Forecasting Model and Estimation of Yield Loss by Rice Sheath Blight Disease

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Rice sheath blight of rice plants has prevailed rapidly in recent years since it was discovered in Japan in 1910, and has become an important problem next to rice blast disease. It is assumed that the recent increase in the occurrence of this disease is associated with the spread of early season culture of rice using seedlings grown in protected nurseries and increased use of early maturing rice varieties. The affected area averages from 1.2 to 1.4 million ha, or about 32 to 50% of the total rice cropping area. Extensive studies on sheath blight have been made in Japan. Sclerotial morphogenesis in the rice sheath blight fungus has been examined.[1,2,4,6] Kozaka[11] reviewed the disease and its control in Japan.

Forecasting techniques were presented by Hori[9,10] on the basis of the following indices: a) estimation of yield losses based on the degree of disease incidence, b) estimation of disease incidence at the maturing stage from the ratio of diseased hills at the booting stage, and c) estimation of the critical point for judging the necessity of chemical control. It is understood, however, that the forecasting system of this disease has not yet been fully established and hence it is still a subject for improvement.

In view of such a background, a method to estimate yield loss or severity of the disease will be described first, followed by a model of vertical disease development expressed by the upward development of lesions, and a model of horizontal disease development expressed by percentage of the number of diseased hills.

Estimation of disease incidence severity by the height of occurrence of lesions on leaf sheath[5]

Methods of estimating severity of rice sheath blight disease caused by *Rhizoctonia solani* Kühn were investigated with the aim of finding a time-saving, simple method. Rice cultivars, 1,429 foreign cultivars from more than 40 countries of the world and 277 domestic cultivars, were used to measure the height of the uppermost lesions on leaf sheath, and relative height of the uppermost lesions to the plant height. On the other hand, their degree of disease incidence was estimated by the Yoshimura's method.[12] All cultivars were inoculated by putting a bit of the mycelia grown on wheat bran medium into each hill on July 15, 1976, and vertical development of the disease was assessed on September 1 to 6.

Vertical development of the disease was always more extensive in early maturing cultivars than in late maturing ones. Statistical analysis enabled one to estimate the degree of incidence (Y) from relative height (X) of the uppermost lesions to the plant height by the following equation,

$$Y=1.62X-32.4 \quad \ldots\ldots\ldots\ldots (1)$$ in Fig. 1.

The value X was estimated as $X=0.73Z-4.13$, where Z is the height of the uppermost lesions. Estimation of the degree of disease incidence by this formula is more efficient and simpler than that by the Yoshimura's method (Fig. 1).

Disease incidence of diseased hills

$$Y = \frac{3n_1+2n_2+1n_3+0n_4}{3N} \times 100 \text{ (Yoshimura's formula)}$$

$$Y = 1.62X - 32.4 \quad \text{------} \quad (1)$$

$$X = \frac{\text{Height of the uppermost lesions}}{\text{Plant height}} \times 100$$

$$\text{Disease incidence (D)} = (1.62X - 32.4) \times \frac{A}{100} \quad \text{------} \quad (2)$$

A: Percentage of diseased hills

Yield loss (per 10 ares)

$$L = (1.62X - 32.4) \times \frac{A}{100} \times 8.5 \times 300 \text{ g} \quad \text{------} \quad (3)$$

$$= (41.31X - 826.2) \times \frac{A}{1000} \text{ kg} \quad \text{------} \quad (4)$$

Fig. 1. An empirical formula for estimating the yield loss caused by rice sheath blight disease

Estimation of yield loss caused by rice sheath blight disease from the height of the lesions and percentage of diseased hills[8]

Estimation of yield loss caused by rice sheath blight disease from the relative height of the lesions to plant height and percentage of diseased hills was studied.

Whole disease incidence (D) at the maturing stage can be represented as the product of disease incidence of diseased hills estimated by relative height of the uppermost lesions to plant height (X) and percentage of the number of hills (A):

$$D=(1.62X-32.4)A/100 \ldots\ldots (2) \text{ in Fig. 1}$$

On the other hand, the loss of fully ripened kernels has been estimated at 8.5 g per 3.3 m^2 for each additional 1% disease incidence, from which the following equation was derived (L represents yield loss in kg per 10 ares):

$$L=(41.31X-826.2)A/1{,}000 \ldots (3) \text{ in Fig. 1.}$$

The yield loss actually observed in paddy fields in 1976 to 1980 was in good accordance with the estimate by the formula.

Influence of environmental and physiological conditions to vertical disease development[3,7]

Thirteen rice cultivars with different heading time were tested for vertical disease development under varied environmental and physiological regimes.

Table 1. Vertical development of lesions on rice plants infected with sheath blight fungus, as related to temperature

Average temperature (°C)	Vertical development of lesions on rice plants under 100% relative humidity (cm/day)
19	0.27
20	0.48
21	0.70
22	0.91
23	1.13
24	1.24
25	1.35
26	1.43
27	1.51
28	1.58
29	1.55
30	1.50

Table 2. Relative humidity correction for vertical development of lesions on rice plants infected with sheath blight fungus

Relative humidity (%)	Index of vertical development[a]
84	0.10
86	0.38
88	0.66
90	0.87
92	0.91
94	0.95
96	0.97
98	0.99
100	1.00

[a] Ratio of vertical development of lesions under various relative humidity to that under 100% relative humidity.

Vertical development of lesions of rice plants under 100% relative humidity (RH) was 0.48 cm at 20°C, 1.13 cm at 23°C, 1.35 cm at 25°C, and 1.58 cm at 28°C (Table 1). The ratios of vertical development of lesions under different relative humidities to that under 100% relative humidity (at 25°C) were 0.99 at 98% RH, 0.97 at 96% RH, 0.87 at 90% RH, and 0.38 at 86% RH (Table 2).

Vertical disease development was always more extensive in early maturing cultivars than in late maturing ones. Delayed sowing resulted in a decreased vertical development. On the other hand, when these varieties were sown and planted to have the same heading date, difference in the degree of vertical development between the early and late cultivars became small. These results suggested that the vertical development of sheath blight was correlated with physiological conditions of sheaths rather than environmental conditions, and led us to analyze starch and nitrogen contents in leaf sheaths as a factor reflecting physiological condition associated with vertical development of the disease. Starch contents in sheaths of the early cultivars were 5.0–21.2 mg/g fresh weight and mycelial growth on nitrogen-containing media added with starch at this range of concentrations was as good as that observed in these sheaths. On the contrary, starch contents in late cultivars were 24.7–32.2 mg/g fresh weight, and the fungal growth on media containing this level of starch was reduced if increasing concentration of nitrogen was added to the media, suggesting that sheaths of the late cultivars might be nutritionally less favorable for the fungal growth than those of the early cultivars. Starch content in the sheaths of early cultivars rapidly decreased with time in contrast to slow decrease in late cultivars. These results suggest that the vertical development of sheath blight is correlated with quantitative change of nitrogen and starch contents in the sheaths. Susceptibility of leaf sheaths to the sheath blight fungus is correlated with their maturity.

The vertical development of lesions observed on 2-, 5-, 10-, and 15-day-old sheaths after heading under the most favorable conditions (at 28°C, 100% RH) was 1.12, 1.32, 1.71, and 1.59 cm per day, respectively (Table 3).

Table 3. Vertical development of lesions as influenced by susceptibility of leaf sheaths after heading under the most favorable conditions

Days after heading	Values influenced by the susceptibility of leaf sheaths (cm/day)
-4	0.74
-2	0.79
0	0.86
2	1.12
4	1.25
6	1.38
8	1.54
10	1.71
12	1.66
14	1.61
16	1.56
18	1.56
20	1.56
22	1.56
24	1.56
26	1.47
28	1.38
30	1.29
32	1.20
34	1.11
36	1.02

Model of vertical development of sheath blight lesions on rice plants[7]

A variety, Koshijiwase, was grown on paddy field, and vertical development of the lesions of sheath blight was examined. At the same time, an attempt was made to produce a model curve which can represent the actual vertical development of the disease under the natural temperature and relative humidity.

First, a model curve was produced as a function of the average temperature at the field. In other words, rate of upward development of lesions was calculated on the basis of the relationship between the development of lesions and temperature shown in Table 1, and was expressed by a cumulative model curve (Fig. 2, A). Second, this model curve was modified by taking into account the effect of relative humidity shown in Table 2 to get the second model curve (Fig. 2, B). Then, a correction as to the susceptibility of leaf sheath was given to the second model curve. When daily values of vertical development of lesions calculated from temperature and relative humidity were larger than the values calculated from the susceptibility of leaf sheaths, the latter was adopted in stead of the former.

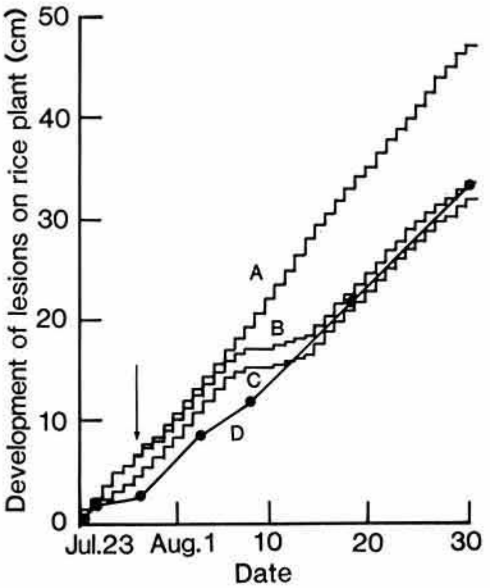

Fig. 2. Comparison between vertical development of lesions actually observed on rice plants infected with sheath blight fungus in fields in 1980 and that estimated by cumulative model curves

A: Cumulative model curve of the vertical development of lesions calculated on the basis of average temperature (Table 1).

B: The model curve modified by taking into account relative humidity (Table 2).

C: The model curve further modified by taking into account susceptibility of leaf sheath (Table 3).

D: The vertical development of lesions actually observed on rice plants in paddy fields. An arrow indicates heading time.

Thus, the final model curve (Fig. 2, C) of the vertical development of lesions calculated from temperature, relative humidity and susceptibility of leaf sheath was obtained. This model curve was found to be in good accordance with the vertical development of lesions actually observed in paddy fields in 1971 to 1981. These models will be useful for forecasting of rice sheath blight.

Model curves of horizontal disease development of sheath blight on rice plants

Horizontal disease development as expressed by percentage of the number of diseased hills was examined with Koshijiwase growing in field under natural temperature and relative humidity. A model curve of the horizontal development of the disease was produced as a function of temperature, relative humidity and density of sclerotia.

It was found out that the response of vertical disease development to average temperature and relative humidity can be used for producing a model curve of horizontal disease development, when the average temperature of each day is higher than 22°C, and at the same time the relative humidity at the height of 5 cm from the soil surface between hills is higher than 96%. First, a model curve B, shown in Fig. 3, was obtained as a function of average temperature (Table 1).

The rate of horizontal development of the disease is influenced by different quantities of existing sclerotia. When the rate for 5×10^4 sclerotia per 10 ares was taken as 1, that for 10×10^4, 20×10^4, 30×10^4, 40×10^4 and 50×10^4 sclerotia was 1.4, 2.3, 3.2, 4.1 and 5.0, respectively (Table 4). Second, when the quantity of sclerotia was larger than 5×10^4 sclerotia per 10 ares, this model curve has to be modified accordingly (Fig. 4). The model curves of the horizontal development of the disease, calculated as above, nearly coincided with the actual horizontal

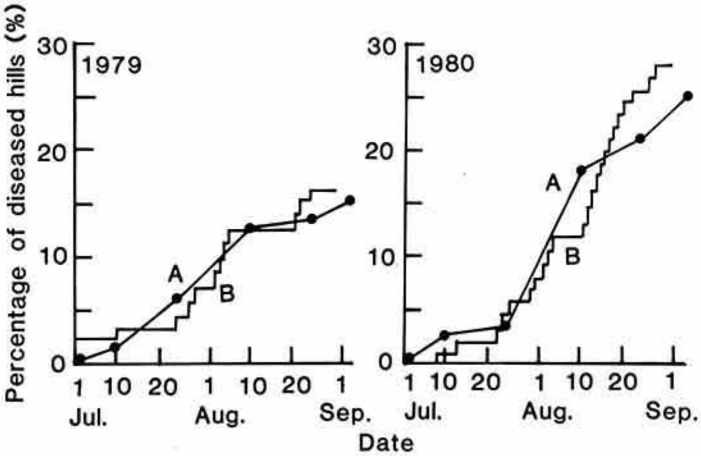

Fig. 3. Comparison between the horizontal development of disease actually observed on rice plants infected with sheath blight fungus in fields in 1979 and 1980 and that estimated by cumulative model curves
A: The horizontal development of disease on rice plants in paddy fields
B: A cumulative model curve of the horizontal development of lesions calculated on the basis of average temperature (Table 1)

Table 4. Relationship of horizontal development of the disease to the quantity of sclerotia in fields

Number of sclerotia*	5	10	20	30	40	50
Index of horizontal development**	1.0	1.4	2.3	3.2	4.1	5.0

* Number of sclerotia ($\times 10^4$) per 10 ares.
** Index is shown as a ratio of the horizontal development under different quantity of sclerotia to that under 5×10^4 sclerotia per 10 ares.

development of the disease observed in paddy fields from 1977 to 1981 (Fig. 3 and 4). These model curves will be useful for forecasting rice sheath blight.

Conclusion

The forecasting of rice sheath blight disease was investigated based on ratio of the height of lesions to the plant height (vertical development of the disease) and percentage of the number of diseased hills (horizontal development of the disease) (Fig. 1(4)).

1) Whole disease incidence (D) at the maturing stage was expressed by the product of degree of disease incidence estimated by the ratio of the height of the uppermost lesions to the plant height (X) and percentage of diseased hills (A):

$$D = (1.62X - 32.4)A/100$$

2) The loss of fully ripened kernels has been estimated at 8.5 g per 3.3 m^2 for each additional 1% disease incidence, from which the following equation was derived:

$$L = (41.31X - 826.2)A/1,000$$

where, L represents yield loss in kg per 10 ares.

3) The model curve for the vertical development of the disease (X) was produced on the basis of temperature, relative humidity and susceptibility of leaf sheath.

4) Model curves of the horizontal development (A) was produced on the basis of tem-

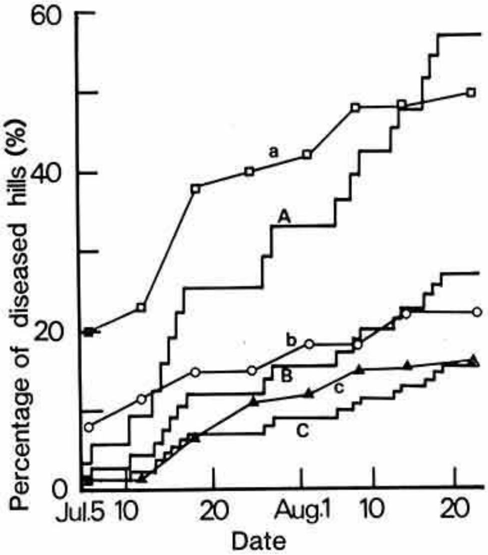

Fig. 4. Comparison between the horizontal development of disease actually observed on rice plants infected with sheath blight fungus in fields in 1977 and that estimated by cumulative model curves

Note: a, b, c: Horizontal development of disease on rice plants actually observed in fields

A, B, C: Cumulative model curves under different quantities of sclerotia per 10 a of paddy field

A, a: 21×10^4 sclerotia, B, b: 7×10^4 sclerotia, C, c: 2×10^4 sclerotia

perature, relative humidity between hills and quantity of sclerotia per unit area of paddy field.

5) The yield loss actually measured in paddy fields in 1976 to 1980 almost coincided with that estimated by the model curves (Table 5).

Table 5. Comparison between actual yield loss observed in fields from 1976 to 1980 and yield loss estimated by the forecasting model

Year		X	A	D	L
1976	1	45.0%	17.0%	6.9%	13.3kg
	2	42.3	22.6	8.4	21.5
1977	1	48.2	23.0	10.5	26.8
	2	51.6	31.7	16.7	42.6
1978	1	37.1	14.0	3.9	9.9
	2	34.0	9.3	2.2	5.5
1979	1	46.0	16.0	6.7	17.2
	2	43.7	19.3	7.6	19.4
1980	1	47.0	25.6	11.2	26.2
	2	51.0	26.4	13.7	34.8

1: Observed value, 2: Estimated value.
X: Relative height of the uppermost lesions to the plant height (%)
A: Percentage of diseased hills (%)
D: Disease incidence (%)
L: Yield loss (kg/10 ares)

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