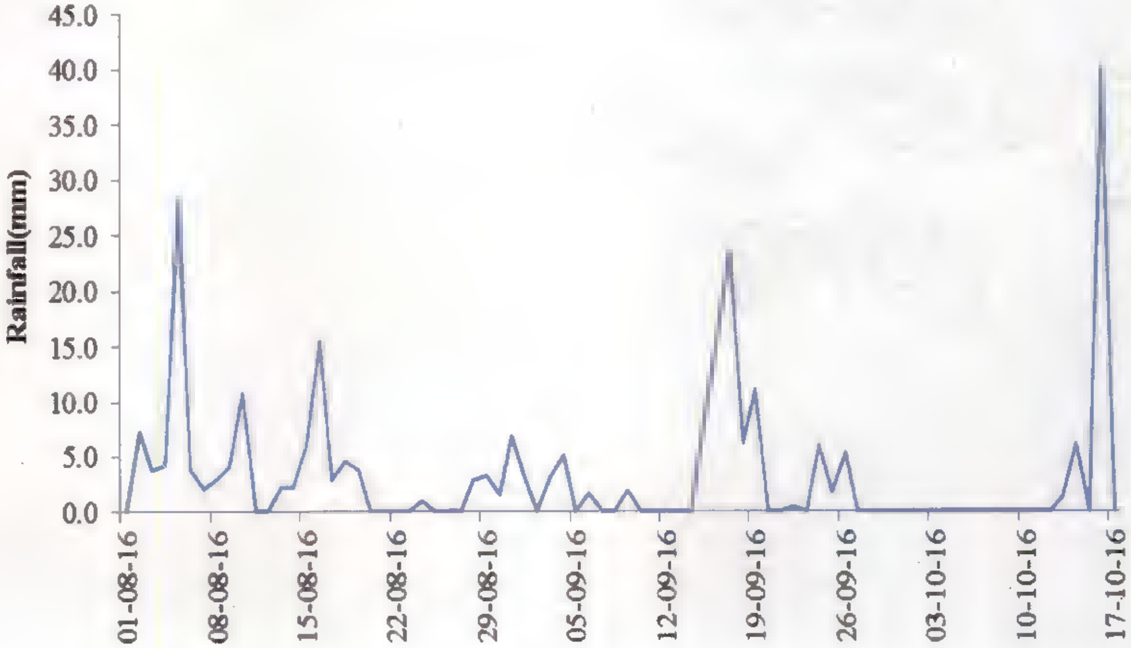

Fig.16. Daily rainfall after inoculation

4.2. IMPACT OF WEATHER PARAMETER ON LEAF BLAST INCIDENCE

4.2.1. Leaf blast incidence in Jyothi

The effect of dates of sowing and varieties on initial Leaf blast incidence and its development was studied and is presented in table 7. It can be clearly observed from the table that the crops sowing June showed a higher disease incidence compared to other dates of sowing. It was also noticed that variety Kanchana is more susceptible to Leaf blast incidence compared to Jyothi. The crops sown on June 16th recorded the highest disease incidence of 4.23% in Kanchana. The least disease incidence was observed Jyothi and Kanchana in crops sowing on June 26th and July 6. 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 Kanchana was 66.03% and Jyothi was 9.85% respectively. Moreover the progression of Leaf blast incidence follows a linear trend.

Table7. Leaf blast incidence in Jyothi and Kanchana

DOS	Incidence(%)	Disease development			
		1 Week	2 Week	3 Week	4 Week
		Kanchana			
May 26	0.80	1.65	1.93	5.94	16.01
June 6	2.30	5.69	15.54	33.93	66.03
June 16	4.23	28.00	62.70	63.40	63.40
June 26	0.00	0.10	0.57	1.98	2.45
July 6	0.00	0.10	0.27	0.46	0.58
		Jyothi			
May 26	1.22	2.05	2.96	5.04	7.20
June 6	0.20	0.92	1.68	2.98	9.85
June 16	0.35	0.79	2.69	3.68	3.79
June 26	0.00	0.03	0.18	0.38	0.72
July 6	0.00	0.00	0.09	0.18	0.21

Simple linear correlations between Leaf blast 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 12 days after inoculation. From the table it can be seen that minimum air temperature, maximum solar radiation, minimum relative humidity, average relative humidity, maximum soil temperature, minimum soil temperature, average soil temperature and average soil moisture was negatively correlated with leaf blast incidence on Jyothi whereas maximum relative humidity, maximum soil moisture, rain fall and maximum air temperature were positively correlated with Leaf blast 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 also be noted that the disease incidence in the consecutive days after the day of inoculation is mainly influenced by air temperature and soil moisture.

4.2.2 Leaf blast incidence in Kanchana

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

The observation was taken 12 days after inoculation. The weather parameter such as maximum temperature, average temperature, maximum soil temperature, minimum soil temperature, average soil temperature and maximum soil temperature was positively correlated with leaf blast incidence on Kanchana. But the other parameter such as minimum relative humidity, average relative humidity and average soil moisture was negatively correlated with leaf blast incidence on Kanchana. Rain fall were initially negatively correlated and then showed positive correlation.

From the table it can be seen that as Minimum relative humidity, average relative humidity and average soil moisture was negatively correlated with leaf blast incidence on Kanchana. Maximum soil moisture were initially negatively correlated and then showed positive correlation. Maximum temperature, average temperature, maximum soil temperature, minimum soil temperature, average soil temperature and maximum soil temperature were positively correlated with leaf blast 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.

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Table.8. Correlation of weather on Leaf blast incidence in Jyothi

Weather	Day1	Day2	Day3	Day4	Day5	Day6	Day7	Day8	Day19	Day10	Day11	Day12
MAXT	-0.12	-0.47*	0.50*	0.57*	0.54*	0.01	0.43	0.53*	-0.17	0.51*	-0.51*	0.43
MINAT	-0.43	-0.30	-0.41	-0.44	-0.20	-0.38	-0.26	-0.08	-0.30	-0.30	-0.32	-0.33
AVGT	0.07	-0.43	0.00	-0.17	-0.10	-0.23	0.11	0.54*	0.06	0.34	-0.60*	-0.15
MAXSR	-0.15	-0.72*	0.61*	-0.56*	-0.07	0.36	-0.13	0.45	-0.07	0.25	-0.40	0.37
AVGSR	0.12	-0.48*	0.25	-0.57*	-0.18	-0.27	-0.17	0.53*	0.06	0.30	-0.40	0.45
MAXRH	0.31	-0.13	-0.23	0.59*	-0.11	0.57*	-0.27	-0.64*	-0.42	-0.11	0.56*	-0.10
MINRH	-0.05	0.18	-0.70*	-0.37	0.30	0.41	0.13	0.40	-0.61*	0.01	-0.51*	-0.75*
AVGRH	0.00	0.30	-0.63*	0.62*	0.15	0.44	-0.36	0.12	-0.56*	-0.11	0.24	-0.42
MAXST	-0.03	-0.72*	0.27	-0.54*	0.10	0.34	0.32	0.74*	0.48*	-0.13	-0.27	0.35
MINST	0.31	-0.52*	0.37	0.07	-0.51*	-0.41	0.37	0.47*	-0.10	0.43	-0.49*	-0.06
AVRST	0.07	-0.56*	0.49*	-0.10	0.17	-0.06	0.27	0.72*	-0.10	0.15	-0.69*	-0.06
MAXSM	0.21	0.24	0.14	-0.45	0.76*	-0.09	0.55	-0.18	-0.07	0.55	-0.16	0.76*
AVGSM	0.39	0.28	-0.49*	-0.47*	-0.20	0.27	-0.29	0.21	-0.37	-0.53*	0.04	0.11
RF	0.41	0.49*	-0.45	-0.25	-0.25	0.01	0.21	-0.31	-0.31	0.07	-0.01	0.19

Table.9.Correlation of weather on Disease incidence in Kanchana

Weather	Day1	Day2	Day3	Day4	Day5	Day6	Day7	Day8	Day19	Day10	Day11	Day12
MAXT	0.26	0.47*	0.04	-0.33	0.39	0.40	0.18	0.13	-0.31	0.06	0.43	0.02
MINAT	-0.44	-0.31	-0.18	-0.35	-0.28	-0.09	-0.32	-0.36	-0.31	-0.31	-0.33	-0.34
AVGT	0.05	0.10	-0.48*	-0.60*	0.04	0.29	0.50*	0.51*	-0.39	-0.43	0.07	0.47*
MAXSR	0.31	-0.14	-0.19	0.05	0.00	0.10	0.08	-0.03	0.06	-0.16	-0.36	0.00
AVGSR	0.19	-0.19	-0.32	-0.31	-0.42	0.29	0.31	0.31	-0.05	-0.17	-0.26	-0.06
MAXRH	0.07	0.21	0.14	0.36	0.15	-0.40	-0.38	-0.02	0.20	0.19	0.29	0.09
MINRH	-0.57*	-0.17	0.21	-0.18	0.15	0.15	-0.20	0.02	-0.40	-0.63*	-0.09	0.10
AVGRH	-0.46	0.01	0.27	0.22	-0.01	-0.38	-0.56*	-0.04	0.08	-0.13	0.17	0.24
MAXST	-0.15	-0.19	-0.40	0.01	0.45	0.47*	0.33	-0.01	0.15	-0.35	-0.03	0.41
MINST	0.12	-0.16	-0.43	-0.02	0.26	0.23	0.50*	0.55*	-0.43	-0.36	0.22	0.53*
AVRST	-0.05	0.02	-0.43	-0.30	0.33	0.47*	0.40	0.24	-0.52*	-0.34	0.14	0.61*
MAXSM	0.19	0.29	0.52*	-0.02	0.05	-0.22	0.00	0.17	0.19	0.33	0.10	-0.02
AVGSM	0.24	0.25	-0.34	-0.18	0.10	0.27	-0.57*	-0.24	0.26	-0.51*	-0.53*	0.26
RF	0.36	0.03	-0.52*	-0.17	-0.04	-0.47*	-0.30	-0.10	-0.23	0.56*	0.56*	-0.34

4.3. IMPACT OF WEATHER ON DISEASE PROGRESSION

4.3.1 Leaf blast progression in Jyothi

Table 10 showed that the correlation between weather parameter and Leaf blast development 6 days after incidence. The weather parameter such as maximum temperature and average soil moisture was positively correlated with leaf blast progression in Jyothi.

Table.10. Correlation of weather on Leaf blast progression in Jyothi one week after incidence

Weather	Day1	Day2	Day3	Day4	Day5	Day6
MAXT	0.01	-0.27	-0.24	-0.16	0.47*	0.40
MINAT	-0.32	-0.23	-0.31	-0.36	-0.38	-0.23
AVGT	-0.16	0.31	-0.27	-0.13	0.20	-0.29
MAXSR	-0.21	-0.17	0.09	0.18	0.43	0.37
AVGSR	-0.15	0.38	-0.25	0.21	0.31	0.14
MAXRH	0.32	-0.36	-0.37	-0.32	-0.03	0.03
MINRH	0.00	0.24	0.09	0.21	-0.32	-0.37
AVGRH	0.41	-0.03	0.24	-0.18	-0.44	-0.34
MAXST	-0.02	0.32	-0.11	0.08	0.43	0.40
MINST	0.32	0.03	-0.46	0.14	0.10	-0.12
AVRST	0.01	0.40	-0.14	0.02	0.34	-0.12
MAXSM	-0.20	0.23	0.06	-0.18	0.31	-0.01
AVGSM	-0.02	0.48*	0.06	-0.23	-0.36	0.02
RF	0.32	0.43	0.14	0.27	-	-

The impact of weather parameters on leaf blast development two weeks after incidence is presented in table 11.Aaverage temperature; rain fall and average solar radiation are positively correlated with disease progression. Maximum relative humidity and minimum soil temperature were negatively correlated with disease progression.

Table.11. Correlation of weather on Leaf blast progression in Jyothi two week after incidence

Weather	Day1	Day2	Day3	Day4	Day5	Day6
MAXT	-0.16	-0.10	-0.08	-0.31	0.12	0.13
MINAT	-0.35	-0.38	-0.10	-0.33	-0.42	-0.45
AVGT	0.43	0.51	0.09	0.47*	0.19	-0.03
MAXSR	-0.19	-0.40	0.29	0.29	0.38	-0.03
AVGSR	-0.16	0.55*	0.51*	0.22	0.00	-0.34
MAXRH	0.05	-0.35	-0.58*	-0.43	-0.24	0.44
MINRH	0.04	0.17	0.30	0.38	0.06	-0.21
AVGRH	-0.09	-0.40	-0.30	0.35	0.01	-0.09
MAXST	-0.09	-0.01	-0.07	-0.16	0.04	0.05
MINST	0.19	0.17	-0.52*	0.45	0.34	0.26
AVRST	0.02	0.20	0.19	0.46	0.14	0.29
MAXSM	0.07	0.30	0.24	0.44	0.39	0.34
AVGSM	0.32	0.23	0.32	0.46	0.32	0.21
RF	-	0.59*	-0.32	-0.32	-0.32	-0.08

The table.12 showed that the correlation between the weather parameter and leaf blast progression three weeks after incidence. The maximum relative humidity, minimum relative humidity, rain fall and average relative humidity was positively correlated with disease progression. The weather parameter such as maximum solar radiation and minimum soil temperature are negatively correlated with disease progression.

Table.12. Correlation of weather on Leaf blast progression in Jyothi three week after incidence

Weather	Day1	Day2	Day3	Day4	Day5	Day6
MAXT	-0.21	-0.21	-0.27	0.08	-0.36	-0.43
MINAT	-0.45	-0.28	-0.21	-0.31	-0.34	-0.33
AVGT	-0.33	-0.24	-0.34	0.03	-0.44	-0.42
MAXSR	-0.14	-0.22	-0.47*	0.04	-0.16	0.09
AVGSR	-0.30	-0.26	-0.33	-0.05	-0.27	0.19
MAXRH	0.44	0.49*	0.04	0.22	-0.33	0.34
MINRH	-0.10	-0.07	0.43	0.31	0.52*	0.04
AVGRH	0.03	0.16	0.38	0.26	0.55*	0.30
MAXST	-0.21	-0.29	-0.27	-0.03	-0.35	-0.40
MINST	0.26	0.20	-0.24	-0.38	-0.50*	-0.27
AVRST	0.15	-0.10	-0.34	-0.08	-0.45	-0.40
MAXSM	0.31	0.33	0.32	0.35	0.32	0.34
AVGSM	0.22	0.36	0.38	0.35	0.31	0.34
RF	0.23	0.39	0.06	0.26	0.50*	0.07

The table.13 presented the correlation between leaf blast development and weather parameter four weeks after incidence. Maximum temperature, minimum air temperature, average temperature, maximum solar radiation, maximum relative humidity, minimum relative humidity, maximum soil temperature and minimum soil temperature was negatively correlated with disease progression. The maximum soil moisture and rain fall was positively correlated with disease incidence.

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Table.13. Correlation of weather on Leaf blast progression in Jyothi four week after incidence

Weather	Day1	Day2	Day3	Day4	Day5	Day6
MAXT	-0.51*	-0.17	-0.51*	0.13	-0.49*	0.51*
MINAT	-0.42	-0.32	-0.36	-0.41	-0.51*	-0.48*
AVGT	-0.51*	0.22	0.34	0.28	-0.51*	0.29
MAXSR	-0.40	0.24	0.03	0.34	-0.42	-0.42
AVGSR	-0.24	0.44	-0.22	0.24	-0.49*	0.02
MAXRH	0.06	-0.11	-0.48*	-0.34	-0.50*	0.39
MINRH	0.34	0.35	0.41	-0.51*	-0.28	0.31
AVGRH	0.40	0.09	-0.38	-0.40	0.31	0.35
MAXST	-0.51*	0.38	0.05	0.01	0.16	0.28
MINST	-0.51*	-0.49*	0.36	0.35	0.27	0.31
AVRST	-0.51*	0.51*	0.28	0.11	-0.29	0.36
MAXSM	0.31	0.37	-0.33	0.49*	0.32	0.47*
AVGSM	0.36	0.36	-0.43	0.46	0.24	0.34
RF	0.51*	-0.34	-0.36	-	-0.34	0.51*

4.3.2 Leaf blast progression in Kanchana

The table.14 showed that the correlation between weather parameter and leaf blast development six days after incidence. Maximum temperature, maximum solar radiation, average solar radiation, maximum soil temperature, average soil temperature and maximum soil moisture was positively correlated with leaf blast incidence on Kanchana. Minimum air temperature, average temperature, minimum relative humidity, rain fall and minimum soil temperature was negatively correlated with leaf blast incidence on Kanchana.

Table.14. Correlation of weather on Leaf blast progression in Kanchana one week after incidence

Weather	Day1	Day2	Day3	Day4	Day5	Day6
MAXT	-0.33	-0.18	0.55*	0.16	0.42	0.39
MINAT	0.18	-0.27	-0.57*	-0.34	-0.21	-0.18
AVGT	-0.64*	-0.49*	0.60*	-0.43	0.14	0.38
MAXSR	0.00	0.08	0.56*	-0.17	0.34	0.70*
AVGSR	0.12	0.72*	0.16	-0.59*	0.68*	0.28
MAXRH	-0.22	-0.63*	-0.21	-0.22	0.41	0.89*
MINRH	0.41	0.27	-0.65*	-0.51*	0.09	0.28
AVGRH	0.32	-0.19	-0.50*	-0.33	-0.32	0.57*
MAXST	-0.17	-0.01	0.50*	0.02	0.52*	0.57*
MINST	-0.49*	-0.49*	0.23	-0.05	0.42	0.46
AVRST	-0.55*	-0.22	0.76*	-0.45	0.13	0.76*
MAXSM	-0.14	-0.58*	0.86*	-0.24	-0.35	0.86*
AVGSM	0.61*	-0.12	-0.25	-0.78*	0.45	0.09
RF	-0.12	0.42	-0.51*	-0.32	-	-

The impact of weather parameters on leaf blast development two weeks after incidence is presented in table 15. Average temperature, average solar radiation, maximum soil moisture, rain fall and average soil moisture were positively correlated with leaf blast incidence in Kanchana. Maximum temperature, maximum relative humidity and minimum relative humidity were negatively correlated with leaf blast incidence in Kanchana.

Table 16 showed that the correlation between weather parameter and leaf blast progression three weeks after incidence. The fourth observation was taken by after 6 days. Maximum relative humidity, average relative humidity, rain fall and average soil temperature were positively correlated with leaf blast incidence in Kanchana. Maximum temperature, minimum air temperature, average solar radiation, maximum soil temperature and minimum soil temperature were negatively correlated with leaf blast incidence in Kanchana.

Table.15. Correlation of weather on Leaf blast progression in Kanchana two week after incidence

Weather	Day1	Day2	Day3	Day4	Day5	Day6
MAXT	-0.50*	-0.20	0.08	-0.54*	0.15	0.10
MINAT	-0.30	-0.39	0.07	-0.34	-0.44	-0.41
AVGT	0.35	0.49*	-0.11	0.44	0.29	-0.11
MAXSR	-0.50*	-0.66*	0.50*	0.09	0.51*	-0.25
AVGSR	-0.42	0.86*	0.53*	0.01	0.08	-0.54*
MAXRH	-0.25	-0.32	-0.63*	-0.33	-0.02	0.41
MINRH	-0.23	0.32	0.18	0.39	-0.06	-0.49*
AVGRH	-0.42	-0.26	-0.32	0.45	-0.09	-0.29
MAXST	-0.38	-0.05	-0.06	-0.39	0.07	0.02
MINST	-0.05	0.15	-0.48*	0.61*	0.17	0.19
AVRST	-0.26	0.30	0.27	0.46	0.18	0.22
MAXSM	-0.22	0.51*	0.02	0.43	0.32	0.30
AVGSM	0.61*	0.07	0.25	0.45	0.27	0.13
RF	[illegible]	0.91*	-0.45	-0.31	-0.31	0.06

Table.16. Correlation of weather on Leaf blast progression in Kanchana three week after incidence

Weather	Day1	Day2	Day3	Day4	Day5	Day6
MAXT	0.10	0.33	-0.59*	-0.27	0.42	-0.46
MINAT	-0.47*	-0.46	-0.36	-0.20	-0.25	-0.47*
AVGT	0.07	0.13	-0.43	-0.33	0.17	-0.28
MAXSR	0.51*	0.43	-0.82*	-0.28	0.29	-0.38
AVGSR	0.10	0.05	-0.89*	-0.17	0.24	-0.55*
MAXRH	0.37	0.50*	0.84*	0.24	-0.71*	0.33
MINRH	0.26	-0.90*	0.84*	0.33	0.33	0.35
AVGRH	0.10	-0.65*	0.89*	0.31	0.25	0.61*
MAXST	0.11	0.26	-0.56*	-0.36	0.34	-0.24
MINST	0.32	0.39	0.42	-0.41	-0.59*	-0.24
AVRST	0.65*	0.43	-0.19	-0.41	-0.10	-0.10
MAXSM	0.34	0.33	0.25	0.32	0.34	0.33
AVGSM	0.29	0.19	0.29	0.39	0.40	0.26
RF	-0.15	0.90*	-0.01	-0.38	0.72*	0.71*

The table.17 presented the correlation between leaf blast development weather parameter four weeks after incidence. Maximum soil moisture and rain fall were positively correlated with leaf blast incidence in Kanchana.

Table.17.Correlation of weather on Leaf blast progression in Kanchana four week after incidence

Weather	Day1	Day2	Day3	Day4	Day5	Day6
MAXT	-0.50*	-0.14	-0.50*	0.10	-0.49*	0.50*
MINAT	-0.40	-0.29	-0.34	-0.38	-0.49*	-0.46
AVGT	-0.50*	0.24	0.32	0.25	-0.50*	0.31
MAXSR	-0.40	0.26	0.00	0.32	-0.42	-0.39
AVGSR	-0.26	0.44	-0.24	0.21	-0.48*	0.05
MAXRH	0.09	-0.08	-0.46	-0.31	-0.48*	0.37
MINRH	0.35	0.36	0.41	-0.49*	-0.30	0.29
AVGRH	0.41	0.11	-0.35	-0.37	0.28	0.33
MAXST	-0.50*	0.36	0.03	-0.02	0.14	0.25
MINST	-0.49*	-0.48*	0.33	0.33	0.29	0.28
AVRST	-0.50*	0.50*	0.25	0.08	-0.30	0.33
MAXST	-0.50*	0.36	0.03	-0.02	0.14	0.25
MINST	-0.49*	-0.48*	0.33	0.33	0.29	0.28
AVRST	-0.50*	0.50*	0.25	0.08	-0.30	0.33
MAXSM	0.29	0.34	-0.34	0.47*	0.33	0.47*
AVGSM	0.33	0.34	-0.43	0.43	0.26	0.35
RF	0.50*	-0.31	-0.34	-	-0.31	0.50*

4.4. EFFECT OF DATES OF PLANTING ON BIOMETRIC OBSERVATION ON RICE

4.4.1 Upland

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 sowing time and variety. All the treatments recorded the maximum height at 10th week. In all the dates of sowing (May 26th, June 6th, June 16th, June 26th and July 6th) variety Kanchana recorded the highest plant height compared to Jyothi. The crops sowing on June 26th recorded the maximum plant height for the variety Kanchana.

Table.18. Plant height

Varieties	Dates of sowing	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9	Week10
Jyothi	May 26	27.66	32.33	36.66	40.50	49.50	52.00	55.46	58.50	56.33	54.50
Kanchana	May 26	31.00	31.33	34.33	38.43	43.33	45.66	48.66	52.43	56.00	61.66
Jyothi	June 6	22.66	26.33	27.90	32.66	37.70	41.66	42.66	45.33	46.83	52.66
Kanchana	June 6	28.76	30.73	33.80	37.13	41.96	48.50	51.46	53.50	57.96	61.46
Jyothi	June 16	22.40	25.83	27.16	28.90	38.16	45.76	48.43	49.50	54.30	52.00
Kanchana	June 16	24.93	28.40	30.40	32.20	38.33	42.73	48.33	50.20	54.16	54.33
Jyothi	June 26	31.63	37.50	41.13	43.30	45.33	46.03	48.50	49.13	50.00	51.63
Kanchana	June 26	34.20	38.33	44.30	47.53	50.93	53.03	54.10	58.66	60.00	62.66
Jyothi	July 6	23.10	24.66	27.23	31.16	33.00	34.50	35.53	37.00	39.13	40.66
Kanchana	July 6	22.16	23.93	26.93	29.03	29.50	31.90	33.36	35.40	40.80	43.70
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.19. Number of tillers

Varieties	Dates of sowing	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9	Week10
Jyothi	May 26	2.00	3.00	4.00	4.00	4.66	4.66	5.00	6.33	7.00	7.33
Kanchana	May 26	2.00	3.00	4.00	4.66	5.33	5.33	6.00	5.00	5.00	5.33
Jyothi	June 6	1.00	1.00	1.00	1.66	2.33	3.66	4.00	5.00	4.33	5.33
Kanchana	June 6	1.00	1.00	1.33	2.33	4.33	9.00	9.66	11.00	10.00	8.66
Jyothi	June 16	1.00	1.00	1.33	1.66	4.33	5.00	6.00	6.00	4.00	3.66
Kanchana	June 16	1.33	1.66	1.66	2.00	5.66	7.00	7.00	7.00	4.33	4.66
Jyothi	June 26	3.33	5.00	3.66	4.00	5.33	3.66	3.33	3.00	2.00	2.00
Kanchana	June 26	4.00	4.33	4.00	5.33	6.33	5.66	3.66	3.66	3.00	300
Jyothi	July 6	1.00	2.00	1.66	2.00	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	4.00	3.00	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.20. Leaf area index

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

Table.21. Plant height-Wet land condition

Varieties	Dates of planting	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9	Week10
Jyothi	Jun-15	39.67	43.00	46.33	51.33	55.17	63.00	72.33	75.90	78.67	82.67
Kanchana	Jun-15	42.00	47.33	51.67	55.33	59.33	66.33	69.00	71.43	89.17	94.67
Jyothi	Jun-26	33.33	35.83	39.50	45.67	52.67	56.00	62.00	66.33	73.00	80.00
Kanchana	Jun-26	35.00	37.50	41.17	50.33	57.00	60.97	67.67	76.67	82.67	91.17
Jyothi	Jul-07	31.00	32.60	35.33	37.67	39.60	50.07	53.33	57.67	62.00	68.67
Kanchana	Jul-07	28.67	31.33	34.67	38.00	41.97	53.57	57.67	65.00	76.33	82.67
Jyothi	Jul-16	32.33	40.57	46.83	54.33	62.00	68.00	73.33	80.30	86.53	95.83
Kanchana	Jul-16	34.00	38.67	42.70	48.70	55.10	61.00	65.67	74.30	85.60	95.63
Jyothi	Jul-26	29.33	34.60	41.4	46.80	52.67	61.00	68.00	79.30	89.00	95.13
Kanchana	Jul-26	29.20	34.33	42.00	49.67	54.67	62.67	71.00	78.00	88.67	95.37
CD 5%	Main Treatments	4.95	5.21	6.44	6.07	6.76	10.28	11.74	12.75	12.81	15.82
	Sub Treatments	1.93	2.85	3.17	3.29	4.62	4.82	5.11	3.97	2.98	6.19
	Main x Sub	4.32	6.36	7.09	7.37	10.32	10.79	11.42	8.88	6.66	13.84

Table.22. Number of tillers-Wet land condition

Varieties	Dates of planting	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9	Week10
Jyothi	Jun-15	4.00	4.67	5.33	6.33	9.67	10.67	11.70	10.33	10.00	9.33
Kanchana	Jun-15	4.33	5.00	5.67	7.00	10.00	9.00	11.30	11.33	11.00	9.00
Jyothi	Jun-26	3.67	4.00	6.33	8.67	9.33	12.00	15.00	15.00	14.33	14.33
Kanchana	Jun-26	3.67	6.00	8.67	14.33	15.33	17.00	19.00	19.67	18.33	17.33
Jyothi	Jul-07	4.00	4.00	6.00	9.00	11.00	1300	12.67	16	18.67	19.67
Kanchana	Jul-07	4.00	3.67	7.00	9.33	11.00	15.33	15.33	16.67	17.67	18.67
Jyothi	Jul-16	6.67	13.00	17.33	19.33	21.67	23.67	25.67	23.67	22.33	20.67
Kanchana	Jul-16	5.00	8.00	11.67	15.00	17.67	19.00	22.33	21.67	19.67	19.67
Jyothi	Jul-26	4.33	5.33	7.00	8.33	8.67	12.33	11.67	9.33	8.00	8.00
Kanchana	Jul-26	8.00	10.67	14.00	16.33	18.33	22.00	22.67	24	25.67	21.67
CD 5%	Main Treatments	2.66	5.14	7.18	8.02	9.03	9.44	9.01	10.63	11.58	11.71
	Sub Treatments	1.12	1.86	2.62	2.95	2.94	3.70	3.66	3.41	3.09	3.16
	Main x Sub	2.51	4.15	5.87	6.59	6.58	8.26	8.18	7.63	6.92	7.06

Table.23. Leaf area index- Wet land condition

Varieties	Dates of planting	Week1	Week2	Week3	Week4	Week5	Week6
Jyothi	Jun-15	0.32	0.36	0.71	0.84	0.53	0.50
Kanchana	Jun-15	0.34	0.36	0.69	0.86	0.58	0.52
Jyothi	Jun-26	0.29	0.31	0.69	0.81	0.54	0.54
Kanchana	Jun-26	0.28	0.29	0.65	0.79	0.57	0.58
Jyothi	Jul-07	0.31	0.35	0.63	0.85	0.54	0.49
Kanchana	Jul-07	0.32	0.34	0.64	0.84	0.59	0.53
Jyothi	Jul-16	0.31	0.36	0.65	0.86	0.73	0.68
Kanchana	Jul-16	0.31	0.35	0.62	0.85	0.75	0.7
Jyothi	Jul-26	0.37	0.39	0.68	0.89	0.75	0.67
Kanchana	Jul-26	0.41	0.43	0.70	0.93	0.75	0.69
CD 5%	Main Treatments	0.05	0.08	0.05	0.08	0.04	0.02
	Sub Treatments	0.05	0.05	0.05	0.05	0.02	0.02
	Main x Sub	0.11	0.11	0.11	0.10	0.03	0.04

4.4.1.2 Number of tillers

The table19 showed that the Number of tillers in weekly. 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.

4.4.1.3 Leaf Area Index (LAI)

The table.20 showed that the weekly Leaf Area Index. The effect of weather on LAI significantly varied with the variety. Kanchana was recorded maximum leaf area index (0.82) when on sown 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

4.4.2. Wetland condition

4.4.2.1 Plant height

The weekly plant height was given in the table.21. The plant height was significantly influenced by both planting time and variety. All the treatments recorded the maximum height at 10th week. In all the dates of planting (June 15th, June 26th, July 7th, July 16th and July 26th) 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.

4.4.2.2 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 (Table 22). The number of tillers per plant was significantly affected by both dates of planting and variety.

4.4.2.3 Leaf area index

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 (Table 23).

4.5 YIELD ATTRIBUTES

4.5.1 Upland

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

4.5.2 Wetland

4.5.2.1 Number 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.

4.5.2.2 Number of spikelet

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.

.4.5.2.3 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 (Table 24). The number of grains per panicle was significantly varied with varieties.

4.5.2.4 Analysis of 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 (Table 24). The effects of weather and varieties on number of panicles per plant were significant, but interaction between the treatments is not significant.

.4.5.2.5. 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 (Table 24). The effect weather on grain yield was significant.

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

Varieties	Dates of sowing	Number of panicles	Number of spikelet	Grains/panicle	1000 grain weight(g)	Grain yield(kg/ha)
Jyothi	June 15	9.66	8.33	93.00	30.40	1945.46
Kanchana	June 15	13.33	6.66	75.33	30.96	2055.42
Jyothi	June 26	10.66	9.00	103.00	30.70	2171.08
Kanchana	June 26	16	6.66	74.66	31.13	2438.47
Jyothi	July 7	7.66	8.33	94.00	29.60	1399.16
Kanchana	July 7	10	8.33	92.66	30.50	1915.22
Jyothi	July 16	14.33	9.00	100.33	29.13	2782.4
Kanchana	July 16	14	7.00	78.33	29.43	2174.83
Jyothi	July 26	10	8.66	97.33	28.36	1830.31
Kanchana	July 26	10.33	8.66	97.66	29.06	1905.31
CD 5%	Main Treatments	2.34	1.86	19.81	0.52	549.71
	Sub Treatments	1.42	0.87	10.50	0.29	458.44
	Main x Sub	3.18	1.96	23.49	0.65	1025.11

4.6 Incubation period

The effects of weather and varieties on leaf blast incubation period were significant, but interaction between the treatments is not significant. Minimum duration of incubation was recorded in Kanchana in the 26th May sowing crop and maximum incubation period was recorded by Jyothi in the 6th July crop (Table 25).

Table.25 Leaf blast Incubation period in rice

Variety	Dates of sowing	Incubation period
Jyothi	May-26	5.33
Kanchana	May-26	4.67
Jyothi	Jun-06	6.33
Kanchana	Jun-06	5.67
Jyothi	Jun-16	5.67
Kanchana	Jun-16	5.67
Jyothi	Jun-26	6.33
Kanchana	Jun-26	6
Jyothi	Jul-06	7.33
Kanchana	Jul-06	7
CD 5%	Main Treatments	0.79
	Sub Treatments	0.39
	Main x Sub	0.88

4.7 Disease severity

The maximum leaf blast severity (66.03%) was recorded by Kanchana in 6th June sowing crop and the minimum (0.21%) was observed in Jyothi when sowing on 6th July (Table 26). The study shows that variety Jyothi was more tolerant to leaf blast incidence.

Table.26 Leaf blast Severity

Varieties	Dates of sowing	Changes in severity after disease incidence				
		1st Week	2nd Week	3rd Week	4th Week	5th Week
Jyothi	May-26	1.22	2.05	2.96	5.04	7.20
Kanchana	May-26	0.80	1.65	1.93	5.94	16.01
Jyothi	Jun-06	0.20	0.92	1.68	2.98	9.85
Kanchana	Jun-06	2.30	5.69	15.54	33.93	66.03
Jyothi	Jun-16	0.35	0.79	2.69	3.68	3.79
Kanchana	Jun-16	4.23	28.00	62.7	63.4	63.4
Jyothi	Jun-26	0	0.03	0.18	0.38	0.72
Kanchana	Jun-26	0	0.1	0.57	1.98	2.45
Jyothi	Jul-06	0	0	0.09	0.18	0.21
Kanchana	Jul-06	0	0.1	0.27	0.46	0.58
CD 5%	Main Treatments	1.94	3.97	7.65	8.16	11.82
	Sub Treatments	1.22	2.76	5.31	5.68	6.67
	Main x Sub	2.73	6.18	11.87	12.71	14.92

4.8. REGRESSION MODELS FOR PREDICTION OF LEAF BLAST INCIDENCE

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

4.8.1 Regression models for Jyothi,

DI= 4.452-0.126AVGSM8+0.171AVGSM9-0.195AVGT12-0.187HRF2 $R^2 = 0.69$

Where,

AVGSM8=Average soil moisture at 8th day (%).

AVGSM9=Average soil moisture at 9th day (%).

AVGT12=Average temperature at 12th day (° C).

HRF2=Average rain fall of 7 to 13 days after inoculation (mm).

4.8.2 Regression models for Kanchana,

DI= 77.22-1.266AVGSM8-0.827AVGSM9+0.178AVGT12-0.328HRF2 $R^2=0.68$

Where,

AVGSM8=Average soil moisture at 8th day (%).

AVGSM9=Average soil moisture at 9th day (%).

AVGT12=Average temperature at 12th day (° C).

HRF2= Average rain fall of 7 to 13 days after inoculation (mm).

4.9 EPIRICE MODEL

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

The observed and simulated blast diseasese severity of variety Kanchana has presented in the Fig 17. RMSE for Kanchana prediction is 0.265. This shows that the predicted leaf blast severity was in good agreement with the observed values. So this model can be used for forecasting the rice blast severity under Kerala conditions.

Table.27 Observed and Predicted Leaf blast severity using EPIRICE model

Week after planting	Disease Severity		RMSE
	Observed	Predicted	
Week 1	0	0	0.265
Week 2	0	0	
Week 3	1	0.85	
Week 4	1	1	
Week 5	1.3	1.19	
Week 6	1.95	1.43	
Week 7	2.05	1.62	

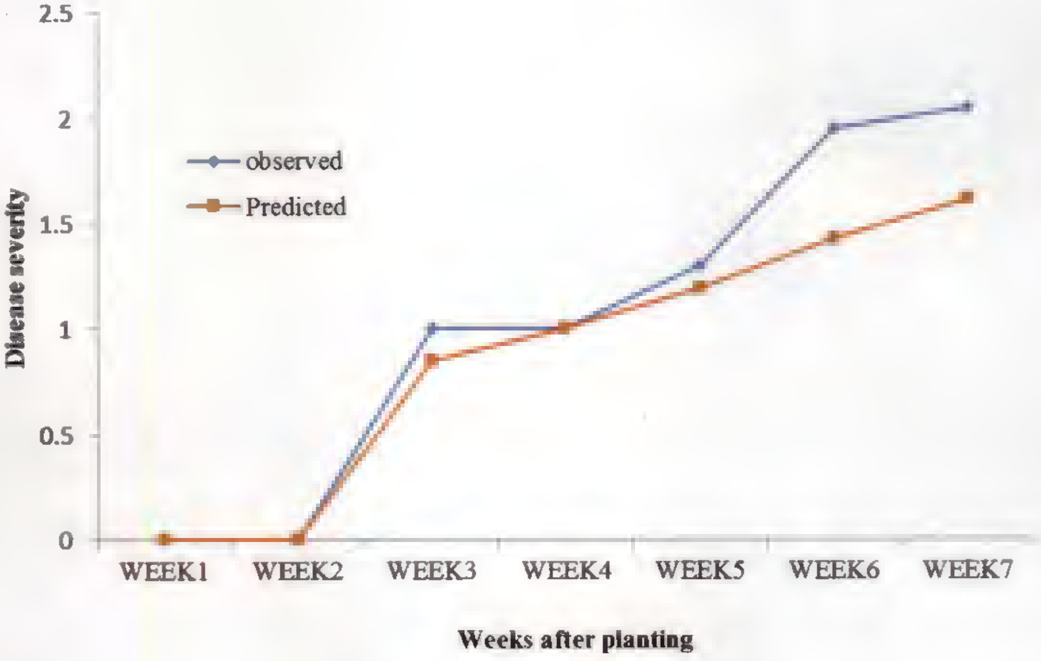
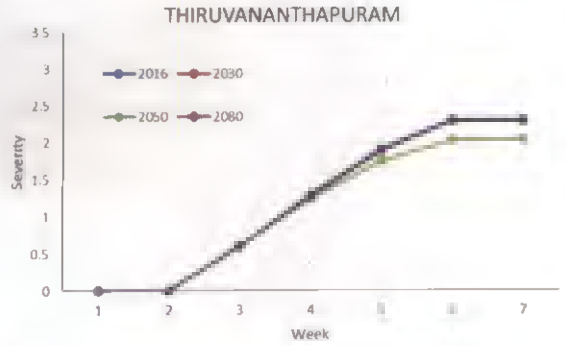


Fig.17 Observed and Predicted Leaf Blast severity

4.10 IMPACT OF CLIMATE CHANGE ON BLAST INCIDENCE

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 blast for the years 2030, 2050 and 2080 in all the 14 districts of Kerala has been presented in the Fig 18. 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 leaf blast severity in the various districts of Kerala showed a varying trend. Except in the northern districts (Malappuram, Wayanad, Kannur and Kasaragod) the disease severity showed a decreasing trend.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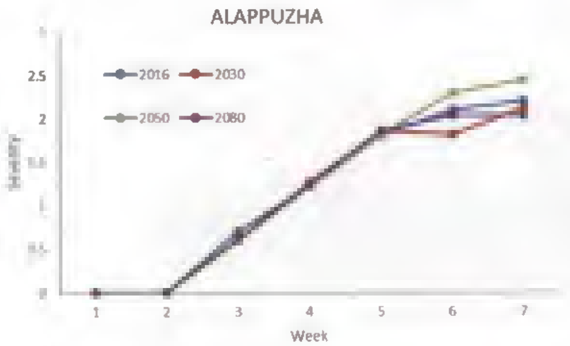
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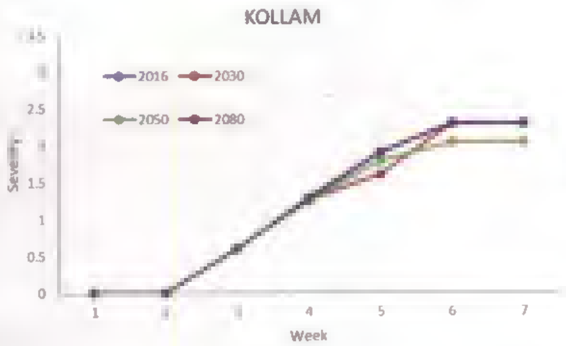
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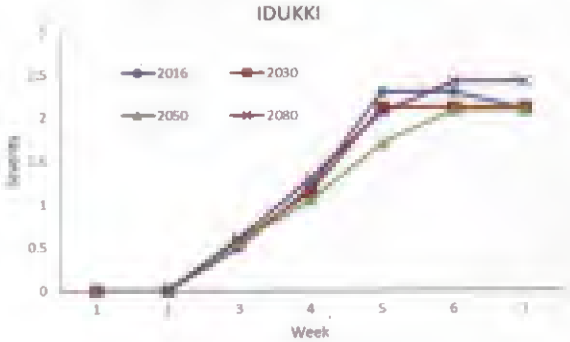
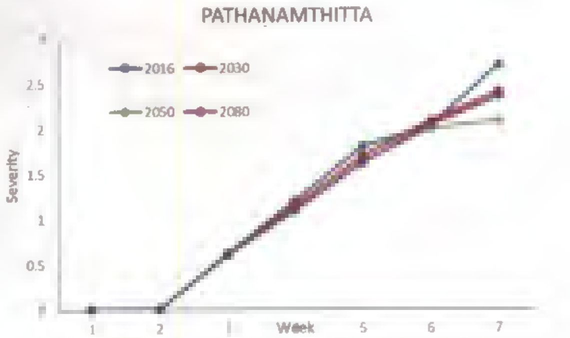

IDUKKI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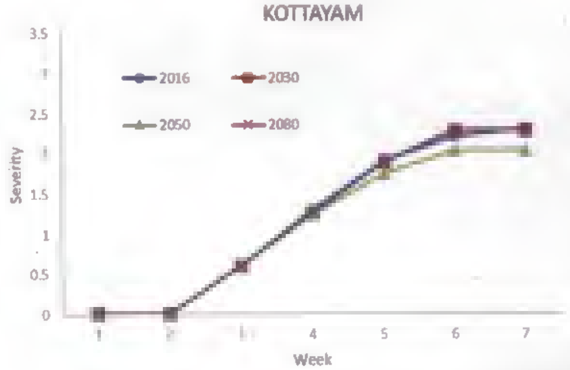
KOTTAYAM

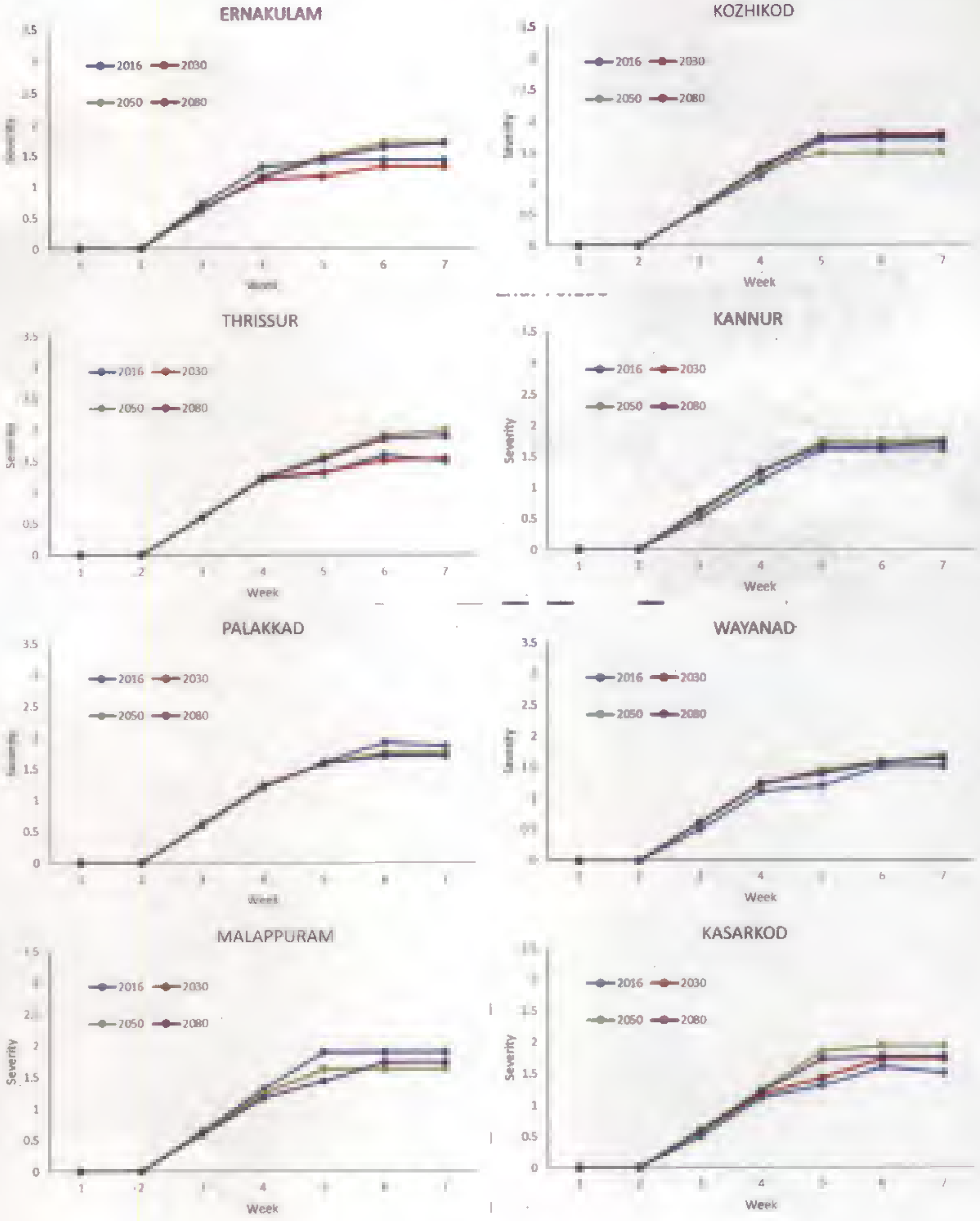

Fig. 18. Impact of projected Climate on leaf blast disease

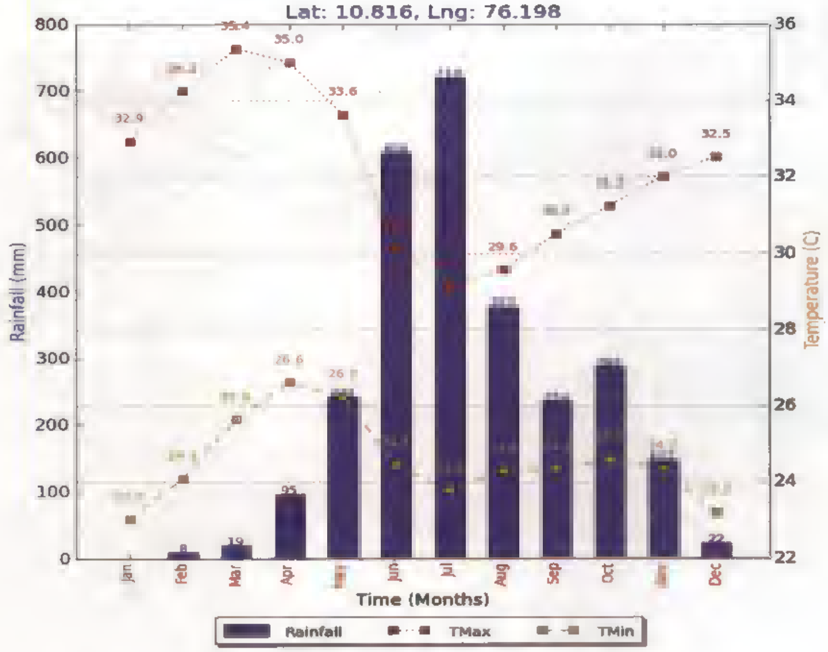

Fig 19. Climate of Pattambi in 2030s under RCP 2.6

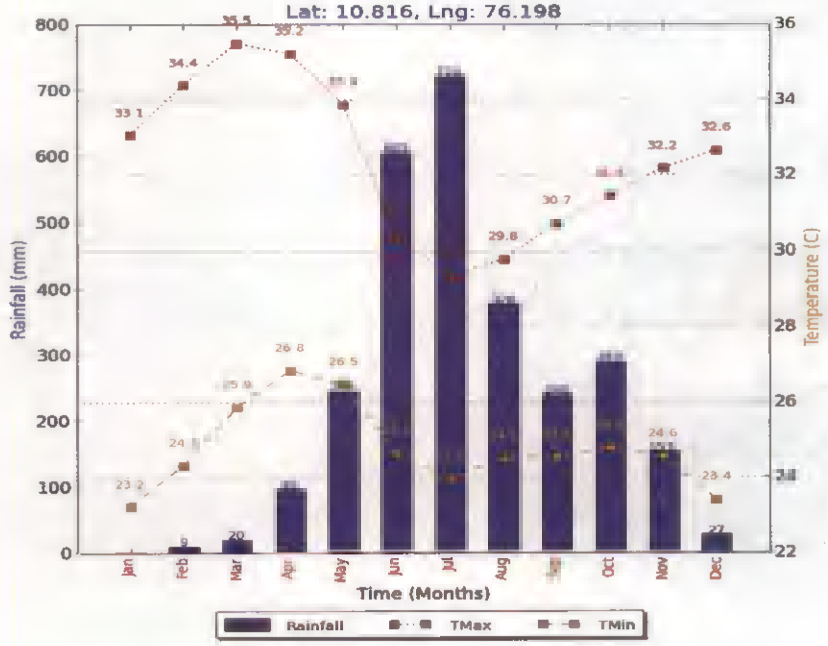

Fig 20. Climate of Pattambi in 2050s under RCP 2.6

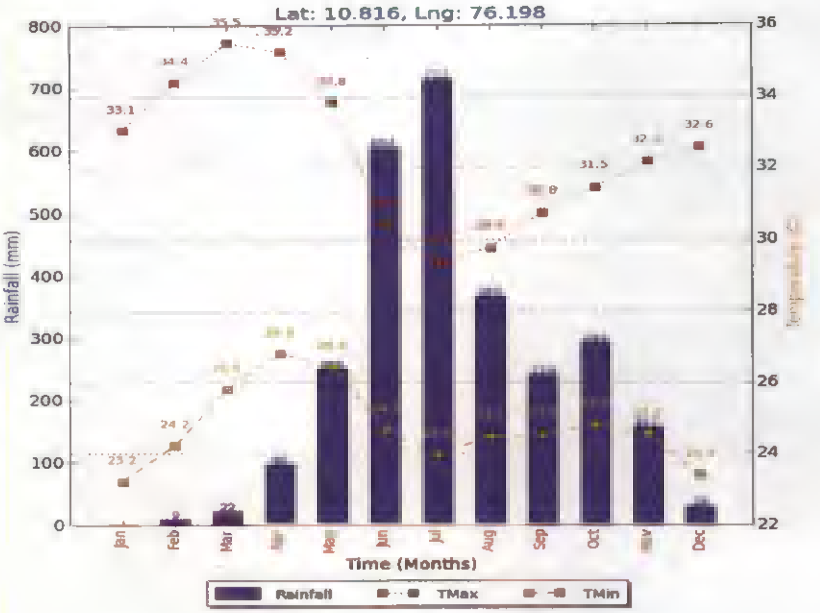

Fig 21. Climate of Pattambi in 2080s under RCP 2.6

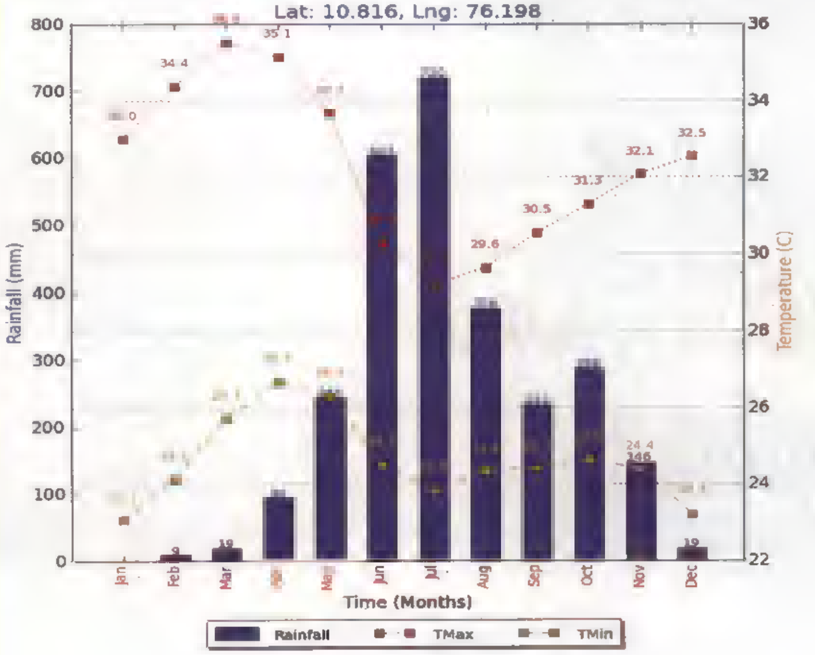

Fig 22. Climate of Pattambi in 2030s under RCP 4.5

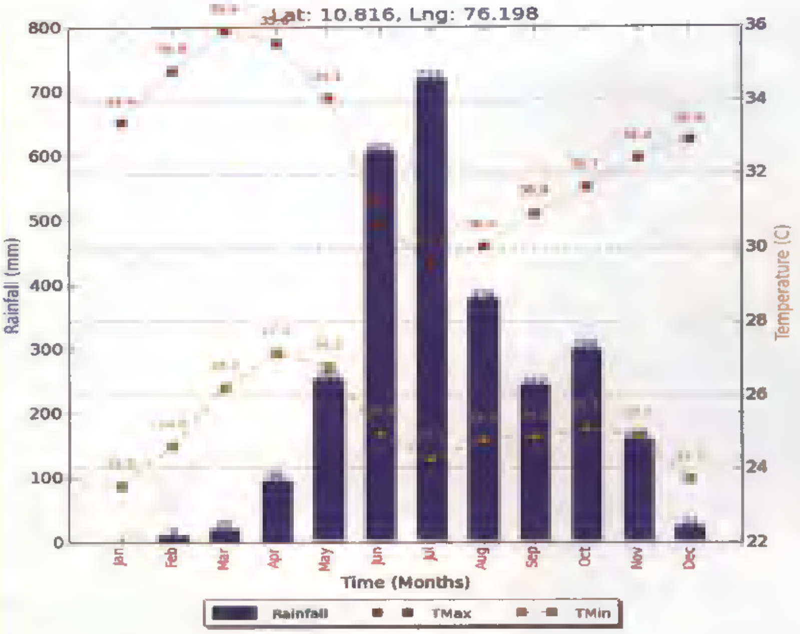

Fig 23. Climate of Pattambi in 2050s under RCP 4.5

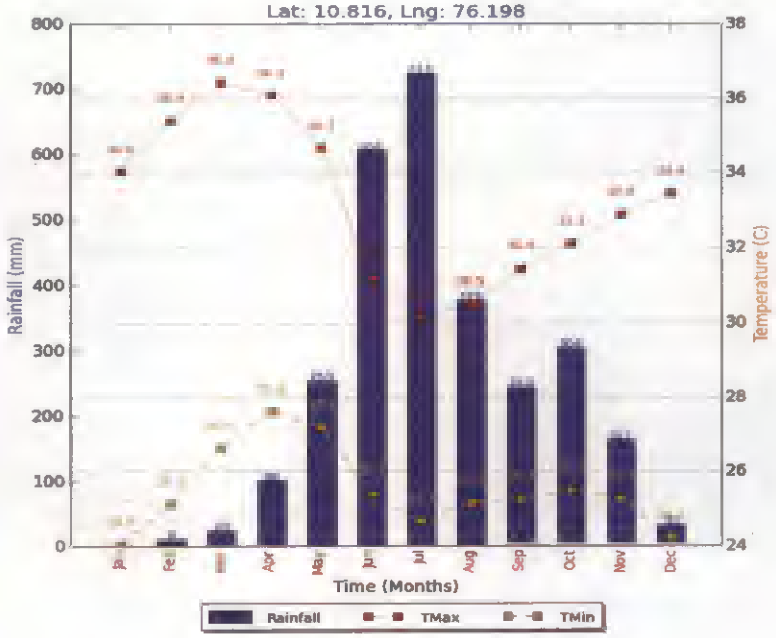

Fig 24. Climate of Pattambi in 2080s under RCP 4.5

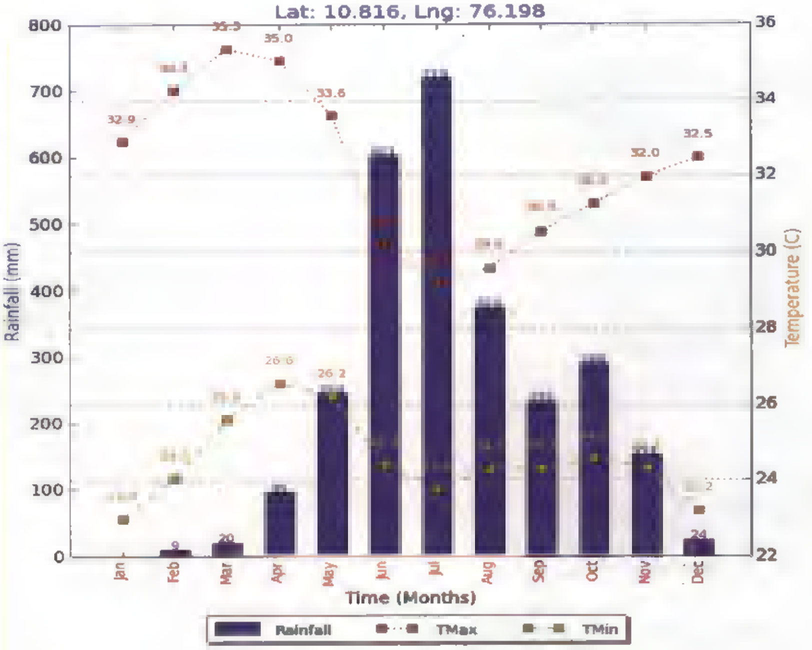

Fig 25. Climate of Pattambi in 2030 under RCP 6.0

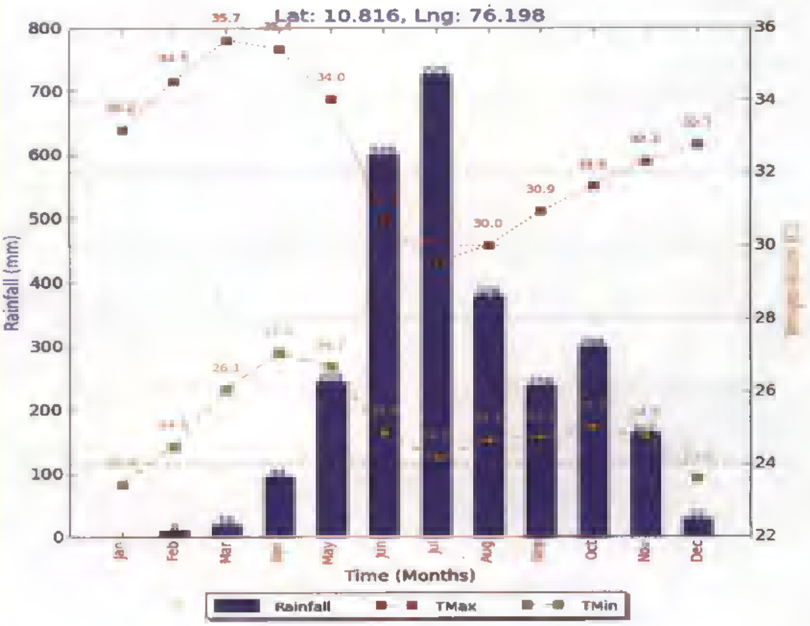

Fig 26. Climate of Pattambi in 2050s under RCP 6.0

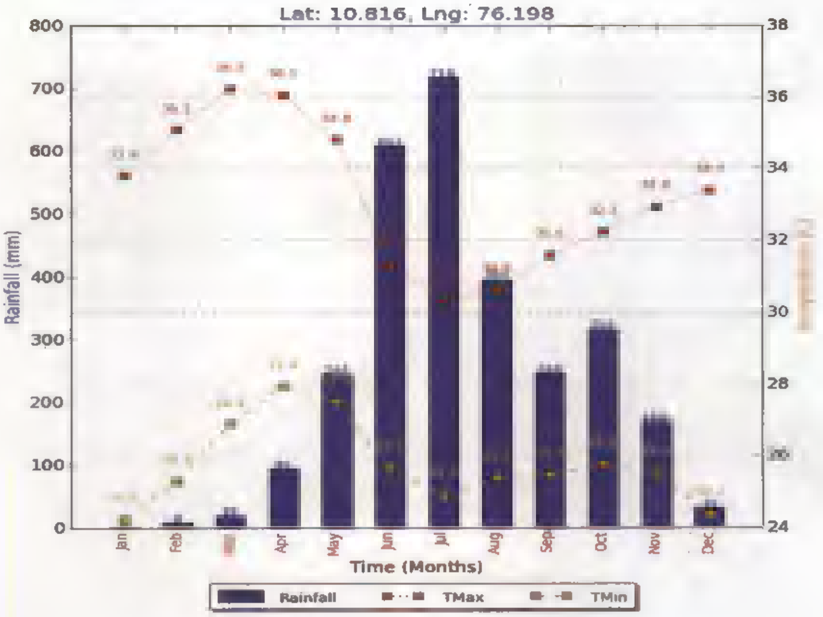

Fig 27. Climate of Pattambi in 2080s under RCP 6.0

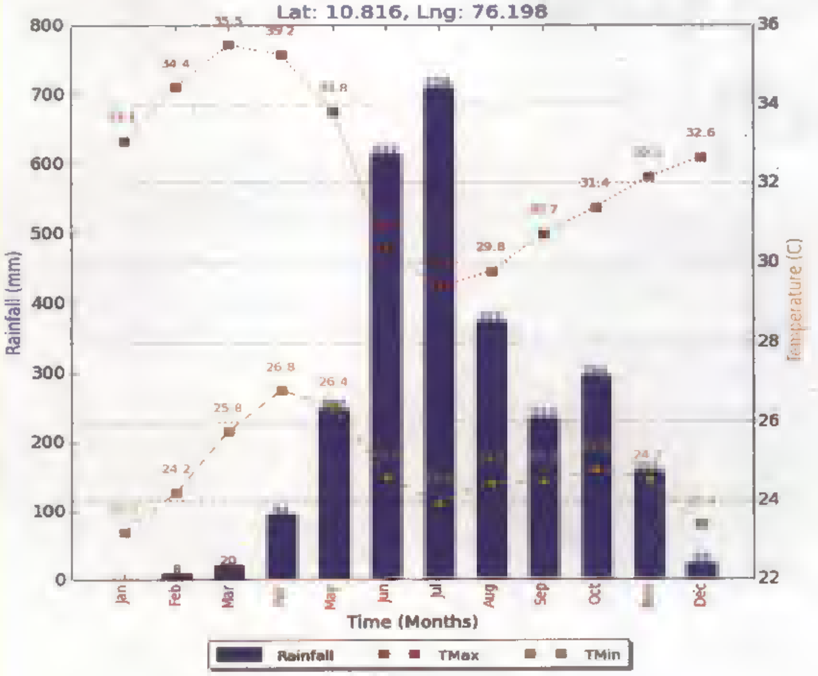

Fig 28. Climate of Pattambi in 2030s under RCP 8.5

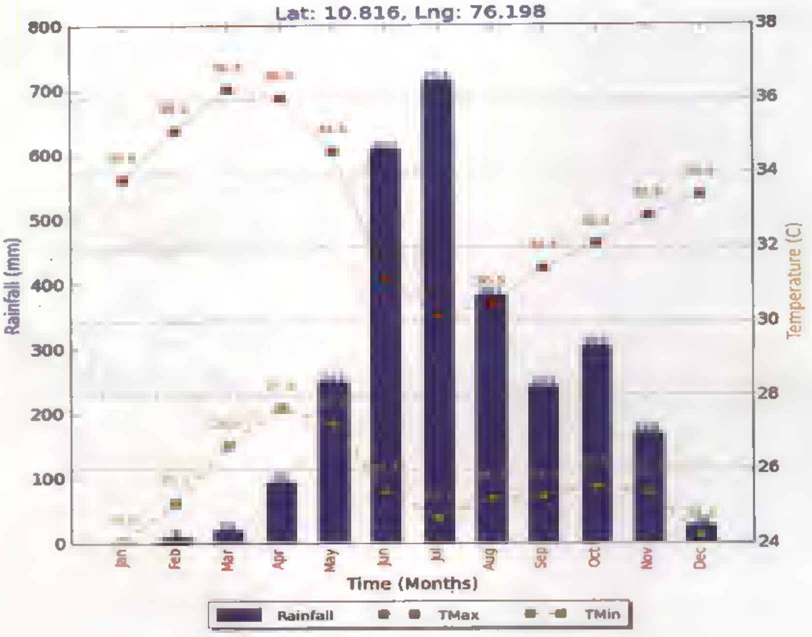

Fig 29. Climate of Pattambi in 2050s under RCP 8.5

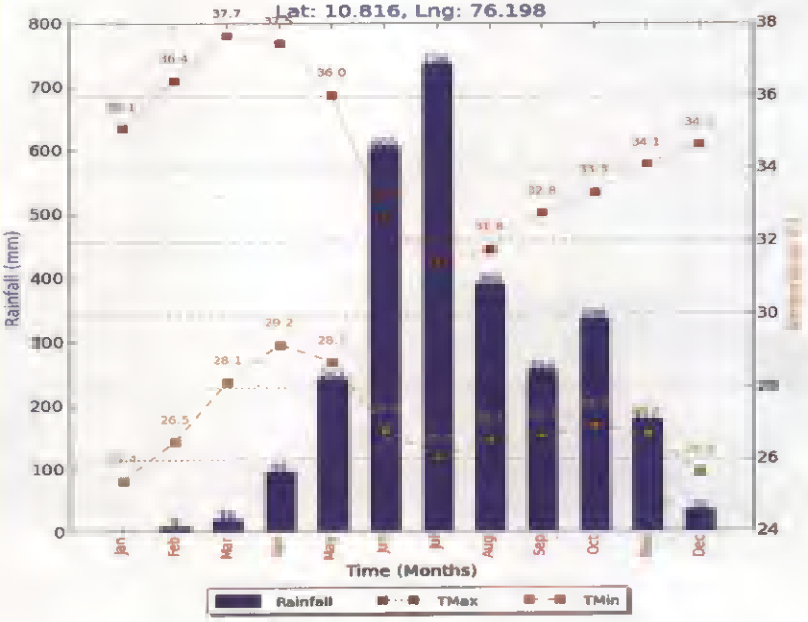

Fig 30. Climate of Pattambi in 2080s under RCP 8.5

CHAPTER. 5 DISCUSSION

This study was taken up to understand the effect of weather on blast 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

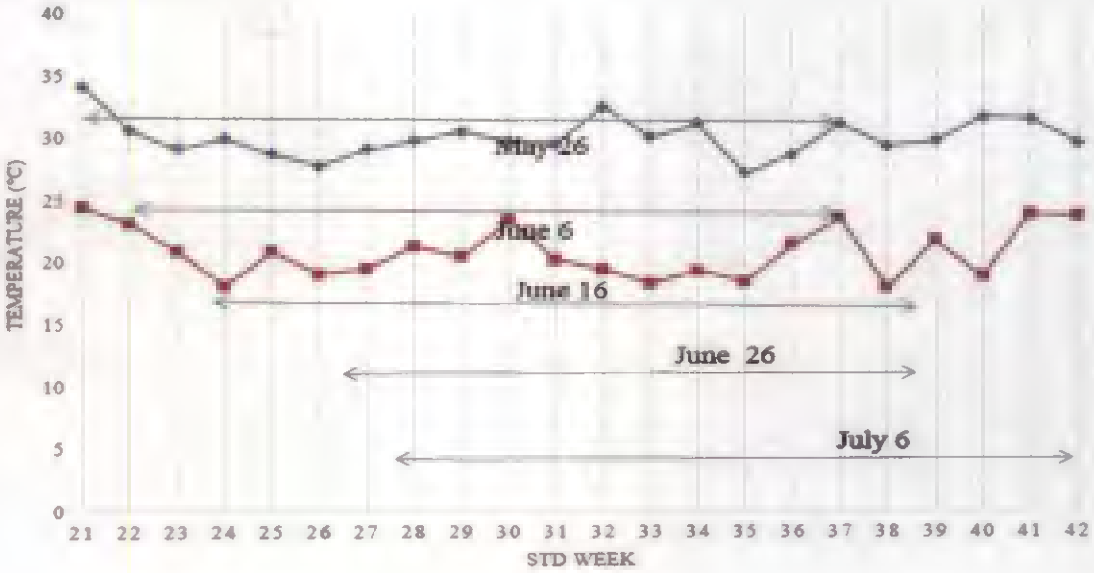

Fig 31. Weekly Temperature

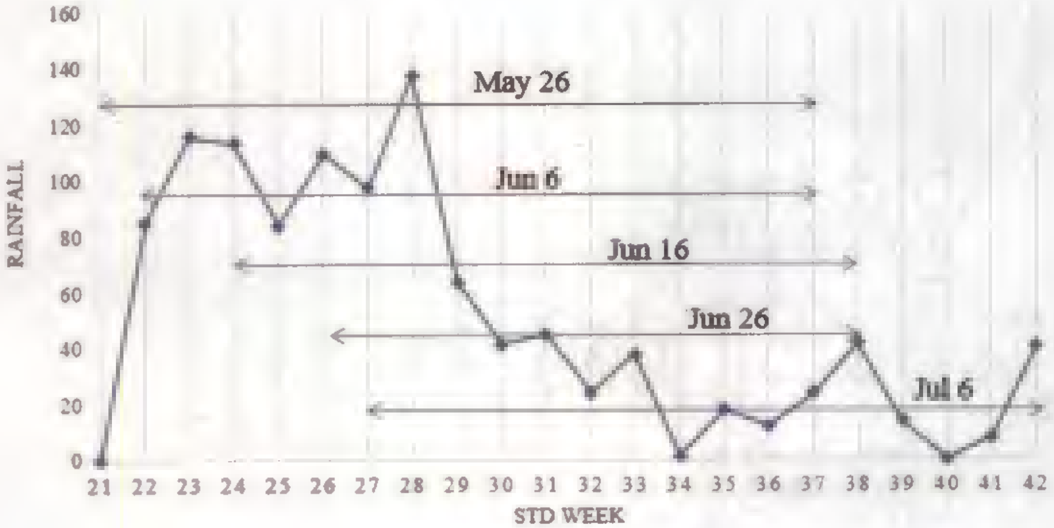

Fig 32. Weekly Rainfall

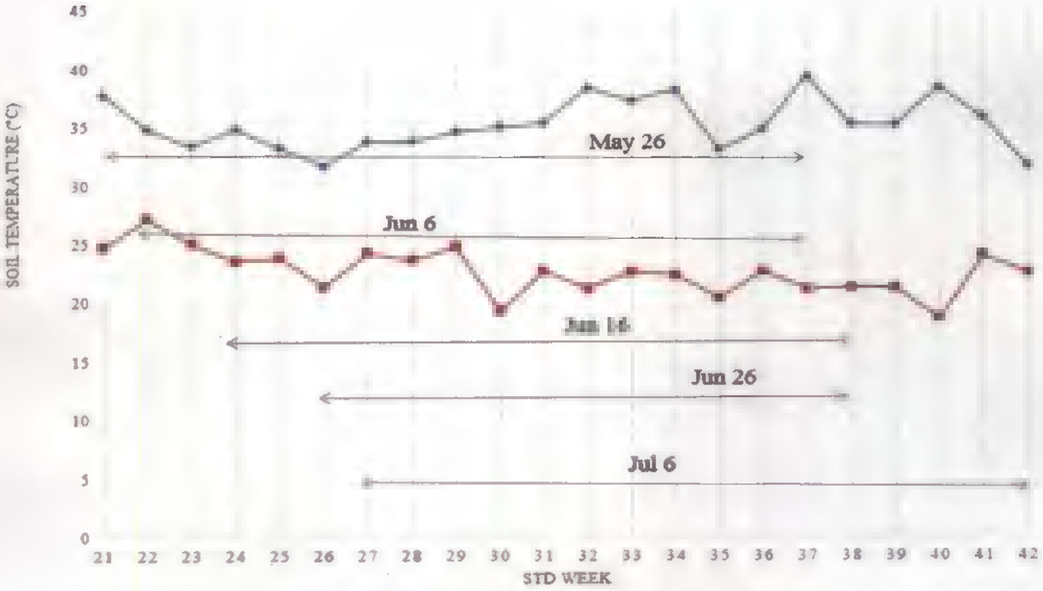

Fig 33.Weekly Soil Temperature

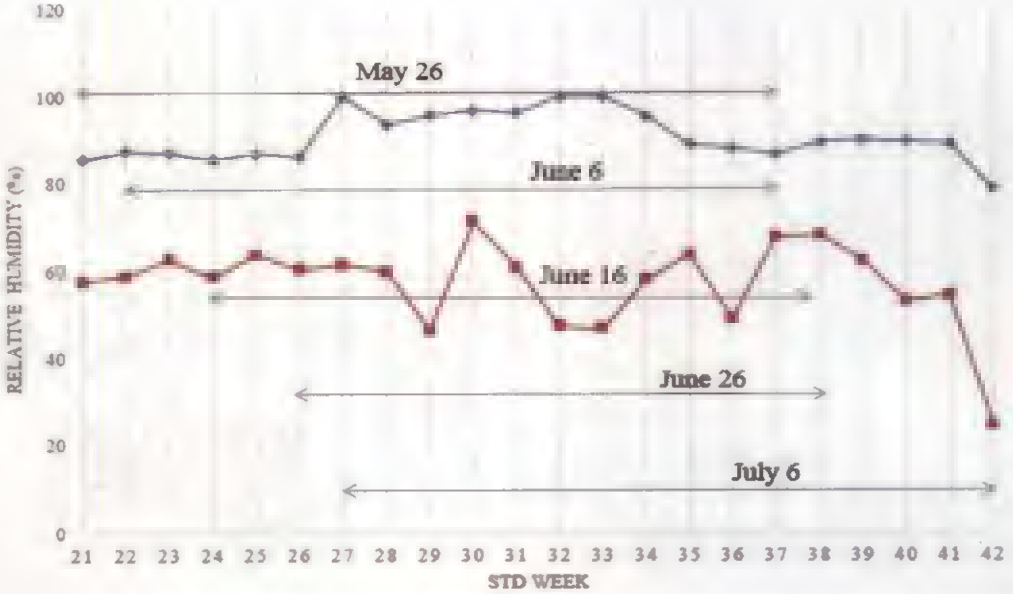

Fig 34. Weekly Relative Humidity

5.2 IMPACT OF WEATHER ON LEAF BLAST INCIDENCE

5.2.1 Leaf blast incidence in Jyothi and Kanchana

The results have showed that the incidence of leaf blast is significantly influenced by the weather parameters and variety. It can be clearly observed from the figure that the early sowing crops showed a higher disease incidence compared to other dates of sowing. It was also noticed that variety Kanchana is more susceptible to leaf blast incidence compared to Jyothi. 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 Upma Dutta and C.S. Kalha (2011)

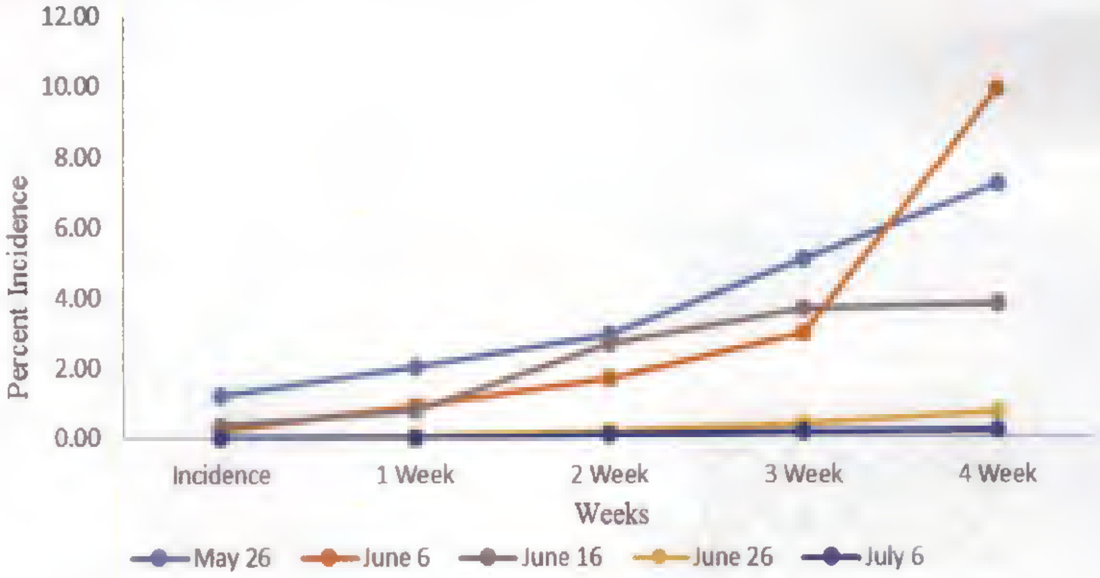

Figure 35. Leaf blast incidence in Jyothi

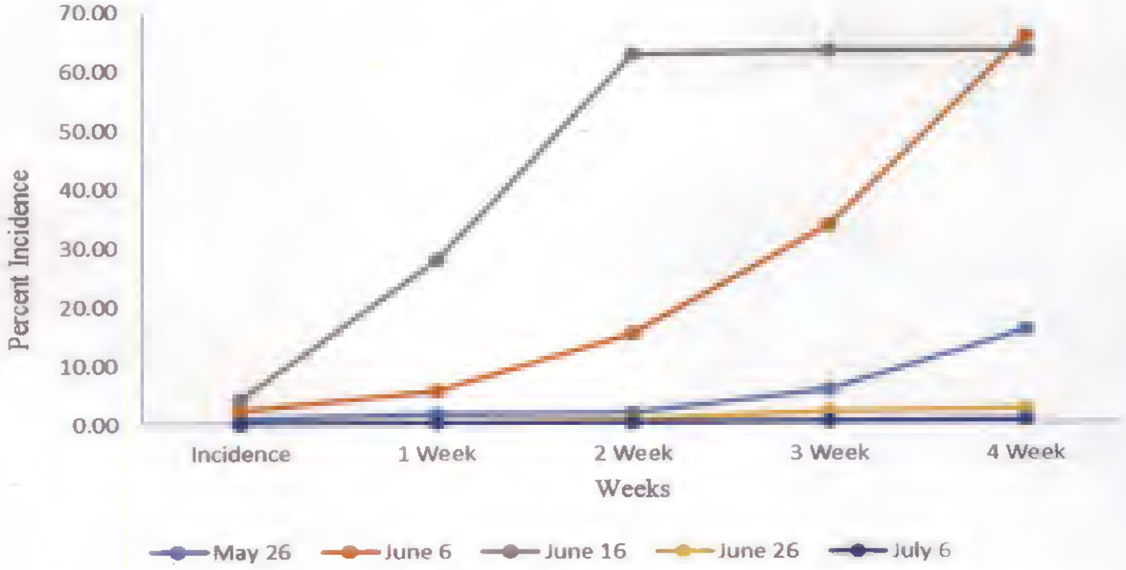

Figure 36. Leaf blast incidence in Kanchana

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.

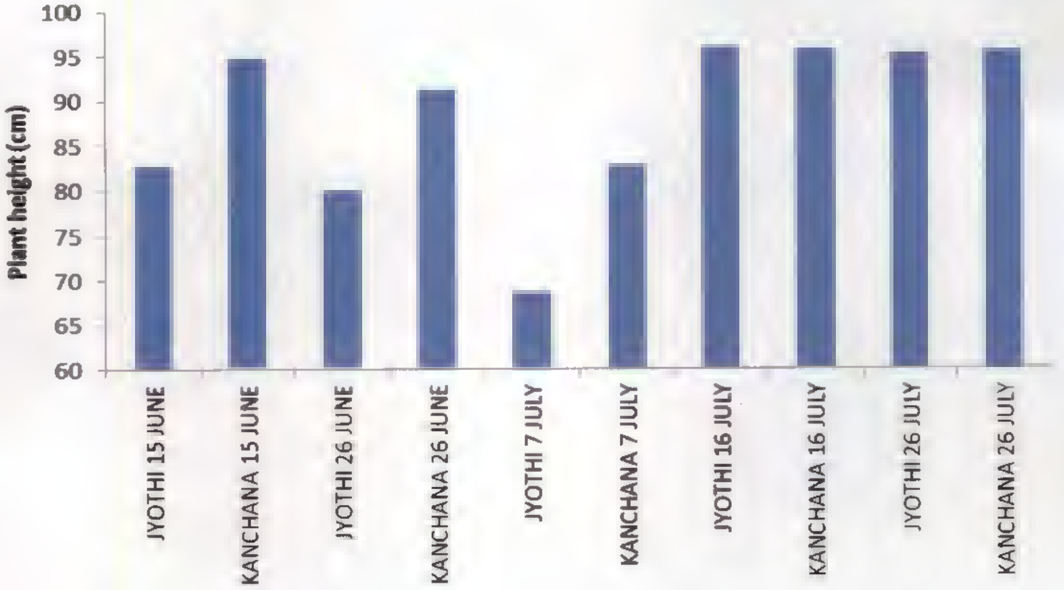

Fig 37. Plant height in wetland

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).

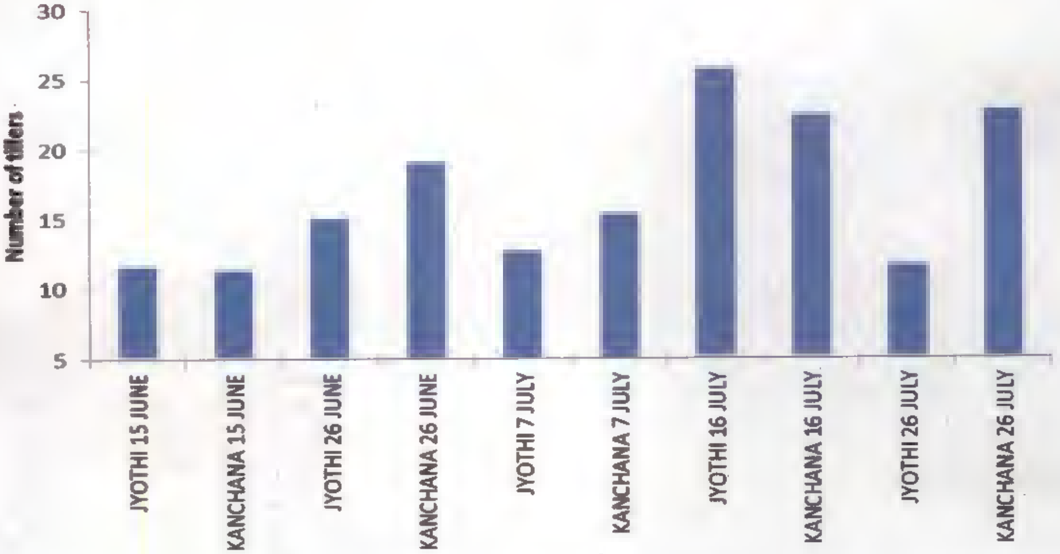

Fig 38. Number of tillers in wetland

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.

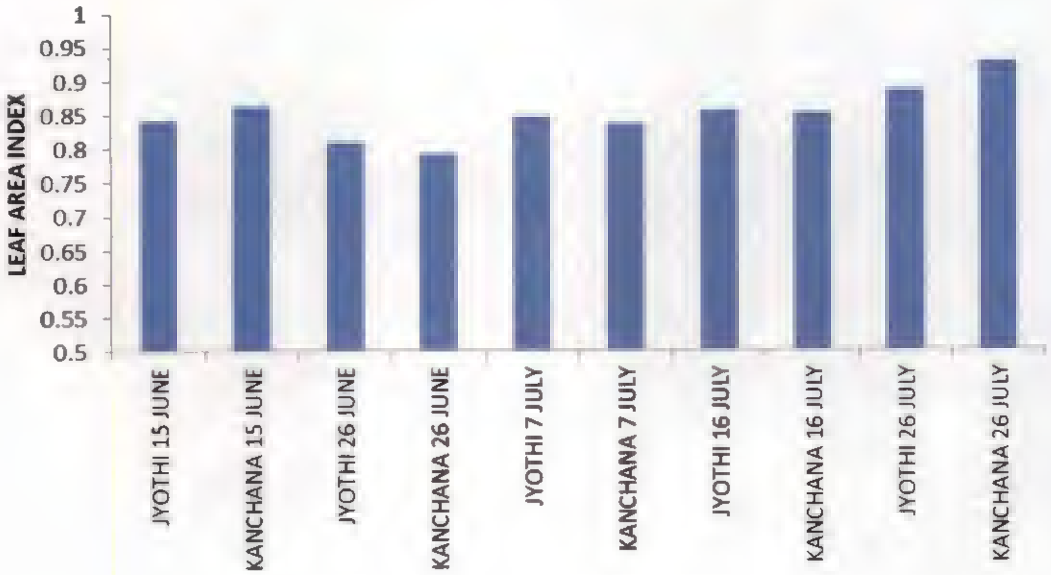

Fig 39. Leaf Area Index in wetland

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.

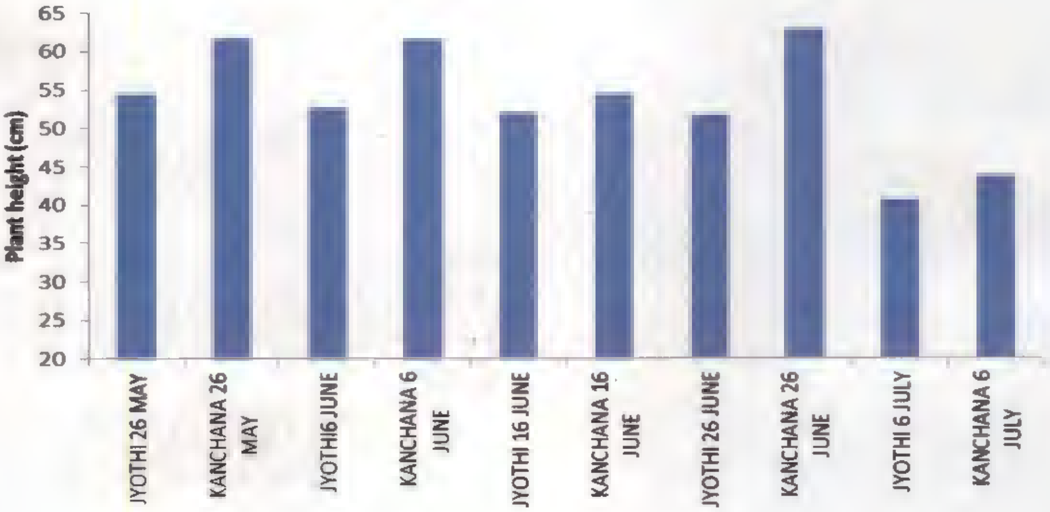

Fig 40. Plant height in upland

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.

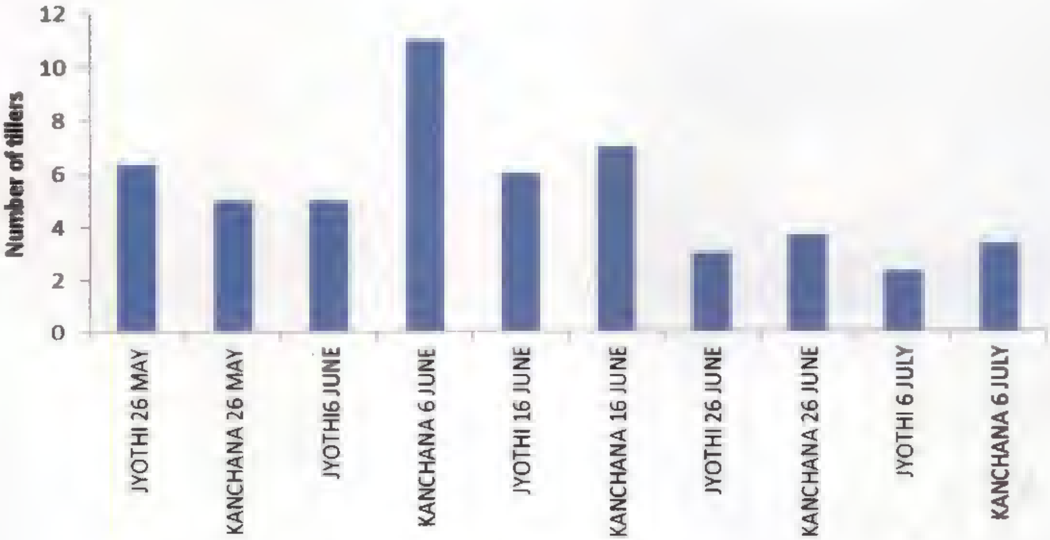

Fig 41. Number of tillers in upland

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.

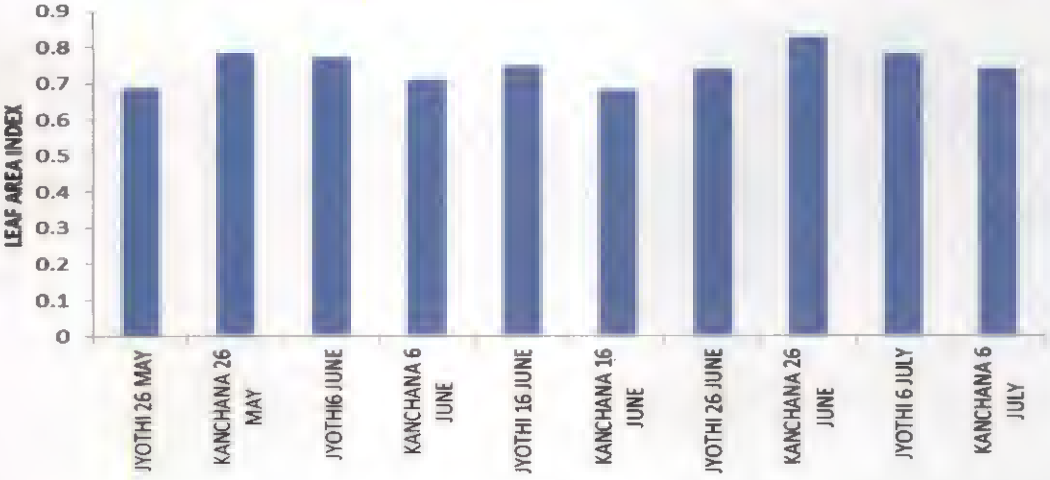

Fig 42. Leaf area index in upland

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.

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

95

treatments is not significant. Reduction in panicle number is mainly attributed by high temperature (Ghosh *et al.*, 1983)

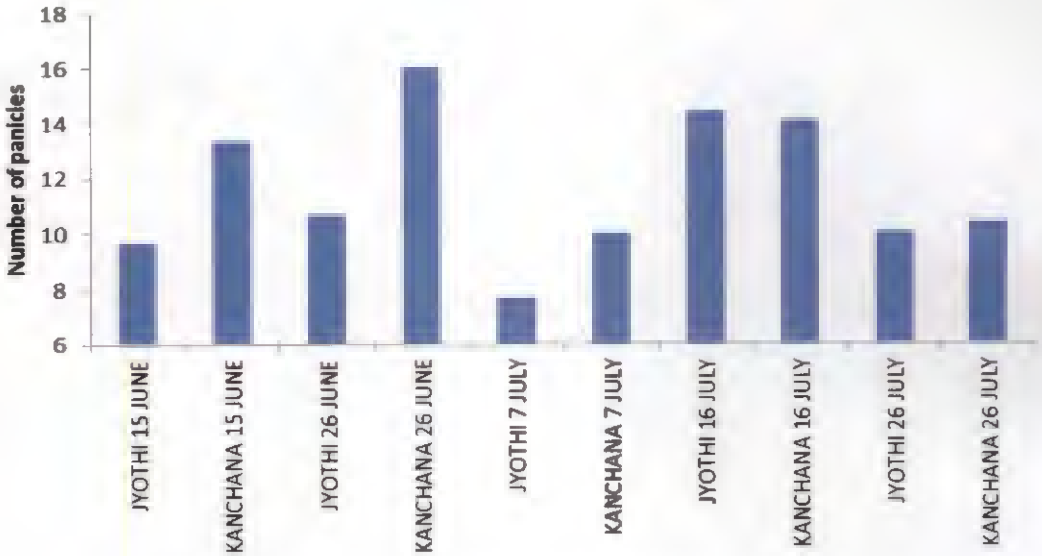

Fig 43. Number of panicles

5.4.1.2 Number of spikelets

The number of spikelets per plant is presented in the figure. 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.

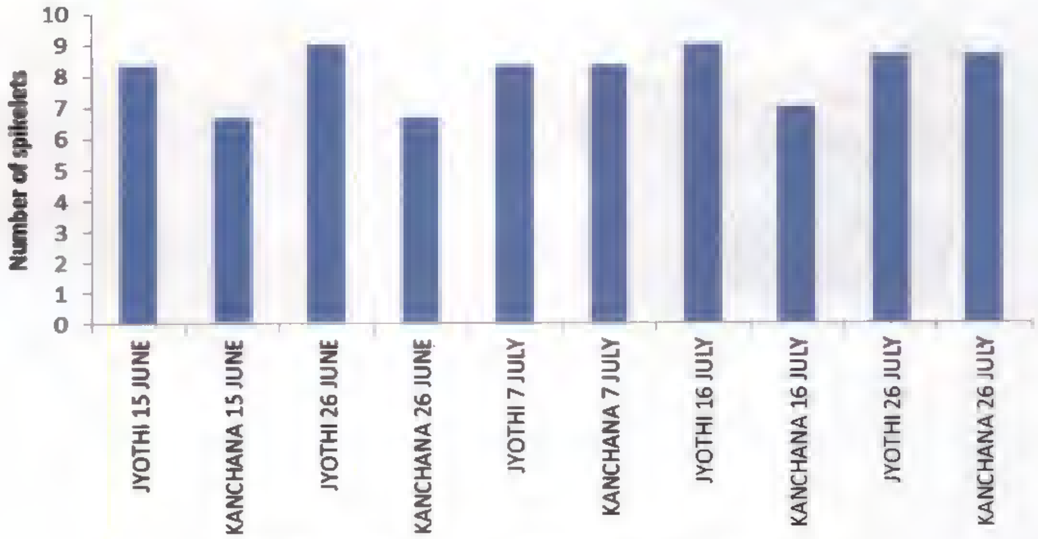

Fig 44. Number of spikelets per panicle

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).

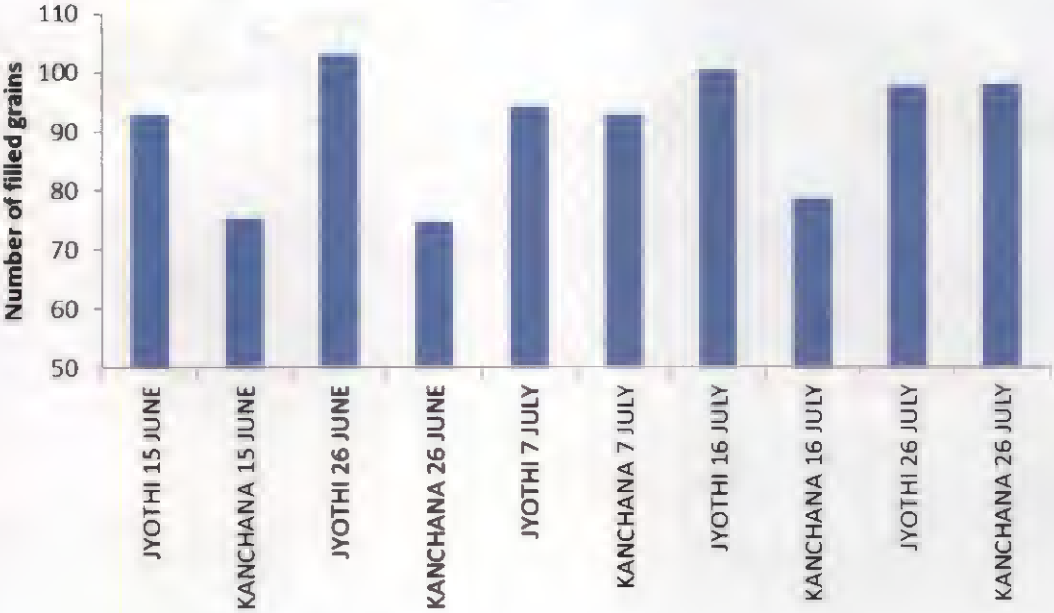

Fig 45. Number of grains per panicle

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.

97

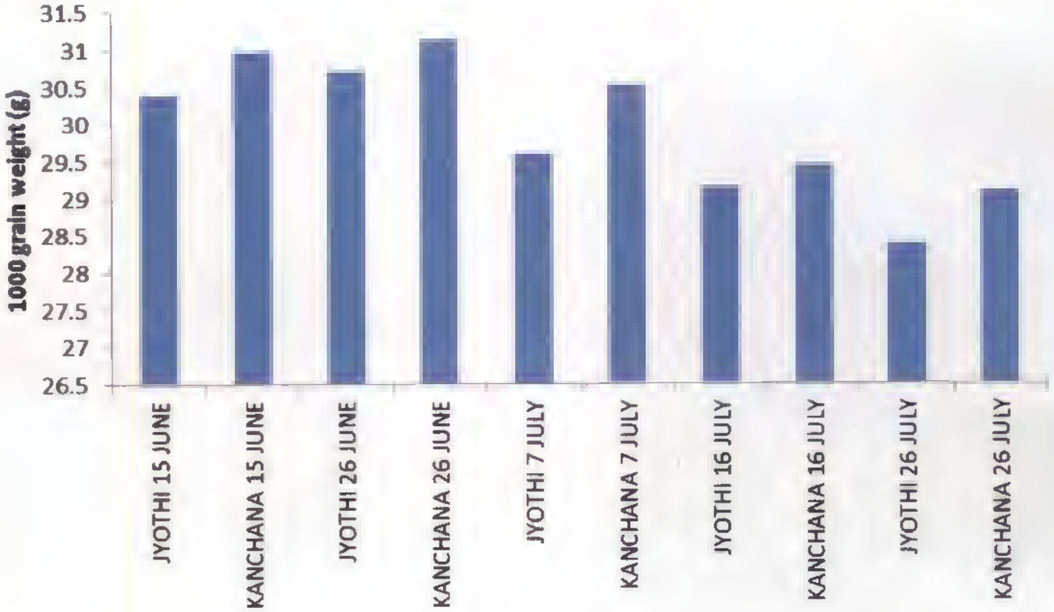

Fig 46. 1000 Grain weight (g)

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 (Table 24). The effect weather on grain yield was significant.

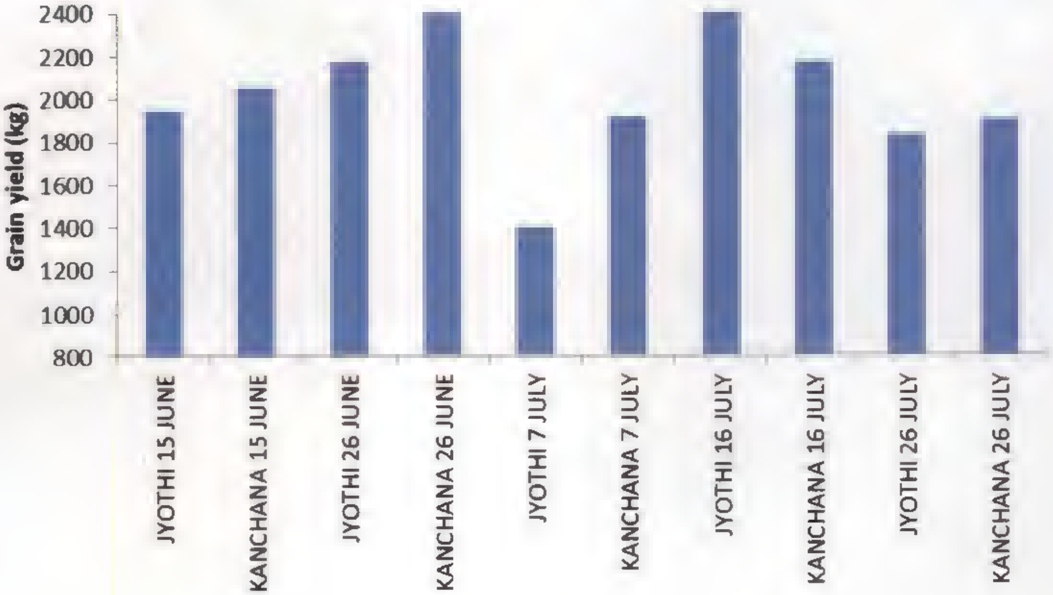

Fig 47. Grain yield (kg per hectare)

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

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 leaf blast incubation period were significant, but interaction between the treatments is not significant. Minimum duration of incubation was recorded in Kanchana in the 26th May planted crop and maximum incubation period was recorded by Jyothi in the 6th July crop.

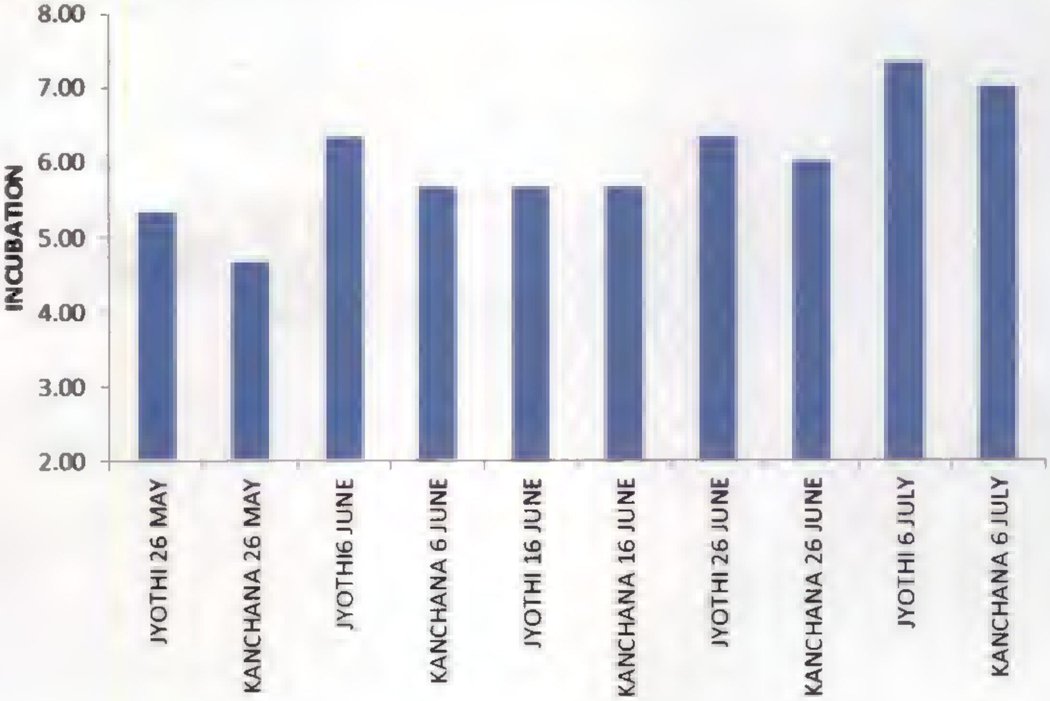

Fig 48. Incubation Period (days) of Leaf blast disease in rice

5.6 Leaf blast severity

The maximum leaf blast severity (66.03%) was recorded by Kanchana in 6th June sowing crop and the minimum (0.72%) was observed in Jyothi when sowing on

26th June. The study shows that variety Kanchana was more susceptible to leaf blast incidence.

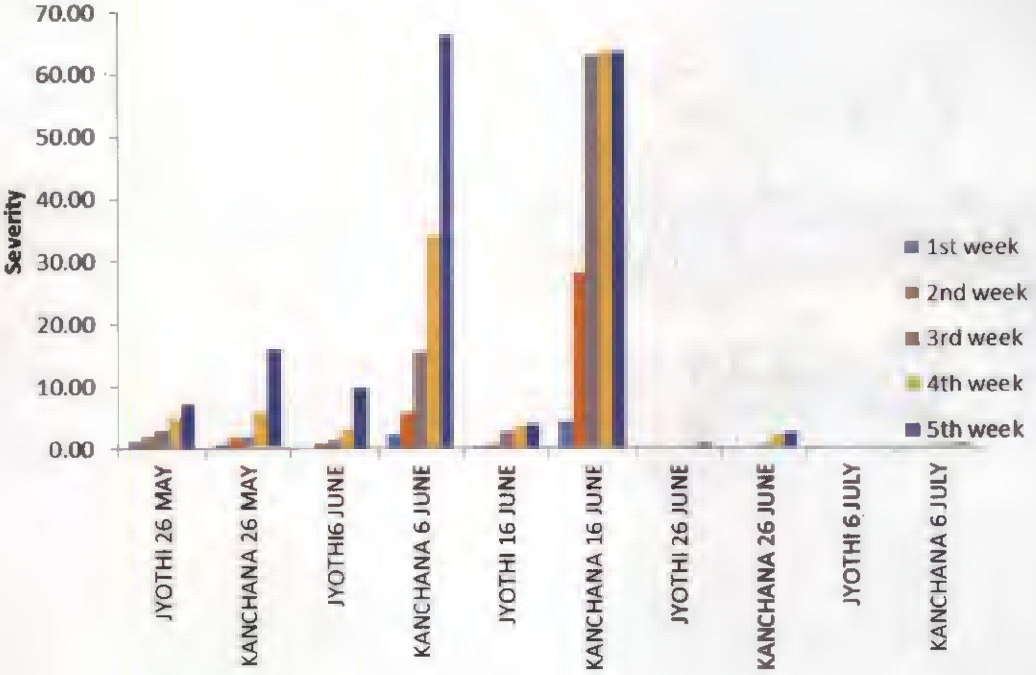

Fig 49. Leaf blast severity

5.7 REGRESSION MODELS FOR PREDICTION OF LEAF BLAST INCIDENCE

The incidence of leaf blast disease in rice results from favourable interaction between weather, host and pathogen. The major weather parameters determining the incidence are temperature, soil temperature and rainfall. Multiple regression equations were developed for the forewarning the leaf blast incidence in rice. As the susceptibility to leaf blast incidence varies with variety separate equations were developed for the two important ruling varieties in Kerala i.e., Kanchana (susceptible) and Jyothi (resistant).

Disease Incidence = DI = 4.452 - 0.126 AVGSM8 + 0.171 AVGSM9 -0.195 AVGT12 - 0.187HRF2 $R^2 = 0.69$

Where,

AVGSM8=Average soil moisture at 8th day (%).

AVGSM9=Average soil moisture at 9th day (%).

101

AVGT12=Average temperature at 12th day (° C).

HRF2=Average rain fall of 7 to 13 days after inoculation (mm).

Disease Incidence = DI = 77.22 - 1.266 AVGSM8 - 0.827 AVGSM9 + 0.178AVGT12 - 0.328HRF2 $R^2=0.68$

Where,

AVGSM8=Average soil moisture at 8th day (%).

AVGSM9=Average soil moisture at 9th day (%).

AVGT12=Average temperature at 12th day (° C).

HRF2= Average rain fall of 7 to 13 days after inoculation (mm).

5.8 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 leaf blast disease severity of variety Kanchana has presented in the Fig 50. RMSE for Kanchana prediction is 0.265.This shows that the predicted leaf blast severity was in good agreement with the observed values. So this model can be used for forecasting the rice leaf blast severity under Kerala conditions. The same results were also reported by Kwang-Hyung Kim *et.al,* 2015.

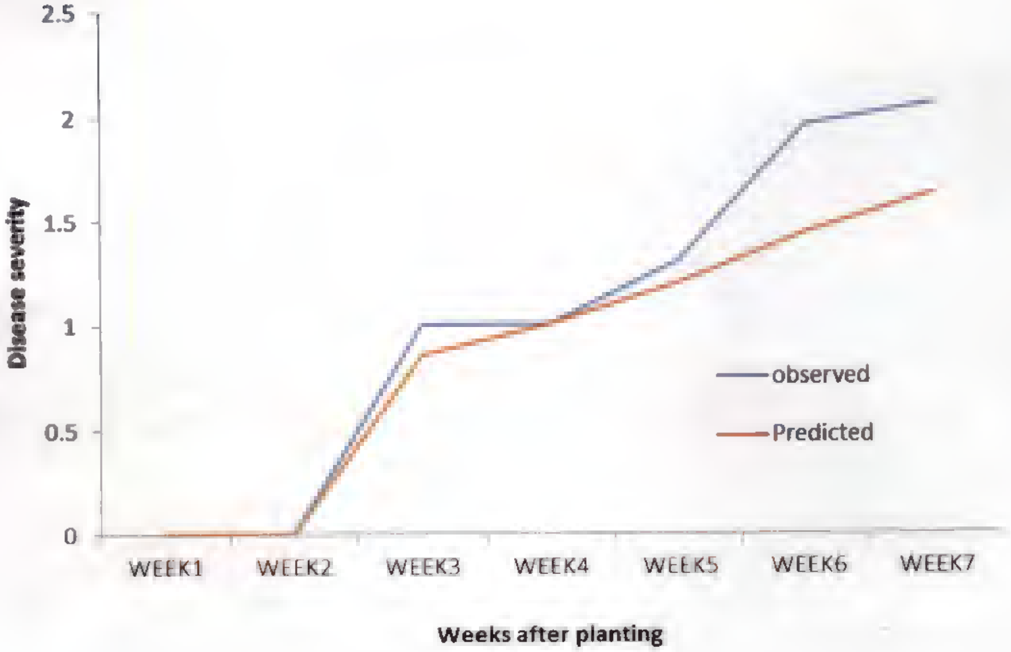

Fig.50 Observed and simulated leaf blast disease severity of variety Kanchana

5.9 IMPACT OF CLIMATE CHANGE ON LEAF BLAST 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 leaf blast for the years 2030, 2050 and 2080 as per RCP 4.5. It can be observed from the study that the severity of leaf blast is going to decrease slightly in future and the southern districts will be less susceptible to disease prone. This is mainly because of high rainfall expected during the first crop season as per climate change projections.

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 leaf blast incidence in rice and predicting potential epidemics under various climate change scenarios, with two varieties, Jyothi and Kanchana. 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 blast for the years 2030, 2050 and 2080.

The observations on morphological, phenological and pathological and weather observations were recorded at different stages of development of the crop. The observations on weather factors were recorded daily to workout crop weather relationship. EPIRICE model was validated and impact of climate change on leaf blast disease in rice was studied.

The salient finding are summarised as follows:

1. Variety Kanchana is more susceptible to Leaf blast incidence compared to Jyothi.
2. The crops sowing on June 16th recorded the highest disease incidence of 4.23% in Kanchana.
3. The least disease incidence was observed Jyothi and Kanchana in crops sowing on June 26th and July 6.
4. The maximum severity recorded for Kanchana was 66.03% and Jyothi was 9.85% respectively.
5. Variety and time of planting has significantly influenced the plant height. Highest plant height observed in Kanchana was 62.6cm and lowest plant height observed Jyothi was 40.6 cm. June 26th sowing has recorded highest plant height and July 6th recoded the lowest plant height in dry land condition.
6. In Kanchana maximum number of tillers per plant was observed (11) in the crop sowing during June 6th, whereas in case of Jyothi crops sowing during July 6th (2.3) was recorded the minimum number of tillers in dry land condition.

7. The maximum LAI recorded by the variety Kanchana was 0.82 by June 26th sowing crop. Whereas Kanchana and Jyothi recorded a minimum LAI of 0.68 by the crop sowing on June 16th and May 26.
8. Jyothi transplanted on July 16th recorded the highest plant height was 95.8 cm. lowest plant height observed in July 17th transplanted crop 68.6cm in case of Kanchana.
9. Crops transplanted during 16th July and 26th July recorded the highest number of tillers per plant (25.6) for Jyothi and Kanchana respectively.
10. 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.
11. 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.
12. Variety Kanchana transplanted on 26th June recorded significantly highest number of panicles (16).
13. The variety Jyothi was recorded maximum number of spikelets (9) when planted on 26th June and 16th July.
14. 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.
15. 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.
16. 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.
17. Minimum duration of incubation was recorded in Kanchana in the 26th May sowing crop and maximum incubation period was recorded by Jyothi in the 6th July crop.

18. The maximum leaf blast severity (66.03%) was recorded by Kanchana in 6th June sowing crop and the minimum (0.21%) was observed in Jyothi when sowing on 6th July.
19. Multiple regression equations was predicted the disease incidence with good accuracy in both the varieties.
20. EPIRICE model was validated and it was given good RMSE value (0.265) for Kanchana.So predicted leaf blast severity was in good agreement with the observed values. So this model can be used for forecasting the rice blast severity under Kerala conditions.
21. The future carbon dioxide concentrations and climate data has been incorporated into disease simulation model-EPIRICE and predicted the future disease incidence possibility of blast for the years 2030, 2050 and 2080 in all the 14 districts of Kerala.
22. The impact of climate change on leaf blast severity in the various districts of Kerala showed an increasing trend. Except in the northern districts (Malappuram, Wayanad, Kannur and Kasaragod) the disease severity showed a decreasing trend.

Abe, T. 1935. On the resistance of conidia of *Pyricularia oryzae* to low temperatures. *Annals of the Phytopathol. Society of Jpn*. 6: 15-26.

Anil Kumar, Satyavir, and Ram Niwas. 1998. Relationship between climatic factors and ignition of red rot infection in sugarcane. *Indian phytopathol.* 51(4): 370-372.

Arunkumar, H. and Singh, R. A. 1995. Differential response of *Pyricularia grisea* isolates from rice, finger millet and pearl millet to media, temperature, pH and light. *Indian J. of Mycology and Plant pathol.* 25: 238 – 242.

Asaga, K., Takahashi, H., and Yoshimura, S. 1971. (Abstract). Observations of sporulation of *Pyricularia oryzae* using scanning electron microscope. *Annals of the Phytopathol. Society of Jpn.* 37-72.

Awoderu, V. A., Esuruoso, O. F., and Adeosun, O. O. 1991.Growth and conidia production in rice NG – 5 /IA – 65 of *pyricularia oryzae cav. In vitro. J. of the Basic Microbiology,* 31: 163 – 168.

Barksdale, T.H. and Asai, G.N. 1961. Diurnal spore release of *Piricularia oryzae* from rice leaves. *Phytopathol.* 51: 313-317.

Bastiaans, L. 1991. Ratio between virtual and visual lesion size as a measure to describe reduction in leaf photosynthesis of rice due to leaf blast. *Phytopathol*. 81: 611-615.

Bastiaans, L. and Kropff, M.J. 1993. Effects of leaf blast on photosynthesis of rice. 2. Canopy photosynthesis. *Neth. J. Plant Pathol.* 99: 205-217.

Beier, R.D., Panzer, J.D., and Tullis, E.C. 1959. The inter relationship of nitrogen and other factors affecting the blast disease of rice caused by *Pyricularia oryzae* Cav. *Plant Dis. Reporter*. 43: 477-482.

Bevitori, R. and Ghini, R. 2014. Rice Blast Disease in Climate Change Times. *J. Rice Res*. 3: 2375-4338.

107

Bhatt, J.C. and Chauhan, V.S. 1985. Epidemiological studies on neck blast of rice in U.P. hills. *Indian Phytopathol.* 38: 126-130.

Bhatt, J.C. and Singh, R.A. 1992. Blast of rice. In: Singh, U.S, Mukhopadhyay, A.N., Kumar, J., and Chaube, H.S. (eds.), *Plant Diseases of International Importance.*, Prentice Hall, New Jersey, pp. 80-115.

Bonman, J. M. 1992. Blast. In: Webster, R.K. and Gunnel, P.S. (eds).), *Compendium of Rice Diseases*. The American Phytopathological Society, St. Paul Minnesota, USA, pp. 14-16.

Bowers, J.H. and Mitchell, D.J. 1988. Path coefficient analysis of epidemiological data. *Phytopathol.* 53

Bowers, J.H., Sonoda, R.M. and Mitchell, D.J. 1990. Path coefficient analysis of rainfall variables on the epidemiology of Phytophthora blight of pepper caused by *Phytophthora capsici. Phytopathol.* 80: 1439-1446.

Campbell, C.L. and Madden, L.V. 1990. *Introduction to Plant Disease Epidemiology.*: John Wiley and Sons, New York, 532p.

Candole, B.L., Siebenmorgen, T.J., Lee, F.N., and Cartwright, R.D. 2000. Effect of rice blast and sheath blight on physical properties of selected rice cultivars. *Cereal Chem.* 77: 535-540.

Chakraborty, S. and Pangga, I. B. 2004. Plant disease and climate change. In: Gillings, M. and Holmes, A. (eds.), *Plant microbiology*. BIOS Scientific, London. pp.163-180.

Chaudhary, R.G. and Vishwadhar, K. 1988. Epidemiology of rice blast and effect of date of sowing under upland conditions of Arunachal Pradesh. *Indian Phytopathol.* 41(4): 552-557.

Chiba, K., Tominaga, T., and Urakawa, F. 1996. Occurrence and control of rice blast disease in northern region of Iwate Prefecture in 1995. Annual Report of the Society of Plant Protection of North Japan. 47: 8-10.

Choi, W.B., Chun, S.J., and Lee, Y.H. 1987. Host range of Korean isolates of

Magnaporthe grisea. *Korea J. of Plant Pathol*. 12(4): 453-454.

Coakley, S.M. 1979. Climatic variability in the Pacific Northwest and its effect on stripe rust of winter wheat. *Clim. Change.* 2: 33-51.

Coakley, S.M., Boyd, W.S., and Line, R.F. 1982. Statistical models for predicting stripe rust on winter wheat in the Pacific Northwest. *Phytopathol.* 72: 1539-1542.

Coakley, S.M., Line, R.F., and McDaniel, L.R. 1988. Predicting stripe rust severity on winter wheat using an improved method for analyzing meteorological and rust data. *Phytopathol.* 78: 543-550.

Coakley, S.M., McDaniel, L.R., and Shaner, G. 1985. Model for predicting severity of Septoriatritici blotch on winter wheat. *Phytopathol.* 75: 1245-1251.

Dash, S.K., Jenamani, R. K., Kalsi, R. S., and Panda, S. K. 2007. Some evidence of climate change in twentieth-century India. *Clim. Change.* 85:299–321

Datnoff, L.E., Raind, R.N., Snyder, G.H., and Jones, D.B. 1991. Effect of calcium silicate on blast and brown spot intensities and yields of rice. *Plant Dis.* 75: 729-732.

Dutta, U. and Kalha, C. S. 2011. Effect of meteorological parameters on development of sheath blight disease in paddy. *Plant Dis. Res*. 26(2): 122-126.

El Refaei, M.J. 1977. Epidemiology of rice blast disease in the tropics with special reference to leaf wetness in relation to disease development. Ph.D thesis. Faculty of the Post-graduate School of Indian Agricultural Research Institute. India. 195p.

Fukuda, H., Matsuhashi, M., Sato, K., and Fukaya, T. 2004. The 2003 outbreak of rice panicle blast in Akita Prefecture and its major cause. Annual Report of the Society of Plant Protection of North Japan. 55: 32-36.

Gaumann, E. 1950 .*Principles of plant infection*. Crosby Lockwood, London, 543p.

Ghosh, S., Saran, S., and Chaudry, R.C. 1983. Correlated response of photo and thermo sensitivity on certain developmental characters of rice. *Oryza*. 20: 243-246.

Gill, M. and Bonman, J. M. 1988. Effects of water deficit on rice blast. I. Influence of water deficit on components of resistance. *J. of Plant Prot. in the Tropics.* 5: 61-66.

109

Goswami, B. N., Venugopal, V., Sengupta, D., Madhusoodanan, M. S., and Prince, K. X. 2006. Increasing trend of extreme rain events over India in a warming environment. *Sci.* 314: 1442–1445

Hashimoto, A. 1981. Water droplets on rice leaves in relation to the incidence of leaf blast: use of the dew balance for forecasting the disease. *Rev. Plant Prot. Res.* 14: 112-126.

Henderson, D., Williams, C.J., and Miller, J. S. 2007. Forecasting late blight in potato crops of southern Idaho using logistic regression analysis. *Plant Dis.* 91: 951-956.

Hirai GI, Nakayama N, Hirano T, Chiyo H, Minato N, Tanaka O. Studies on the effect of relative humidity of atmosphere on growth and physiology of rice plants. VI. Effect of ambient humidity on dry matter production and nitrogen absorption at various temperatures, Japanese J Crop Sci. 1989; 58(3):368-373.

Houghton, J. 2004. *Global warming, The complete briefing* (3rd Ed.). Cambridge University Press, Cambridge, UK. 351 p.

IRRI [International Rice Research Institute]. 1993. *Rice* Research in a Time of Change: IRRI's Medium Term Plan for 1994-1998. *International Rice Research Institute Manila, Philippines, 80pp.*

Ishiguro, K. and Hashimoto, A. 1989. Recent advances in forecasting of rice blast epidemics using computers in Japan. *Trop. Agric. Res. Ser.* 22:153-162.

Ito, S. and Kuribayashi, K. 1931. Studies on the rice blast *disease.* Farm. Bulletin, Department of Agricultural Forestry, Japan, *30: 1-81.*

Iwadate, Y., Chiba, K., Sasaki, N., and Tominaga, T. 2004. Outbreak of rice panicle blast disease in Iwate prefecture in 2003 and effect of its suppression using blasticides. *Annual Report of the Society of Plant Protection of North Japan.* 55: 11-15.

Izadyar, M. and Baradaran, P. 1990. A new method for rice leaf blast forecasting. *Iranian J. of Plant Pathol.* 26: 11-14.

Jeyanandarajah, P., Seneviratne, S.N., and de, S. 1991. Fungi seed-borne in rice (*Oryza sativa)* in Sri Lanka. *Seed Science and Technology.* 19: 561-569.

110

Johnson, D.A., Alldredge, J. R., and Vakoch, D.L. 1996. Potato late blight forecasting models for the semi-arid environment of South-Central Washington. *Indian Phytopathol*. 86(5): 480-84.

Kahn, R.P. and Libby, J. L. 1954. The effect of environmental factors and plant age on the infection of rice by the blast fungus, *Pyricularia oryzae. Phytopathol.* 58: 25-30.

Kamalam, J., Menon, P. K. G., and Koruth, A. 1988. Influence of weather parameters on wetland rice yields in Kerala. *Oryza*. 25: 365-368.

Kapoor, A.S. and Singh, B. M. 1977. Overwintering of *Pyricularia oryzae* in Himachal Pradesh. *Indian Phytopathol.* 30: 213.

Kapoor, A.S., Prasad, R., and Sood, G. K. 2004. Forecasting of rice blast in Kangra district of Himachal Pradesh. *Indian Phytopathol.* 57(4): 400- 445.

Kato, H. 1974. Epidemiology of rice blast disease. *Review of Plant Protection Research.* 7: 1-20.

Kato, H. and Kozaka, T. 1974. Effect of temperature on lesion enlargement and sporulation of *Pyricularia oryzae* on rice leaves. *Phytopathol.* 64: 828-840.

Kato, H., Sasaki, T., and Koshimizu, Y. 1970. Potential for conidium formation of Pyricularia *oryzae* in lesions on leaves and panicles of rice. *Phytopathol.* 60: 608-612.

Kim, C.H., MacKenzie, D.R., and Rush, M.C. 1988. Field testing a computerized forecasting system for rice blast disease. *Phytopathol.* 78: 931-934.

Kim, C.H., MacKenzie, D.R., and Rush, M.C.1987. A model to forecast rice blast disease based on weather indexing. *Korean J. of Plant Pathol.* 3: 210-216.

Kim, C.K. 1987. Disease forecasting: past and future in Special reference to rice leaf blast. *Korean J. of Plant Prot.* 3: 304-312.

Kim, C.K. and Yoshino, R. 1987. Epidemiological studies of rice blast disease caused by *Pyricularia oryzae* Cavara. *Korean J. of Plant Pathol.* 3: 120-123.

Kim, C.K. and Yoshino, R. 1987. Epidemiological studies of rice blast disease caused by *Pyricularia oryzae* Cavara. *Korean J. of Plant Pathol.* 3: 120-123.

Kim, C.K. and Kim, C.H. 1991. Predicting rice blast outbreaks in Korea. In: *Rice Blast Modeling and Forecasting: Proceedings of the International Rice Research Conference, Suweon, Korea.* Manila, Philippines. International Rice Research Institute, pp. 53-68.

Kingsolver, C.H., Barksdale, T.H., and Marchetti, M. A. 1984. *Rice blast epidemiology.* Bulletin of the Pennsylvania Agricultural Experimental Station. 853p

Kobayashi, T., Ishiguro, K., Nakajima, T., Kim, H. Y., Okada, M. and Kobayashi, K. 2006. Effects of elevated atmospheric CO2 concentrationon the infection of rice blast and sheath blight. *Phytopathol.* 96: 425–431.

Kobayashi, T., Ishiguro, K., Nakajima, T., Kim, H. Y., Okada, M., and Kobayashi, K. 2006. Effects of elevated atmospheric CO2 concentration on the infection of rice blast and sheath blight. *Phytopathol.* 96: 425–431.

Koizumi, S. and Kato, H. 1991. Dynamic simulation of blast epidemics using a multiple canopy spore dispersal model. In: *Rice Blast Modeling and Forecasting: Proceedings of the International Rice Research Conference, Suweon, Korea.* Manila, Philippines: International Rice Research Institute, pp.75-88.

Koutroubas, S.D. and Ntanos, D.A. 2003. Genotypic differences for grain yield and nitrogen utilization in Indica and Japonica rice under Mediterranean conditions. *Field Crop Res*. 83: 251-260

Kovi, M. R., Bai, X., Mao, D., and Xing, Y. 2011. Impact of seasonal changes on spikelets per panicle, panicle length and plant height in rice (*Oryza sativa* L.) *Euphytica.* 179: 319–331

Lee, J.T., Yun, S.H., Kim, C.K., Im, J.N., and Jung, Y.S. 1989. *Forecasting model of rice leaf blast (Pyricularia oryzae) by meteorological data.* Research Reports of the Rural Development Administration. *Crop Prot. 31: 9-16.*

Levy, M., Correa-victoria, F. J., Zeigler, R.S., Xu, S. and Hamer, J. E. 1993. Genetic diversity of the rice blast fungus in a disease nursery in Colombia. *Phytopathol.*

112

83: 1427-1433.

Liu, Y.F., Chen, Z.Y., Hu, M., Li, Lian., and Liu, Y.Z. 2004. Distribution of *Magnaporthe grisea* population and virulence of predominant race in Jiangsu Province. *China Rice Sci*. 11(3): 324-330.

Mackill, D.J., Coffman, W.R., and Rutger, J.R. 1982. Pollen shedding and combining ability for high temperature tolerance in rice. *Crop. Sci*. 22: 730-733.

Manibhushanrao, K. 1994. *Rice Blast Disease*. 1st Ed.), Daya Publishing House, Delhi. 1p.

Manibhushanrao, K. and Krishnan, P. 1991. Epidemiology of blast (EPIBLA): a simulation model and forecasting system for tropical rice in India. In: *Rice Blast Modeling and Forecasting: Proceedings of the International Rice Research Conference, Suweon, Korea*. Manila, Philippines. International Rice Research Institute, pp. 313-318.

Manning, W. J. and Tiedemann, A. V. 1995. Climate change: potential effects of increased atmospheric carbon dioxide (CO2), ozone (O3), and ultraviolet-B (UVB) radiation on plant diseases. *Environ. Pollut*. 88: 219–245.

Mian, M.S., Stevens, C., and Mia, M. A. T. 2003. Diversity of the rice blast pathogen *Pyricularia grisea from* Bangladesh analyzed by DNA fingerprinting. *Bangladesh J. of Plant Pathol.* 19(2): 81-85.

Monma, Y., Kanagawa, M., and Sasahara, M. 2004. Outbreak of rice blast disease and its causal factors in Miyagi prefecture in 2003. *Annual Report of the Society of Plant Prot. of North Jpn*. 55: 16-19.

Nakamura, K. 1971. The relation between the number of *dispersed spores and the number of the effective spores of* Pyricularia oryzae. *Cav.* Bulletin of Hiroshima Prefecture Agriculture Experimental Station. *30: 25-30.*

Nishikado, Y. 1927. Studies on rice blast disease. *Jpn. J. of Bot.* 3: 239 –244.

Okeke, B., Segigle, M. F., Steiman, R. and Sage, L. 1992. Investigation on cultural and cellulolytic activity in *pyricularia oryzae* cav. *Agron*. 12: 325 – 329.

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Ono, K. and Suzuki, H. 1959. (Abstract). Spore formation of blast fungus on water surface. I. Dropped conidia. *Annals of the Phytopathol. Society of Jpn.* 24: 3-4.

Osada, A., Sairapa, V., Raliong, M., Dhammanuvong, S., and Chakrabandlue, H. 1973. Abnormal occurrence of empty grains of indica rice plants in the dry, hot season in Thailand. *Proc. Crop Soc. Jpn.* 42: 103-109.

Ou, S. H. 1985. *Rice Diseases*. Kew, Surrey, Commonwealth Agricultural Bureau. England, 380p.

Ou, S.H., Awoderu, V .A., and Ebron, T.T. 1974. Daily periodicity of the conidia release of *Pyriculariaoryzae* over a rice blast nursery. *Plant Dis. Reporter.* 58: 544-548.

Ou, S.H.1980. A look at worldwide rice blast disease control. *Plant Dis.* 64: 439-445.

Padmanabhan, S. Y. 1974. *Fungal Diseases of Rice in India*. (1st Ed.). Indian council of Agriculture Research, New Delhi, 15p.

Padmanabhan, S.Y. 1965. Estimating losses from rice blast in India. In: *The Rice Blast Disease.* Baltimore, Md: John Hopkins Press, pp. 203-222.

Padmanabhan, S.Y., Chakrabarti, N.K., and Row, K. V. S. R. K. 1971. Forecasting and control of rice diseases. *Proceedings of the Indian Academy of Science.* 37: 423.

Paik, S.B. 1975. The effects of silicate, nitrogen, phosphorous, and potassium fertilizers on the chemical components of rice plants and on the incidence of blast disease of rice caused by *Pyricularia oryzae* Cavara. *Korean J. of Plant Prot.* 14: 97-109.

Prajneshu. 1998. A nonlinear statistical model for aphid population growth. *.J. of the Indian Society of Agric Statist.* 51: 73-80.

Rahnema, I. 1978. Simulation of the effect of different water regime on germination and formation of appressoria of *Pyricularia oryzae. J. of Plant Dis. and Prot.* 86: 315-219.

Rakesh Kaundal, Kapoor, A. S., Gajendra, P.S., and Raghava. 2006. Machine learning techniques in disease forecasting: a case study on rice blast prediction.

Ramanathan, V., Chung, C., Kim, D., Bettge, T., Buja, L., Kiehl, J.T., Washington, W. M., Fu, Q., Sikka, D. R and Wild, M. (2005). Atmospheric brown clouds: impacts

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on South Asian climate and hydrological cycle. *Proc. Natl. Acad. Sci.* 102: 5326–5333

Ramasubramaniun, V., Sharma, M.K., and Walia, S.S. 2006. Statistical Models for forewarning Incidence of Major Pests of Paddy. *Abstract Statistical Application.* 4: 1-81.

Raupach, M.R., Marland, G., Ciais, P., Le Quere, C., Canadell, J.G., Klepper, G., and Field, C.B. 2007. Global and regional drivers of accelerating CO2 emissions. Proceedings of the National Academy of Sciences, 104: 10288–10293.

Reddy, M. M., Reddy, C.S and Reddy, A. G. R. 2001. Influence of weather parameters and insect pest populations on incidence and development of sheath rot of rice. *Indian phytopathol.* 54 (2): 179-184.

Scherm, H. and Yang, X. B. 1995. Inter annual variations in wheat rust development in China and the United States in relation to the El NinÄ o/Southern Oscillation. *Phytopathol*. 85: 970-976.

Shafaullah, K., Khan, M.A., Khan, N.A., and Yasir, Mahmood. 2011. Effect of epidemiological factors on the incidence of paddy blast (*Pyriculariaoryzae*) disease. *Pakistan J. of Phytopathol*. 23(2): 108-111.

Sheikh Gulzar, Ahmad, Garg, V.K., Pandit, A.K., Ali Anwar, and Salim Aijaz. 2011. Disease incidence of paddy seedlings in relation to environmental factors under temperate agro climatic conditions of Kashmir valley. *J. of res. and development.* 1:

Shen, Y., Yuan, X.P., Adreit, H., and Wang, Y. L. 1993. Molecular probes for epidemiological studies of the rice blast fungus. *J. of Southwest Agric. Univ.* 20(5): 401-408.

Singh, N.I. 1988. The fungal air-spora of Imphal, its seasonal fluctuations and relationship with occurrence and intensity of major crop diseases. *Int. Aerobiology Newsl.* (28): 15-17.

Solanki, V.A., Patel, B.K., and Shekh, A.M. 1999. Meterological variables in relation to an epiphytotic of powdery mildew disease of mustard. *Indian phytopathol*. 52 (2): 138-141.

Sonia, C. and Gopalakrishna, T. 2005. Genetic diversity of Indian isolates of rice blast pathogen (*Magnaporthe grisea*) using molecular markers. *Current Sci*. 88(9): 1466-1469.

Sreenivasan, P. S. 1985. Agroclimatology of rice in India. In: Jaiswal, P. L., Wadhwani, A. M., Singh, R., Chhabra, N. N. and Chhabra, N. (eds.), *Rice research in India*. ICAR, New Delhi, pp. 203-230.

Strange, R.N. and Scott, P.R. 2005. Plant disease: A threat to global food security. *Annual Review of Phytopathol*. 43:83-116.

Surin, A., Arunyanart, P., Rojanahusdin, W., Munkong, S., and Dhitikiattipong, R. 1991. Using empirical blast models to establish disease management recommendations in Thailand. In: *Rice Blast Modeling and Forecasting: Proceedings of the International Rice Research Conference,* Suweon, *Korea.* Manila, Philippines: International Rice Research Institute, pp. 69-74.

Suzuki, H. 1969. Temperature related to spore germination and appressorium formation of rice blast fungus. *Proceedings of the Association of Plant Protection Hokuriku.* 17: 6-9.

Suzuki, H. 1975. Meteorological factors in the epidemiology of rice blast. *Annual Review of Phytopathol.* 13: 239-256.

Tashiro, T. and Wardlaw, I. F. 1989. A comparison of the effect of high temperature on grain development in wheat and rice. *Ann. Bot*. 64: 59-65.

Teng, P.S. 1993. (Draft). The epidemiological basis for blast management. In: *Proceedings of the Wisconsin Blast Symposium, August 1993.* Madison: University of Wisconsin.

Teng, P.S. 1994. The epidemiological basis for blast management. In: Zeigler, R.S., Leong, S.A., and Teng, P.S. (eds.), *Rice blast disease*. Wallingford, Oxon (United

Kingdom): CAB International, Los Baños (Philippines): International Rice Research Institute. pp. 409-434.

Teng, P.S. and Calvero, S.B. 1991 (Abstract). Computer simulation of tropical rice-leaf blast pathosystem using BLASTSIM.2. *Phytopathol.* 81: 1143.

Teng, P.S. and Yuen, J.E. 1990. Epidemic models: lessons from plant pathology. In: Levin, M. and Strauss, H. (eds.), *Risk Assessment in Genetic Engineering: Environmental Release of Organisms.* New York: Mc-Graw Hill Publishing Company, pp. 211-220.

Teng, P.S., Klein-Gebbinck, H., and Pinnschmidt, H. 1991. An analysis of the blast pathosystem to guide modeling and forecasting. In: *Blast Modeling and Forecasting, Proceedings of the International Rice Research Conference, Suweon, Korea.* Manila, Philippines: International Rice Research Institute, pp. 1-30.

Torres, C.Q. 1986. Effect of plant age on the expression of resistance to *Pyriculariaoryzae* Cav. in upland rice varieties. Ph.D thesis. University of the Philippines, Los Banos, 82p.

Torres, C.Q. and Teng, P.S. 1993. Path coefficient and regression analysis of the effects of leaf and panicle blast on tropical rice yield. *Crop Protect*. 12: 296-302.

Tsai, W. H. 1986. Prediction of rice leaf blast. III. Meteorological variables and percentage of leaf area infected by *Pyricularia oryzae. Plant Protection Bulletin (Taiwan, R.O.C.)* 28: 111-117.

Tschen, J. S. M. and Yein, C.F. 1984. Effect of rice hulls applied to rice fields. 3. Comparison on the response of sodium silicate fertilizer and rice hull application. *J. of Agric. For.* 33: 85-93.

Uehara, Y., Imoto, M., and Sakai, Y. 1988. Studies on the forecasting of the rice blast development using weather data from AMeDAS. *Bulletin of the Hiroshima Prefecture Agricultural Experiment Station.* 51p.

Umer Jamshed, Ghazalanasim, and GhulamRasool. 2008. Correlation and regression for prediction of wheat leaf rust severity in Bahawalpur and Multan using relevant meterological data. *Mycopathol.* 6(2): 23-29.

Venkatarao, G., and Muralidharan, K. 1982. Effect of meteorological conditions on the incidence and progress of blast disease on rice. *J .of Plant Dis. Prot.* 89: 219.

Venkateswarlu, B., Prasad, V. V. V. S., and Rao, A.V. 1977. Effects of light intensity of different growth phases in rice. *Plant. Soil.* 47: 37-47.

Vijaya, M. 2003. Influence of weather parameters in relation to rice blast. *JNKVV Res. J.* 37(1): 107-108.

Volk, R.J., Kahn, R.P., and Weintraub, R.L. 1958. Silicon content of the rice plant as a factor influencing its resistance to infection by the blast fungus *Piricularia oryzae. Phytopathol.* 48: 121-178.

Webster, R.K. and Gunnell, P.S. 1992. Compendium of rice diseases. The American Phytopathological Society, St Paul, MN, USA.

Yang, H., Yang, X.H., Lu, C.M., and Wang, Y.Y. 2011. The correlation analysis between blast resistance and genetic diversity of 39 Yunnan glutinous rice varieties. *J. of Yunnan Agric. Univ.* 26(1): 1-5.

Yoshida, S. 1978. Tropical Climate and its Influence on Rice. Research Paper Series No. 20, International Rice Research Institute, Los Baños, Philippines.

Yoshida, S. and Parao, F.T. 1976. *Climate and Rice,* IRRI, Phillippines, pp. 471-494.

Yoshida, S. 1983. Rice. In: Smith, W.H. and Banta, S.J. (eds.), *Potential Productivity of Field Crops under Different Environments*. International Rice Research Institute, Los Banos, Philippines, pp. 103-127.

Yoshino, R. 1972. Influence of temperature on the incubation period of *Pyricularia oryzae* and early detection on lesions by staining with iodine potassium iodide. *Review of Plant Prot. Res. 5: 105-107.*

Yoshino, R., Yamaguchi, T. 1974. Influence of sunshine andshade conditions on the occurrence of rice blast caused by *Pyricularia oryzae* Cavara. *Bulletin of the Hokuriku Agricultural Experiment Station.* 16: 61-119.

Zeng, Q. C., Fan, J.H., Zhu, Z., Chen, H.R., Wang, Y.Y., and Tan, X.L. 2002. Genetic diversity of the rice blast fungus *Magnaporthe grisea* and its 131 distribution in Central Yunnan. *J. of Yunnan Agric. Univ.* 17(4): 313-315

Zhejiang Research Group Computerized Forecast Rice Blast, 1986. A study on computerized forecast of rice blast. *Zhejiang Agricultural Science* 2: 74-79.

Zibaee, A.2013.Rice: Importance and Future. *J Rice Res* 1:1000-1002

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

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ABSTRACT OF THE THESIS

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The rate of global warming is expected to continue increasing if no mitigation efforts take place to reduce the carbon intensity of the world economy and the consequent emission of green-house gases (Raupach *et al.*, 2007). Agricultural production, and thus global food security, is directly affected by global warming (Ainsworth and Ort, 2010).

Rice production plays an essential role in feeding the world's population and will continue to be in the future, because rice is the most important global staple food in many countries. The production of rice, along with other agricultural crops, will be impacted by climate change. There is still great uncertainty about how climatic and atmospheric changes will affect the future productivity of food crops. Major future impacts of climate change are expected on food security and agricultural incomes, including shifts in production areas across the world.

In addition to affecting rice production, climate change may alter pathogen dissemination and development rates, and modify the resistance, growth and metabolism of host plants. The geographical distributions of pathogens are very likely to change, and losses can be expected, in part due to altered effectiveness of control strategies. Thus climate change is a serious threat to agriculture because it can lead to significant changes in the occurrence and severity of plant diseases. All phases of the disease cycle, from the germination of spores to the development of lesions, are considerably influenced by climatic factors. The most important climatic factors are temperature and precipitation. These factors may be modified by the coming climate changes. Recent research indicates that the monsoon has changed in two significant ways during the past half-century: it has weakened (less total rainfall during June–September; Ramanathan *et al.* 2005; Dash *et al.* 2007), and the distribution of rainfall within the monsoon season has become more extreme (Goswami *et al.* 2006; Dash *et al.* 2009).

Rice blast caused by *Pyricularia oryzae* an important disease of rice worldwide is known to cause severe yield losses in rice production area where high inputs of nitrogen fertilizer and favourable climatic conditions occur. Sometimes the yield losses reach as high as 50% in upland cultivations.

Objectives of the study were to Study the effect of various weather parameters and climate change on incidence and development of leaf blast disease of rice and evaluation of disease forecasting models for leaf blast 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 sowing June showed a higher disease incidence compared to other dates of sowing. It was also noticed that variety Kanchana is more susceptible to Leaf blast incidence compared to Jyothi. The effect of weather on LAI significantly varied with varieties. The effect of weather on grain yield was significant. Under upland condition the sheath blight disease incidence was not observed even after artificial inoculation.The effects of weather and varieties on leaf blast incubation period were significant.

EPRICE model developed by Savary *et al.*, (2012) was used to forecast the disease severity of leaf blast 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 Kanchana prediction is 0.265. This shows that the predicted leaf blast severity was in good agreement with the observed values. So this model can be used for forecasting the rice blast 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 blast for the years 2030, 2050 and 2080 in all the 14 districts of Kerala. The climate data for the years 2030, 2050 and 2080 under different RCPs. The impact of climate change on leaf blast severity in the various districts of Kerala showed a varying trend. Except in the northern districts (Malappuram, Wayanad, Kannur and Kasaragod) the disease severity showed a decreasing trend.