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A Model to Forecast Rice Blast Disease Based on Weather Indexing

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氣象指數에 依한 벼稻熱病 豫察의 한 모델

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ABSTRACT

A computer program written to predict blast occurrence based on microclimatic events was developed and tested as an on-site microcomputer in field plots in 1984 and 1985. A microcomputer unit operating on alkaline batteries; continuously monitored air temperature, leaf wetness, and relative humidity; interpreted the microclimate information in relation to rice blast development and displayed daily values (0-8) of blast units of severity (BUS). Cumulative daily BUS values (CBUS) were highly correlated with blast development on the two susceptible cultivars, M-201 and Brazos grown in field plots. When CBUS values were used to predict the logit of disease proportions, the average coefficients of determination (R^2) between these two factors were 71 to 91%, depending on cultivar and year. This was a significant improvement when compared to 61 to 79% when days were used as a predictor of logit disease severity. The ability of CBUS to predict logit disease severity was slightly less with Brazos than M-201. This is significant inasmuch as Brazos showed field resistance at mid-season. The results in this study indicate that the model has the potential for future use and that the model could be improved by incorporating other variables associated with host plants and pathogen races in addition to the key environmental variables.

Key Words: Rice blast, epidemiology, computerized forecasting system, weather indexing.

要　　約

微氣象 狀態에 依하여 벼 稻熱病을 豫察하기 위한 電算化 豫察모델을 開發하여 그 正確度를 電算모델을 收錄한 現地位置型 小型 電算機로서 1984年과 1985年에 실제 圃場에서 試驗하였다. 乾電池 作動型 小型

電算機는 벼 群落內 溫度, 濕度, 잎이 젖어있는 時間을 繼續的으로 測定하여 그 狀態를 稻熱病 發生可能性과 關聯하여 評價해서 每日의 病發生可能性 數値(BUS)로 表現한다. 每日의 BUS의 累積値(CBUS)와 두 罹病性 品種, M－201과 Brazos에서의 稻熱病 進展程度와는 密接한 相關이 있었다. 發病葉率의 logit 値를 CBUS로 回歸하였을 때 平均 決定係數(R^2)는 品種과 實驗한 해에 따라 71%～91%였으며 이것은 時間을 獨立變數로 使用하였을 때의 決定係數 61～79%에 比하여 顯著히 높았다. 決定係數는 M－201에 比하여 生育後期에 圃場抵抗性을 보인 Brazos에서 더 낮았다. 以上의 結果, 現豫察 모델은 實際로 使用可能性이 있지만 앞으로 寄主의 抵抗性이나 病原菌 集團의 病原性과 聯關한 變數들을 氣象環境의 變數와 함께 統合함에 依하여 보다 正確한 豫察모델로 開發할 수 있으리라 생각한다.

INTRODUCTION

The rice blast disease caused by *Pyricularia oryzae* Cav. is a major constraint on rice production (1, 18). The association of specific weather conditions with blast incidence has long been recognized (14). Systems to forecast this disease were reviewed by Ono (17) and Kingsolver *et al* (12). The earlier systems of blast forecasting were based largely on recording weather conditions favorable for disease development. In those systems factors of physical environment, such as temperature, relative humidity, rainfall, dew period, sunshine etc were widely used as prediction parameters individually or in combination in the simple or multiple regressions that were used to predict blast development (12, 17). These methods, however, have not been successful because of inaccuracy or unavailability on a timely, regular and localized basis for use.

The objectives of this research were to develop a forecasting system with the intention of developing a dependable, locally useful, and a widely distributed automatic device to predict rice blast epidemics and to test the accuracy of that system in field conditions. Preliminary reports and related portions of this research have been published elsewhere (5-11).

DEVELOPMENT OF THE FORECASTING SYSTEM

The system was designed to predict the initial occurrence and subsequent increase of rice blast disease based on an empirical model to determine periods when microenvironmental conditions were favorable for blast development. The empirical model was derived and synthesized from previous research (3, 4, 12, 17). and uses a combination of three main environmental factors to describe the observed relationships between blast development and its microenvironment. Mean air temperature, the hours of leaf wetness, and hours of relative humidity above 90% were combined to derive daily rating values of blast units of severity (BUS). The algorithm for BUS is listed in Table 1. Mean temperature outside a range of 15 to 38°C is considered to be unlikely weather for blast occurrence and is assigned a BUS value of 0, regardless of other factors. Within this temperature range, more than 9 hr duration of leaf wetness are required to obtain a given BUS value and thereafter, the value of BUS increases as leaf wetness hours increases. In addition, mean temperatures between 19 and 29°C,

Table 1. Algorithm of blast units of severity (BUS) values as a function of ambient air temperature, leaf-wetness period and relative humidity

I. If Tem. $<$ 15 C or Tem. $>$ 38 C, then BUS = 0.
II. If LW $<$ 9 hr, then BUS = 0.
III. If Tem. $>$ 14 C, then BUS = LW/4 hr.
IV. If RH $>$ 16 hr, then BUS = (III) + (RH-12 hr)/6.
V. If Tem. $<$ 23 C or Tem. $>$ 26 C, then BUS = (IV) - 2.
VI. If Tem. $<$ 19 C or Tem. $>$ 29 C, then BUS = (V) - 2.
VII. If BUS $<$ 0, then set BUS = 0.

Codes – Tem.: Temperature (C)
LW : Hours of leaf wetness
RH : Hours of relative humidity above 90%

Table 2. An example of computer program for the calculation of BUS (blast units of severity), written for TRS-80 handheld computer

```
 10  "A" PAUSE "RICE BLAST FORECASTER"
 20  PAUSE "FUNCTIONS AVAILABLE:"
 30  PRINT "A: SHOW FUNCTIONS"
 40  PRINT "C: CLEAR MEMORY"
 50  PRINT "D: DISPLAY CUM. BUS"
 60  PRINT "S: SET STORED VALUES"
 65  PRINT " = : RESTART UPDATE"
 70  END
 80  "C" BEEP 1: PAUSE "CLEAR MEMORY"
 85  INPUT "CONTINUE? (Y/N)" ; Z$: IF Z$ = "Y" CLEAR:Y 5E55: BEEP: PRINT "MEMORY CLEARED
     !!": END
 86  IF Z$ = "N" END
 87  GOTO 85
100  "B" PAUSE "UPDATE BUS TOTAL"
105  IF Y <> 5E55 GOTO 500
110  A = A + 1
120  "=" INPUT "MIN TEMP?"; C
130  INPUT "MAX TEMP?"; D:IF D < C BEEP 2:GOTO 130
140  E = (C + D)/2: PAUSE "AVG. TEMP"; E
150  INPUT "HOURS OF LEAF WETNESS?": F:IF F > 24 BEEP 2:GOTO 150
160  INPUT "HOURS RH > 90%?"; G:IF G > 24 BEEP 2:GOTO 160
180  PAUSE "CLACULATING  BUS..........."
190  IF E < 15 LET I = 0: GOTO 300
195  IF E > 38 LET I = 0:GOTO 300
200  IF F < 9 LET I = 0: GOTO 300
210  IF E > 14 LET I = F/4
220  IF G > 16 LET I = I + (G-12)/6
230  IF E < 23 LET I = I-2
235  IF E > 26 LET I = I-2
240  IF E < 19 LET I = I-2
245  IF E > 29 LET I = I-2
250  IF I < 0 LET I = 0
260  I = INT (I + .5) : B = B + 1
300  BEEP 3
305  BEEP 2:PRINT "TODAY'S BUS IS"; I
310  BEEP 2:PRINT "DAYS ELAPSED = "; A
320  BEEP 2:PRINT "CUMULATIVE BUS IS"; B
330  END
500  FOR W = 1 TO 5 : BEEP 1 : PAUSE "****MEMORY ALTERED****": NEXT W
510  GOTO "C"
600  "S" PAUSE "SET STORED VALUES"
610  INPUT "ELAPSED DAYS"; A
620  INPUT "CUM. BUS"; B
630  Y = 5E55
640  END
700  "D" IF Y <> 5E55 GOTO 500
710  GOTO 305
```

particularly in the range 23-26°C, and greater than 16 hr of relative humidity above 90% are considered to be highly favorable conditions for blast development. According to this model, the most favorable condition for blast development is a mean temperature between 23 and 26°C, 24 hr of leaf wetness, and 24 hr of high relative humidity. The value of BUS corresponding to this condition is given as 8 by the algorithm (Table 1).

The model was computerized for rapid and accurate data analysis (Table 2). The algorithm was incorporated into an on-site microcomputer (model BC-560, manufactured by Omnidata International, Inc., Logan Utah 84321, U. S. A.). The microcomputer was watertight. It operated on 8 alkaline batteries (size AA, 1.5V) which last up to a year and had a temperature sensor, a relative humidity sensor, and a leaf wetness sensor. When positioned in the rice field, the microcomputer scanned its sensors eight times per hour, calculated daily the hours of leaf wetness, hours of relative humidity above 90%, average temperature derived from maximum and minimum temperature measurements. The microcomputer interprets those data in relation to the likelihood of blast occurrence, and continuously displayed the cumulative BUS (CBUS) values for the season.

APPLICATION OF THE SYSTEM

Cultural conditions. Two rice cultivars; M-201, susceptible to blast, and Brazos, partially resistant to blast, were drill-planted with drills spaced 18 cm apart at the rate of 112 kg/ha in 1984 and 1985. Fertilizer was applied at planting at 672 kg/ha of 20-10-10 (N-P_2O_5-K_2O). A randomized block design was employed with three replications. The approximate plot size was 4.6 x 6.1m. After planting, plots were flushed as necessary for plant growth.

An on-site microcomputer was placed in a wooden weather shelter located 25 cm above ground in the center of the experiment area at 17 and 24 days after planting (24 and 11 days before inoculation) in 1984 and 1985, respectively. Sensors of temperature, relative humidity and leaf wetness were calibrated in the laboratory or in the field by following the operator's manual. BUS values were recorded at 1-2 day intervals from the microcomputer.

Each plot was inoculated with isolate 74L2 of *Pyricularia oryzae* by transplanting one infected plant into the center of the plot at 41 and 35 days from the planting. Disease progress was recorded at 3 to 7 day intervals.

The data were analyzed using the Statistical Analysis System (SAS). CBUS values were used as the independent variable to predict the logit of the proportion of disease severity (X) with a linear regression. Time in days was also used to predict logit (X) (19). The regression coefficients and coefficients of determination were compared for the two equations. CBUS values were plotted against days to examine the relationship between the rate of BUS accumulation over days.

BUS accumulations. There were 98 and 52 BUS values accumulated for the 55 and 52 day period after inoculation in 1984 and 1985, respectively (Fig. 1). Daily BUS values ranged from 0 to 6, but were commonly from 1 or 2. Rarely were more than 3 units accumulated per day. The rate of BUS accumulation over time varied with year. The rate was somewhat similar between 1984 and 1985 for the period of early epidemic, but thereafter was significantly greater in 1984 than in 1985.

Relationships between CBUS and blast development. CBUS values were used as independent variable to predict the logit of disease severity (X) and were compared to time in days as a predictor of the logit of disease severity with simple linear regression. Both CBUS and days were correlated with logit (X) (Table 3). Coefficients of determination for individual epidemics when time in days was used as the independent variable, ranged from 0.678 to 0.795 for Brazos. The precision of estimates of logit (X) in the middle was appreciably improved, regardless of cultivar, when CBUS was used as the predictor of logit (X) rather than days. This was evident from the greater values for the coefficients of determination associated with the model when using CBUS. The coefficients of determination for individual epidemics in this model ranged from 0.735 to 0.913 for M-201 and from 0.710 to 0.825 for Brazos. The coefficients of determination were

Table 3. Comparison of regression coefficients and model fitness between the logistic models using time in days and those using cumulative blast units of severity (CBUS) values as independent variables for the development of epidemics in field plots of the cultivars, Brazos and M-201 in 1984 and 1985

Cultivar	Year	Rep.[a]	Logit (X)[b]		Slope[c]		R^2[d]	
			Minimum	Maximum	Days	CBUS	Days	CBUS
M-201	1984	I	-9.43	0.90	0.174	0.106	0.693	0.735
		II	-9.90	0.21	0.162	0.105	0.705	0.746
		III	-8.22	1.13	0.156	0.101	0.747	0.788
	1985	I	-6.98	1.05	0.144	0.163	0.795	0.913
		II	-9.90	1.11	0.179	0.210	0.678	0.840
		III	-8.18	1.61	0.164	0.187	0.753	0.885
Brazos	1984	I	-7.07	0.40	0.134	0.087	0.680	0.721
		II	-6.61	0.34	0.124	0.081	0.678	0.720
		III	-9.03	-1.03	0.136	0.088	0.678	0.710
	1985	I	-6.78	-0.16	0.105	0.125	0.610	0.784
		II	-11.51	-0.08	0.192	0.224	0.671	0.825
		III	-9.72	-0.56	0.156	0.182	0.667	0.823

[a] Replicated plots.

[b] The value of ln $[X/(1-X)]$, where X is a disease severity proportion. Disease severity was examined 11 and 9 times in 1984 and 1985, respectively.

[c] Regression coefficients obtained from the regressions, ln $[X/(1-X)]$ = days and ln $[X/(1-X)]$ = CBUS (cumulative blast units of severity).

[d] Coefficients of determination from the regression. All models were significant at $P = 0.05$.

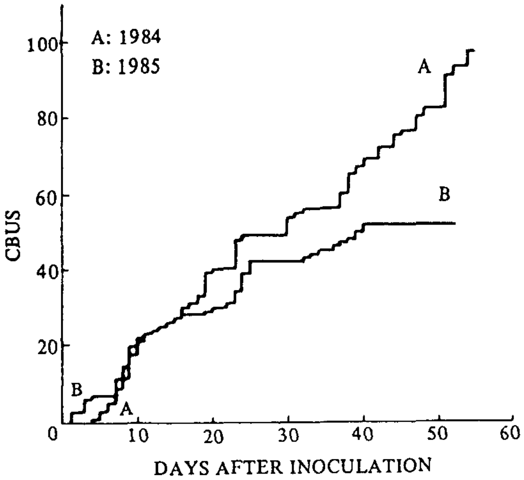

Fig. 1. Cumulative daily blast units of severity (CBUS) values in rice field plots for 55 and 52 day periods following inoculation in 1984 and 1985, respectively.

less with Brazos than M-201 due to the field resistance of Brazos that became apparent after midseason. The coefficients of regression slopes obtained from the linear model using days were significantly correlated with the slopes of the regressions using CBUS (r = .656). When CBUS obtained from

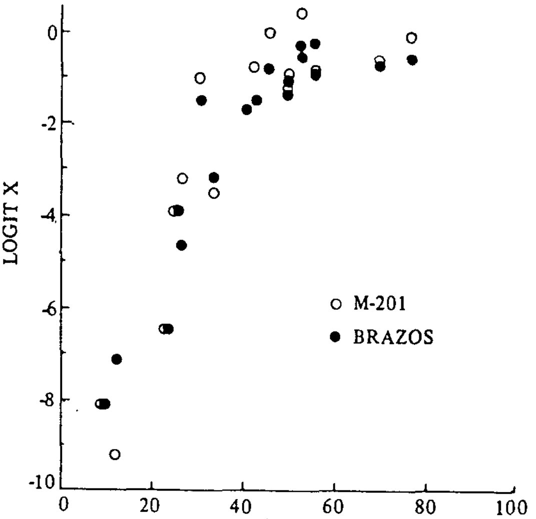

Fig. 2. Relationships between cumulative blast units of severity (CBUS) and logit transformed average disease proportions (LOGIT X) of blast developed on rice cultivars, M-201 and Brazos grown in field plots in 1984 and 1985. Simple regression equations generated from the observed relationships are LOGIT X = -7.813 + 0.136 CBUS (R^2= .684) for M-201 and LOGIT X = -7.308 + 0.117 CBUS (R^2= .740) for Brazos. Both the linear models are significant at P = .05.

both 1984 and 1985 was used as a predictor to predict logit (X) on M-201 and Brazos in both years with a simple linear regression (Fig. 2), coefficients of determination were 0.684 and 0.740 for M-201 and Brazos, respectively. Most part of remaining variations was due to the differences in unit change of logit (X) per CBUS between the two seasons.

DISCUSSION

Systems of disease forecasting based on weather indexing in relation to the likelihood of disease development have been developed with potato late-blight and several other crop diseases by several researchers (2, 13, 15, 16, 20). In those systems daily severity values, obtained from the evaluation of some key environmental data, functioned as epidemiological units of time for scheduling fungicide applications. Other units of time are needed because all days were not equally favorable for disease development. MacKenzie (15) proposed the use of severity values for standardization of epidemics that occur under variable weather conditions. For example, the comparison of epidemics in different locations is often difficult, since epidemics may vary from year to year and from location to location. The use of severity values rather than days as an independent variable in calculating the apparent infection rate may provide a standardized predictor for epidemics that occur in different times and regions. Based on this scheme, regional disease prediction may be facilitated.

In this study, the logistic model using CBUS as predictor of epidemics explained a relatively large portion of the statistical variability as compared to the model using time in days as a predictor. This indicates that the model has the potential for future use. Nevertheless, there were still considerable variations that could not be explained by the current model. Although the initial inoculum was uniform, there were large variations in disease severity at the time of the first disease assessment between epidemics under the same treatments. This suggests the possibility of differences in initial rate of disease development among plots. This may be a part of reason for the observed variations.

Although apparent infection rate using days as an independent variable was significantly correlated with the apparent infection rate using CBUS as a predictor of logit disease, the degree of correlation was relatively low. This indicates that significant variation still existed among regression slopes using CBUS when compared days as a predictor. In other words, one epidemic may have less disease per BUS than another epidemic and have the same apparent infection rates when calculated with days. These differences in the proportion of disease severity per BUS indicated the presence of other important variables that were not included in the current BUS model.

The forecasting system in this study was only based on air temperature, leaf wetness period, and relative humidity. The results of this study show that to improve accuracy of the current model, the model needs to be modified to include some other important variables associated with host plants (eg. inherent resistance, growth stage) and pathogen races (eg. virulence), in addition to other important environmental variables (eg. soil moisture). The microcomputer units could be retrofitted with those variables and algorithm for BUS adjusted. Future research in this area is necessary to make the computerized blast forecasting system dependable, locally useful, and a widely distributed automatic device for predicting rice blast epidemics and scheduling fungicides.

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