A Statistical Method of Predicting Outbreaks of Rice Panicle Blast

Tsugio Sasaki and Hajime Kato

Tohoku National Agricultural Experiment Station, Omagari, Akita-ken, and National Institute of Agricultural Sciences, Nishigahara, Kita-ku, Tokyo, Japan, respectively.

We thank Dr. and Mrs. C. Okuno, and the members of the Statistical Research Group on Epiphytotics of the National Institute of Agricultural Sciences for their advice. We also appreciate the help of A. E. Dimond in editing the manuscript.

Accepted for publication 7 April 1972.

ABSTRACT

A statistical method of forecasting panicle blast after heading has been developed. Cumulative numbers of diseased spikelets, plotted against time, formed a sigmoid curve for all cultivars grown under different conditions for the years 1962 through 1967. Based on 112 sets of readings, each linear equation has been developed, relating the logit of the percentage of diseased spikelets 12 days after the middle stage of heading (MSH) and the rate of increase during the following 6 days. With these equations, numbers of spikelets blasted in the next 6 days can be forecast by extrapolation. Predicted values and values calculated from each regression formula based on real readings had a coefficient of determination $R^2 = .714$ ($P < .01$). Between logits of diseased spikelets 24 days after MSH and of diseased neck nodes 30 days after MSH, the R^2 was .591 ($P < .01$). The amount of neck node blast corresponding to the amount of spikelet blast predicted can be estimated by means of this regression formula. The amount of diseased portions in panicle branches can be predicted by the same procedure.

Phytopathology 62:1126-1132.

Additional key words: Pyricularia oryzae, Oryza sativa, epidemiology, disease increase.

During the heading period, chemicals are routinely applied once or twice to rice plants (*Oryza sativa* L.) to protect them from panicle blast, consisting of neck node blast, panicle branch blast, and spikelet blast caused by *Pyricularia oryzae* Cav. As application of fungicides to plants after heading is not unusual, forecasting the amount of panicle blast is required. A simple method of forecasting based on the chronological change in quantity of disease lesions per unit area of a field is proposed. The change of amount of disease reflects the affinity of the parasite to its host, the relationships between virulence and disease proneness, and the influence of climatic factors upon infection and disease development (12). This change is also affected by the amount of initial inoculum (3, 4). The number of diseased spikelets resulting from initial inoculum and the rate of their increase with time have been adopted as indicators. Use of amount of diseased spikelets as a measure has advantages over other disease readings. The incubation period for spikelet infections is shorter than for other organs of the panicles (2, 4, 5). It is from 7 to 12 days at 20 C and from 5 to 10 days at 25 and 30 C (H. Kato & T. Kozaka, *unpublished data*), and the latent period is the same as the incubation period (5). Disease on the spikelet is easily diagnosed in the case of japonica rice, and can be expressed quantitatively.

MATERIALS AND METHODS.—For surveying disease increase, two or more cultivars of rice were employed under different growing conditions in different locations from 1962 through 1967. Data are based upon plots arranged in randomized blocks as described below. (i) The japonica cultivars, Hatsunishiki and Chokai, were each planted in stand densities of 9, 12, 19, 28, 35, and 78 plants/m^2 in 1964, 1965, and 1966. (ii) The same cultivars, planted at a density of 19 plants/m^2, were top-dressed with varying amounts of nitrogen 30 days before heading. In 1964, they were fertilized with 0, 5, 10, or 15 kg of nitrogen/hectare, and in 1966, these cultivars received 0, 15, or 20 kg of nitrogen/hectare. (iii) Thirteen different japonica cultivars were compared under the same conditions. They were Shinsetsu, Towada, Hatsunishiki, Fujiminori, Yoneshiro, Miyoshi, Chokai, Fukei 69 (a hybrid of Tadukan), Fukunishiki (a hybrid of Zenith), Ugonishiki (a hybrid of To-to), Otori, Norin 21, and Norin 41. (iv) The cultivars Hatsunishiki and Chokai were raised in six locations in the Senboku plain of Akita-ken.

Plots 1 through 3 contained seedlings that were transplanted from a water-logged nursery to a flooded paddy on 5 June. Plot four was planted on 20 May, using seedlings that had been grown in an upland nursery, covered with vinyl film. Every field was fertilized with 12,000 kg compost, 300 kg $(NH_4)_2SO_4$, 300 kg $Ca(H_2PO_4)_2$, and 120 kg KCl/hectare before transplanting.

Disease incidence was determined 5 times at 6-day intervals after the middle stage of heading (MSH). MSH was defined as the time when 50% of the stems in a population of rice had panicles protruding. In all, 112 cases consisting of 5 readings of disease incidence each were made. However, the initial readings were discarded, because about half the number of spikelets were still undergoing incubation at that time. When disease incidence was abundant, disease incidence was determined from readings on 11 plants; when lesions were less frequent, incidence was determined from 30 plants. In either case, plants were randomly selected initially. On these plants, the number of diseased spikelets, diseased portions of panicle branches, and diseased neck nodes were counted, together with the total numbers of panicles and spikelets.

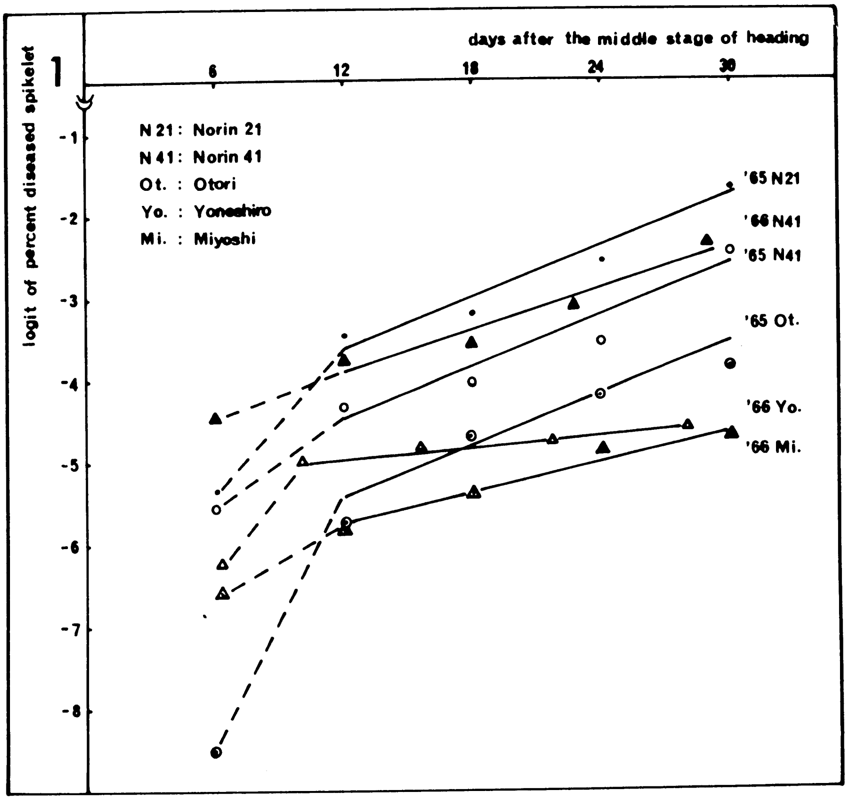
RESULTS.—The increase in number of diseased organs with time generates a sigmoid curve, as was shown by data for the season of 1962 on numbers of diseased spikelets, portions of panicle branches, and neck nodes (5).

For the growing seasons of 1962 through 1967, data on percentages of diseased spikelets were multiplied by 10, then transformed to Berkson's logits (1, 12, 13), a function that has a linear regression with time (Fig. 1). All regressions were examined by the "Student" t-test, and in every case the regression was significant at the 5% probability level. Regression coefficients ranged from .007 to .260. Surveys of disease were made over an extended period of time, during which weather factors varied. The temperature ranged from 9.5 to 35 C, and the precipitation was recorded on 40.0 to 63.9% of total days during each surveying season from 1962 through 1967. Based on the above results, a method for forecasting disease was developed and tested. The procedure consists of two steps: (i) estimation of the incidence of diseased spikelets a few days hence by extrapolation of the linear line; and (ii) estimation of the percentage of diseased neck nodes by use of the correlation between disease in spikelets and neck nodes.

As the first step of the procedure, the percentage of diseased spikelets on days 12 and 18 after MSH were transformed, and amounts of disease in logits (S_e) were plotted against time (t). The constants a and b in the linear equation $S_e = at + b$ were evaluated (Fig. 2). From this line, the estimated amount of disease in logits ($\overline{S}_e$) on day 24 was determined by extrapolation.

For all data covering the period 1962 through 1967, values of $\overline{S}_e$ for day 24 were obtained from their estimating equations, and compared with the corresponding values of $\overline{S}_r$, obtained from the regression equation in each of real readings $\overline{S}_r = a't + b'$. The relation of $\overline{S}_e$ to $\overline{S}_r$ is described by the linear equation $\overline{S}_r = 0.666\ \overline{S}_e - 1.995$ (Fig. 3). The coefficient of determination between two variables was 0.714 ($P < .01$), and the standard error, $SE = (.0077 + .0016\ \overline{S}_e^{2})^{1/2}$. After an estimate of the amount of diseased spikelets on day 24 by the first procedure, estimated value can be statistically revalued by using this formula. The revalued estimate of the 95% confidence interval will be evaluated when $l = \overline{S}_r \pm 1.982$ SE.

Reduction in yield of rice grains as a consequence of infections is best known in terms of infections of neck nodes (6, 8). For this reason, the second step in the procedure was an examination of the degree of correlation between amount of disease in spikelets and in neck nodes when both are expressed in logits (Table 1, Fig. 4). The correlation is highest between spikelet blast on day 24 and neck node blast on day 30, at which time the coefficient of determination was 0.591 ($P < .01$) and the standard error was $(.0090 + 0.0049\ SP_3^{2})^{1/2}$ for the regression equation $NN_4 = 0.920\ SP_3 + 0.518$. Here, NN_4 is the percentage of diseased neck nodes on day 30 and SP_3 is the percentage of diseased spikelets on day 24, both expressed in logits.



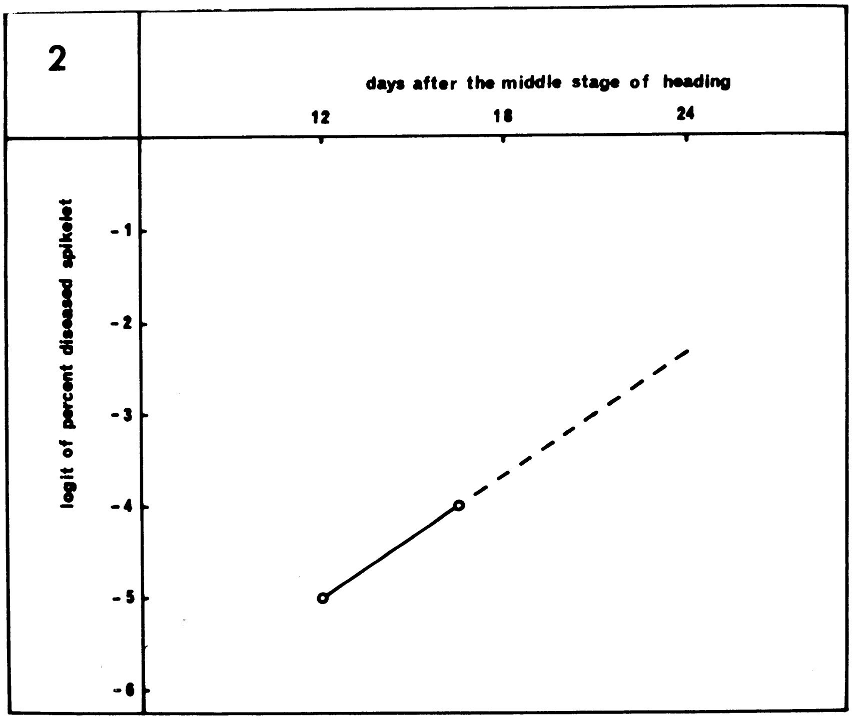


Fig. 1-2. 1) Typical regression line, $S_r = a't + b'$, between logits of the percentages of blasted spikelets of rice caused by *Pyricularia oryzae* (S_r) and time (t). About half the spikelets were within incubation periods for infection on day 6 after the middle stage of heading (MSH). 2) Method of estimating amount of spikelet blast on day 24 after MSH ($\hat{S}_e$) from disease readings on days 12 and 18, $S_e = at + b$.

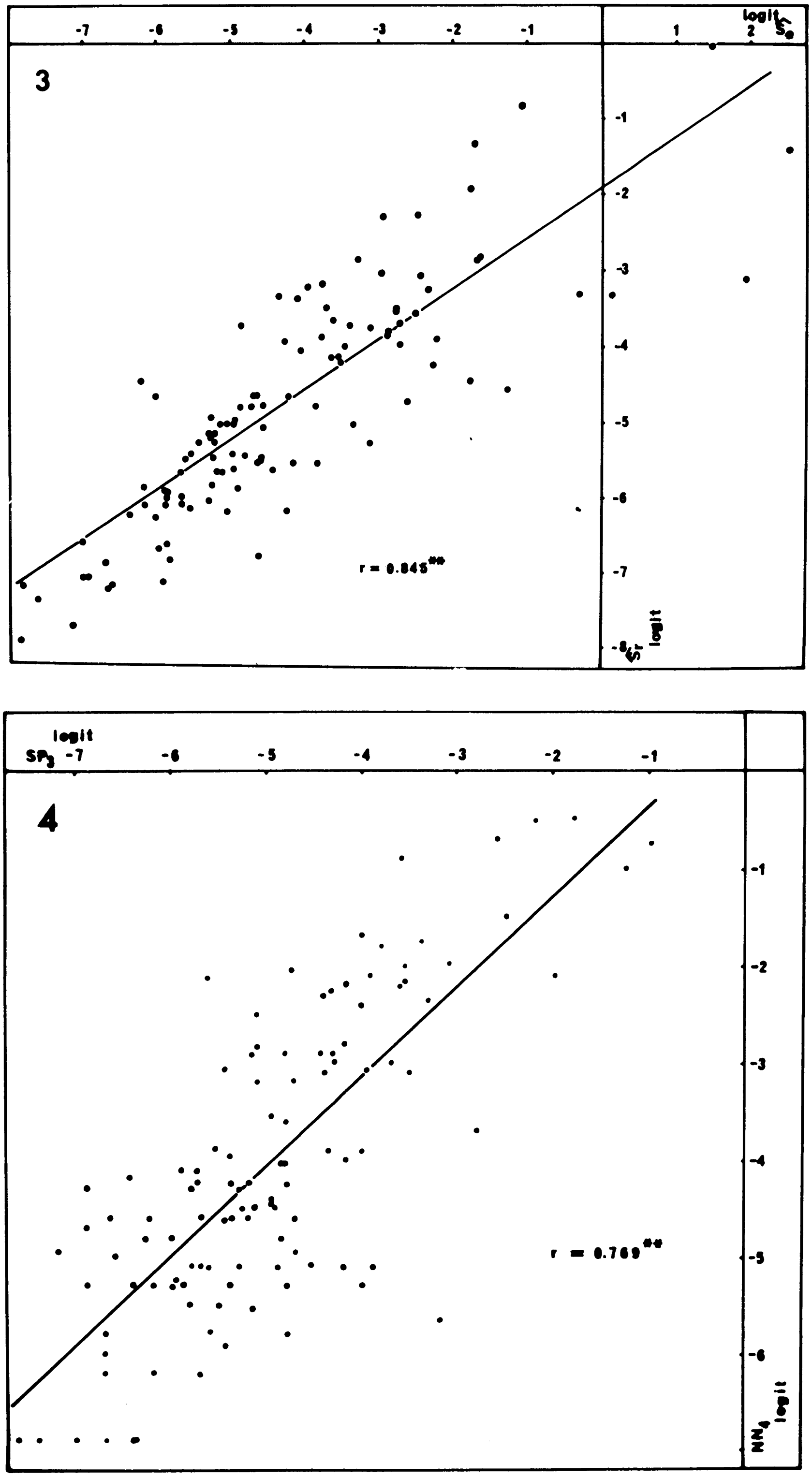
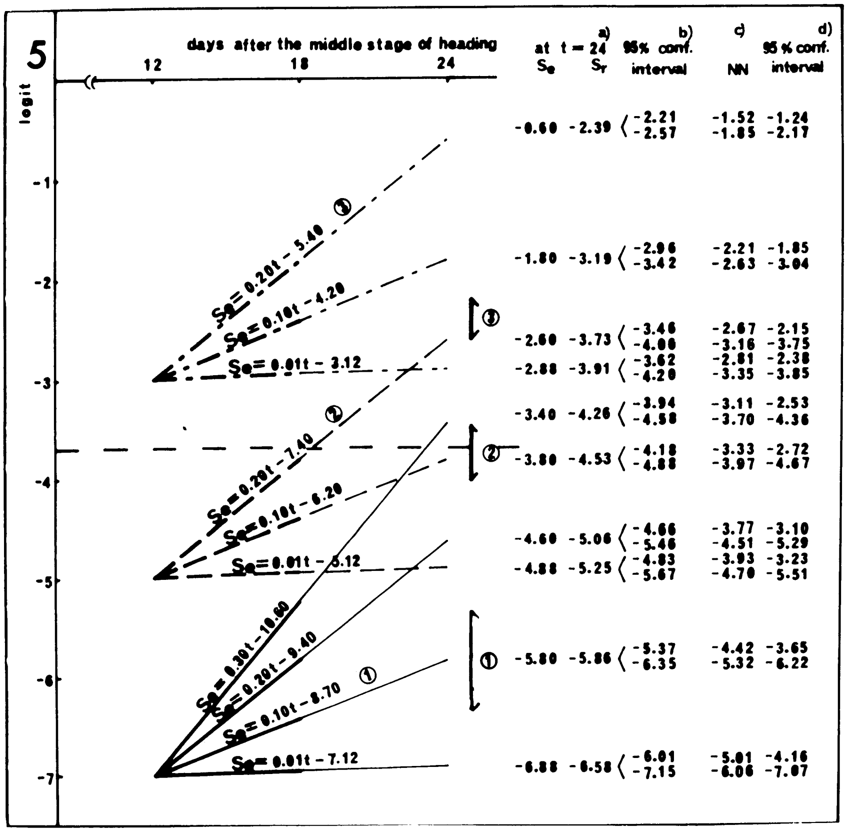
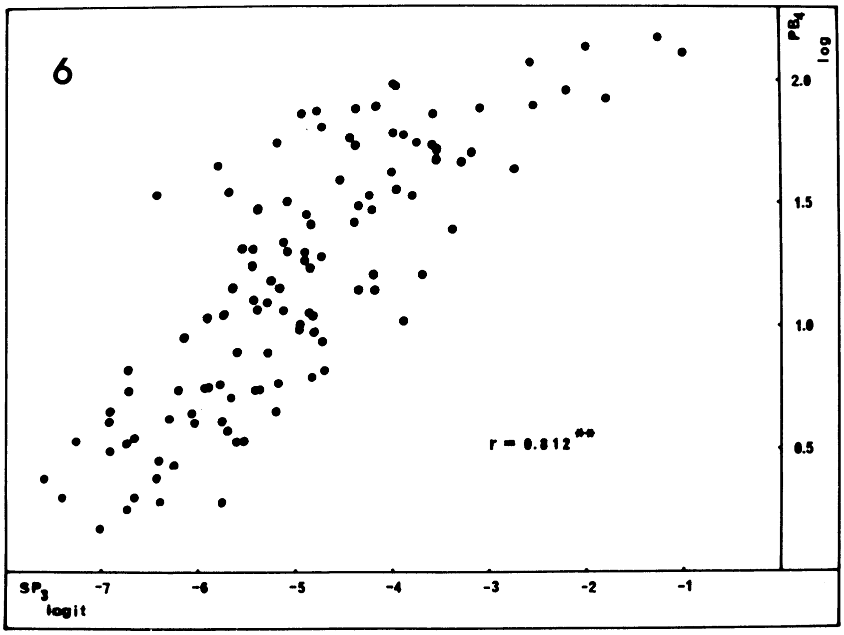


Fig. 3-4). 3) Correlation between $\hat{S}_e$ on day 24, obtained from estimating equation $S_e = at + b$, and $\hat{S}_r$ on day 24, obtained from regression equation $S_r = a't + b'$ for seasons of 1962 through 1967. Equation for the line is $\hat{S}_r = .666\ S_e - 1.995$. 4) Correlation of logits of neck node blast 30 days after MSH (NN_4) with spikelet blast 24 days after MSH (SP_3). The regression equation is presented as $NN_4 = .920\ SP_3 + .518$.

The method of calculating confidence limits of estimated values is illustrated in the following example (Fig. 5). Where the incidence of diseased spikelets in logits, S_e, is −5.00 on day 12, time t, and the rate of increase is 0.20 (Fig. 5, 2), the linear equation can be written as $\hat{S}_e = 0.20\,t - 7.40$. In this equation, disease in spikelets, $\hat{S}_e$, is estimated on day 24 to be −2.60. Substituting the value of $\hat{S}_e$ in the regression equation, $\hat{S}_r = 0.666\,\hat{S}_e - 1.995$, we have $\hat{S}_r$, the revalued estimated amount of disease as −3.73





logit. The confidence limit, ± 0.27 (P = .05), is calculated from the relationship given above, 1.982 $(.0077 + 0.0016\ \hat{S}_e^2)^{1/2}$.

In the second step of the procedure, the estimates of disease in neck nodes are obtained by use of the standard regression equation $NN_4 = 0.920\ SP_3 + 0.518$ when the limits of estimated disease in spikelets, −3.73 ± 0.27, or −4.00 and −3.46, are taken as values for SP_3. Resulting estimates of disease in neck nodes are −3.16 and −2.67 logits. Confidence intervals for disease in neck nodes, given by substitution in the formula 1.982 $(.0090 + .0049\ SP_3{}^2)^{1/2}$, are −3.16 ± 0.59 and −2.67 ± 0.52, respectively. Therefore, the range from −3.75 to −2.15 represents the confidence interval for the estimated amount of disease in neck nodes corresponding to the estimated amount of disease in spikelets.

In later stages of development, spikelet and panicle branch blast were better correlated than spikelet and neck node blast (Table 1, Fig. 6). Panicle branch blast was estimated from spikelet blast, using the same procedure as was employed for estimating neck node blast. The coefficient of determination between spikelet blast and numbers of diseased portions of panicle branches per 100 panicles was .659 (P < .001), and the standard error was $(.0077 + .0005\ SP_3{}^2)^{1/2}$.

DISCUSSION.—In order for logistic curves to serve as a basis for disease forecast, a number of conditions must be met. Firstly, during the onset stage of the disease, the amount of primary inoculum is the limiting factor for the biotic potential of the pathogen. Secondly, the number of susceptible, healthy host plants decreases with time and becomes the factor limiting the rate of increase of disease. Thirdly, the pathogen must have a definite generation time. Finally, the degree of affinity in the host-parasite interaction remains constant over the reproductive period (13, 14).

In an outbreak of spikelet blast, the first and second conditions are satisfied when forecasts are made during the period following the final stage of heading in a population of rice. The generation time is governed by combinations of races and cultivars and by prevailing temperatures. As for the fourth condition, spikelets are susceptible to infection over a 25-day period after their emergence from the sheath of the flag leaf. Disease proneness decreases with age (4, 11). Moreover, the potential for formation of conidia in a diseased spikelet changes with time. Diseased pedicels, panicle branches, and neck nodes simultaneously serve as sources of inoculum, even though there is a time lag (4). The number of conidia deposited per unit area depends upon atmospheric stability (9) and wind velocity (7, 10). Such considerations suggest that a logistic curve could be fitted empirically.

TABLE 1. Coefficients of correlation of logit number of diseased spikelets with log number of diseased portions of panicle branches or with logit number of diseased neck nodes

	Coefficient of correlation[b]	
Variable[a]	PB_4[c]	NN_4[c]
SP_1	.592	.602
SP_2	.748	.755
SP_3	.812	.769
SP_4	.852	.744

[a] SP_1, SP_2, SP_3, and SP_4: logits of percentages of diseased spikelets 12, 18, 24, and 30 days after the middle stage of heading (MSH), respectively.

[b] All coefficients are significant at 1% probability level.

[c] PB_4: log of diseased portions of panicle branches per 100 panicles 30 days after MSH. NN_4: logits of percentages of diseased neck nodes 30 days after MSH.

To be useful for forecasting, data must be obtained on disease as early as possible. The peak of appearance in spikelet blast was detected 7 days after the emergence of each panicle in the field (5). This result can be expected by the experiment to determine the incubation period mentioned before. Therefore, lesions on panicles begin to appear in the middle stage of heading if sufficient conidia are liberated in a population during the initial stage of heading and climatic conditions are appropriate for infection. If the first reading could be based reliably on the number of diseased spikelets on day 6, at the stage of completion of heading and 6 days later, forecasts could be made 6 days earlier than in the method presented here. However, surveys based on earlier observations yield curvilinear, rather than rectilinear, relationships (Fig. 1). This relationship is a result of the sequence of events during heading. The spikelets having lesions at the final stage of heading

◄———

Fig. 5-6. 5) An example illustrating the use of the method. Each column shows the following formulas; (a) $\hat{S}_r = .666\ \hat{S}_e - 1.995$ as described in Fig. 3; (b) $\hat{S}_r \pm 1.982(.0077 + .0016\ \hat{S}_e^2)^{1/2}$, the confidence interval at 5% probability level; (c) $NN_4 = .920\ SP_3 + .518$ as described in Fig. 4; and (d) $NN_4 \pm 1.982(.0090 + .0049\ SP_3{}^2)^{1/2}$, the confidence interval at 5% probability level. A horizontal broken line shows the limiting condition for protection, if less than 3% of loss in yield is to be achieved (6). Suppose that the initial levels of logits of blasted spikelets on day 12 after MSH are −3.00, −5.00, or −7.00, and the rates of increase are .01, .10, .20, or .30. The linear line, S_e = at + b, can be obtained as shown in this figure. The amount of spikelet blast suggests no benefit from protection when equation 1 applies. When equation 2 applies, protection is desirable, and when equation 3 applies, protection is necessary. Each arrow with the number shows the confidence interval of estimated amount of diseased spikelets at 5% probability level. **6)** Correlation between logarithms of numbers of diseased portions of panicle branches 30 days after MSH (PB_4) and logits of percentage of spikelets blasted 24 days after MSH (SP_3).

were infected before the middle stage of heading. The infected spikelets protruded after the middle stage of heading were still undergoing incubation at that time. This leads to an underestimate. A more nearly correct percentage could be approximated by a division of the number of diseased spikelets by one-half the number of grains observed rather than the total number.

According to Katsube & Koshimizu (6), the percentage of loss in yield (Y) is related to percentage of blasted neck nodes (X) by the equation $Y = 0.57\ X$ when disease incidence was estimated 30 days after heading. If loss of yield is to be kept less than 3%, protective measures are to be carried out when neck node blast exceeds 5.3% (i.e., when blast of neck nodes exceeds −2.88 logit or when blast of spikelets exceeds −3.69 logit). This limit is shown as a broken horizontal line in Fig. 5. When equation 1 of Fig. 5 applies, the amount of spikelet blast suggests no benefit from protection. When equation 2 applies, protection is desirable, and when disease levels are in the range of equation three, protection is necessary if loss in yield is to be avoided.

So long as regression and correlation are used, results of surveys are valid only if taken during the same stage of development and in environmental conditions similar to those prevailing when the original samples were collected. Modification techniques to allow for specific inhibitory or stimulatory effects on rate of change of infection levels should be evaluated and developed.

LITERATURE CITED

1. BERKSON, J. 1953. A statistically precise and relatively simple method of estimating the bio-assay with quantal response, based on the logistic function. J. Amer. Statist. Ass. 48:565-599.
2. HIRANO, K., & K. GOTO. 1963. Pathogenesis and ecology of panicle branch blast of rice plant [in Japanese, English summary]. Bull. Nat. Inst. Agr. Sci. Ser. C 16:1-58.
3. KATO, H., & T. SASAKI. 1968. Temporal estimation of strength of blast inocula distributed on panicles of rice [in Japanese]. Ann. Phytopathol. Soc. Japan 34:174 (Abstr.).
4. KATO, H., T. SASAKI, & Y. KOSHIMIZU. 1970. Potential for conidium formation of Pyricularia oryzae in lesions on leaves and panicles of rice. Phytopathology 60:608-612.
5. KATO, H., T. SASAKI, & Y. KOSHIMIZU. 1970. The role of diseased spikelets as the secondary inoculum source in the infection chain of rice blast [in Japanese, English summary]. Bull. Tohoku Nat. Agr. Exp. Sta. 39:33-54.
6. KATSUBE, T., & Y. KOSHIMIZU. 1970. Influence of blast disease on harvests in rice plant. 1. Effect of panicle infection on yield components and quality [In Japanese, English summary]. Bull. Tohoku Nat. Agr. Exp. Sta. 39:55-96.
7. KURIBAYASHI, K., & H. ICHIKAWA. 1952. Studies on the forecasting of the rice blast disease [In Japanese]. Bull. Nagano Agr. Exp. Sta. 13:1-229.
8. PADMANABHAN, S. Y. 1965. Estimating losses from rice blast in India, p. 203-221. The rice blast disease. Symp. Int. Rice Res. Inst. Proc., Johns Hopkins Press, Baltimore, Md.
9. SASAKI, T., & H. KATO. 1967. Microclimatic conditions for dispersal of Pyricularia oryzae [In Japanese]. Ann. Phytopathol. Soc. Japan 33:79 (Abstr.).
10. SUZUKI, H. 1969. Studies on the behavior of rice blast fungus spore and application to outbreak forecast of rice blast disease [In Japanese, English summary]. Bull. Hokuriku Agr. Exp. Sta. 10:1-118.
11. TOKUNAGA, Y., T. KATSUBE, & Y. KOSHIMIZU. 1966. Studies on the relationship between metabolism of rice plant and its resistance to blast disease. 3. Correlation of nitrogen metabolism and blast disease in rice plant [In Japanese, English summary]. Bull. Tohoku Nat. Agr. Exp. Sta. 34:37-79.
12. VAN DER PLANK, J. E. 1960. Analysis of epidemics, p. 229-289.s, *In* J. G. Horsfall & A. E. Dimond [ed.]. Plant pathology, Vol. III, Academic Press, New York.
13. VAN DER PLANK, J. E. 1963. Plant diseases: epidemic and control. Academic Press, New York. 349 p.
14. ZADOKS, J. C. 1961. Yellow rust on wheat. Studies in epidemiology and physiologic specialization. Tijdschr. Plantenziek. 67:69-256.