INTEGRATED INSECT PEST MANAGEMENT FOR RICE IN JAPAN

Keizi KIRITANI*

Introduction

The strategy and tactics involved in the integrated pest management (IPM) of insect pests of rice, have already been critically reviewed by Kiritani (1972; 1977; 1979). In spite of repeated emphasis on the urgent necessity of IPM by its advocates, the implementation of IPM by farmers still remains far behind. To bridge this apparent gap, it is anticipated that many obstacles should be overcome not only in technology but also in socio-economic sectors (Kiritani, 1979).

Socio-economic problems of rice production in Japan

Rice has long been the staple food in Japan, and it is so still now. However, a great change in the rice consumption has occurred with increasing living standards. In 1962, the consumption of rice in Japan was 118.3 kg/head/year, while it decreased by 30% or to 82 kg in 1978. As a result, the surplus of domestic rice has accumulated to some 6.5 million tons of stored rice. In association with this change, a growing demand for better quality of rice arose. Recent insect pest problems of rice which are characterized by the injury of heteropterous plant bugs are closely linked with this tendency (Fig. 1).

Since 1970, the cropping restriction of rice has been implemented through government subsidy. It is expected that about 840,000 ha or 27% of the total acreage of paddy fields in Japan, i.e. 3,173,000 ha in 1967, will be withdrawn from rice production by 1980. The cropping restriction has resulted in an increase of fallow paddy fields which provide wild host plants for such rice pests as heteropterous plant bugs and overwintering nymphs of the green rice leafhopper, *Nephotettix cincticeps*. Currently the planting of upland crops other than rice, eg. soybeans, buckwheat, etc. on these idle lands is being encouraged. Since the acreage planted to soybeans is expanding rapidly with the support of government subsidy, the damage of rice caused by heteropterous bugs which feed on both rice and soybeans might become more serious before long.

Rice production in a high-technology system, as exemplified by Japan, involves heavy investment in pesticides, fertilizers, agricultural machines, and the cultivation of high yielding varieties (Fig. 1). An energy balance sheet for rice production in Japan shows that energy input in terms of fertilizers, machinery, fuel, and pesticides increased 4, 12, 23 and 33 fold, respectively, during the period of 1950-74, whereas the rice yield only rose about 1.5-fold (Udagawa, 1976). The ratio of output to input was 1.27 in 1950, but it decreased to 0.38 in 1974 (Udagawa, 1976). It is evident that an intensive rice production system is becoming uneconomical in terms of energy balance and that a reduction in energy input without impairing the rice yield is urgently needed. This differentiates the strategies in rice production: minimizing input, or agricultural chemicals in Japan and maximizing output, or yield in the tropics (Kiritani, 1979).

Characteristics of rice cultivation in relation to pest management

Since the Japanese main islands—Hokkaido, Honshu, Shikoku and Kyushu—extend over 1,500km from north to south with different climatic conditions, the faunal composition of insect pests and its economic importance greatly differ depending on the locality (Fig. 2). Rice plants of *japonica* type are grown once a year mostly under irrigated conditions during April to October. *Japonica*

* Chief, Laboratory of Insect Ecology, Department of Plant Pathology and Entomology, National Institute of Agricultural Sciences, Yatabe, Tsukuba, Ibaraki 305, Japan

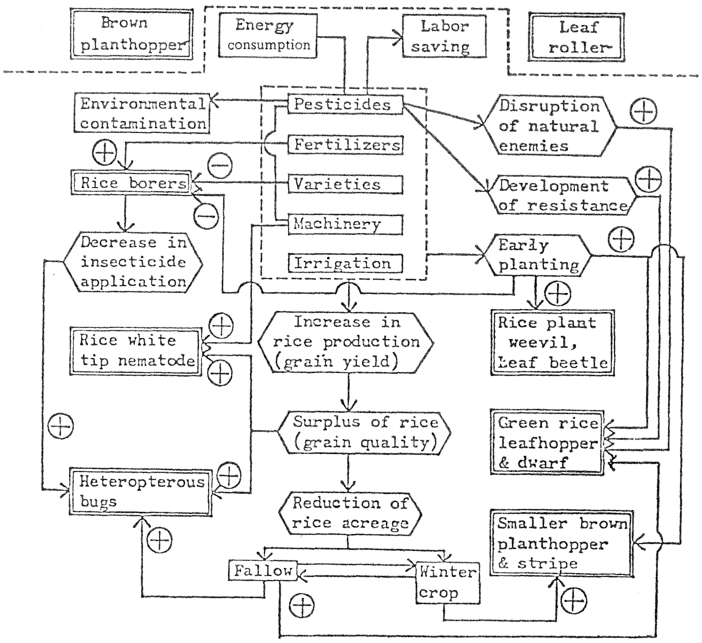

Fig. 1 Rice production matrix in relation to pest status

lowland rice varieties, in contrast to *indica* type, lack genes resistant to most of the important rice insects and insect-borne virus diseases. This situation has encouraged the unilateral dependence on pesticides in controlling rice pests in Japan.

After harvest, paddy fields are either left fallow or utilized for winter crops. Insecticides are applied 3-4 times on an average during the growing seasons, although the frequency of applications has begun to decrease recently. In 1976, rice growers spent ¥46,090 (US$230) per ha on buying pesticides including insecticides, fungicides and herbicides. This suggests about 10 applications of pesticides for one rice cropping.

The heavy use of insecticides, particularly BHC which was completely banned for use in 1971 has resulted in environmental contamination including insecticide residues in food as well as human milk, the development of resistance in insect pests, and the disruption of natural enemy complexes in the paddy fields. In parallel with this, some monophagous pest species, i.e. *Tryporyza incertulas*, and univoltine species, e.g. the Japanese black rice bug, *Scotinophora lurida* and rice grass hoppers, *Oxya* spp. disappeared almost entirely from the rice fields before 1960. A similar type of change was also observed for the larval parasite complex of the rice stem borer, *Chilo suppressalis* (Kiritani 1972; 1975; 1976). By contrast, those species that survived during this period may be characterized as polyphagous, multivoltine, small in body size, and having relatively high mobility (Hirano and Kiritani 1975). These characteristics may also be conducive to the development of insecticide resistance. Among those species *N. cincticeps* represents a notable example. This species developed resistance to organophosphorus insecticides by the early 1960s and then to carbamates by the early 1970s in various parts of Japan (Hama, 1975; Asakawa and Kazano, 1976). This multiresistance of *N. cincticeps* threatened the insecticidal approach in controlling the leafhopper.

The magnitude of disruption of natural enemy complex is exemplified by the fact that the percentage parasitism of *Chilo* eggs by trichogrammatids declined to less than 10% throughout

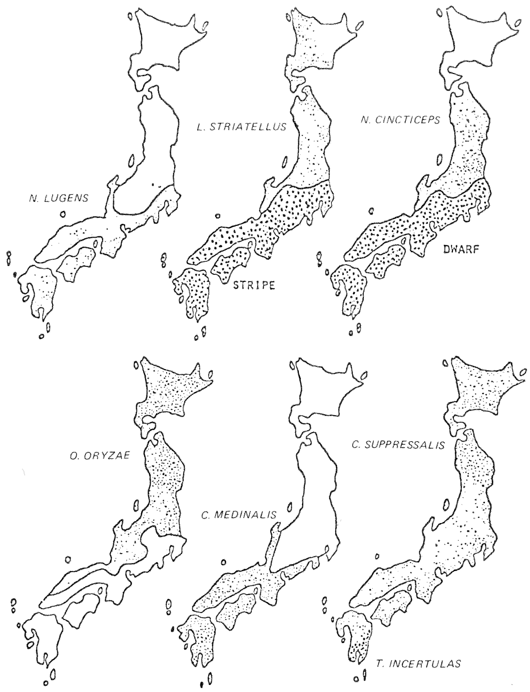

Fig. 2 Geographical range of economic infestation by different rice insect pests and insect-borne virus diseases

Japan since the early 1960s, while it used to be more than 50% before the intensive use of insecticides (Kiritani, 1972; 1979).

The Japanese arthropod fauna of paddy fields including natural enemies is mostly composed of endemic species, except for such overseas migrant species as *Nilaparvata lugens, Sogatella furcifera* and the grass leaf roller, *Cnaphalocrocis medinalis*. The occurrence of the rice water weevil, *Lissorhoptrus oryzophilus* , in central Japan in 1976 is another case of establishment of introduced species (Tsuzuki *et al.*, 1977). This introduced beetle is currently expanding its distribution range at a rate of 16km per year threatening rice cultivation owing to the difficulty in controlling it by insecticides. The endemic type of rice pest fauna may be related to the difficulty of biological control of rice insect pests unless it is integrated under a scheme of pest management.

Tempo-spatial changes in pest status and damage due to insect pests

Fig. 2 shows the geographical range of economic damage due to some major insect pests and insect-borne virus diseases. Damage due to *C. suppressalis* occurs all over the Japanese islands, while infestation with *T. incertulas* is currently limited only to the southernmost area of Kyushu. Before the advent of synthetic insecticides, *T. incertulas,* however, was distributed chiefly in the area of southern Japan facing the Pacific Ocean. The infestation by the overseas migrant species, i.e. *N. lugens* and *C. medinalis*, is normally limited to southern Japan. The distribution of insect-borne virus diseases, i.e. stripe transmitted by *Laodelphax striatellus* and dwarf by *N. cincticeps,* is also mainly

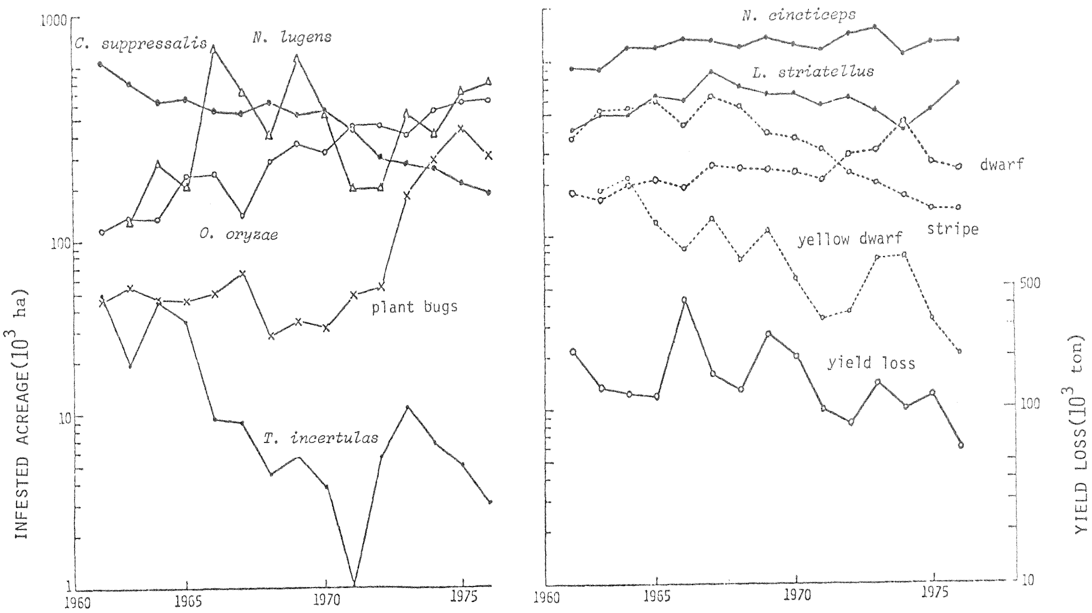

Fig. 3 Annual changes in infested acreage of paddy field for major rice insect pests and insect-borne virus diseases

confined to southern Japan in spite of the fact that the vector species occur in northern Japan as well as in the South. By contrast, *Oulema oryzae* infests rice planted in northern Japan and its distribution range extends southwards along the Sea of Japan.

Annual changes in acreage of infested paddy fields are shown in Fig. 3. Ever-decreasing trends in infested acreage are remarkable for rice borers, i.e. *C. suppressalis* and *T. incertulas.* In general, stripe virus disease and its vector, *L. striatellus* have decreased since 1972, while *N. cincticeps* has shown a relatively stable endemic infestation during the last 15 years. Of the virus diseases vectored by *N. cincticeps*, yellow dwarf has shown an ever-decreasing trend, while dwarf an upward trend until recently. Remarkable increases in infested acreage can be seen for *O. oryzae* and for heteropterous plant bugs. The factors triggering the rapid increase of *O. oryzae* have largely remained unknown. However, changes in agronomic practices, specifically early planting of rice in association with machine transplanting are considered to be responsible for this increase (Takayama, 1977; Emura and Kojima, 1978). In spite of such great changes in pest status of various rice insect pests, the overall yield loss due to insect pests is gradually decreasing, showing wave-like fluctuations. It could be said from Fig. 3 that the national yield loss depends primarily on the infestation by *C. suppressalis* and *N. lugens.* It is unlikely that *N. cincticeps, L. striatellus, O. oryzae* and heteropterous plant bugs inflict substantial losses to rational rice production. Since the increasing trend in infected acreage by dwarf is compensated by the decreasing trend of stripe, the effect of these virus diseases on the yield, is not evident. It is concluded that, in terms of the rice yield, *C. suppressalis* and *N. lugens* are the key pests which determine the amount of rice production in Japan. In view of the fact that *C. suppressalis* has become less important year after year since the early 1960s, *N. lugens* can be ranked in the first order of importance among rice pests. On the other hand, rice-infesting heteropterous plant bugs which include almost 40 species of different families are increasing in importance only as a result of the recent growing demand for better quality of rice. It is anticipated, however, that the increase in acreage of fallow paddy fields planted to soybean may amplify the problem of heteropterous plant bugs in the foreseeable future.

Economic and tolerable injury levels and control threshold

Iwao and Kiritani (1973) defined tolerable injury level (TIL) as the maximum injury level that will cause practically no yield loss. The economic injury level (EIL) here refers to the injury level at which the cost of control is compensated for by the resulting increase in crop yield. Control threshold (CT) refers to the pest density at which control measures should be executed to prevent an increasing pest injury.

Takaki *et al.* (1958) demonstrated that a 95% confidence limit of variation of the mean rice yield was ±3.5% on the basis of rice yields in 100 fields. Taking into consideration the cost of insecticide application, which is roughly equivalent to about 7kg or 1.5% of 450kg, which is the mean yield of husked rice per 10a in Japan, it is reasonable to propose 5% of yield loss as the economic injury level (EIL). In Table 1, values for TIL and EIL calculated respectively in terms of yield loss of 3.5 and 5.0% are listed for different rice pest species. As a matter of course, these levels are affected by various factors including physico-chemical and biological ones (Smith, 1969). In addition, variations in survivorship of insect population make the determination of CT difficult, particularly when the time interval between CT and EIL is long (see Kojima and Emura, this symposium). Indeed regarding the TIL for the rice leaf beetle, *O. oryzae*, 20% of injured leaves (Emura and Kojima, 1978), 19% (Koyama, 1978a), 14% (Okamoto and Ohohata, 1973) and 30-50% (Fujita, 1972 cited from Takayama, 1977) have been reported. Similarly, CT values for overwintered adults of *O. oryzae* are 0.05 adults/hill (Emura and Kojima, 1978), 0.1-0.4 (Shimizu, personal communication) and less than 0.5 (Takamura, personal communication) showing a 10-fold difference.

Deterioration of grain quality caused by heteropterous plant bugs introduced some complex problems from the view-point of integrated pest management. The quality standards for husked rice provided by the Farm Product Inspection Law request less than 0.1% of spotted grains for the first grade rice. Rice grains containing more than 0.8% are ranked as "sub-grade" and rejected from the market.

Since heteropterous plant bugs that infest rice panicles in a given field are normally composed of several species at different developmental stages, some device is necessary for calculating CT. Nakasuji (1973) attempted to convert the number of individuals of species other than *Nezara viridula* into that of adults of *N. viridula* by taking into account the difference in ability of producing spotted grains per day per insect. Shimizu and Maru (1978) calculated the CT as the product of the following components by using computer simulation: change in density of nymphs originating from immigrant adults (A), change in number of spotted grains produced by one adult per day in relation to the maturation of grains (B), and the relative ability of different nymphal stages to produce spotted grains (C). The product of A, B and C was 90.2 spotted grains for *Cletus trigonus.*

Assuming that a 60 net stroke covers 157.5m^2 or 5.2 million grains with a sampling efficiency of 0.2 (0.05 for nymphs) for adults, it was estimated that one immigrant adult caught by a 60 net stroke would produce 0.009% of spotted grains, by using the formula $0.009 = 90.2 \times 100/0.2 \times 5.2 \times 10^6$. Similarly for *Leptocorisa chinensis*, the estimation was 0.015%. The authors proposed the following equation: $Y = 0.009X_1 + 0.015X_2$, where Y is the percentage of spotted grains when infested by the mixed population of adults of *C. trigonus*(X_1) and *L. chinensis*(X_2).

Values calculated for CT for different species of plant bugs are shown in Table 2 in relation to the quality standards of husked rice. It should be emphasized that there is no change in taste nor any reduction in yield even in the "sub-grade" rice which contains about 1% of spotted grains. It is considered that one application of insecticide is enough to enable an advance by one grade.

Table 1 EIL and TIL calculated from expressions proposed for loss assessment due to rice insect pests

Species & generation	Expression for loss assessment (Y: % yield loss, X: variable)	EIL	TIL	Ref.
C. suppressalis				
1st gen.	$0.291X+0.0029X^2$ (% injured stems)	15	11	6
	% of dead hearts x 0.35	14	10	7
2nd gen.	% of injured stems at harvest x 0.3	17	12	7
	$0.119X+0.0045X^2$ (ditto)	23	18	8
T. incertulas	% of white heads x 1.15	4	3	7
Chlorops oryzae				
1st gen.	% of stalks with injured leaves x 0.35	14	10	7
2nd gen	% of injured panicles x 0.45	11	8	7
L. striatellus				
Stripe	% of diseased stalks x 1	5	3.5	7
N. lugens	No. insects/100 strokes x 0.035	143	100	7
	% of hopperburn x 0.8	6	4	7
Scotinophora lurida	Total no. of nymphs & adults/100 hill x 0.33	15	11	7
	% of injured panicles x 1	5	3.5	7
Oulema oryzae	% of injured leaves x 0.18	27	19	3
	% of injured leaves x 0.25	20	14	7
	$-20.22+0.39X$ (ditto)	64	61	2
Parnara guttata	% of injured leaves x 0.35	14	10	7
	No. of larvae/m^2 x 0.6	8	6	7
	No. of pupae/hill x 6.0 (in 1977)	0.8	0.6	1
	No. of pupae/hill x 2.4 (in 1978)	2.1	1.5	1
N. cincticeps	Early infected hills (%) x 0.8	6	4	5
Dwarf	Late infected hills (%) x 0.3	17	12	5
	$0.13X+0.004X^2$ (% of infected hills)	23	18	8
	% of infected stalks x 0.86	6	4	8

1: Aoki(p.c.), 2:Emura and Kojima(1978), 3:Koyama(1978), 4:Muramatsu *et al.*(1963), 5:Nakasuji and Nomura(1973), 6:Nishino(1959), 7:Okamoto and Ohohata(1973) and 8:Sugino (1975)

Table 2 Quality standards of husked rice in relation to the control threshold of plant bugs in terms of the number of adults per 50 net stroke at milky stage of rice

Grade	1st	2nd	3rd	sub-grade	Author
% of spotted grains	0.1	0.3	0.7	0.8	
Leptocorisa chinensis	6	17	39	–	Shimizu and Maru (1978)
Nezara viridula	2	5	13	–	Nakasuji (1973)
Total no. of plant bugs[1)]	2	6	17	–	Nakazawa *et al.* (1972)

1) Mainly *L. chinensis* and *Nezara antennata.* Calculated from $Y = 0.018 + 0.015X$, where X is the total number of plant bugs per 40 net stroke and Y is the percentage of spotted grains.

Such dynamic nature of CT, EIL and TIL requires a systems oriented approach involving population model of insect, plant growth model and loss-damage or insect-plant interaction model. For this approach, we should use the concept of insect/days (number of insects × duration of infestation) and the amount of damage/insect/day. When the duration of confinement and number of insects used vary with the investigators, difficulty often arises in comparing results from various sources. Also concepts of DAT (days after transplanting) and DAH (days after heading) are preferable in that the growth stage of rice plant is defined. Utilization of Matsushima's (1960) theory is relevant for the assessment of yield loss, as it demonstrates that the rice yield is expressed by the following equation:

$$\text{Grain yield/ unit area} = \text{Density of panicles} \times \text{Mean no. of grains/ panicle} \times \text{\% of ripened grains} \times \text{Mean weight of 1,000 grains}$$

These components are arranged along the time axis of plant growth. The most important component that affects the yield is the density of panicles and the percentage of ripened grains. The assessment of yield loss of rice due to insect pests should be carried out in relation to these yield-controlling components. By such component analysis of yield loss, we could identify more clearly the nature of injury for each insect pest species.

The yield loss due to infestation of certain rice pests at the vegetative stage of rice plants mainly results from the reduction in panicle density, e.g. dwarf (Muramatsu *et al.*, 1963), *O. oryzae* (Emura and Kojima, 1978), the 1st generation of *C. suppressalis* (Koyama, 1973; Sugino, 1975). Since there was a strong negative correlation between panicle density and percentage of ripened grains (Matsushima, 1966), the damage at an early stage of rice plants would be compensated for to some extent. In order to replace the current empirical concept of TIL with a more theoretical one, it seems necessary to conduct more detailed quantitative studies on such aspect of compensation of rice plants in relation to pest injury.

Locality-based vs field-based CT and EIL

Forecasting of insect pests and diseases is being made by the nation-wide network of Prefectural Agricultural Experiment Stations and District Plant Protection Service Stations. About 700 full-time staffs are engaged in this business. The information issued from this network is locality- or district-based. Aside from its reliability, such an overall information is not always effective in the withdrawal of insurance control at individual grower's field. This is because the locality-based mild infestation, for instance, means implicitly that most of the fields are slightly infested, but some fields might be or will be infested moderately or even severely.

It should be emphasized that insurance is rewarding only when it is operated as a group of the insured. A balance sheet incorporating such probability in the incidence of infestation among fields with cost of chemical control is presented in Table 3. The calculation was made assuming the incidence of spotted rice grain due to the southern green stink bug, *Nezara viridula*, follows the equations proposed by Nakasuji in 1973. Other parameters necessary for calculation were obtained from the report published by the Kochi Prefectural Association for Improved Pest Control (1976).

Actually, the rice fields covering 350ha in Aki district were treated by insecticides to control stink bugs 1.4 times on an average. The balance sheet, however, indicates that the monetary gain in terms of the entire district would be the greatest when no insecticides are applied. It should be mentioned, however, that if either the density of *N. viridula* or the rice yield per hectare were much greater than in this case the conclusion would be different; at least one application would be a better strategy with minimum total cost. Table 3 suggests that if all the growers deposited the money which was saved by the withdrawal of insecticide application, i.e. 1,818 − 1,459 = 359/10a, or about 34% of

Table 3 Total costs of insecticidal control of *Nezara viridula* in middle-season rice, Aki, Kochi

Grade of brown rice	Losses (¥/1,000m²)	No. applications of insecticide 2	1	0
		Probabilities of losses		
1–2	0	0.75	0.70	0.50
3	1,400	0.14	0.16	0.17
4	2,900	0.07	0.09	0.22
5	5,300	0.04	0.05	0.11
Subgrade	18,000	0.00	0.00	0.00
Expected losses (¥/10*a*)		611	750	1,459
Control cost (¥)				
labour		480	240	0
insecticide		1,656	828	0
Total cost (¥/1,000m²)		2,747	1,818	1,459

Note:
i) Total acreage is 350 ha with 350 kg/10 *a* brown rice.
ii) Mean adult densities of *Nezara* were 0.03 and 0.09 per hill, respectively, at milky and dough-ripe stage in insecticide-free fields.
iii) Cost and rice price are on 1976 basis.

the control cost, the total would be ¥1.25 million. If the monetary loss of 11% of growers whose rice was graded 5 were covered by this deposit money for the monetary difference between grades 4 and 5, the compensation would reach ¥0.92 million. The surplus money is still ¥0.33 million. In addition, side-effects of insecticidal application in the district could be kept minimum.

There are many kinds of conflict in implementing IPM between individual vs community or field vs locality. Without an optimum compromise of these conflicts no IPM will be in operation on individual grower's base.

Problems in implementing integrated pest management in rice

Control of rice pests still depends mostly on insecticides in Japan. Utilization of varietal resistance, natural enemies, cultural practices and sex attractant substances with the exception of varietal resistance is not considered practical for the time being.

Nowadays, in Japan, hand planting of rice is rapidly being replaced by machine planting. Insecticidal application to the nursery box before transplanting is currently being carried out in an attempt to control insect pests that infest young rice and insect-borne virus diseases. The prophylactic nature of this method demands development of a precise forecasting system to make this a treat-when-necessary application.

At present some local populations of *N. cincticeps* show more than a 100-fold resistance to some carbamates and as high as a 600-fold resistance to malathion (Hama, 1975; Hama and Iwata, 1973). This multiresistance of *N. cincticeps* has threatened the insecticidal approach in controlling leafhoppers. In the framework of pest management, an insect species at an economically tolerable density, but with a high level of resistance, is no longer a real pest, whereas a high density of susceptible strains is an economic menace to rice culture. Optimization should be looked for to compromise these conflicts among tolerable pest density (damage), degree of control, and the risk of breakdown of control tactics through the development of new genetic make-up (Kiritani, 1979).

The first step that can be taken immediately is to reduce the quantity of insecticides through the use of low rate treatments with a minimum number of applications. Also the effectiveness of chemical control has to be assessed not in terms of percentage kill but in terms of the degree to which injury or damage by insect pests is reduced.

And we must substitute treat-when-necessary insecticide applications for presently employed routine insecticide treatment (Kiritani, 1976).

One of the barriers to the implementation of treat-when-necessary application of insecticides exists in the current terms of the Agricultural Mutual Aid Insurance. This insurance pays compensation to farmers for the damage due to pest infestation under the condition that the paddy field concerned has been treated with pesticides against the pest. These terms, as a result, encourage the pesticide control for insurance.

Application of severe standards for grain quality control as exemplified in the case of spotted grains due to plant bugs drives farmers to the insurance insecticide applications after panicle formation of rice plants, which in turn not only increase the risk of contamination of rice grains by insecticide residues, but also encourage the development of insecticide resistance in other insect pests, e.g. *N. cincticeps.*

A great reduction in the acreage treated with insecticides has been demonstrated in Akita Prefecture by the vigorous endeavor to disseminate the concept of EIL to rice growers. The prefecture-wide surveillance in 1977 for the infestation of 1st generation of *C. suppressalis* indicated that all the paddy fields inspected were below the TIL (or less than 5% of deadhearts). Since the introduction of this TIL or CT (12% of injured leaf-sheaths) as control guideline, the acreage which was treated against the first generation borers decreased rapidly down to the level of 1960 in 1977 when the aerial spray was also suspended (Koyama, 1976). Since this insecticide treatment was conducted in aiming at the simultaneous control of *O. oryzae,* withdrawal of control against the 1st generation borer was successfully practised by the establishment of EIL for *O. oryzae* (Koyama, 1978a;b). A similar sort of problem exists in the middle-season rice area where simultaneous chemical control of the 2nd generation borer and *N. lugens* is the conventional practice.

So far emphasis has been placed on the key-pest-oriented aspect in integrated pest management. The successful control of the key pest, however, might work in favor of other potential pests creating conditions that encourage their multiplication. For instance, cropping of wheat and barley in the fallow paddy fields will decimate the overwintering population of *N. cincticeps,* but it is conducive to the population increase of *L. striatellus.* To solve such problems, pest management aimed at optimization would ultimately replace the key-pest-oriented control. It should be recognized, however, that when successful control of the key pest is achieved through the use of control tactics other than insecticides, it will contribute to a great reduction in the application of insecticides, which in turn not only contributes to the slowdown of the development of insecticide resistance in other pest species, but also favors the multiplication of natural enemies in the paddy fields.

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