Disease Forecasting : Past and Future in Special Reference to Rice Leaf Blast

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INTRODUCTION

Plant disease forecasting dates far back into the prehistoric history of man. Merrill(12) stated that the first written reference to plant disease forecasting was mentioned in the ancient Sumerian text on the cultivation of barley and its "samana" disease. Over the last fifty years several different disease forecasting schemes have been developed and refined by trial and error methods(12). Forecasting program for potato late blight was reported in early 1950s in the United Kingdom and the United States (23). In Japan rice leafhopper and rice blast epidemics in 1940 resulted in a great loss of rice yield and became a direct motive to start a nation-wide forecasting system in 1941(24).

The greatest threat for crop cultivation is yield losses due to abnormal climate as well as diseases and insects. At present most of the climatic disorders are difficult to prevent artificially. The factors conditioning yield losses such as biotic agents, however, are able to control by means of chemical spray or biological control. In this sense forecasting program has been known the best advantage to condition the control process by agrochemicals and thus benefits timely application of fungicides and/or insecticides.

Modern plant disease forecasting is functionally depending upon epidemiology. Furthermore, in the recent twenty years, computer simulation models have been popularized for potato late blight, wheat and barley rusts and southern corn leaf blight based on the epidemiological backgrounds.

Table 1. A brief chronology of simulation

Year	Scientists	Model	Disease	Reference No.
1968	Waggoner, P. E.	EPDEM	Potato late blight	20
1968	Zadoks, J. C.		Wheat rust	26
1969	Waggoner, P. E. et al.	EPIDEM	Tomato early blight	21
1971	McCoy, R. E.		Chrysanthemum ascochyta blight	11
1972	Waggoner, P. E. et al.	EPIMAY	Southern corn leaf blight	22
1973	Kranz, J. et al.	EPIVEN	Apple scab	8
1973	Massie, L. B.	EPICORN	Southern corn leaf blight	10
1975	Shrum, R.	EPIDEMIC	Wheat stripe rust	15
1979	Gurevich, B. I. et al.	EPIPHTORA	Potato late blight	3
1980	Stephan, S. et al.	SIMPHYT	Potato late blight	16
1980	Teng, P. S. et al.	BARSIM-1	Barley leaf rust	17
1980	Sall, M. A.		Grape powedery mildew	14
1980	Koizumi, M.		Citrus melanose	6
1981	Zeng, S. M. et al.		Wheat stripe rust	28
1981	Levy, Y. et al.		Northern corn leaf blight	9
1981	Zadoks, J. C.	EPIPRE	Wheat rust	27
1982	Koshimizu, Y.	BLASTAM	Rice leaf blast	7
1983	Aust, H. J. et al	EPIGRAM	Barley powdery mildew	1
1983	Payen, D.		Sclerotinia on sunflower	13
1984	Hashimoto, A. et al.	BLASTL	Rice leaf blast	4

CHRONOLOGY OF DISEASE FORECASTING

As shown in Table 1, the first simulation models of plant disease epidemics were developed by Waggoner and Zadoks in the late 1960s. The research targets of these teams were potato late blight called EPDEM(20) and wheat rust(26). Since that time, many models were published : EPIDEM (21) for tomato early blight, EPIMAY(22) and EPICORN(10) for southern corn leaf blight, EPIVEN(8) for apple scab, EPIDEMIC(15) for eheat stripe rust, EPIPHTORA(3) and SIMPHYT (16) for potato late blight and BARSIM-1(17) for barley leaf rust. For rice leaf blast forecasting, Japanese scientists have recently developed s-imulation models BLASTAM(7) and BLASTL(4). However, not all those models are sufficient for the quantitative speculation of disease outbreak or indrease in intensity. There might be two possible involvements for this. One is that simulation models have been built based on published literatures and data from different environments(18) and the other is the complexity of continuous secondary cycles of the pathogen, i.e. *Pyricularia oryzae*.

FORECASTING OF RICE LEAF BLAST

Plant disease forecasting principally aims to predict either time of probable outbreaks or rate of increases in intensity of disease. Under a proper disease forecasting system and disease management technology, farmers can avoid excess and untimely application of agrochemicals and thus the f-orecasting program benefits the farmers by saving their labor, materials and money and finally leads them to a better harvest.

BLASTAM, one of the leaf blast simulation models, was developed by Koshimizu in 1982(7) which backbone data are derived from AMeDAS (Automated Meteorological Data Acquisition System) data. Out of 1,300 spots all over the country, daily successive data of rainfall, t-emperature, sunshine hour and wind velocity from 840 spots are automatically deposited in a grand computer installed in Tokyo. From these data, leaf wetness hour, mean temperature during leaf wetness hour and mean temperature of pre-5 days from judgement are calculated and utilized in judgement of appearance of favorable condition for leaf blast infection. In this sense, BLASTAM is considered enough to satisfy the need for prediction of time of probable outbreaks of leaf blast, but not for rate of increases in intensity of disease.

Nobody can deny the fact that the success or failure of modern disease forecasting relies upon the epidemiological background of the pathogen. It is said that there are three methods of approach for disease forecasting based on epidemiological characteristics(2). First, an assessment of the amount or efficacy of initial inoculum if it is most important for disease development. Second, an assessment of the speed of secondary cycles when the rapidity of secondary cycles of pathogens is most important for disease development, and third, when the amount of initial inoculum is large and secondary cycles are potentially rapid and many, then forecasts should consider both. Rice leaf blast fits the second case. Therefore, it is very important to consider some epidemiological aspects of rice blast fungus, *Pyricularia oryzae*.

Druing leaf blast season, one cycle is completed within a week(Fig. 1). In every step of life cycle, it has different range of requirements for t-emperature and relative humidity(RH). For leaf blast, the life cycle of *P. oryzae* usually starts in the middle June and normally ends in the early August in Korea. Considering the duration of a single cycle, the secondary cycle repeats almost 8-11 times during leaf blast season and we can imagine that a tremendous population of inoculum exists in the nature. Since I have felt the need of developing a quantitative simulation model for leaf blast, I have concentrated my research target on sporulation and conidia release phase because this was the least known area among the life cycle of *P. oryzae* under the natural conditions.

When the lesion bearing leaf is wet enough, the

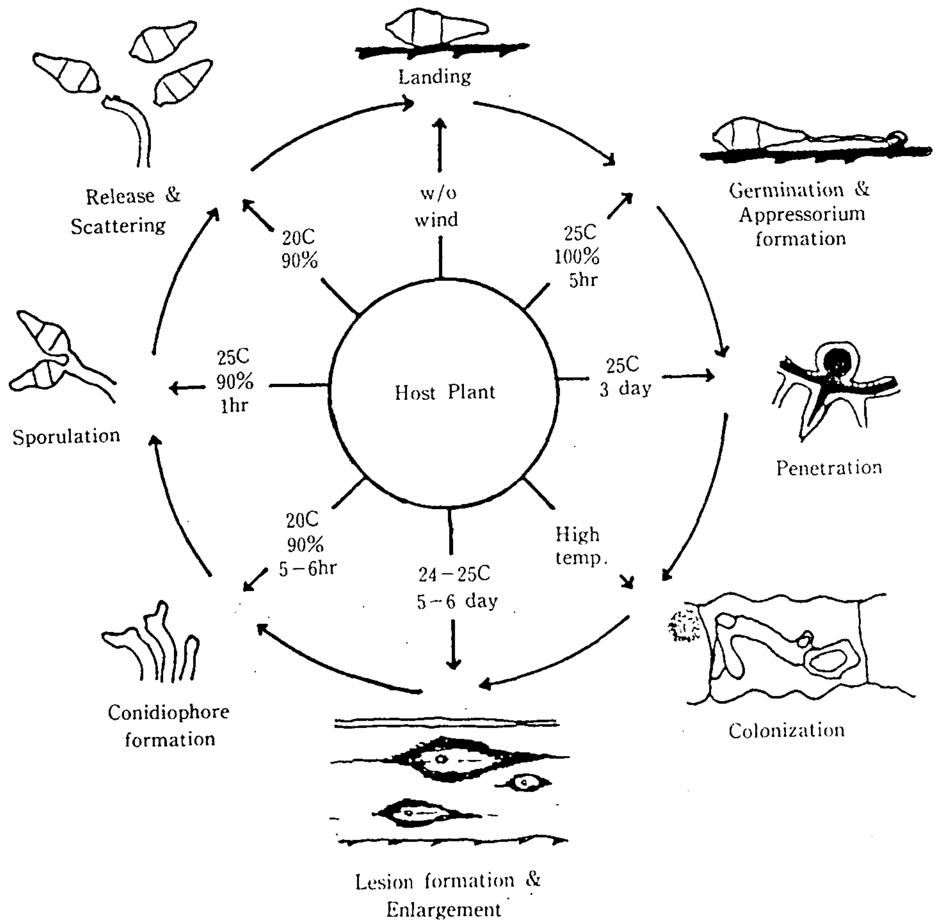

Fig. 1. Life cycle of *Pyricularia oryzae*

lesion starts to produce conidiophores 4hr later and the conidiophore starts sporulation and it takes 40 min for a conidium to mature. After 20min pause, the second conidium is produced. In such a way, total seven conidia are produced from a single conidiophore during one night. Five hour after sporulation, it starts to release and the lesion reaches peak of release at 13hr after leaf wetness (19).

In 1985, I tested sporulation potential of *P. oryzae* using two types of naturally infected lesions(Table 2). kato et al.(5) defined sproulation potential as the number of conidia produced from lesions at 28C and 95% RH for 15hr under dark condition. Sporulation potential was higher on the fresh lesions and the peak was 5-7 days after lesion appearance.

Time requirement for successful penetration of *P. oryzae* is dependent upon leaf wetness hour(LWH) and temperature. In the nature, dew period is a very important factor for germination, appressorium formation and penetration to occur. However, relatively shorter dew period is required for same level of percent penetration to occur at higher temperature until 25C(Table 3)(25).

Table 2. Sporulation potential[a] of *Pyricularia oryzae* by two types of lesions in 1985 test

Date	No. of conidia produced from lesions appeared	
	July 8-10	July 15-16
July 18	1,300	7,500
20	1,800	4,900
22	1,700	7,500
24	4,100	1,050
26	1,300	4,200

[a]28C, 95% RH, 15hr under dark condition(Kato et al., 1974)

Table 4 shows us how the blast fungus reacts sensitively against temperature change. I checked

Table 3. Percent penetration of *Pyricularia oryzae* based on mean temperature and leaf wetness hour after Yoshino, 1979

Temperature	Leaf wetness hour	Percent penetration
15C	17hr	4.5%
16	15	4.2
17	14	4.6
18	13	4.6
19	12	4.3
20	11	3.7
21	11	4.7
22	10	3.5
23	10	3.9
24	10	4.2
25	10	4.2

lesion size from July 2 to 10 by two-day interval in 1986. There passed a low temperature period from June 29 to July 4 and the minimum temperature of canopy on July 3 was 12.6C. During this period the lesions enlarged only 0.4 mm/day while they enlarged more or less 3 mm since the temperature has recovered above 15C. One thing here to remember is the temperature affects not only the lesion enlargement but also sporulation and conidia release phase.

There are some reports concerned with conidia release from lesions by artificial inoculation in the greenhouse condition. But very few is known under the natural conditions. Thus, Dr. Yoshino, a Japanese epidemiologist and I conducted some preliminary trials in 1985 to develop a new spore trap which could ideally measure the amount of conidia released in the field conditions. As a result we deviced a new trap as in Fig. 2(KY type). Part A is rain protector and a discrete lesion bearing leaf is attached here using both side adhesive Shurtape. Part D is a basin type capsule and the length is 40mm considering the size of lesion. There is 5mm distance between lesion and top of capsule to allow inflow of air which will permit the same condition as nature.

Table 5 shows conidia release pattern from single lesions using two cultivars and five lesions, respectively. On July 2, I chose newly appeared 2 mm long acute type lesions and checked the number of conidia released by 24hr interval. Number of

Table 4. Enlargement of leaf blast lesion size under different temperature conditions in 1986 test

Lesion No.	Size of lesion(mm)								
	July 2		4		6		8		10
1	2.4		3.3		10.7		19.4		24.8
2	1.3		2.7		7.8		12.5		18.1
3	1.6		2.1		6.8		13.6		17.4
4	1.7		2.3		7.8		13.3		19.0
Mean	1.8		2.6		8.3		14.7		19.8
Enlargement/day	–		0.4		2.9		3.2		2.6
Canopy Min.	14.6	12.6	13.1	15.8	15.4	17.2	18.3	17.3	18.3
Temp. (C) Max.	18.9	18.3	18.7	18.6	20.6	22.2	23.6	20.2	23.4

Table 5. Number of *Pyricularia oryzae* conidia released from single lesions on rice cultivar Jinheung and Jinjubyeo in 1987 test

Date	No. of conidia[a] released per day from									
	Jinheung					Jinjubyeo				
	1	2	3	4	5	1	2	3	4	5
July 3	40	80	500	220	40	160	140	460	80	160
4	280	460	320	420	60	600	220	980	200	520
5	140	180	680	80	340	700	300	720	120	420
6	100	460	320	100	120	720	0	280	300	960
7	100	380	920	320	540	700	280	740	280	220
8	120	5,360	10,620	2,620	5,660	15,800	7,060	13,720	8,860	5,420
9	300	2,720	5,900	940	3,480	12,600	2,680	30,560	4,240	10,720
10	2,960	–	3,000	880	1,200	–	820	1,240	1,500	–
11	100	–	140	40	180	–	80	–	–	–

[a] $\frac{\Sigma X}{n} \times \frac{1}{10} \times 2,000$

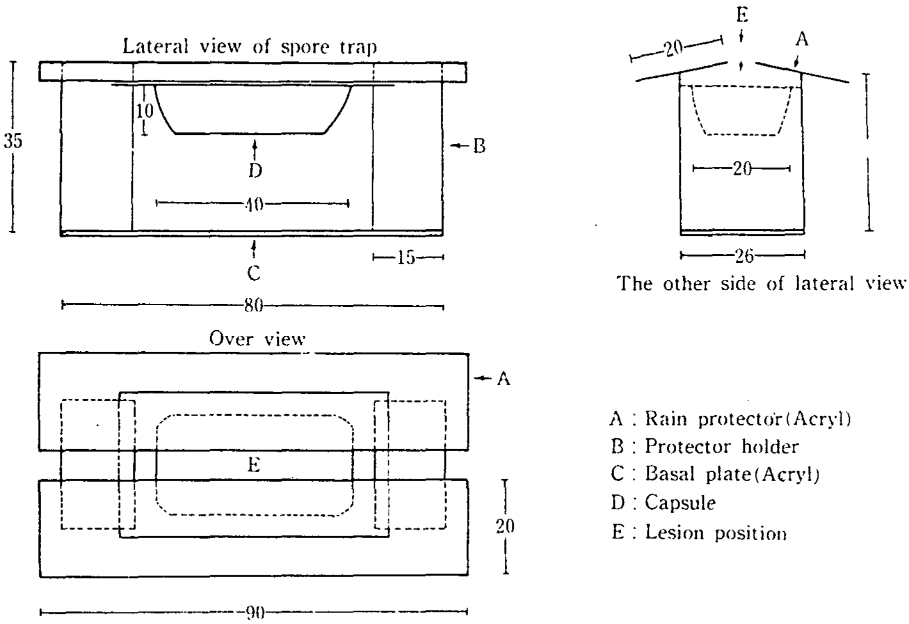

Fig. 2. Scatch map of a new type of spore trap(Scale in millimetre).

conidia released was less than one thousand until July 7, but the number was apparently increased to several thousand to 30 thousand spores thereafter. This result reveals that this new type of spore trap is reasonable to measure conidia release phase under the natural conditions. At the same time, the peak of conidia release is supposed to be one week after lesion appearance.

It is very important to realize the pattern of conidia release and dispersal phase hourly in a day. Thus, I conducted experiments of spore catch for three times using three different types of spore trap in 1987. They are KY type spore trap for measurement of spore release, rotary spore trap and horizontal spore trap.

Fig. 3 is the first trial from 6PM of July 9 to 5PM of July 10. The weather condition was fine on July 9 and it became cloudy from 2AM on July 10. Dew was formed at 8PM. Straight line indicates conidia release and dotted lines indicate dispersal. Up to date it is known that peak of conidia release and dispersal comes at 2−3AM. But here it came at 5−7AM showing coincidence of release and dispersal comes at 2−3AM. But here it came at 5−7AM showing coincidence of release and dispersal. Based on the microclimate data, temperature became 20C from 11PM and RH was over 90% but wind velocity was below 1m/s until 8AM. It means that microclimate from 8PM became favorable for production of coidiophore, sporulation and release which finally led the peak at 5−7AM.

Fig. 4 is the second trial between July 14 to 15. The weather condition was continuous coludy but it started to rain from 8AM. Temperature was more or less 22C from 9PM to 5PM and RH was over 95% except 5−6PM on July 14. Wind velocity was near zero until 6AM. This time the peak lasted rather longer from 1AM to 8AM. During this period conidia release and dispersal were disturbed at 4AM and 7AM due to the wind velocity near 2m/s. Because of the continuous cloudy condition, I think sporulation from pre−existing conidiophore started earlier and lasted until 8AM.

Fig. 5 is the third trial from July 23 to 24. The weather condition this time was also continuous cloudy. The peak came between 12PM to 7AM. Temperature during this period was 20C with very high humidity and wind velocity was almost zero. Then why is the range of peak so wide? On this matter I think under the continuous cloudy

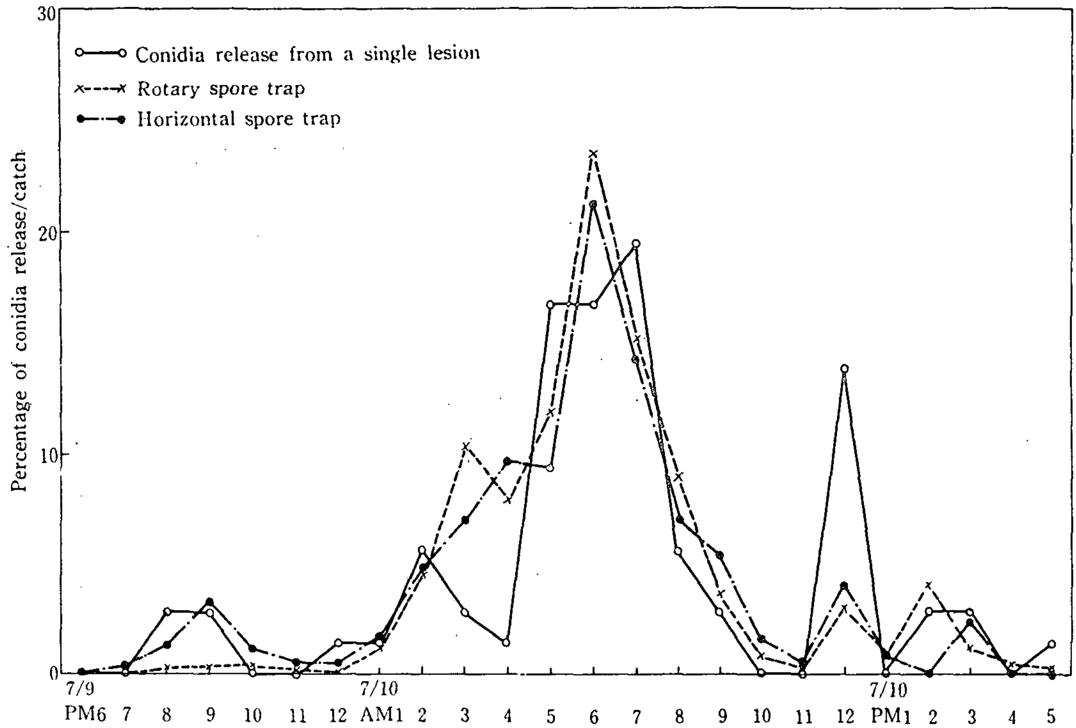

Fig. 3. Conidial release and trap pattern of *Pyricularia oryzae* by different types of spore trap measured hourly from 6PM of July 9 to 5PM of July 10.

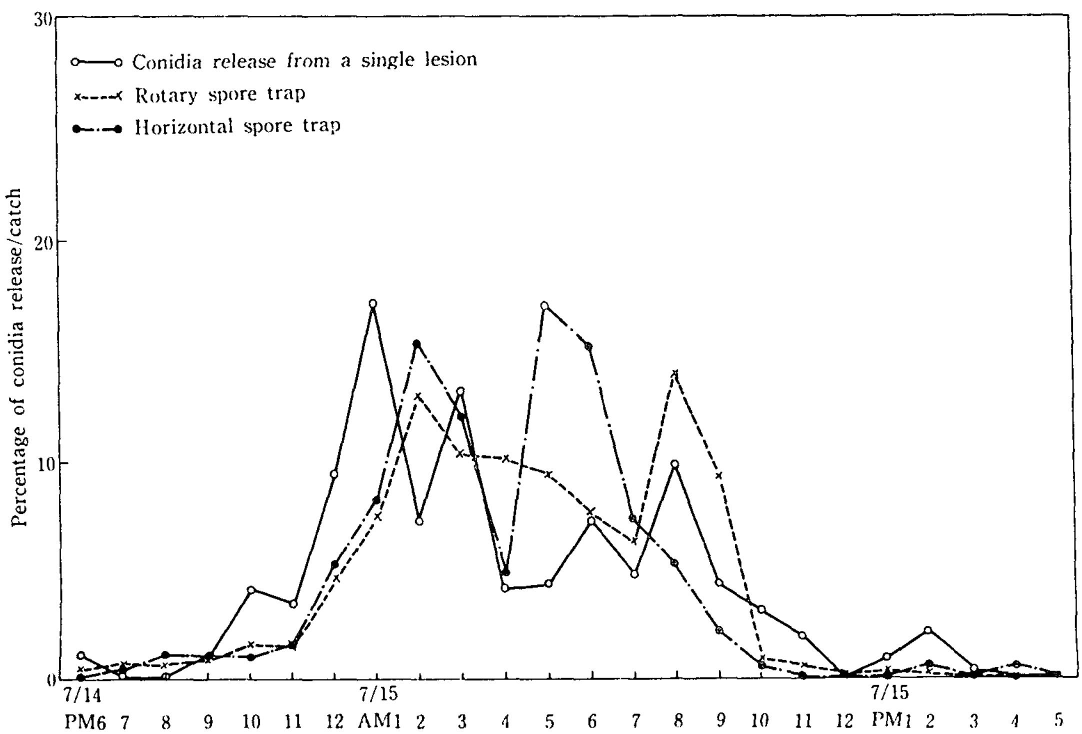

Fig. 4. Conidial release and trap pattern of *Pyricularia oryzae* by different types of spore trap measured hourly from 6PM of July 14 to 5PM of July 15.

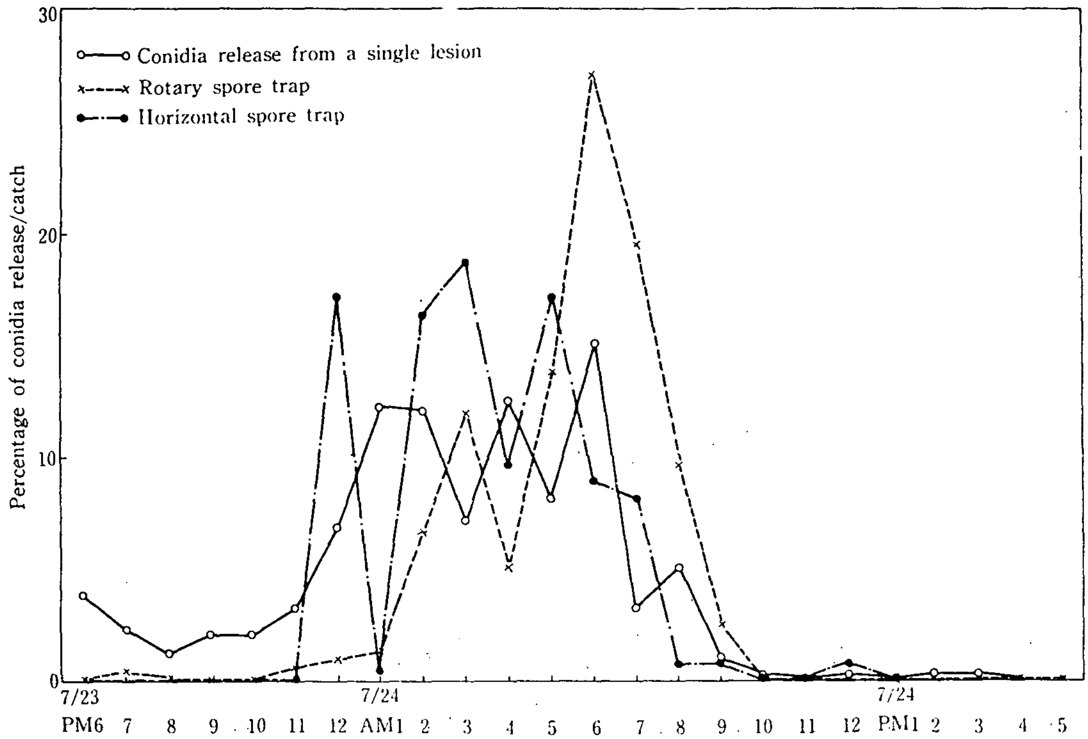

Fig. 5. Conidial release and trap pattern of *Pyricularia oryzae* by different types of spore trap measured hourly from 6PM of July 23 to 5PM of July 24.

conditions conidiophores and conidia are still remained during daytime but relatively higher temperature and lower humidity are not favorable for release and dispersal. But once dew is formed and RH goes up and temperature goes down, they start to release and make one peak before 4AM and the other peak at 6AM is originated from newly produced conidiophores.

Previously I mentioned that the secondary cycle of *P. oryzae* repeats 8−11 times during one leaf blast season. Now let's think about the inoculum potential of *P. oryzae* in the nature. Number of plants per 1,000m² is 24,000 and let's supose there is only one lesion per plant and daily number of conidia released is 2,000. Then total number of conidia per day becomes 4.8×10^7. If there is one lesion per leaf, then the number will be tremendously increased. Sporulation potential of one lesion in the nature continues about 20 days and there are various types of lesions and stages of conidia present. This complexity is the reason why quantitative forecasting of rice leaf blast is difficult.

CONCLUSION

The ultimate goal of forecasting is to predict not only the time of probable disease outbreak but also the amount of disease incidence at a certain point. Therefore, I think knowledge on the sporulation potential and conidia release phase and penetration of *P. oryzae* in the nature and microclimate which affects those factors, host condition such as plant age and leaf index and type, age, position and number of lesions will contribute to develop a quantitative simulation model for rice leaf blast in the near future.

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