Implications of an unintended area-wide IPM for *Chilo suppressalis* in Japan

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Abstract

This paper discusses the success of an unintended area-wide integrated pest management (IPM) for *Chilo suppressalis* in Japan. *Chilo* was considered as one of the country's major rice insect pests causing significant yield loss during the pre-war period, along with *Scirpophaga incertulas*. *Chilo* population density declined through the years, which was considered to be induced by modern farming technologies associated with various improved agronomic practices, particularly farm mechanization, which were aimed at increasing rice production and saving labor rather than decreasing *Chilo* population. Based on the case of Japan, other density-dependent factors associated with the low population of *Chilo* include the following: a) the duration of the IPM scheme, either intended (planned) or unintended, should at least cover a full decade (10 years); b) the area should be wide enough to cover population displacement of *Chilo* stem borers; and c) integrated pest management of key pests should be implemented in complementation with modern farming technologies. It was also noted that environmental factors associated with the maintenance of low density of *Chilo*, and possibly its total extinction in the future, must be considered in developing rice management strategy. This includes maintaining a balance between integrated pest management and conservation of the paddy ecosystem, also known as integrated biodiversity management (IBM).

Introduction

Integrated pest management (IPM) was defined by Smith and Reynolds (1966) as "a pest population management system that utilizes all suitable techniques in a compatible manner to reduce pest populations and maintain them at levels below those causing economic injury". The IPM definition involves three key concepts; first the utilization of all available control techniques, secondly, use of economic injury level for control decision, and finally maintenance of pest population density below the EIL. The EIL concept was originally developed with the objective of reducing insecticide use. Thus EILs have always found most application with insecticidal control measures (Pedigo et al. 1986). In addition, IPM was developed for the implementation at the single-field level. Most of the decision-making tools, such as EILs and monitoring systems, were designed for single-field use. (Norris et al. 2003).

In the single-field approach of IPM, the third item of IPM concept that is to maintain the key pest population density below the EIL over a wide area for successive cropping seasons is very difficult to realize. Because many pests are highly mobile and occurrence in one field is likely to influence events in neighboring fields.

Knipling (1979) was an early proponent of the concept of suppression of insect pests over large areas, instead of the field-by-field approach of contemporary pest control programs. The areawide pest management projects (a) must be conducted on large geographic areas; (b) should be coordinated by organization rather than by individual farmers; (c) should focus on reducing and maintaining key pest populations at acceptable low densities; and (d) involve active grower participation through environmentally sound, effective, and economical approaches (Knipling 1979; Calkins 1996; Kogan 1998). Area-wide pest management projects use all of the technological tools available, including mating disruption by sex pheromone, biological control with parasitoids, predators and pathogens, the sterile insect technique, agricultural practices and insecticides. Examples were found in those projects against codling moth, corn rootworm (*Diabrotica* spp.), cotton bollworm and Mediterranean fruit fly in the USA (Calkins 1996).

In monsoon Asia, we often encounter rice basins with a vast area. Unlike the USA, most rice growers are small-scale farmers with a limited area of fields. The number of rice growers, for example in Japan, is 3.7million, and 85% of the farmers are growing less than 1ha of rice (Kiritani and Naba, 1994). Consequently, area-wide pest management projects in Asia as well as in Japan are requested a close coordination between farmers and organizers of the projects.

The terms strategy and tactic are the two fundamental components of any IPM system. In IPM, the tactics are the methods available for pest control and how to integrate them to manage the within-field pest population below the EIL specific to each grower. Strategies are the various ways tactics are deployed to suppress and maintain the population under the EIL in a wide area for successive cropping seasons. Strategic approaches are necessary for many insect-borne virus diseases and for some mobile insects and nationwide key pests and require the cooperation of farmers (Frans 1993). In an extreme case, some growers have to leave their farms free from insecticides either to secure the persistence or to propagate natural enemies in the locality concerned. Strategies might include such things as monitoring or prediction, feasibility studies and management or regulation strategies.

The two species of rice borers

Control of rice insect pests has been the central problem among farmers in Asia who depend primarily on rice as a subsistence crop. In Japan, the endemic damage caused by the rice borers *Scirpophaga incertulas* (hereafter *Scirpophaga*) and *Chilo suppressalis* (hereafter *Chilo*) and the sudden occurrence of epidemics of the brown planthopper, *Nilaparvata lugens*, were the major causes of loss in rice yield during the pre-war period (Kiritani 1979). *Scirpophaga* is monophagous on rice having 3 generations per year and was distributed in southern Japan, while *Chilo* is oligophagous having 2 generations and occurs all over Japan.

The outbreaks of *Scirpophaga* were observed during 1945-50 and again to a lesser extent in the early 1960s. The major factor responsible for the outbreaks was the staggered planting of rice. Suppression of *Scirpophaga* was conducted by the late planting of rice and the chemical control with BHC and parathion. It began to decrease sharply in 1952-53; no measurable infestation has been reported since 1965 and believed to be extinct from Japan (Fig. 1).

The remarkable effect of insecticides in preventing borers' damage encouraged the nation-wide campaign for chemical control. There have been some disputes about the role of insecticides in suppressing the *Chilo* population.

For example, some localities in Shizuoka Prefecture conducted jointly the cooperative areawide control of *Chilo* treating with parathion twice a year for successive 10 years, as a result, the annual light-trap catches was reduced to around 1000 moth range as compared with over 4000 moths before the initiation of cooperative control (Miyashita 1982). Although pesticide treatment had been effective in protecting the rice from *Chilo* larvae, there was a limitation in controlling the *Chilo* population itself.

Decline of *Chilo* populations in Japan

I would like to refer to *Chilo* as a case study of an area-wide IPM that has been unintentionally achieved in Japan. The decline of *Chilo* started after about 15 years following the decrease of *Scirpophaga*. The sign of decreasing *Chilo* has been observed since the early 1960s and further became evident in the 1970s. The decline is considered to have been induced by the following factors; the cultivation of early planted rice since 1955; replacement of heavy panicle-type varieties with panicle number types that have more tillers of slender, stiff, and short stalks since the late 1950s; use of BHC granules since 1960; early harvest of middle-season rice by 2-3weeks since 1960; increase in the amount of slag ($CaSiO3$) by two to three times since 1965; and the mechanical harvesting with combined harvesters in association with burning straw since 1965 (Table 1).

Singly or jointly, these factors reduced survival rate of either over wintering or growing larvae of *Chilo.* Except for the use of BHC granules, these new technologies have been aimed mainly at increasing rice production and saving labor (Kiritani 1979). Starting from the early planting rice in 1955 to the initiation of mechanization of rice culture in 1970, about 15 years had been passed before the decline of *Chilo* became evident all over Japan.

Decline of *Chilo* in temperate Asian countries

Decreases in *Chilo* were observed first in the early 1960s in Japan, followed by the same pattern in Taiwan, Korea and Guanzhou, China. Any decrease in abundance became evident first in the light trap catches, then in the reduction of the area infested by borers (Kiritani 1990;2005b).

As one of the indices of modern farming technology, the numbers of mechanized rice transplanters introduced in the following three countries were compared; the mechanization first began in Japan, followed by Taiwan, and Korea (Kiritani 1990). This order was the same as that observed in the decline of *Chilo*. Among the factors contributing to the decline of *Chilo*, the early planting of rice was suggested to be a common factor being associated with various agronomic practices, especially, the utilization of machinery had accelerated a further decline in *Chilo* over an extended area (Kiritani 1990).

Mechanism that maintain a low density of *Chilo* without extinction

Effects of withdrawal of insecticidal control against the first generation of *Chilo* in paddy fields of 17ha for five successive years were examined in terms of the percentage of injured sheaths caused by *Chilo* (Table 2). Obviously, the results showed no significant difference in the percentage of injured sheaths from those in the conventional control areas (Emura and Kojima 1979). This indicated that some environmental factors other than the insecticides would be contributing in the maintenance of a low density of *Chilo*.

If an ever-decreasing trend of *Chilo* is to be continued, the extinction of *Chilo* population could be expected locally somewhere in Japan. However, there has been no report of such local extinction. Therefore it is reasonable to look for some density-dependent factors that are preventing *Chilo* from extinction.

Chemical control of *Chilo* also brought about a great change in its larval parasitoid complex, specialists that include *Temelucha biguttula, Chelonus munakatae* and other species had been predominant and were characterized by solitary parasitism with relatively narrow host range having one to two generations per year, were replaced almost completely by a generalist, *Apanteles chilonis*, which is gregarious, polyphagous, and multivoltine. This change first took place in southern Japan in the late 1950s several year earlier than in northern Japan, because of more intensive use of insecticides in the former region (Table 3) (Kiritani 1973).

We have data on the percentage parasitism of over wintering *Chilo* larvae over 23 years in Aomori, a northern prefecture in Japan. When the moth catches exceeded 1.000 per year, as before 1964, the percentage of parasitized larvae showed a negative correlation with moth density as reflected in numbers trapped. This relationship then became positive density-dependent after 1965, when catches fell to less than 1,000. This means a new regulatory mechanism or natural control by a larval parasitoid came into operation for *Chilo* populations, which were forced to fluctuate in a new lower domain of population dynamics (Fig. 2).

The current situation of *Chilo* can be illustrated by a reproduction curve with higher and lower points of equilibrium (Fig. 3). *R* indicates a release point, of which escape from natural enemy action can be expected, corresponding to annual catches of 1.000 moths in the northern Japan. A low density induced by modern farming technology seems to provide an arena where the interaction system between parasitoids, mainly *Apanteles* and *Chilo*, works around a new low equilibrium point, indicated by *SL* in the curve.

So far there have been no cases of successful biological control of rice borers in the world (Kiritani 1979). The current status of *Chilo* might illustrate the feasibility of biological control of rice borers, through the more sophisticated manipulation of the agroecosystem (Kiritani 1988). When *Chilo* density was too low to parasitize, the generalist parasitoid, *A. chilonis*, might select *Chilo* larvae inhabiting *Zizania latifolia* as one of its alternative hosts.

The area to be covered by an area-wide IPM

To what extent the area should be wide enough to implement an area-wide IPM for *Chilo* is not clear. An administrative district used to be selected for the implementation of IPM. In the study of outbreaks of *Chilo*, their spatial limitations have often been neglected as compared with the intensity or the duration of the outbreaks.

Outbreaks of *Chilo* occurred in 1953 almost all over the south-western Japan. Kiritani and Oho (1961) analyzed catch records of *Chilo* moths by light traps in 30 stations in Kyushu Island and found that the peak years of catches did not synchronize even among observatory points located in the same prefecture. The 1953 outbreak was only observed in the north-western part of

Kyushu Island with a remarkable spatial limitation. The first peak of the outbreak was in the second (summer) generation of 1953 at Saga and Shirota that were located at the centre of Saga Plane. Then the occurrence of peak generation delayed as remote from the centre until the outbreak came to an end at Hirado, 70km west of Saga, where the peak came at the second generation of 1956 (Fig. 4). Stations with the same outbreak year were encircled as shown in Fig. 4. The centrifugal extension of outbreaks took its way to southward coastal region rather than to northward mountainous region.

It has been claimed that outbreaks of *Chilo* is triggered by a low temperature during the larval period of first generation or late July by reducing the larval mortality due to high temperatures of irrigation water. The peak density is reached at the first generation in the following year and crashes in the second generation (e.g. Miyashita 1982, Kiritani 2005b). Low temperatures in July preceded the 1953 outbreak during 1950-1952. It is impossible, however, to explain the delayed occurrence of outbreaks in centrifugal manner by the climatic release theory. Dispersal of moths was strongly suggested for this phenomenon. The fact that the coverage of the 1953 outbreak was within 150km in diameter also rejects the possibility of delayed occurrence of climatic factor. The geographical limitation of the 1953 outbreak in Kyushu suggested the area to be covered when area-wide IPM of *Chilo* is planned.

Single-field viz area-wide EIL and monitoring system

Carlson (1979) describes a dilemma of centralized pest control decisions: what level of control should be provided, and how should the members of the group be charged ? Pest severity is not likely to be equal on all farms in the areas, and farmers differ in their tolerances for pest damage or risk of pest damage. Therefore, one of the major problems for the implementation of an area-wide pest management program is how to determine an appropriate level of pest suppression to be provided (Kiritani 1992).

Because pest control recommendations are utilized over a wide area and include several thousand rice growers, they tend to be issued in favor of chemical control. When an overall density of pests in one locality is just equal to the CT or EIL, the pest density in half of the fields would be less than CT or EIL.

Consequently, Kidokoro and Kiritani (1982) have proposed the use of statistical EIL for small size farm conditions. Since the frequency distribution of *Chilo* injury to paddy fields in a particular area has been shown to follow a Poisson distribution, this gives a statistical projection for the probability that a given field has a pest density greater than the EIL. With a within-field-EIL of 30% hill infestation for *Chilo*, the proportion of fields with greater than 30% infestation can be calculated (Fig. 5). We can make recommendations to individual growers concerning the insecticide control with the probability of risk that his field has a pest density greater than the EIL (Andow and Kiritani 1983).

IPM perspective in relation to biodiversity

In the past, most studies on paddy ecosystems have focused on productivity and its stability in terms of rice yields. Arthropods in paddy ecosystems can be classified into three main groups according to their ecological requirements: (1) resident species adapted to the continuous cropping of rice in the same field, e.g. *Chilo*; (2) migratory species adapted to exploit rice as an annual crop, e.g. planthoppers and (3) aquatic species originating from still water habitats in wetlands. Concerning groups 1 and 2, integrated pest management (IPM) programs, which have a primary objective of maximizing economic profit on the farm, have been implemented with various degrees of success. Although IPM is becoming widespread, those insects (Tada-nomushi = species of unknown or uncertain function that routinely occur in the habitat) that have no direct economic impact on rice production have been mostly ignored as an important element in the rice ecosystem. Consequently, some aquatic insects are in danger of extinction, thus requiring conservation. It is recommended to adopt IPM strategies and tactics that are compatible with conservation (Kiritani 1979, 2000, Kiritani and Naba 1994).

A new concept, integrated biodiversity management (IBM), has been proposed under which IPM and conservation are reconciled and made compatible with each other (Kiritani 2000). IPM requires that densities of each pest species be kept below their specific economic injury level. In conservation, target species have to be managed to remain above a specific extinction threshold levels (Fig. 6). The status of a pest species could be changed by IPM into a Tada-no-mushi (minor or nontarget insect), which can function as potential food for generalist predators or parasitoids. *Scirpophaga* is currently almost extinct in Japan. From the viewpoint solely of an economically oriented IPM, however, this is of little consequence because *Scirpophaga* was an important rice pest to be controlled. But, in view of IBM, such relatively rare species, such as *Scirpophaga* and some aquatic insects can be considered a target for conservation.

Farm management techniques that make the difference between the population levels for an EIL and an extinction threshold as great as possible should be introduced in the IBM system. As an alternative to the EIL, we could use another EIL in which the "E" refers to "ecological or environmental." This new EIL, however, has yet to be established (Kiritani,2005a).

In general, global warming may work in favor of natural enemies (except for spiders) by increasing the number of generations (Kiritani, 1999). Biological control is expected to become a more important control tactic in the future. Uncertainty remains, however, regarding the extent to which host-parasitoid phenology will be synchronized after an increase in the number of generations. Parasitism and predation would be expected to increase through this numerical response and enhance the natural control.

Conclusion

Our experience in Japan as well as in temperate Asia strongly suggests that (a) cultural practices should be a nucleus in implementing the pest management system for *Chilo*; (b) it requires at least one decade for a system to be fully effective, even under a planned scheme; (c) the area should be large enough to cover population displacement of rice stem borers, and (d) the integrated management of the key pest could be achieved under a high-technology system of rice production without impairing the yield.

The paddy field is not only the habitat of rice arthropods, but it is also an alternative habitat for many endangered aquatic insects associated with the vanishing natural wetlands. Therefore, the rice management strategy should strike a balance between IPM and conservation, which is referred to as IBM (Kiritani 2000, 2005a). This is the prerequisite to develop the sustainable agriculture system arewide in paddy ecosystems.

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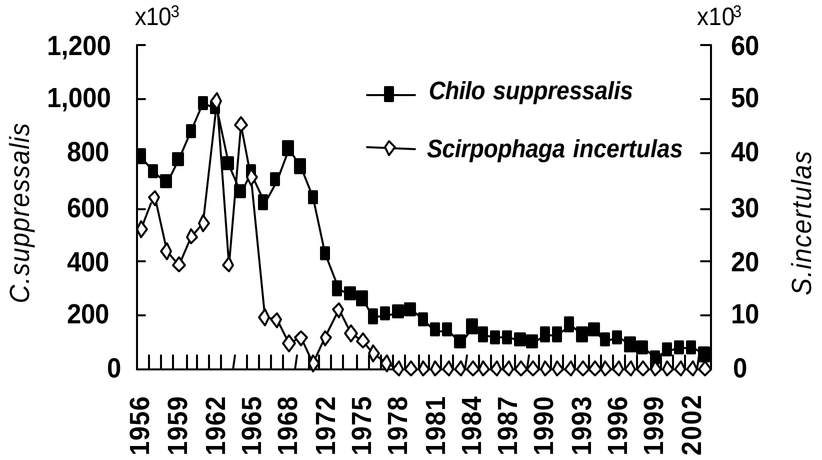

Fig.1. Decline in hectares of rice fields infested by borers.

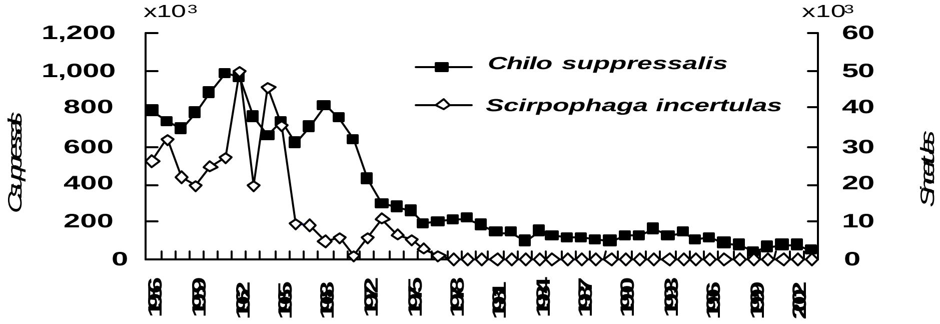

Fig. 2 . Larval parasitism (%) in relation to the annual moth catches at Kuroishi, Aomori Prefecture.

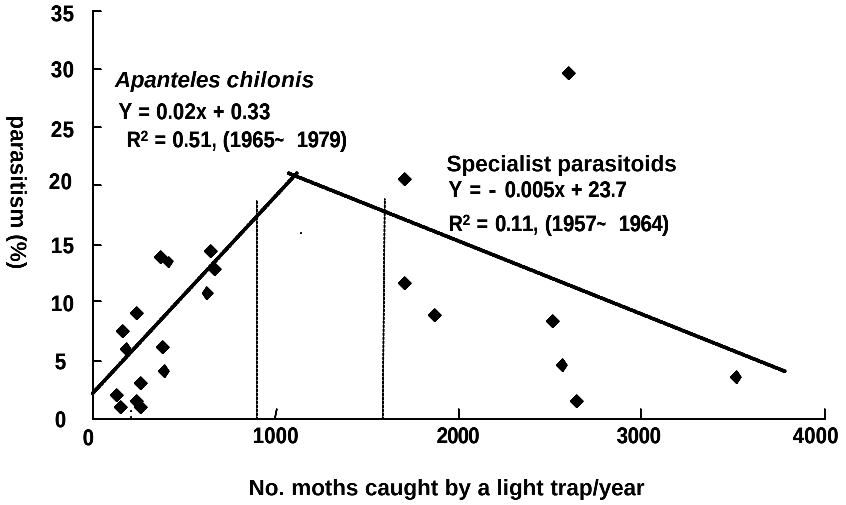

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Fig. 3. A hypothetical reproduction curve for *Chilo suppressalis.*
S_L: Low equilibrium due to parasites.
S_H : High equilibrium due to intraspecific competition.

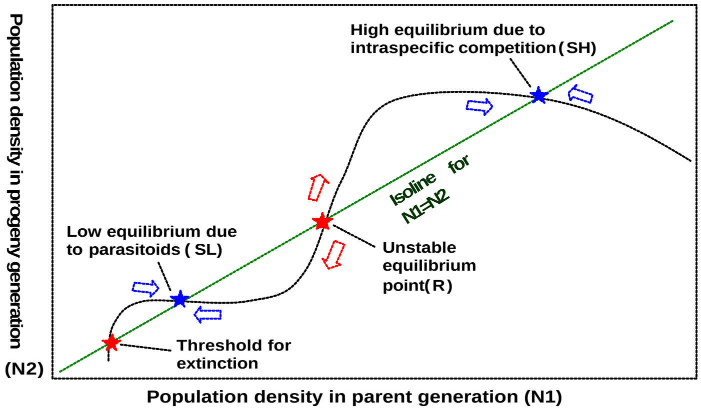

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Fig. 4. Centrifugal extention of the 1953 outbreak of *Chilo suppressalis* in Kyushu. 1 Shirota; 2 Saga; 3 Tara; 4 Itoshima; 5 Munakata; 6 Imari; 7 Tosu; 8 Yukuhashi; 9 Isahaya; 10 Chikugo; 11 Shimabara; 12 Asakura; 13 Futsukaich; 14 Ukiha; 16 Togitsu; 17 Kikuchi; 18 Kumamoto; 19 Kuchinotsu; 20 Seto; 21 Amakusa; 22 Sasebo; 23 Hirado.

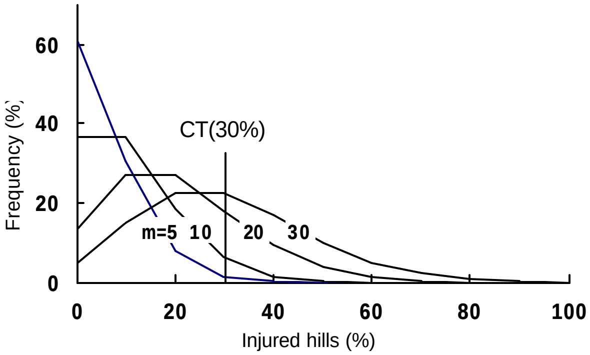

Fig. 5. Frequency curves of *Chilo suppressalis* injury to paddy fields, for different within paddy mean injury levels (*m*). The frequency of distribution follows a Poisson distribution. The area under the curves that is to the right of the CT gives the proportion of paddies with infestations causing economic damage (5% yield loss).

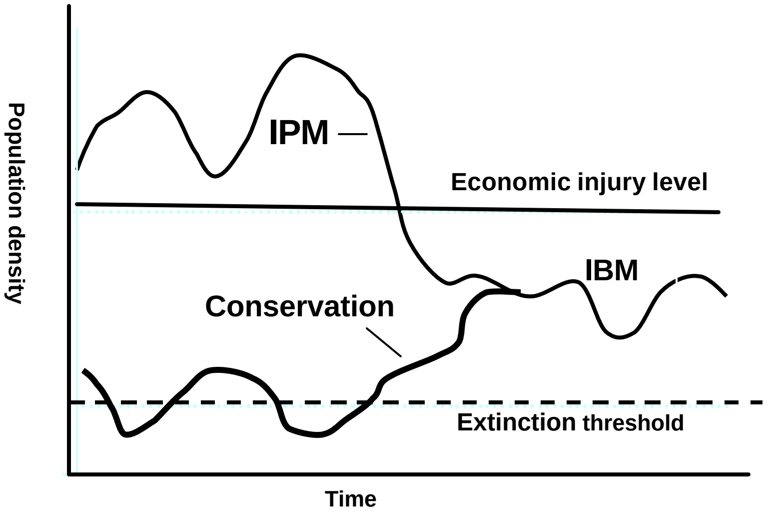

Fig. 6. Illustration of the concepts of IPM, conservation, and IBM.

Table 1. Factors responsible for the population decrease in *Chilo supperssalis*. (Kiritani 1988)

Factors	Stage of larvae affected	Since around
Cultivation of early planted rice	Overwintering larvae in the second genearation	1955
Replacement of panicle weight type with paniclue number type varieties*	Growing larvae of the first and second generations	1955
Use of BHC granules	Growing larvae of the first and second generations	1960
Utilization of stalks as manure for vinyl house culture	Overwintering larvae in the second generation	1960
Early harvest of middle season rice by 2-3 weeks	Overwintering larvae in the second generation	1960
Increase in amount of slug by 2-3 times	Growing larvae of the first and second generations	1965
Introduction of combined harvester in association with burning stalks	Overwintering larvae in the second generation	1965
Nursery tray insecticide treatment in association with machine planting	First generation larvae	1970

*Panicle weight type: big (heavy) panicles, but less in number of panicles.
Panicle number type: more panicles, but each panicle is smaller.

Table 2. Comparison between the areas with and without insecticidal controls in terms of injured sheaths caused by C. suppressalis in Niigata Prefecture. (Emura and Kojima 1979)

Year	No insecticide treatment (17ha)	Conventional control area (1200 ha)
1975	First year of expt.	First year of expt.
1976	2.5*	2.5*
1977	2.1	3.1
1978	2.0	3.5
1979	2.3	3.7

* Paddy fields were examined for injured sheaths before the chemical treatment

Table 3. Time when Apanteles chilonis became dominant dominant among larval parasitoids of Chilo suppressalis in Japan. (Kiritani 1988)

Prefecture	Time	References
Fukuoka	1955-57	Gyotoku 1960;Tateishi 1962
Fukui	1962	Tomonaga and Imamura 1966
Tochigi	around 1964	Katayama 1971
Aomori	1963	Toki, Fujimura and Fujita 1974