3. EPIDEMIOLOGY OF RICE DWARF VIRUS IN JAPAN

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Introduction

Rice dwarf virus (RDV) is transmissible by the green rice leafhopper *Nephotettix cincticeps* and two other leafhoppers. The virus can multiply in a vector and can be transmitted by means of transovarial transmission (FUKUSHI, 1940). The virus multiplied in the vector affects seriously the physiological conditions of the vector as indicated by shortened longevity of adults and lesser fecundity of female adults (NASU, 1963; NAKASUJI & KIRITANI, 1970).

With respect to the population dynamics of *N. cincticeps*, intensive studies were recently conducted by some workers (KUNO, 1968; KIRITANI *et al.*, 1970; HOKYO, 1972). They have found that the natural population of *N. cincticeps* was strictly controlled through density dependent processes.

In spite of such abundant accumulation of pathological and ecological knowledge, the analytical study on the prevalent factor of RDV has been scarcely performed. In the present paper, the authors would like to find factors which are responsible for the prevalence of this disease, with special reference to the ecological factors.

Epidemics of RDV in Japan

Some sporadic outbreaks of RDV which were discovered at first in Shiga Prefecture in 1883, prevailed in Kanto, Tokai, Kinki, Chugoku and Kyushu areas during the period of 1889–1930 (FUKUSHI, 1934). These outbreaks were the mosaic pattern of infected areas without regional continuity and lasted only for one or two years. But after World War II, around 1955, this disease began to extend progressively its distribution to the coastal regions of the Pacific and Seto Inland Sea. The characteristics of the epidemics were the continuity in time and space over an extended area (1st epidemic period). The prevalence in the 1st period went down temporarily during the period of 1959–1964. Since around 1965, the epidemics have resumed their prevalence in southern Japan (2nd epidemic period) including inland regions. Nowadays, the infected area of about 300,000 ha have covered 30 prefectures.

Causess of the Epidemics

1. **First epidemics.** After World War II, early rice cultivation became possible because of the wide-spread use of protected semi-irrigated rice nursery by the utilization of polyfilm, and use of synthetic pesticides which protect rice plants from the serious infestation of disease and insect pests.

The early cultivation of rice spread rapidly in southern Japan to avoid the damage inflicted by typhoons. The area cultivated with early planted rice began to increase rapidly after 1955 and attained up to 200,000 ha in 1958. Such an increase of early planted rice cultivation might have caused the prevalence of RDV because of the following two reasons:

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The first reason is that the introduction of early planted rice into the middle-season rice cultivation areas resulted in the mixed cropping of rice which induces changes in the abundance and pattern of the occurrence of the green rice leafhopper. Annual catches of *N. cincticeps* by light traps in mixed cropping areas are about five times as much as those in the single cropping areas.

HARA (1967) also reported that *N. cincticeps* in the first generation increased in Kagoshima Prefecture apparently after the introduction of early planted rice cultivation. These changes in abundance as well as seasonal prevalence of *N. cincticeps* followed the prevalence of RDV in these areas.

The second reason is that the pattern and level of the intergenerational changes in the percentage of RDV infected insects are changed by the introduction of early planted rice cultivation (NAKASUJI & KIRITANI, 1971). In the early planted rice area, adults of the overwintering generation transmit RDV to early planted rice and cause disease of rice plants at the nymphal period of their offspring. Under this condition, the percentage of RDV infected insects increased rapidly in the 1st generation through oral acquisition of RDV by nymphs.

On the other hand in the middle-season rice area, the percentage in the first generation does not increase because the insects of the 1st generation develop on gramineous weeds, e.g. *Alopecurus acqualis* which are relatively immune from RDV infection.

In summer, the percentage of infected insects decreases in either area because of the death rate increases by the physiological adverse effect of RDV under high temperatures (NAKASUJI & KIRITANI, 1970).

The percentage of infected insects increases again in the fourth and fifth generations in the middle-season rice area where paddy field are illdrained. This is caused by the tillers developed on the infected stubbles as an extraordinary sucking source of virus. Generally speaking, the high percentage of infected insects seems not to be maintained because the percentage in the first generation does not increase but continues to decline in the middle-season rice area.

Another cause of RDV prevalence besides the introduction of early planted rice is the use of synthetic insecticides. The year, around 1955, when RDV began to prevail corresponds to the time when the utilization of such broad spectrum insecticides as BHC, parathion, etc. to control the rice stem borer *Chilo suppressalis* started in paddy fields. The light trap records of many regions manifested that the abundance of *N. cincticeps* increased remarkably in every region from this period without any respect to the change of rice cropping (KIRITANI, 1972).

The reason for the increased abundance of *N. cincticeps* is that the insecticides applied to control rice stem borer also killed the spiders which are the important natural enemy of the leafhopper (KOBAYASHI, 1961; ITO *et al.*, 1962; KIRITANI *et al.*, 1971).

KIRITANI *et al.* (1972) investigated the predation of spiders and presumed that 44–100 percent of nymphs and 9–100 percent of adults of *N. cincticeps* were preyed upon by spiders.

It is known that emulsion of γ-BHC kills one-half of spiders with its concentration of 2 to 4 percent of the LC_{50} for *N. cincticeps* (KAWAHARA *et al.*, 1971). Even granular BHC, the insecticide is toxic to spiders passing through a food-chain from irrigated water, via rice plants, leafhopper, and finally to a spider (KIRITANI & KAWAHARA, 1973).

The increased incidence of *N. cincticeps* owing to the application of synthetic insecticides may be related to the prevalence of RDV. However, the increase in *N. cincticeps* itself is not enough as a trigger to induce RDV prevalence everywhere because the occurrence of RDV prevalence is confined to such areas where the mixed cropping of early and middle-season rice is practiced.

2. **Second epidemics.** Since around 1965, the prevalence of RDV began to spread to the single cropping area of middle-season rice in many regions. The most conspicuous change which occurred during the 2nd epidemic period in the rice cultivation system is the increase of fallow paddy fields which have been utilized for winter cropping of barley and wheat.

Since 1960, the acreage of barley and wheat decreased continuously and about 1965, it became almost one-half of the acreage used before 1960. This mainly attributed to the domestic wheat and barley lost in the competition for market with the imported ones due to their higher cost.

As a result, a vast area of paddy field was left as fallow paddy fields which was allowed to grow such gramineous weeds as *A. aequalis* on which nymphs of the overwintering and the 1st generations of *N. cincticeps* develop. The density of adult population of overwintering generation that emerges in such fallow paddy fields was estimated at 7–40 individuals per m^2 (MURAMATSU *et al.*, 1970; HOKYO, 1972, KAWAHARA *et al.*, 1971). The density may be far higher than that when barley and wheat was cultivated.

The role of fallow paddy fields played in the prevalence of RDV was shown by the investigation conducted in three localities, i.e. Kochi, Kagawa and Okayama (NAKASUJI & KIRITANI, 1976). In a prevalent area of RDV in Kochi, RDV epidemics were put down almost completely within two years by winter ploughing of fallow fields (300 ha in area). Fallow paddy fields are ploughed in winter to control weeds in southern Okayama where rice is cultivated by means of direct seeding. The incidence of infected rice hills in this area was only one-fifth compared to that observed in other localities where the conventional cultivation of rice was undertaken. Even now, wheat and barley are cultivated to some extent in southern Kagawa (inland region in Kagawa). RDV is not a matter problem in this area, notwithstanding the severe RDV prevalences in the coastal regions of northern Kagawa.

The second epidemics of RDV is partly due to the development of insecticidal resistance in *N. cincticeps* to carbamate insecticides used to control this insect. About 1969 and since then, the development of insecticidal resistance was recognized in many regions in southern Japan, e.g. Ehime, Hiroshima, etc. (YOSHIOKA *et al.*, 1972; HAMA & IWATA, 1973). Aerial and/or cooperative simultaneous spray of insecticides, which is one of the effective methods to prevent RDV infestation, may accelerate the development of insecticidal resistance.

Simulation of the Epidemiology of RDV by Means of the System Model

1. **Descriptive model of the natural spread of RDV-infestation by N. cincticeps.** NAKASUJI & KIRITANI (1972) described a system model for the natural spread of RDV-infestation. The model was composed of submodels describing the changes in population densities of *N. cincticeps* and in the percentage of infected insects among the vector population; also the ones describing processes of the transmission of RDV to rice plants by the vector and of the feeding acquisition of vector from the infected rice plants.

The submodel for the changes in the percentage of infected insects among the vector population was described by a modified equation of KONO (1966)'s model which had originally been proposed to describe the relationship between rice stripe virus and its vector, the small brown planthopper *Laodelphax striatellus*.

Recently, SASABA & KIRITANI (1975) developed a system model describing the population dynamics of *N. cincticeps*. Combining the system models of RDV-infestation and of population dynamics of the vector, and epidemiological model of RDV was developed (NAKASUJI et al., 1975). The new model permits us to evaluate the role of individual factors being responsible for the prevalence of RDV.

2. **Detection of contributing factors to RDV prevalence by simulation.** Simulation tests by the epidemiological model were conducted to examine the following factors on the prevalence of RDV: the vector density, the efficiency of feeding acquisition of RDV of the vector, and the efficiency of RDV transmission by the vector to the rice plant (NAKASUJI *et al.*, 1975). Computations were performed by a computer.

The degree of the prevalence of RDV after ten years was assessed in terms of changes in percentages of infected insects, of infected rice hills and of reduction in yield of brown rice by the infection. Both percentages of infected insects and infected rice hills increased rapidly with increasing vector density within a range of low vector density. This simulation indicated that the present population density of the vector in Kochi must be decreased to less than one-tenth to reduce the percentage of loss in yield to below ten percent.

The percentage of infected insects decreased linearly when the aquisitive coefficient was decreased, but the percentage of infected rice hills was affected to a lesser extent. The percentage of infected insects and that of infected rice hills decreased exponentially with decreasing values of the transmission coefficient.

From the practical point of view, the second and third simulations correspond to the genetic manipulation of the aquisitive ability of virus by the vector and the utilization of varietal resistance of rice to RDV infection, respectively. The latter method is most influential to prevent the prevalence of RDV. Regrettably, most varieties of the japonica type of rice are believed to be susceptible to RDV (ISHII *et al.*, 1969).

Forecasting of RDV Infestation

It is important to know early the percentage of hills which will be infected by RDV. In areas of middle-season rice cultivation, we can survey easily the density of *N. cincticeps* in the 1st generation by sweeping with a net in a fallow paddy fields in late May.

The number (N_{A1}) of adults per hill which invaded paddy fields is given by multiplying the number (N_{FAL1}) of insects by 10 double sweepings in fallow paddy fields by a coefficient, i.e. 0.046 (HORIKIRI *et al.*, unpublished). The percentage (P_{OW}) of infected insects among vector population of overwintering generation can be measured until late May by either method of serological or feeding test. The percentage (P_1) of infected insects of the first generation decreased to 60 percent of that (P_{OW}) of the overwintering generation in the area of middle-season rice cultivation or $P_1=0.6\,P$ (NAKASUJI & KIRITANI, 1971). Then, the percentage (A_T) of infected rice hills can be estimated by the following equation (NAKASUJI & KIRITANI, 1972):

$$A_T=0.113 \log N_{A1}P_1+0.491$$

The percentage of infected rice hills in paddy field can be related to logarithm number of insects swept in fallow paddy fields by substituting $0.005N_{FAL1}$ for N_{A1} in the above equation with varying values of P_1. It is elucidated that a measurable yield loss will result when RDV infected hills (A_T) exceeds 15 percent (SUGINO, 1975). Based on the model mentioned above, the control threshold densities which are expressed in terms of the total number of *N. cincticeps* excluding young nymphs are calculatel as 5, 7, 15, 22 and 46 individuals by ten double sweepings in fallow paddy fields in late May, when percentages of RDV infected insects are 10, 7, 5, 3, 2, and 1 percent, respectively.

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Discussion

K. C. Ling, IRRI: 1. How do you use your model to forecast the incidence of rice drwaf disease in a paddy field?

2. What are the reason for the infective insects of the 2nd generation lower than that of the 1st generation?

Answer: 1. We have not used the model to forecast the incidence of RDV. We believe that our forecasting model is applicable.

2. The decrease in the percentage of infective insects in the 2nd and 3rd generations was caused by the physiological adverse effects of RDV on the vector. The degree of the adverse effects is generally higher in the summer season.

I. N. Oka, Indonesia: With respect to the difference in occurrence of the RDV in the early, mid season and late planted rice, is it possible to device cultural control of the disease, such as time of planting to avoid the disease?

Answer: It will be possible in mixed cropping areas. But farmers have to plough fallow paddy fields in the winter season even in such areas. Because the fallow paddy field which is allowed to grow host plants of the vector, e.g. *Alopecurus acqualis,* plays an important role in the prevalence of RDV. However, the change in the cultivation practice will be very difficult, because the cultivation of early planted rice spread in southern Japan to avoid the damage inflicted by typhoons.

D. A. Benigno, Philippines: 1. From your slide presentation you have shown direct correlation of virus infected plants to leafhopper population. Do you think this will hold true also if you have the following conditional factor:

a) Have you a leafhopper resistant rice variety?

b) Have you a virus resistant rice variety?

Answer: The former condition corresponds to the first simulation in our study. In this case, we must select resistant varieties in a high degree to *N. cincticeps*.

The latter condition corresponds to the 3rd simulation. Varietal resistance of rice to RDV will be more effective than the varietal resistance of rice to *N. cincticeps*.

K. C. Ling, IRRI: How do you determine the transmission coefficient?

Answer: We determine the transmission coefficient from the relationship between the density (N.P.) of infective insects in paddy fields and the percentage (AT) of infected rice hills. The coefficients in the equation show the efficiency of transmission of RDV by the vector.