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Development of weather based forewarning systems for rice blast

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Abstract

The analysis of average daily weather variables of a week earlier to threshold levels (0.05 %) of years 1991 to 2000 showed that maximum temperature of 23.5 to 27.7°C, minimum of 17.6 to 20°C, relative humidity of > 80 % with exception to 1996 and 1998, rainfall of more than 3 mm per day and more than 4 rainy days per week were critical in the progress of rice leaf blast. The neck blast data (1997–2000) revealed that maximum temperature of 25 to 26.4°C, minimum of 15.6 to 18.4°C, RH ≥ 59%, rainfall more than 1 mm per day and ≥ 3 rainy days per week were critical for neck blast. Regression equations used as models to predict leaf and neck blast at three locations; Palampur, Malan and Pharer, were generated for four consecutive years (2001-2004) using critical weather factors of respective rice seasons of the years. The mean maximum and minimum temperatures mean maximum and minimum relative humidity, and rainy days per week were found critical predictors of leaf and neck blast at all the three locations. Validation studies showed models predicted leaf and neck blast reasonably well especially in farmers' fields.

Key words: Rice, rice blast, forewarning, *Pyricularia grisea*, prediction

Introduction

Rice blast caused by *Pyricularia grisea* Sacc. is still an enigmatic problem in several rice ecosystems both temperate and tropical regions of the world . The potential of this pathogen to infect rice crop at different growth stages and its wide adaptation are the indications that this disease is a weather driven disease (Bonman *et al.* 1992: Teng, 1994). Fungicide is still the preferred strategy against blast and for their judicious use; development of forecasting models is needed. Simulation models have been developed to predict rice blast in Japan (Uehara *et al.*, 1988; Ishiguro & Hashimoto, 1991), Korea (Choi *et al.*, 1988; Lee *et al.*, 1989; Kim and Kim, 1993) India (Manibhushanrao & Krishnan, 1991) and in Philippines (El Refaei, 1977; Calvero *et al.*, 1996). However, most of them have not been used by farmers. In India the major bottleneck in the development of forewarning systems is the unavailability of rice blast data for relatively long duration from hot spots despite weather data records being easily available. So an attempt has been made to develop weather based forewarning systems for rice blast.

Material and Methods

Collection of historical data: Historical data of rice blast and meteorological data of Palampur location for the last 10 years (1991 to 2000) were collected and computed for developing model(s) using step-wise regression analysis.

Field experiments

Field trials were conducted at three locations *viz.*, Palampur, Rice and Wheat Research Station Malan and Pharer (Farmers' fields). At Palampur and Malan locations, date of transplanting of most susceptible cv Himalaya 2216 was made in an area of 300 m^2. In farmers' fields, local Parmal cv transplanted by the farmers was selected. At Palampur and Malan, recommended package of practices were adopted. Data on leaf blast and neck blast were recorded as per Standard Evaluation System for rice (IRRI, 1996). Observations were recorded on 25 quadrates, each of 1 m^2 area, marked at random. In each quadrate, 10 randomly selected tillers were tagged and observations were recorded from the time of occurrence of the disease at regular intervals (5- 7 days). In farmers' fields, 10 fields with same variety were selected. Observations on each field were recorded on 25 randomly selected quadrates of 1 m^2 in each field. Meteorological data were recorded from thermo hygrograph installed in the farm and in farmers' field till the termination of experiments each year. Meteorological data were also collected from Automatic Micro Weather Station at Palampur location.

Statistical analysis

All the data collected including meteorological data were computed and subjected to step-wise regression analysis for the development of rice blast prediction model(s).

Results and Discussion

The favourable weather for rice leaf blast development was invariably available in the first fortnight of July, and maximum disease reached from 2nd fortnight of August to first fortnight of September. During 1991, disease appeared on 25th July and reached maximum in between 29 August to 5th September. Similarly, in 1992, disease appeared on 20th July and progressed comparatively more rapidly than 1991 giving positive skewed graph. Environmental factors were more favourable during 1992, especially relative humidity (RH), rainfall, and rainy days which led to rice epidemic during 1992. All these studies revealed that most of the congenial weather variables for rice blast were available in the month of August. The analysis of average daily weather variables of a week earlier to these threshold level (0.05 %) of years 1991 to 2000 showed that maximum temperature of 23 to 28°C, minimum of 17.6 to 20°C, RH of more than 80 % with exception during 1997 and 1998, rainfall of more than 3 mm per day and more than 4 rainy days per week were critical in the progress of rice leaf blast (Table 1). Similarly the neck blast data (1997 – 2000) revealed that maximum temperature of 25 to 26.4°C, minimum of 15.6 to 18.4°C, RH ≥ 59%, rainfall more than 1 mm per day and ≥ 3 rainy days per week were critical for neck blast (Table 2). The meteorological database from 1991 to 2000 revealed that most of the critical weather variables *viz.* temperature (both maximum and minimum), RH and amount of rainfall were invariably congenial to leaf blast and neck blast. However, rainy days per week differed and it seems that other critical weather conditions such as leaf wetness period, distribution of rainfall and intensity of rainfall are more important in influencing the epidemic of rice blast.

Development of regression models

Historical data

Regression models for leaf blast at Palampur location during different years were developed from the historical pooled data for the years 1991-96, 1997-2000 and 1991-2000 (Table 3). Out of these equations, the regression equation of the pooled data of 1997-2000, was found to be the best fit equation with R = 0.64 and $R^2 = 0.41$

Table 1. Average daily weather conditions of a week earlier to the threshold level (0.05%) of rice leaf blast during different years

Weather factors	Year									
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Temperature (Max °C)	26.3	24.4	25.0	25.7	25.7	27.4	26.4	27.7	25.1	23.5
Temperature (Min °C)	20.4	17.6	19.9	20.1	20.1	20.2	20.9	19.5	19.9	19.4
RH (%)	81	82	83	82	82	76	85	76	86	89
Rainfall (mm)	31.50	19.26	27.66	13.10	27.76	3.23	8.77	9.02	39.30	30.37
Rainy days	6	5	6	7	6	4	5	7	5	7

Table 2. Average daily weather conditions of a week earlier to the threshold level (1%) of rice neck blast during different years

Weather factors	Year			
	1997	1998	1999	2000
Temperature (Max °C)	25.9	26.4	26.0	26.3
Temperature (Min °C)	16.1	16.5	18.4	15.6
Relative Humidity (%)	67	78	82	59
Rainfall (mm)	0.66	7.29	12.77	0.00
Rainy days	3	5	4	0

Table 3. Pooled regression models for leaf blast at Palampur during different years developed from the historical data

Year		Equation	R	R^2
1991 to 1996		= 5.66+3.39X_1-9.75X_2+1.09X_3+0.47X_4- 0.25X_5-1.13X_6	0.49	0.24
1997 to 2000		=-20.53+3.16X_1-7.28X_2+0.60X_3+0.54X_4- 0.36X_5+1.60X_6	0.64	0.41
1991 to 2000		=11.543+1.749X_1-5.950X_2+0.211X_3+0.696X_4- 0.233X_5+1.760X_6	0.60	0.36

Where, Y= Disease variable, X_1 = T maximum, X_2 = T minimum, X_3 = RH maximum, X_4 = RH minimum, X_5 = Rainfall, X_6 = Rainy days/week. R= Multiple correlation coefficient: R^2 = Coefficient of determination.

Regression models for leaf blast

During 2001 at Palampur location the combined effects of T_{max}, RH_{min} and rainy days/4 days resulted in significant effect on leaf blast severity with the best fit model ; = -120.141+5.497X_1 (max. temp.)-0.608X_4 (min. RH) +7.479X_6 (rainy days) whereas during 2002, the best fit regression equation for leaf blast at Palampur location was found to be = 74.981-3.468X_2+0.221X_1+0.492X_3 (Table 4). During 2003, RH_{max} (X_8), rainfall (X_5) and bright sunshine hours (X_{13}) were critical weather variables in predicting leaf blast resulting in R = 0.85. During 2004, T_{max} (X_1), RH_{max} (X_3), rainfall (X_5), rainy days per 4 days (X_6) and bright sunshine hours (X_{10}) were critical weather variables in predicting leaf blast resulting in R = 0.93. At Malan, during 2001, the best predictors were mean RH, rainfall and rainy days/week for leaf blast severity whereas at Pharer (Farmers' fields), it was RH_{min} and rainy days/week. For leaf blast prediction, model developed for Malan location during 2001; = -127.61+2.642X_8-0.114X_6-5.419X_9 was found to be more efficient as compared to the other locations. Whereas during 2002 minimum temperature and RH_{max} were found more critical variables in predicting leaf blast however, at Pharer, minimum temperature and rainfall were good predictors. During 2003 at Malan location and at farmers' fields, the best fit equations were found to be Y = 224.905 – 13.196X_{10} + 1.136X_7 – 1.069X_1 with R = 0.99 and Y = 692.531 – 18.851X_9 + 1.628X_{10} – 2.105X_8 – 1.772X_1 + 11.593X_{12} with R = 0.92 respectively. During 2004, at Malan location, T_{max} (X_1), RH_{max} (X_3), RH_{nnn} (X_4), rainfall (X_5) and rainy days per week (X_6) were found to be good predictors of leaf blast. At farmers' fields at Pharer, variables X_1 to X_6 were found to be important in predicting leaf blast (Table 4).

The rice leaf blast pooled data from 2001 to 2004 for each location revealed that at Palampur location, Y= 39.161+0.075X_1-1.917X_2+0.76X_3-0.705X_4-0.222X_5+0.887X_6 with R = 0.66 , whereas, Y = 166.27-1.352X_2-0.731X_3-0.603X_4-0.164X_5-1.778X_6 with R = 0.82 for Malan location and Y=32.105+4.798X_1-6.333X_2+0.353X_3-0.202X_4+0.008X_5-4.449X_6 with R = 0.77 for farmers' fields at Pharer were found to be the best fit equations.

Regression models for neck blast

During 2001, the regression equations for neck blast revealed significant combined effects of RH_{max} and RH $_{min}$ on neck blast development. During 2002, T_{min} (X_2) and RH_{max} (X_3) were found more critical factors whereas at Malan location, maximum temperature (X_1) and minimum temperature (X_2) were critical factors in predicting neck blast. The combined effects of different weather variables in 2003, especially rainfall, RH_{min}, T_{min}, bright sunshine hours and rainy days/4 days at all the locations were found critical factors in predicting neck blast except at farmers' fields where low neck blast pressure was observed (Table 5). During 2004 , at Palampur T_{max} (X_1), T_{min} (X_2) and RH_{min} (X_4) were found to be significant with the best fit equation as Y = 22.251-0.984X_1+0.395X_2-0.714X_6 with R = 0.99. The combined effects of T_{max} (X_1), T_{min} (X_2) and RH_{min} (X_4) were found to be significant in predicting neck blast epidemic at Malan location. At farmers' fields at Pharer, Y = 26.409-2.731X_1+2.022X_2-0.469X_3+0.505X_4-0.006X_5 with R = 0.97 was found as the best fit equation (Table 5).

The rice neck blast pooled data from 2001 to 2004 revealed that at Palampur location, Y = 9.875-0.217X_1-0.461X_2+0.052X_3+0.042X_4-0.278X_5+0.206X_6 with R = 0.74 whereas, at Malan and at farmers' fields (Pharer), the

regression models $Y = 92.289-1.481X_1-0.61X_3-0.37X_5+2.125X_6$ with R = 0.91 and $Y = 14.909-0.282X_1-0.06X_3-0.012X_4$ with R = 0.64 respectively, were found to be the best fit equations.

Table 4. Regression equations for leaf blast at different locations over the years (2001-04)

Location	Year	Regression equation	R	R^2
Palampur	2001	$= -120.141+5.497X_1-0.608X_4+7.479X_6$	0.83	0.70
	2002	$Y = 33.607-0.419X_1-2.374X_3+2.139X_4+ 0.245X_5-0.941X_6-0.189X_7 +0.518X_9$	0.95	0.90
	2003	$Y = -261.574 + 2.359X_2 + 3.386X_3 - 1.038X_4 - 0.549X_5 + 5.928X_{10}$	0.89	0.79
	2004	$Y=88.816+2.14X_1-12.023X_2+0.039X_3+1.034X_4-0.106X_5-0.695X_6+1.493X_{10}$	0.93	0.87
	Pooled	$Y = 39.161+0.075X_1-1.917X_2+0.76X_3-0.705X_4-0.222X_5+0.887X_6$	0.66	0.43
Malan	2001	$= -127.61-0.114X_5-5.419X_6+2.642X_8$	0.99	0.99
	2002	$Y = 302.399 - 5.245X_2 - 2.063X_3$	0.98	0.97
	2003	$Y = 224.905 – 13.196X_2 + 1.136X_4 – 1.069X_5$	0.99	0.98
	2004	$Y = 337.518-6.654X_1+12.278X_2-1.781X_3-3.178X_4-0.254X_5+1.113X_6$	0.99	0.99
	Pooled	$Y = 166.27 - 1.352X_2 - 0.731X_3 - 0.603X_4 - 0.164X_5 - 1.778X_6$	0.82	0.68
Pharer (Farmers' fields)	2001	$= -57.148+4.441X_1-7.117X_6$	0.99	0.99
	2002	$Y = 4.984 - 0.161X_2 - 0.003X_5$	0.97	0.94
	2003	$Y = 692.531 – 18.851X_1 + 1.628X_2 – 2.105X_3 - 1.772X_5 + 11.593X_6$	0.92	0.84
	2004	$Y = 12.183+1.561X_1+1.083X_2+0.589X_3-0.588X_4+0.003X_5-0.168X_6$	0.92	0.84
	Pooled	$Y = 32.105+4.798X_1-6.333X_2+0.353X_3-0.212X_4+0.008X_5-4.449X_6$	0.77	0.60

Where, y = Disease variable, X_1 = Maximum Temperature, X_2 = Minimum Temperature, X_3 = Maximum Relative Humidity, X_4 = Minimum Relative Humidity, X_5 = Rainfall, X_6 = Rainy days per 4 Days at Palampur & per week at Malan and Pharer, X_7 = Hrs. with RH>85%, X_8 = Average relative humidity, X_9 = Leaf wetness, X_{10} = Bright Sunshine Hours. Palampur-I, II, and III are 1st, 2nd, and 3rd dates of sowings= Multiple correlation coefficient: R^2 = Coefficient of determination.

Table 5. Regression equations for neck blast at different locations over the years (2001-04)

Location	Year	Regression equation	R	R^2
Palampur	2001	$Y = 24.83 - 0.29X_3 - 1.52X_4$	0.86	0.74
	2002	$Y = 46.625 – 0.558X_2 – 0.469X_3$	0.99	0.99
	2003	$Y = 16.427 – 1.066X_2 + 0.563X_6 + 0.409X_{10}$	0.99	0.99
	2004	$Y = 22.251 - 0.984X_1 + 0.395X_2 - 0.714X_6$	0.99	0.99
	Pooled	$Y = 9.875-0.217X_1-0.461X_2+0.052X_3+0.042X_4-0.278X_5+0.206X_6$	0.74	0.55
Malan	2001	$Y = 9.62 – 0.28X_1 – 0.08X_5$	0.99	0.99
	2002	$Y = 7.338 – 0.51X_1 + 0.399X_2$	0.99	0.99
	2003	$Y = 38.341 – 0.26X_3 – 0.209X_4 + 1.685X_6$	0.99	0.99
	2004	$Y = 62.288-1.58X_1-0.697X_2+1.426X_3-1.445X_4+0.373X_5-2.359X_6$	0.99	0.99
	Pooled	$Y = 92.289 - 1.481X_1 - 0.61X_3 - 0.37X_5 + 2.125X_6$	0.91	0.83
Pharer (Farmers' fields)	2001	$Y = 23.146 - 0.305X_1 - 0.178X_2 + 0.789X_5 - 0.176X_8$	0.99	0.99
	2003	$Y = 8.488 + 0.019X_5 + 0.197X_6 - 0.431X_2$	0.99	0.99
	2004	$Y = 26.409 - 2.731X_1 + 2.022X_2 - 0.469X_3 + 0.505X_4 - 0.006X_5$	0.97	0.94
	Pooled	$Y = 14.909 - 0.282X_1 - 0.06X_3 - 0.012X_4$	0.64	0.41

Where, Y= Disease variable , X_1 = Maximum Temperature, X_2 = Minimum Temperature, X_3 = Maximum Relative Humidity, X_4 = Minimum Relative Humidity, X_5 = Rainfall, X_6 = Rainy days per 4 Days at Palampur & per week at Malan and Pharer, X_7 = Hrs. with RH >85%, X_8 = Average relative humidity, X_9 = Leaf wetness, X_{10} = Bright Sunshine Hours. R= Multiple correlation coefficient: R^2 = Coefficient of determination.

Table 6. Regression equations for leaf / neck blast at different locations over the years (2001-03)

Disease	Location	Regression equation	R	R^2
Leaf blast	Palampur	$Y = 63.208-0.165X_1-3.437X_2+0.866X_3-0.68X_4-0.203X_5+2.32X_6$	0.76	0.58
	Malan	$Y = 419.568-2.863X_1-2.205X_2-3.164X_3+0.159X_4+0.004X_5-2.422X_6$	0.87	0.76
	Pharer	$Y = 166.295-4.179X_2+2.365X_3-2.928X_4-0.103X_5-4.665X_6$	0.82	0.67
Neck blast				
	Palampur	$Y = 21.074 - 0.625X_2 - 0.133X_3 + 0.044X_4$	0.87	0.76
	Malan	$Y = 24.411 - 0.387X_2 - 0.378X_3 + 0.254X_4$	0.94	0.89
	Pharer	$Y = 10.489 - 0.01X_1 - 0.162X_2 - 0.021X_3 - 0.071X_4 + 0.31X_6$	0.99	0.98

Where, Y= disease variable, X_1 = Maximum Temperature, X_2 = Minimum Temperature, X_3 = Maximum Relative Humidity, X_4 = Minimum Relative Humidity, X_5 = Rainfall, X_6 = Rainy days per 4 Days at Palampur & per week at Malan and Pharer, X_7 = Hrs. with RH>85%, X_8 = Average relative humidity, X_9 = Leaf wetness, X_{10} = Bright Sunshine Hours. R= Multiple correlation coefficient: R^2 = Coefficient of determination.

Validation of models

Regression models for leaf blast at Palampur during different years developed from the historical pooled data for the years 1991-96, 1997-2000 and 1991-2000 were validated with the 2001 weather variables for the prediction of leaf blast severity. Validation of the model $Y = -20.53+3.16X_1-7.28X_2+0.60X_3+0.54X_4-0.36X_5+1.60\ X_6$ was found to be more realistic on farmers' fields data (Fig1)

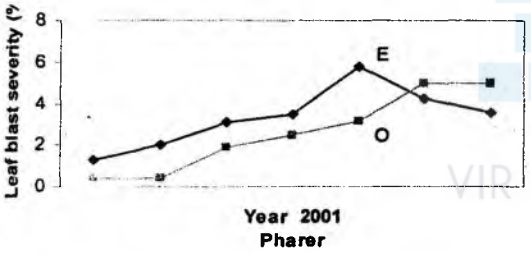


Fig.1 Validation of leaf blast model (1997-2000) at farmers' fields during 2001

O= observed and E = estimated disease severity

Regression models developed from the pooled rice blast and weather data of 2001 to 2004 were validated in the 2004 weather data for the prediction of leaf/neck blast severity. However, due to low disease pressure during the year 2004, efficient predictions could not be made so rice blast data was pooled from 2001 to 2003 to develop models (Table 6) and validated these models for each location with the 2003 weather variables. The observed and predicted disease severity was plotted against time (Fig 2 & 3).

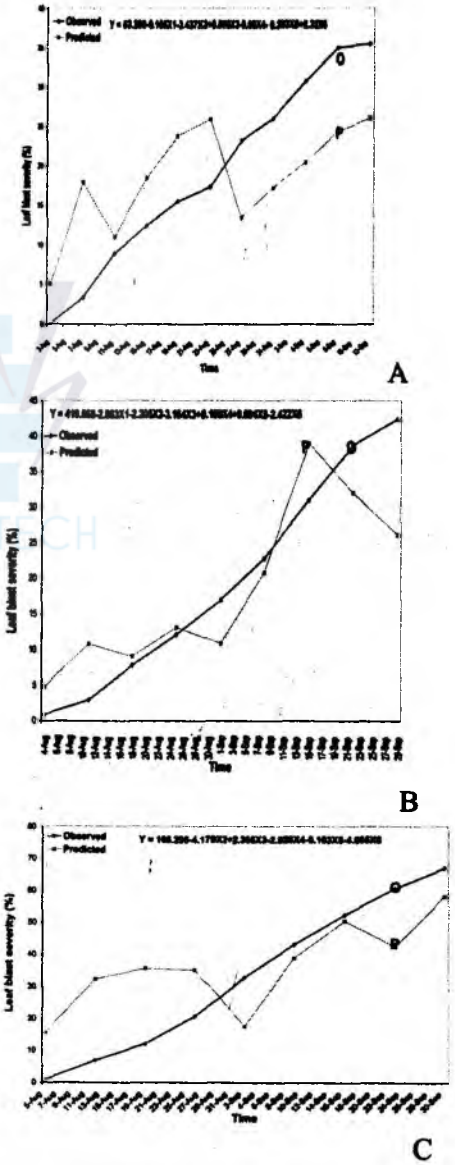


Fig. 2 Validation of leaf blast models at Palampur (A), Malan (B) and Pharer (C)

O= Observed and P= predicted disease severity

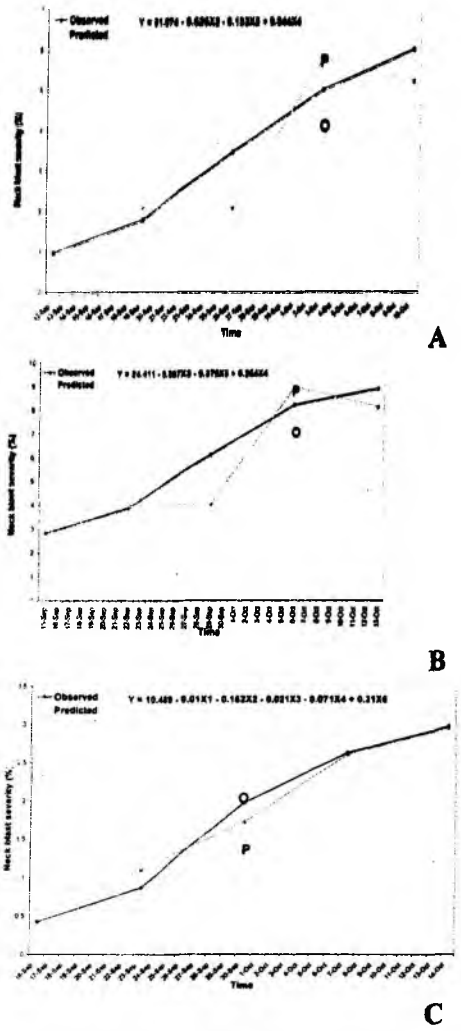


Fig. 3 Validation of neck blast models at Palampur (A), Malan (B) and Pharer (C)
O= observed and P= predicted disease severity

Overall results of validation of these models were very encouraging. Best validation was observed for predicting neck blast epidemic at farmers' fields. The validation tests showed, models predicted leaf blast and neck blast reasonably well; however future validation is needed to improve their predictive ability for making them as real knowledgeable tools in integrated management of rice blast.

The critical weather parameters a week prior to threshold levels (Table 1) describe the effects of different weather factors on disease infection and development. It has been shown that temperature of 24°C to 28°C favours the infection (Hashioka, 1965). Andersen *et al.* (1947) found maximum infection on plants at temperature 24-28°C and 16-24 hrs continuous wetting. Low temperature (15-20°C) especially during night predisposed even resistant variety to attack by *P. grisea* (Suryanarayanan, 1958).It has been shown that high humidity favours release of inoculum and facilitates infection (Kato, 1974; Suzuki, 1975; El Refaei, 1977; Kinglolver *et al.*, 1984; Choi *et al.*, 1988). Models developed from historical databases predicting rice blast severity gave significance in response to mean maximum and mean minimum temperature, mean maximum and minimum RH, total rainfall and rainy days. At high humidity (> 80 %) a large number of conidia survive to initiate infection (Hashioka, 1965; Kapoor & Singh, 1977). Relative humidity and rainfall provide free moisture that aids spore germination, penetration and infection at optimum temperature. At Palampur location, mean maximum temperature , mean minimum relative humidity , rainy days , period of RH ≥ 85% were invariably found good predictors of leaf blast. However, pooled data of three years showed the importance of mean maximum and minimum temperature, mean maximum and minimum RH, total rain fall and rainy days in predicting leaf blast at all the three locations. This supports the epidemiological concepts of rice blast. For predicting neck blast, total rainfall, mean minimum RH, mean minimum temperature, sunshine hours and rainy days were found critical weather parameters. The mean minimum temperature between 15-20°C and more rainy days , high rainfall and high RH have been shown to be important factors for the development pf neck blast (Bhatt & Chauhan , 1985). Manibhushanrao and Krishnan (1991) developed a computerized forecasting system for rice leaf blast, based on spore count, relative humidity and temperature. Kapoor *et al.* (2004) developed simple rice leaf blast forecasting rules and also developed forecasting models based on temperature, relative humidity and rainfall. The importance of consecutive days with RH ≥ 80%, number of days with RH ≥ 80, consecutive days with precipitation, and number of days with precipitation ≥ 84 mm per day have been shown important variables predicting blast at one location and precipitation variables, mean minimum and maximum temperatures and wind velocity above 3.5ms^{-1} as important at another location (Calvero *et al.*, 1996) and developed empirical forecasting models for rice blast based on weather factors. Validation of model developed from historical data (Fig.1) showed very encouraging results especially in farmers' fields. Similarly pooled data from 2001-2003

(Table 6) when validated with the data of 2003, predictions were realistic both for leaf and neck blast predictions (Fig. 2 &3).The models developed from these studies can be a part of knowledge tools required in the blast management tool kit proposed by Teng (1994). So the validation studies confirmed that the equations developed are applicable in forewarning both leaf and neck blast at the three locations.

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