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EFFECT OF WEATHER FACTORS ON SPORE POPULATION DYNAMICS OF RICE BLAST FUNGUS IN GUILAN PROVINCE

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Abstract: Effect of weather factors on fluctuations of spore population of *Pyricularia grisea* and the occurrence of the disease was considered. During growing seasons of 2006–2007, paddy fields were chosen in distance of five kilometers from weather stations of Rasht, Lahijan and Anzali in Guilan province and spore population (Ps) were measured daily using sporetraps. Weather data including precipitation (P), daily maximum and minimum temperature (T_{max}, T_{min}), daily maximum and minimum relative humidity (RH_{max}, RH_{min}) and sunny hours (SH) were obtained from weather stations. The relationship between spore population fluctuations and weather data was analyzed and the most important weather factors affecting spore population and predicting blast were determined. Accordingly, weather factors such as P, T_{max}, RH_{min} and SH are the most important factors predicting rice blast in Guilan and enough precipitation, increased daily RH_{min}, decreased daily T_{max} and SH result in increased spore population and blast occurrence during next 7–10 days. To predict final leaf blast severity (Y_{flbs}) and neck blast index (Y_{nbi}), factors such as T_{max}, T_{min}, $\overline{T}$, RH_{max}, RH_{min}, $\overline{RH}$, P and SH and Ps were used for modeling. For leaf blast, these factors were considered for June and July and for neck blast, the same factors used for August. Step wise regression was applied for modeling. Statistics like r, R^2, aR^2, SE, F and Durbin-Watson were applied for evaluating the models. Finally, the two quantitative models:

$Y_{flbs} = –2.41–2.80\ T_{min}+0.68RHmin–0.015Ps–0.014P+0.052SH\ (R^2 = 96.73\%)$ and

$Y_{nbi} = –24.11+0.08T_{max}+0.19\ RH_{max}+0.034Ps–0.015P+0.016SH\ (R^2 = 73.97\%)$,

were introduced for predicting final leaf blast severity and neck blast index, respectively.

Related to effects of amount of applied N fertilizer (F) and date (D) and space (S) of transplanting, the results showed high correlation between F and Y_{flbs} and Y_{nbi}, but such high correlation was not observed for D and S. The best function for predicting Y_{flbs} was $Y = 4.46–4.12F+1.93F^2\ (R^2 = 96.37)$. The best equation for predicting Y_{nbi} acquired when F, D and S were applied in multiple regression, $Y = 2.06+0.33F+0.10D–0.03S(R^2 = 54.40)$.

Key words: rice, blast, *Pyricularia grisea*, forecasting, epidemiology

INTRODUCTION

Rice is the second most important crop in Iran and is considered to be the main staple food in the Iranian diet. Annually, various factors including pests, diseases, weeds, drought, harvest and storage losses etc. threaten rice production. Rice blast caused by *Pyricularia grisea* (Cooke) Sacc., teleomorph: *Magnaporthe grisea* (Hebert) Barr, is considered the most important rice disease in Guilan province. Despite the availability of resistant varieties to blast and increased their cultivation in recent years, farmers in Guilan still prefer their own susceptible local varieties because of their quality. In order to maintain the crop yield and control the disease, farmers apply fungicides frequently without adequate planning and proper time which adversely affect the sustainable production and agricultural environment. To provide an effective programming for the blast chemical control, it is essential to evaluate key factors involved in the disease progress and forecasting system. Many factors affect the blast severity including susceptibility of varieties, date and space of transplanting, amount of applied N fertilizer and weather factors such as daily relative humidity, daily temperature, amount of precipitation, dew, velocity and direction of wind and the amount of sunshine. Thus to introduce a forecasting model, it is necessary to consider the effects of these factors on the blast occurrence and its severity.

In different areas of rice production in the world, many researches were done to introduce a forecasting model for blast disease and in some of them number of spores caught in certain periods was applied for forecasting leaf or neck blast (Kuribayashi and Ichikawa 1952; Ono 1965; Kim 1982). Sometimes the disease predicted based on weather factors affect its epidemic. For example Ono used mean per cent of sunshine, temperature or precipitation for forecasting neck or leaf blast outbreak in Japan. In another model introduced by Ono (1965), factors such as sum of sunny days and manure index were used for predicting rice blast. In other studies, factors like dew period (El Refaei 1977), temperature (Yoshino 1971) or minimum dew

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period required for infection, as a function of temperature (Kingsolver *et al.* 1984), were included in the models.

Tsai (1986) and Tsai and Su (1984) gathered data on disease progress and weather factors during 1979–1984 in Taiwan and worked out several multiple regression equations to predict infected leaf area percentage. Uehara (1985) used multivariate statistical analysis techniques, such as principal components and cluster analysis to classify regions according to the degree of occurrence of leaf and panicle blast. Kim *et al.* (1987, 1988) developed an algorithm to index weather in respect to blast suitability. Kim *et al.* (1987) also showed the importance of soil moisture conditions in forecasting rice blast. In India, Padmanabhan (1965) applied minimum temperature and relative humidity (RH) to predict blast occurrence.

Calvero *et al.* (1996) generated some regression equations based on consecutive days with RH ≥ 80% (CDRH80), number of days with RH ≥ 80% (NDRH80), consecutive days with precipitation and number of days with precipitation ≥ 84 mm day^{-1}, mean maximum and minimum temperatures and number of days with wind speed above 3.5 m/s to predict the disease.

Sometimes the blast disease is predicted using a combination of factors. For example forecasting can be based on weather and spore catch. El Refaei (1977) used data from blast nursery trials to develop several linear regression equations that separately relate the number of lesions per seedling to weather variables (dew period, mean day or night temperature, mean day or night RH and rainfall) and airborne inoculum density. Other workers also have used this approach (Chien *et al.* 1984; Tsai and Su 1985). Tsai (1986) and Tsai and Su (1984) included data on spore catch on several rice varieties.

Some of complicated forecasting models are based on weather, spore catch, disease parameters and host plant criteria. For example a method to predict the number of leaf blast lesions per plant using multiple criteria was developed in Korea (Kim *et al.* 1975). Kingsolver *et al.* (1984) presented multiple regression equations for predicting the number of leaf blast lesions for different inoculum densities or different varieties. Other scientists in Japan (Muramatsu and Koyanagi 1977; Kono 1977; Shimizu 1980; Hashiguchi and Kato 1983) also tried to develop statistical methods, such as multiple regression analysis, for quantitative forecasting. The independent, predictor variables used, were date of initial leaf blast occurrence, plant height, tillers per hill, per cent diseased plants on 15 July (the early stage of the leaf blast epidemic), cumulative number of spores trapped from transplanting to 15 July, monthly mean temperature and precipitation, plant height in late June and minimum temperature or duration of sunshine in July and August.

The first studies on rice blast forecasting in Iran was carried out by Esmailpoor (1980). In this study, blast severity was evaluated on different local cultivars based on mean temperature, relative humidity, dew and precipitation. The relationship between the blast severity and number of trapped spores using sporetrap was also determined.

Izadyar (1983) studied the relationship between weather conditions and the leaf and neck blast progress on different cultivars in Guilan province. He concluded that blast occurrence and progress in the field is highly related to favourable weather conditions during susceptible stages of these varieties and the infection would not occur if the minimum night temperature was not higher than 19.5°C. The relationship between the minimum temperature during transplanting to the initial disease occurrence in the field and the leaf blast severity was determined by Izadyar (1993) as well. He related the higher mean of minimum temperature during transplanting until initial disease occurrence to the higher severity of the leaf blast and also shorter period between transplanting and initial disease occurrence. In other words, there is a negative correlation between the mean minimum temperature and a temporal gap between transplanting and initial disease occurrence.

At the present, a comprehensive study is performed to determine the predicting factors of rice blast occurrence and loss assessment in Guilan province. In this study, the effect of weather factors on the fluctuations of field spore population and forecasting the disease are taken into consideration.

MATERIALS AND METHODS

In order to introduce a forecasting model for rice blast disease in Guilan province, it is necessary to determine key factors affecting the disease epidemic. Studies have shown that these factors include the level of host susceptibility, date and space of transplanting, number of seedlings per hill, the amount of applied N fertilizer and time of its application, date of initial disease occurrence and its initial incidence or severity, the airborne spore population, weather factors such as soil and water temperatures, day and night relative humidity (RH), precipitation, hours of dew and its amount, leaf wetness duration, wind speed and direction and the amount of sunshine and the fungicide applied (mode of action, date of application and careens duration). In this research, during growing seasons of 2006–2007, some fields were chosen in distance of five kilometers from weather stations in three regions of Guilan province including Rasht, Anzali and Lahijan. The daily airborne spore population in these fields was measured using sporetraps. Sporetraps used in this research included a woody stalk with 1.5 m height on which two lines of microscope slides (five slides in each line) were placed on two pieces of glass (10x20 cm). Four sporetraps were used for the fields of each region and these stalks were placed in four directions. Each slide was covered with vaseline to absorb the airborne spores. Slides were collected every evening and the absorbed spores counted by light microscope (100x). Weather data like precipitation (P) (mm), maximum and minimum daily temperature (T_{max}, T_{min}) (°C), maximum and minimum daily relative humidity (RH_{max}, RH_{min}) (%) and sunny hours (SH) were obtained from weather stations. Then the relationship between spore and weather factors fluctuations was considered and the most important factors affecting airborne spore population and finally disease forecasting was determined.

Three fields in Anzali, three in Lahijan and one in Rasht were selected and final leaf blast severity was measured on 1000–1500 leaves on each of these fields by random selection of the tillers in the fields' diagonal, using the international scale (IRRI 1996) and finally, the mean of leaf blast severity was computed for each field. The number of infected panicles (neck blast) of total 1 000 panicles in each field and their infection types were also recorded. Then neck blast index was computed for each field using the following equation (IRRI 1996):

$$P = 10(N_1)+20(N_3)+40(N_5)+70(N_7)+100(N_9)/N$$

P = Neck blast index, N = Total number of panicles evaluated

N_1, N_3, N_5, N_7 and N_9 = Number of infected panicles in each type

Using the experimental design of split-plot (in three replications) for local cultivar Hashemi, the effect of two dates (one week gap) and two spaces of transplanting (20x20 and 25x25 cm) and three levels of N fertilizer (75, 125 and 175 kg/ha) on leaf and neck blast occurrence were investigated. The plots were 4x5 m^2 and the mean final leaf blast severity and neck blast index were computed by evaluating 150 leaves or panicles (IRRI 1996).

In order to predict the final leaf blast severity (Y_{flbs}) and the neck blast index (Y_{nbi}), weather factors including T_{max}, T_{min}, $\overline{T}$, RH_{max}, RH_{min}, $\overline{RH}$, P, SH and number of spores trapped (Ps), were used for developing predictive models. For predicting leaf blast, these factors were considered for June and July and for neck blast, the same factors were used for August. Stepwise regression analysis was applied for introducing the models using State Graphics plus 3.0. Analysis of variance and comparison of means were done using SAS v 6.12 and data were transformed to arcsin√X. Statistics like r, R^2, aR^2, SE, F and Durbin-Watson were applied to compare the models efficacy and selecting the best one.

RESULTS

During this study, the blast airborne spores daily population was determined by observing covered with Vaseline slides under light microscope (100x) and maximum of trapped spores were recorded for each region. In 2006, the first blast spores were trapped on June 13 in three regions and trapping of spores was continued for 50 days until August 1. Figure 1 shows the spore daily population in three regions during this period. Three peaks of spore were recognized in these regions. The first peak of spores started on June 16 in Rasht and Lahijan and June 15 in Anzali and finished on June 22 in three regions. The second peak started on July 12 in all three regions and finished on July 17 in Rasht and July 14 in Anzali and Lahijan. The third peak started on July 24 and finished on July 28.

The spore population and weather factors fluctuations were considered together in these regions in 2006 to find out the relationship between these two phenomena (Fig. 1). In Rasht (Fig. 1a) precipitation was 9.2 and 3.6 mm on June 12 and 13, respectively, and during these days, daily T_{max} decreased from 30°C to 25–27°C, while the daily T_{min} did not decrease, but increased as much as 1–2°C reaching 20°C. The daily RH_{min} also increased by 7–10%, but daily RH_{max} did not change much. Also during this period, sunny hours were 0–1.5 h per day and it was mostly cloudy.

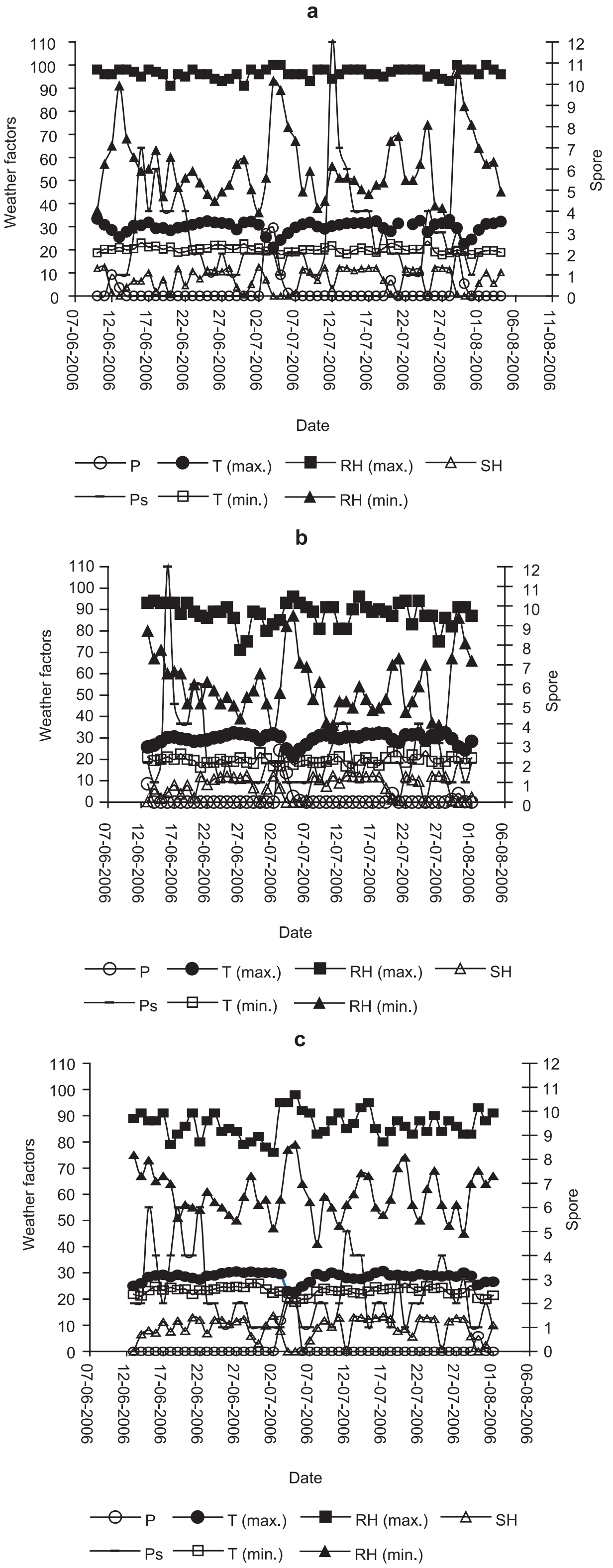

Fig. 1. Correlation between number of trapped spores of blast fungus and weather factors fluctuations in Rasht (a), Lahijan (b) and Anzali (c) in 2006. P, precipitation [mm], T, temperature [°C], RH, relative humidity [%], SH, sunny hours, Ps, spore population

The second peak of spores in Rasht started on July 12. Considering the weather factors before this peak, there was 27.1, 29.5, 9.1, 1.3 and 0.1 mm precipitation on July 3–6 and 11 respectively, the decrease of daily T_{max} by 5–7°C and the increase of daily RH_{min} by 30–40%, but daily T_{min} did not change much. Some days before coming up the third peak of spores in Rasht, weather factors followed the same changes, but with less consistency. Thus, spore population did not increase much and a small peak occurred.

The spore and weather factors fluctuations in Lahijan are shown in figure 1b. Accordingly, some days before the observation of first peak of spores, on June 12 and 13, some precipitation occurred. Also during this period, daily T_{max} decreased by 1–4°C, daily RH_{min} increased by 10–30% and sunny hours reached 0.3–3.3 h per day and these conditions lead to the increase of airborne spore population some days later. Also on July 3–6, precipitation was 24.2, 13.7, 2.6 and 0.7 mm respectively, and during these days, daily T_{max} decreased by 4–9°C, daily RH_{min} increased by 20–50% and sunny hours reached even zero. These changes resulted in the increase of airborne spore population 4–5 days later. This good relationship was also observed for the third peak.

About 4–5 days before observing the first peak of spores in Anzali, decrease of sunny hours was observed, but precipitation, decrease of daily T_{max} or increase of daily RH_{min} did not occur (Fig. 1c). Four to five days before the second peak, on July 3–5, the precipitation was 11.8, 21.9 and 22.9 mm respectively, and daily T_{max} decreased by 1–7°C, daily T_{min} decreased by 2–5°C, daily RH_{min} and RH_{max} increased by 20–25% and sunny hours reached zero. These trends were also observed for the third peak.

In the second year of the experiment (2007), the first spores were trapped on June 7 and trapping of the spores continued until August 16. Totally, three spore peaks were observed in each of three locations (Rasht, Lahijan and Anzali). In Rasht, the first peak started on July 11 and finished on 15. The second peak started on July 20 and finished on July 22. The third peak was from August 12 until 13. In Lahijan and Anzali, the first peak of spores started on July 14 and finished on July 15. The second peak started on July 20 and finished on July 22. The third peak in Lahijan was from August 12 to 13 and for Anzali from August 10 to 12 (Fig. 2).

Considering weather conditions during the spore trapping period, until July 11 in Rasht, weather conditions were not favourable for blast fungus sporulation. Until July 11, daily T_{max} was higher or lower than 26–28°C (that is favourable to blast fungus), or RH_{min} was lower than suitable (higher than 60%). From July 11 to 15, especially on July13 and 15, because of increasing of RH_{min} and suitable temperature (simultaneously), the population of airborne spores increased. From July 20 to 22 and August 12 to 13, again similar weather conditions were observed (Fig. 2a). Also, before the occurrence of these suitable temperature and humidity conditions, decreasing of sunny hours and precipitation occurred.

In Lahijan, the first peak of spores was observed when RH_{min} increased and T_{max} was between 26 and 28°C (on July 14 and 15). The second and third peaks were also observed when there were similar weather conditions on July 20–22 and August 12–13. Decrease of SH and also precipitation were the other two favourable conditions which occurred before the peaks (Fig. 2b).

In Anzali, similar relationship between spore population fluctuations and weather conditions was observed (Fig. 2c).

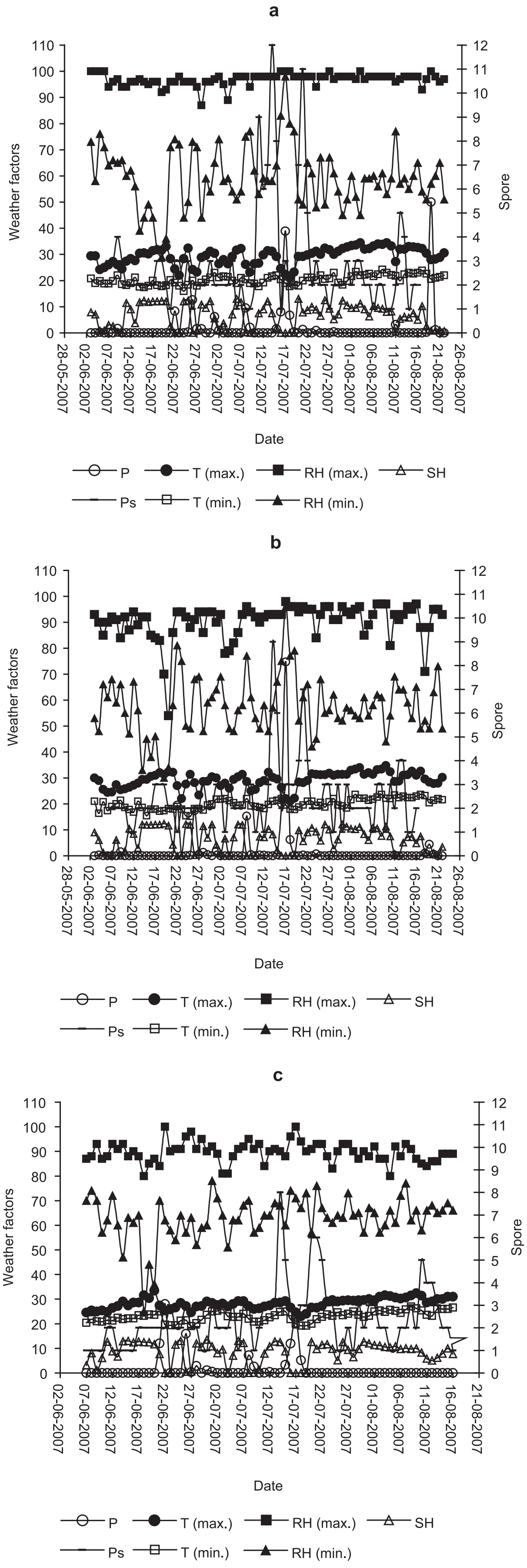

Fig. 2. Correlation between number of trapped spores of blast fungus and weather factors fluctuations in Rasht (a), Lahijan (b) and Anzali (c) in 2007. P, precipitation [mm], T, temperature [°C], RH, relative humidity [%], SH, sunny hours, Ps, spore population

Variance analysis of final leaf blast severity for the years 2006 and 2007 showed a significant difference between these years ($\alpha < 0.01$), but there was not any significant difference between the fields in each year. Mean comparison based on Duncan's multiple range test ($\alpha = 0.05$), didn't show any difference between the fields, but there was significant difference between years.

Based on variance analysis of the neck blast index, there was not any significant difference between the two years and different fields in each year, but some differences were shown by comparing the means.

In order to introduce a forecasting model for rice blast disease in Guilan province, weather factors such as T_{max}, T_{min}, $\overline{T}$, RH_{max}, RH_{min}, $\overline{RH}$, P and SH and Ps were used as independent variables. For leaf blast, these factors were considered for June and July and for neck blast, the same factors were used for August. The data of three regions were applied for introducing a model for the whole province.

Tables 1 and 2 show the models resulted from step wise regression for predicting final leaf blast severity (Y_{flbs}) and neck blast index (Y_{nbi}). Statistics like r (correlation coefficient), R^2 (coefficient of determination), aR^2 (adjusted R^2), SE (standard error), F and Durbin-Watson were used for selecting the best model(s). Among independent variables used for predicting Y_{flbs}, variables such as Ps, P and SH showed high correlation with final leaf blast severity, but such high correlation were not observed for temperature and relative humidity.

Among single point models, predictors such as T_{min} and RH_{min} (during June and July) as polynomial equations and Ps, P and SH as linear models showed good correlation with final leaf blast severity ($R^2 \geq 50\%$). These five factors were used for creating multiple regression equations. Increased number of independent variables in the models resulted in increasing the statistics, so considerable incremen in R^2 and aR^2 and decrease in SE were observed. The Durbin-Watson statistic as an indicator of the autocorrelation between errors was considered. Finally, the best model for forecasting Y_{flbs} was the one that five predictors were applied as variables in it ($R^2 = 96.73\%$):

$$Y_{flbs} = -2.41 - 2.80\ T_{min} + 0.68\ RH_{min} - 0.015\ Ps - 0.014\ P + 0.052\ SH$$

In forecasting neck blast disease, independent variables such as RH_{max}, P and SH during August, showed high correlation with neck blast index (Table 2). When the resulted single predictor models were compared using above mentioned statistics, only maximum relative humidity and precipitation as linear or polynomial models showed good correlation with neck blast index. But, regarding to approved effects of temperature, total number of spores and sunny hours on blast incidence and severity and the correlation between different predictors with Y_{nbi}, five factors including T_{max}, RH_{max}, Ps, P and SH were applied for neck blast forecasting as multiple regression equations. Finally, the best model was considered to be the one with five predictors, as the following ($R^2 = 73.97\%$):

$$Y_{nbi} = -24.11 + 0.08\ T_{max} + 0.19\ RH_{max} + 0.034\ Ps - 0.015\ P + 0.016\ SH$$

The effects of amount of applied N fertilizer and date and space of transplanting on the means of early and final leaf blast severity and neck blast index were studied in 2006 and 2007. In the first year of the experiment (2006), the effects of N fertilizer levels (75, 125 and 175 kg/ha) and the space of transplanting (25 x 25 and 20 x 20 cm) on the leaf and neck blast occurrence on cv. Hashemi (susceptible to leaf and neck blast) were investigated.

Variance analysis and comparison of the means of early and final leaf blast severity and neck blast index for this year, showed significant difference between replications and N fertilizer levels ($\alpha < 0.05$) for early leaf blast severity, but mean comparison based on Duncan's multiple range test ($\alpha = 0.05$) did not show any significant difference. Also, no significant difference was observed between replications or N levels for final leaf blast severity and neck blast index in 2006.

In 2007, variance analysis showed significant difference between N fertilizer levels, date (one week gap) and space of transplanting and the interaction of N fertilizer levels and date of transplanting ($\alpha < 0.01$) and the interaction of date and space of transplanting ($\alpha < 0.05$) for early leaf blast severity. Based on means comparison, N fertilizer levels and date and space of transplanting were segregated into three and two groups, respectively. For final leaf blast severity, N fertilizer levels and space of transplanting showed significant difference ($\alpha < 0.01$ and $\alpha < 0.05$, respectively) and based on mean comparison, N levels were grouped in A, B and C. For neck blast index, also significant difference was observed between replications ($\alpha < 0.05$) and N fertilizer levels ($\alpha < 0.01$) and three N levels were grouped in A and B based on mean comparison. Two dates of transplanting were also divided into two groups based on mean comparison ($\alpha = 0.05$).

Tables 3 and 4 show resulted models for forecasting Y_{flbs} and Y_{nbi} based on the amount of applied N fertilizer and date and space of transplanting during 2006 and 2007. There was a high correlation between N fertilizer application (F) and Y_{flbs}, but this high correlation was not observed for space of transplanting (Table 3). For Y_{nbi}, the inverted trend was observed. We observed high correlation between N fertilizer application and Y_{flbs} and Y_{nbi}, but this high correlation was not noticed for date and space of transplanting (Table 4). The best equation for predicting Y_{flbs} was for 2007 as a polynomial equation ($R^2 = 96.37$), based on R^2, aR^2, SE, F and Durbin-Watson statistics:

$$Y_{flbs} = 4.46 - 4.12\ F + 1.93\ F^2$$

Adding date and space of transplanting to this equation did not help much to increase R^2 and usually decreased it.

The best equation for predicting Y_{nbi} was also obtained for 2007 when N fertilizer level and date and space of transplanting were used simultaneously in a multiple regression equation ($R^2 = 54.40$):

$$Y_{nbi} = 2.06 + 0.33\ F + 0.10\ D - 0.03\ S$$

Adding date and space of transplanting to this equation did not help much to increase R^2 and using N fertilizer levels in a polynomial equation alone resulted in $R^2 = 52.34$.

Table 1. Different predictive models and their statistics for forecasting final leaf blast severity (Y_{flbs}) in Guilan province using field data of 2006 and 2007

Independent variable	Model	r	R^2	aR^2	SE	F	DW
T_{max} (1)	$Y_{fli} = -12.45+0.60\,T_{max}$ (linear)	0.16	2.79		3.64	0.34	
	$Y_{fli} = 674.70-48.01\,T_{max}+0.85\,T^{2}_{max}$ (Polynomial)	0.23	5.49	0.00	3.75	0.32	0.40
T_{min} (2)	$Y_{fli} = 1.11+0.17\,T_{min}$	0.08	0.72		3.68	0.09	
	$Y_{fli} = 929.98-92.71\,T_{min}+2.30\,T^{2}_{min}$	0.82	67.58	61.68	2.19	11.47**	1.02
$\overline{T}$ (3)	$Y_{fli} = -56.94+2.55\,\overline{T}$	0.33	11.30		3.48	1.53	
	$Y_{fli} = 6784.47-564.196\,\overline{T}+11.7^{3}\overline{T}\ 2$	0.54	30.05	17.33	3.23	2.36	0.70
RH_{max}(4)	$Y_{fli} = 42.12-0.41\,RH_{max}$	–0.30	9.10		3.52	1.20	
	$Y_{fli} = 3685.15-78.67\,RH_{max}+0.41\,RH^{2}_{max}$	0.47	22.17	8.03	3.40	1.57	0.41
RH_{min}(5)	$Y_{fli} = 5.52-0.01\,RH_{min}$	–0.02	0.04		3.69	0.01	
	$Y_{fli} = 690.69-23.96\,RH_{min}+0.20\,RH^{2}_{min}$	0.88	78.97	75.15	1.77	20.66**	0.94
$\overline{RH}$ (6)	$Y_{fli} = 21.94-0.23\,\overline{RH}$	–0.17	2.93		3.64	0.36	
	$Y_{fli} = 1821.35-48.93\,\overline{RH}+0.3^{2}\,\overline{RH}^{2}$	0.45	20.50	6.05	3.44	1.42	0.29
Ps(7)	$Y_{fli} = 24.73-0.18\,Ps$	–0.78	61.95		2.28	19.54**	
	$Y_{fli} = 112.95-1.72\,Ps+0.0065\,Ps^{2}$	0.96	92.88	91.59	1.03	71.81**	1.73
P(mm)(8)	$Y_{fli} = 12.10-0.076\,P$	–0.89	79.80		1.66	47.41**	
	$Y_{fli} = 23.52-0.32\,P+0.0011\,P^{2}$	0.98	96.36	95.70	0.73	145.93**	3.12
SH(9)	$Y_{fli} = -18.04+0.04\,SH$	0.88	77.85		1.74	42.19**	
	$Y_{fli} = -0.13-0.027\,SH+0.000072\,SH^{2}$	0.88	78.56	74.66	1.78	20.16**	1.47
2.5	$Y_{fli} = 3.67+2.70\,T_{min}-0.91\,RH_{min}$	0.37	14.03	0.00	3.58	0.90	0.56
2.7	$Y_{fli} = 27.81-0.13\,T_{min}-0.18\,Ps$	0.78	62.38	55.54	2.36	9.12**	0.92
2.8	$Y_{fli} = 15.93-0.18\,T_{min}-0.078\,P$	0.89	80.57	77.04	1.70	22.82**	1.59
2.9	$Y_{fli} = -5.75-0.86\,T_{min}+0.055\,SH$	0.95	91.79	90.30	1.10	61.55**	2.10
5.7	$Y_{fli} = 26.27-0.02\,RH_{min}-0.18\,Ps$	0.78	62.09	55.19	2.37	9.01**	0.92
5.8	$Y_{fli} = 14.42-0.039\,RH_{min}-0.076\,P$	0.89	80.11	76.49	1.72	22.15**	1.59
5.9	$Y_{fli} = -7.18-0.23\,RH_{min}+0.05\,SH$	0.93	87.36	85.06	1.37	38.03**	1.76
7.8	$Y_{fli} = 19.30-0.083\,Ps-0.056\,P$	0.93	87.21	84.89	1.38	37.53**	1.33
7.9	$Y_{fli} = -10.20-0.039\,Ps+0.038\,SH$	0.88	78.69	74.82	1.78	20.32**	1.29
8*9	$Y_{fli} = -1.86-0.044\,P+0.021\,SH$	0.91	83.57	80.58	1.56	27.98**	1.71
2.5.7	$Y_{fli} = 29.68-1.17\,T_{min}+0.36\,RH_{min}-0.20\,Ps$	0.79	63.77	52.90	2.43	5.87*	0.99
2.5.8	$Y_{fli} = 16.17-1.21\,T_{min}+0.36\,RH_{min}-0.08\,P$	0.90	82.08	76.70	1.71	15.27**	1.66
2.5.9	$Y_{fli} = -8.71-2.87\,T_{min}+0.66\,RH_{min}+0.064\,SH$	0.98	96.54	95.50	0.75	93.08**	3.00
2.7.8	$Y_{fli} = 24.48-0.23\,T_{min}-0.086\,Ps-0.057\,P$	0.94	88.48	85.02	1.37	25.61**	1.25
2.7.9	$Y_{fli} = -11.24-0.94\,T_{min}+0.032\,Ps+0.062\,SH$	0.96	92.28	89.96	1.12	39.86**	2.50
2.8.9	$Y_{fli} = -3.44-0.80\,T_{min}-0.0087\,P+0.05\,SH$	0.95	91.94	89.53	1.14	38.07**	2.11
5.7.8	$Y_{fli} = 21.53-0.038\,RH_{min}-0.083\,Ps-0.056\,P$	0.93	87.50	83.75	1.43	23.35**	1.29
5.7.9	$Y_{fli} = -11.38-0.25\,RH_{min}+0.025\,Ps+0.055\,SH$	0.93	87.65	83.95	1.42	23.68**	1.97
5.8.9	$Y_{fli} = -2.14-0.19\,RH_{min}-0.019\,P+0.039\,SH$	0.93	88.12	84.56	1.39	24.74**	1.81
7.8.9	$Y = 20.63-0.086\,Ps-0.058\,P-0.0016\,SH$	0.93	87.22	83.39	1.44	22.76**	1.31
2.5.7.8	$Y_{fli} = 28.16-2.52\,T_{min}+0.79\,RH_{min}-0.11\,Ps-0.065\,P$	0.97	94.71	92.37	0.98	40.35**	1.78
2.5.7.9	$Y_{fli} = -10.29-2.84\,T_{min}+0.65\,RH_{min}+0.0097\,Ps+0.066\,SH$	0.98	96.58	95.06	0.78	63.62**	3.16
2.5.8.9	$Y_{fli} = -6.36-2.81\,T_{min}+0.66\,RH_{min}-0.0088\,P+0.059\,SH$	0.98	96.69	95.23	0.77	65.90**	3.10
2.7.8.9	$Y_{fli} = -15.98-1.03\,T_{min}+0.046\,Ps+0.0087\,P+0.071\,SH$	0.96	92.34	88.93	1.18	27.13**	2.67
5.7.8.9	$Y_{fli} = 3.54-0.15\,RH_{min}-0.021\,Ps-0.027\,P+0.03\,SH$	0.93	88.20	82.95	1.46	16.82**	1.66
2.5.7.8.9	$Y_{fli} = -2.41-2.80\,T_{min}+0.68\,RH_{min}-0.015\,Ps-0.014\,P+0.052\,SH$	0.98	96.73	94.69	0.81	47.39**	2.92

r – correlation coefficient
R^2 – coefficient of determination
aR^2 – adjusted R^2
SE – standard error
F – F statistic
DW – Durbin-Watson statistic
*significant in 5% level, **significant in 1% level

Table 2. Different predictive models and their statistics for forecasting neck blast index (Y_{nbi}) in Guilan province using field data of 2006 and 2007

Independent variable	Model	r	R^2	aR^2	SE	F	DW
T_{max} (1)	$Y_{nbi} = 1.03+0.031\ T_{max}$	0.11	1.37		0.33	0.17	
	$Y_{nbi} = –134.05+8.70\ T_{max}\ –0.13\ T^2_{max}$	0.38	14.93	0.00	0.32	0.97	2.55
T_{min} (2)	$Y_{nbi} = 2.35–0.014\ T_{min}$	–0.08	0.71		0.33	0.09	
	$Y_{nbi} = –8.25+0.94\ T_{min}\ –0.021\ T^2_{min}$	0.17	2.93	0.00	0.34	0.17	2.18
$\overline{T}$ (3)	$Y_{nbi} = 0.28+0.065\ \overline{T}$	0.09	0.83		0.33	0.10	
	$Y_{nbi} = –271.04+20.41\ \overline{T}–0.3^8\ \overline{T}^2$	0.23	5.42	0.00	0.34	0.32	2.17
RH_{max}(4)	$Y_{nbi} = –4.09+0.067\ RH_{max}$	0.67	45.04		0.25	9.83**	
	$Y_{nbi} = 99.97–2.19\ RH_{max}+0.012\ RH^2_{max}$	0.76	58.01	50.37	0.22	7.60**	2.03
RH_{min}(5)	$Y_{nbi} = 1.73+0.0052\ RH_{min}$	0.11	1.22		0.33	0.15	
	$Y_{nbi} = –10.37+0.45\ RH_{min}\ –0.0041\ RH^2_{min}$	0.45	21.08	6.73	0.31	1.47	2.22
$\overline{RH}$ (6)	$Y_{nbi} = –1.24+0.044\ \overline{RH}$	0.44	20.07		0.30	3.01	
	$Y_{nbi} = 1.93–0.044\ \overline{RH}+0.0006^1\ \overline{RH}^2$	0.44	20.09	5.56	0.31	1.38	2.39
Ps(7)	$Y_{nbi} = 1.83+0.0049\ Ps$	0.26	7.13		0.32	0.92	
	$Y_{nbi} = 0.24+0.10\ Ps–0.0012Ps^2$	0.31	9.81	0.00	0.33	0.60	2.58
P(mm)(8)	$Y_{nbi} = 1.89+0.013\ P$	0.59	35.81		0.27	6.70*	
	$Y_{nbi} = 1.81+0.032\ P–0.00033\ P^2$	0.63	40.24	29.38	0.27	3.70	1.70
SH(9)	$Y_{nbi} = 2.80–0.0029\ SH$	–0.35	12.28		0.31	1.68	
	$Y_{nbi} = 1.44+0.0076\ SH–0.000019\ SH^2$	0.35	12.92	0.00	0.33	0.82	2.61
1.4	$Y_{nbi} = –2.81–0.10\ T_{max}+0.089\ RH_{max}$	0.74	54.88	46.68	0.23	6.69*	2.19
1.7	$Y_{nbi} = –0.068+0.059\ T_{max}+0.0061\ Ps$	0.33	11.44	0.00	0.33	0.71	2.59
1.8	$Y_{nbi} = 2.64–0.024\ T_{max}+0.014\ P$	0.60	36.51	24.97	0.28	3.16	1.99
1.9	$Y_{nbi} = 2.52–0.0083\ T_{max}\ –0.0028\ SH$	0.35	12.37	0.00	0.33	0.78	2.59
4.7	$Y_{nbi} = –4.10+0.066\ RH_{max}\ –0.004\ Ps$	0.63	40.79	40.66	0.25	5.45*	2.36
4.8	$Y_{nbi} = –3.45+0.06\ RH_{max}+0.0018\ P$	0.67	45.22	35.26	0.26	4.54*	1.98
4.9	$Y_{nbi} = –4.00+0.066\ RH_{max}\ –0.0001\ SH$	0.67	45.05	35.06	0.26	4.51*	2.02
7.8	$Y_{nbi} = 1.72+0.0043\ Ps+0.013\ P$	0.64	41.29	30.62	0.27	3.87	2.40
7.9	$Y_{nbi} = 2.89–0.00069\ Ps–0.0031\ SH$	0.35	12.33	0.00	0.33	0.77	2.59
8.9	$Y_{nbi} = 2.32+0.012\ P–0.0015\ SH$	0.62	38.95	27.85	0.27	3.51	2.23
1.4.7	$Y_{nbi} = –2.99–0.089\ T_{max}+0.085\ RH_{max}+0.0019\ Ps$	0.74	55.80	42.54	0.24	4.21*	2.34
1.4.8	$Y_{nbi} = –3.93–0.11\ T_{max}+0.10\ RH_{max}\ –0.0036\ P$	0.74	55.49	42.14	0.24	4.16*	2.27
1.4.9	$Y_{nbi} = –2.83–0.10\ T_{max}+0.089\ RH_{max}+0.000029\ SH$	0.74	54.88	41.35	0.24	4.06*	2.18
1.7.8	$Y_{nbi} = 1.76–0.0012\ T_{max}+0.0043\ Ps+0.013\ P$	0.64	41.29	23.68	0.28	2.34	2.40
1.7.9	$Y_{nbi} = 2.36+0.011\ T_{max}+0.00041\ Ps–0.0026\ SH$	0.35	12.37	0.00	0.34	0.47	2.59
1.8.9	$Y_{nbi} = 3.41–0.033\ T_{max}+0.012\ P–0.0017\ SH$	0.63	40.28	22.36	0.28	2.25	2.32
4.7.8	$Y_{nbi} = –3.42+0.058\ RH_{max}+0.004\ Ps+0.002\ P$	0.70	50.00	35.00	0.26	3.33	2.35
4.7.9	$Y_{nbi} = –10.97+0.11\ RH_{max}+0.018\ Ps+0.0083\ SH$	0.80	65.44	55.08	0.21	6.31*	2.42
4.8.9	$Y_{nbi} = –3.13+0.057\ RH_{max}+0.0022\ P–0.00025\ SH$	0.67	45.28	28.87	0.27	2.76	2.02
7.8.9	$Y_{nbi} = 1.58+0.005\ Ps+0.013\ P+0.00042\ SH$	0.64	41.37	23.78	0.28	2.35	2.40
1.4.7.8	$Y_{nbi} = –3.85–0.098\ T_{max}+0.098\ RH_{max}+0.0017Ps\ –0.0028\ P$	0.74	56.16	36.68	0.25	2.88	2.38
1.4.7.9	$Y_{nbi} = –13.7+0.056\ T_{max}+0.11\ RH_{max}\ +0.023\ Ps+0.01\ SH$	0.81	66.40	51.47	0.22	4.45*	2.43
1.4.8.9	$Y_{nbi} = –4.35–0.11\ T_{max}+0.10\ RH_{max}\ –0.0041\ P+0.00032\ SH$	0.74	55.59	35.85	0.26	2.82	2.23
1.7.8.9	$Y_{nbi} = 0.64+0.02\ T_{max}+0.007\ Ps+0.013\ P\ +0.0012\ SH$	0.64	41.49	15.49	0.29	1.60	2.42
4.7.8.9	$Y_{nbi} = –19.44+0.19\ RH_{max}+0.025\ Ps–0.014\ P\ +0.012\ SH$	0.84	72.06	59.65	0.20	5.81*	2.80
1.4.7.8.9	$Y_{nbi} = –24.11+0.08\ T_{max}+0.19\ RH_{max}+0.034\ Ps\ –0.015\ P+0.016\ SH$	0.86	73.97	57.71	0.21	4.55*	2.78

r – correlation coefficient
R^2 – coefficient of determination
aR^2 – adjusted R^2
SE – standard error
F – F statistic
DW – Durbin-Watson statistic
*significant in 5% level, **significant in 1% level

Table 3. Predictive models for forecasting final leaf blast severity (Y_{flbs}) and neck blast index (Y_{nbi}) based on applied N fertilizer and space of transplanting (2006)

Dependent variable	Independent variable	Model	r	R2	aR2	SE	F	DW
Y_{fli}	N fertilizer applied (1)	$Y_{fli}=1.28+0.70F$ $Y_{fli}=2.81-1.13F+0.46F^2$	0.61 0.65	37.65 43.00	 30.33	0.81 0.81	6.04* 3.40	 0.92
Y_{fli}	Space of transplanting (2)	$Y_{fli}=2.23+0.30S$	0.16	2.69		1.01	0.28	
Y_{fli}	1 . 2	$Y_{fli}=0.81+0.70F+0.30S$	0.63	40.34	27.08	0.83	3.04	0.75
Y_{nbi}	N fertilizer applied (1)	$Y_{nbi}=3.05-0.09F$ $Y_{nbi}=3.13-0.19F+0.02F^2$	–0.14 0.14	2.02 2.08	 0.00	0.56 0.59	0.21 0.10	 2.89
Y_{nbi}	Space of transplanting (2)	$Y_{nbi}=1.96+0.60S$	0.57	33.01		0.46	4.93	
Y_{nbi}	1 . 2	$Y_{nbi}=2.14-0.09F+0.60S$	0.59	35.03	20.59	0.48	2.43	2.38

r – correlation coefficient
R^2 – coefficient of determination
aR^2 – adjusted R^2
SE – standard error
F – F statistic
DW – Durbin-Watson statistic
*significant in 5% level, **significant in 1% level

Table 4. Predictive models for forecasting final leaf blast severity (Y_{flbs}) and neck blast index (Y_{nbi}) based on applied N fertilizer, date and space of transplanting (2007)

Dependent variable	Independent variable	Model	r	R2	aR2	SE	F	DW
Y_{fli}	N fertilizer applied (1)	$Y_{fli}=-1.99+3.63F$ $Y_{fli}=4.46-4.12F+1.93F^2$	0.93 0.98	88.00 96.37	 96.15	1.12 0.62	249.48** 438.56**	 2.12
Y_{fli}	Date of transplanting (2)	$Y_{fli}=5.06+0.13D$	0.02	0.04		3.25	0.01	
Y_{fli}	Space of transplanting (3)	$Y_{fli}=4.73+0.35S$	0.05	0.31		3.24	0.11	
Y_{fli}	1 . 2	$Y_{fli}=-2.19+3.63F+0.13D$	0.93	88.05	87.32	1.14	121.58**	0.83
Y_{fli}	1 . 3	$Y_{fli}=-2.52+3.63F+0.35S$	0.93	88.31	87.61	1.12	124.75**	0.80
Y_{fli}	2 . 3	$Y_{fli}=4.53+0.13D+0.35S$	0.059	0.35	0.00	3.29	0.06	0.18
Y_{fli}	1 . 2 . 3	$Y_{fli}=-2.72+3.63F+0.13D+0.35S$	0.94	88.36	87.27	1.14	80.99**	0.81
Y_{nbi}	N fertilizer applied (1)	$Y_{nbi}=2.17+0.33F$ $Y_{nbi}=2.07+0.46F-0.03F^2$	0.72 0.72	52.19 52.34	 49.45	0.27 0.27	37.12** 18.12**	 1.83
Y_{nbi}	Date of transplanting (2)	$Y_{nbi}=2.68+0.10D$	0.14	2.01		0.38	0.70	
Y_{nbi}	Space of transplanting (3)	$Y_{nbi}=2.89-0.03S$	–0.04	0.20		0.39	0.07	
Y_{nbi}	1 . 2	$Y_{nbi}=2.01+0.33F+0.10D$	0.73	54.20	51.42	0.26	19.53**	1.81
Y_{nbi}	1 . 3	$Y_{nbi}=2.22+0.33F-0.03S$	0.72	52.39	49.51	0.27	18.16**	1.81
Y_{nbi}	2 . 3	$Y_{nbi}=2.73+0.10D-0.03S$	0.14	2.21	0.00	0.39	0.37	0.80
Y_{nbi}	1 . 2 . 3	$Y_{nbi}=2.06+0.33F+0.10D-0.03S$	0.73	54.40	50.13	0.27	12.73**	1.80

r – correlation coefficient
R^2 – coefficient of determination
aR^2 – adjusted R^2
SE – standard error
F – F statistic
DW – Durbin-Watson statistic
*significant in 5% level, **significant in 1% level

DISCUSSION

Three peaks of spores were recognized in Rasht, Lahijan and Anzali. Considering that Anzali is near the Caspian Sea, we can interpret some differences existing in the weather factors fluctuations between Anzali and Rasht and Lahijan, because Rasht and Lahijan are same distance away from the sea. It is interesting that, the dates of starting and finishing the peaks in Rasht, Lahijan and Anzali was consistent with the dates of starting and finishing favourable weather conditions (for example compare the first peak in Rasht with Lahijan and Anzali and the third peak of Lahijan with Anzali in 2007).

These results showed that the key weather factors for predicting spore peaks and the occurrence of rice blast epidemic in Guilan province are consequently precipitation, daily T_{max}, daily RH_{min} and SH and factors such as daily T_{min} and daily RH_{max} are less important. Our data indicate that higher spore population occurred 3–5 days after precipitation, decrease or increase of daily T_{max} reaching 26–28°C, increase of daily RH_{min} reaching 60–70% and decrease of SH reaching less than 1–3 h per day. These conditions lead to the occurrence of blast lesions and increasing blast incidence and severity (on leaves and panicle necks) 7–10 days after suitable weather conditions.

These results are consistent with the results of studies done by Esmailpoor (1980), Izadyar (1983) and other studies conducted in other rice growing areas, based on factors like precipitation, the decrease of daily temperature and having temperate condition, the increase of daily RH and decrease of sunny hours were used for blast disease forecasting. These results help to predict blast disease in Guilan province and to have suggestions about the date of fungicide application and how often it should be applied.

Variance analysis of final leaf blast severity in 2006 and 2007 and their mean comparison using Duncan's multiple range test, showed significant difference between two years, but there was not any significant difference among the experimental fields surveyed in each year. This is possibly due to similar weather conditions in Rasht, Lahijan and Anzali and different weather conditions during 2006 and 2007, especially in June and July.

On the basis of variance analysis of the neck blast index, there was not any significant difference between two years and different fields in each year, but some differences were observed by mean comparison. This similarity was due to similar prevailing weather conditions during August for two years and also leading to the point that, if there is a minimum population of spores for neck infection and usually this minimum exists because of leaf infection, neck blast infection is not determined by final leaf area infection.

Among independent variables used for predicting final leaf blast severity, variables such as Ps, P and SH showed high correlation with final leaf blast severity, but correlation between temperature and relative humidity with the same index was low. Positive correlation between temperature and final leaf blast severity was due to cool weather during June and July, therefore during this period, T_{max} would not exceed the suitable range for blast disease (26–28°C) leading to low blast severity. There was negative and insignificant correlation between RH and final leaf blast severity. Negative correlation between Ps and final leaf blast severity and positive correlation between SH and final leaf blast severity indicate that Ps and SH are not the only determinants of the blast severity, therefore forecasting based on these predictors is not reliable. Negative correlation between precipitation and final leaf blast severity was because of removing the spores from the air and excluding them from the disease cycle by strong rain, so that the increase of the amount of precipitation during June and July in 2006, resulted in the decrease of leaf blast severity in comparison with 2007. Then, only the amount of precipitation necessary for providing high RH is suitable and increasing its amount will have negative effects on blast severity.

The model introduced for predicting final leaf blast severity in Guilan province is similar to the models introduced by Calvero *et al.* (1996), in independent variables which were used as predictors. This model which has high coefficient of determination will be introduced for predicting final leaf blast severity in Guilan province, after being validated and determination of the model ability for forecasting.

Independent variables such as RH_{max}, P and SH during August, exhibited high correlation with neck blast index. Regarding the increasing of temperature during August, the temperature effect on neck blast severity would be decreasing and considering the low precipitation during this month in Guilan, having high precipitation would increase neck blast occurrence. In this investigation, T_{min} and RH_{min} were used for leaf blast forecasting, but for neck blast, T_{max} and RH_{max} were used, because during August we usually have high T_{min} and RH_{min} in Guilan and therefore they are not good predictors for neck blast severity, so having suitable T_{max} and RH_{max} during this period is considered to be determinant factor for the blast severity. Thus high T_{max} (more than 30 Ċ) and low RH_{max} (less than 88%) will stop blast progress on the panicles.

The model introduced for predicting neck blast index here is similar to the models introduced by Calvero *et al.* (1996), in the case of independent variables were used as predictors. Our model that has high coefficient of determination will be introduced for forecasting neck blast index in Guilan province, after validation and determination of the model ability for forecasting.

The effects of amount of applied N fertilizer and date and space of transplanting on the means of early and final leaf blast severity and neck blast index were studied in 2006 and 2007. Variance analysis and comparison of the means of early and final leaf blast severity and neck blast index for these years, showed significant difference between replications and also N fertilizer levels and to some extent, date and space of transplanting, for early leaf blast severity, final leaf blast severity and neck blast index in 2006 and 2007. These results show that the amount of applied N fertilizer has a significant effect on early and final leaf blast severity and neck blast index and increasing the amount of N results in increment the blast disease in all stages of rice growth, but date and space of transplanting are less effective.

This research is a starting point for a comprehensive study about blast forecasting in Guilan province which will be completed in the near future. We hope to help our farmers in blast chemical control by introducing a suitable forecasting model and inhibit the yield loss because of the disease or overuse of fungicides.

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POLISH SUMMARY

DZIAŁANIE CZYNNIKÓW POGODOWYCH NA DYNAMIKĘ POPULACJI ZARODNIKÓW GRZYBA WYWOŁUJĄCEGO ZGORZEL RYŻU W PROWINCJI GUILAN

Omówiono wpływ czynników pogodowych na wahania w populacji zarodników *Pyricularia grisea* i występowanie choroby. W okresach wegetacji lat 2006–2007 wytypowano podmokłe pola w odległości pięciu kilometrów od stacji meteorologicznych w Rasht, Lahijan i Anzali w prowincji Guilan; populację zarodników określano wykorzystując pułapki zarodników. Dane pogodowe obejmujące opady, temperatury dobowe, minimalne i maksymalne, dobową wilgotność względną i godziny nasłonecznienia otrzymano ze stacji meteorologicznych. Analizowano związek pomiędzy wahaniami populacji zarodników i danymi pogodowymi mogącymi wpływać na populację zarodników, a prognozowaniem wystąpienia zgorzeli ryżu. Opady, maksymalne temperatury, minimalna wilgotność względna i godziny nasłonecznienia są najważniejsze dla prognozowania choroby w Guilan, a wystarczająca ilość opadów zwiększała dobową wilgotność względną, zmniejszała dobową maksymalną temperaturę i ilość godzin nasłonecznienia, powodując zwiększanie populacji zarodników i wystąpienie zgorzeli ryżu w okresie następnych 7–10 dni. W celu uzyskania danych o nasileniu zgorzeli ryżu i wskaźnika zgorzeli szyjki, dane te były wykorzystane do modelowania przebiegu choroby. Dla zgorzeli liści wzięto pod uwagę informacje z czerwca i lipca, a dla zgorzeli szyjki dane z września. Do modelowania wykorzystano metodę stopniowej regresji. Do oceny modeli wykorzystano statystykę taką jak

r, R^2, aR^2, SE, F i Durbin-Watson. W końcu opracowano dwa ilościowe modele:

$Y_{flbs} = -2,41-2,80\ T_{min} + 0,68RHmin - 0,015Ps - 0,14P + 0,052SH$ ($R^2 = 96,73\%$) i

$Y_{nbi} = -24,11 + 0,08T_{max} + 0,034Ps - 0,015P + 0,016SH$ ($R^2 = 73,97\%$),

co zostało wprowadzone odpowiednio do przewidywania końcowego indeksu nasilenia zgorzeli liści i szyjki. W stosunku do efektu zastosowanego nawożenia azotowego (F), terminu (D) i rozstawy (S) przy przesadzaniu, wyniki wykazały wysoką korelację pomiędzy F i Y_{flbs} i Y_{nbi}, ale takiej wysokiej korelacji nie obserwowano dla D i S. Najlepszą funkcją do przewidywania Y_{nbi} była: $Y = 4,46-4,12+1,93F^2$ ($R^2 = 96,37$). Gdy F, D i S były stosowane w wielokrotnej regresji najlepszym równaniem do przewidywania $Y_{nbi,}$ było $Y = 2,06+0,33F+0,10D-0,035$ ($R^2 = 54,40$).