Action Range of the Sex Pheromone of the Rice Stem Borer Moth, *Chilo suppressalis* (WALKER) (Lepidoptera: Pyralidae)¹

Akira KONDO and Fukusaburo TANAKA

Okayama Prefectural Agricultural Experiment Station,
Sanyo-cho, Okayama 709-08, Japan

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To obtain the basic information for establishing the pheromonal monitoring system in *C. suppressalis*, the range of stimulation and the sampling range of the synthetic sex pheromone were estimated. In a playground the range of stimulation was estimated by observing behavioural responses of caged male moths to be 36.8 m at a wind speed of 0.36 m/s with little difference between the generations. The daily sampling range in the paddy field was estimated by trap interaction experiments to be more than 100 m in radius for the overwintered generation and ca. 50 m in radius for the first one. Also, the mean flight distance of marked male moths during one night was significantly longer in the overwintered generation (112.0 m) than in the first (18.8 m).

Key words: *Chilo suppressalis*, sex pheromone, range of stimulation, sampling range

INTRODUCTION

The rice stem borer, *Chilo suppressalis* (WALKER) is a significant rice pest in temperate and subtropical Asia, and has two generations a year in most parts of Japan (e.g. MIYASHITA, 1982). The pest status of the borer in Japan has become low recently (KIRITANI, 1992), but small local outbreaks have been observed since 1978 (TANAKA et al., 1981; SUGIURA, 1984). For instance, such local outbreaks are common to some regions of the Okayama Prefecture where severe damage to rice crops have occurred almost every year, despite the overall population density in the prefecture being low. Under these circumstances, it is desirable that appropriate control for the borer should be done by the fine-grained population monitoring system. The light trap has been a main tool for the population monitoring to date, but it is difficult to monitor such fine-grained populations by the light trap due to the difficulty in placement and the serious census labor. TATSUKI et al. (1983) identified the third component, (Z)-9-hexadecenal, of the female sex pheromone of *C. suppressalis*. Since then, several studies for developing the monitoring system by using the 3-component blend have been made (e.g. KANNO et al., 1985; TATSUKI, 1990; KONDO and TANAKA, 1991).

The action range of sex pheromones is a fundamental subject in developing the pheromonal monitoring system for insect pests. Thus, many studies on the action

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range, especially for Lepidoptera, have been conducted (e.g. NAKAMURA and KAWASAKI, 1977; ISHII et al., 1981; VAN DER KRAAN and VAN DEVENTER, 1982; PERRY and WALL, 1985). However, the estimated ranges, even in the same insect under similar experimental conditions, may differ considerably for each researcher because of the lack of established definitions. WALL and PERRY (1987) proposed the following three definitions to clarify terms. (1) Sampling range: the maximum distance where insects can be shown to reach the source in a given time period. It comprises the radial distance from the source travelled both before stimulation and during attraction. (2) Range of stimulation: the maximum distance at which an attractive source can be shown to elicit a response. (3) Range of attraction: the maximum distance over which insects can be shown to direct their movement to the source. According to these definitions, we estimated in this study the sampling range and the range of stimulation of the synthetic sex pheromone of *C. suppressalis* to obtain the basic information for establishing the monitoring system.

MATERIALS AND METHODS

Insects. Larvae of *C. suppressalis* were taken from the rice stems at harvest in Sanyo-cho on 26 October, 1989 and on 26 October, 1990. These larvae in the stems were placed in the field until pupation and were served for the overwintered generation moths. For the first generation moths, egg masses on rice seedlings and also female moths were collected in Sanyo-cho on 13–15 June, 1990 and 12–14 June, 1991, and standard laboratory rearings (UCHIUMI, 1974) under a 16L–8D photoregime (3:00–19:00 light phase) at 25°C were conducted for each year until the pupal stage. Male moths of each generation were emerged under the same photoregime at 25°C.

Range of stimulation. Behavioral responses of male moths to a pheromone source at various distances were observed to estimate the maximum response distance. The synthetic sex pheromone used was a mixture of (Z)-11-hexadecenal, (Z)-13-octadecenal and (Z)-9-hexadecenal (48:6:5). The mixture (0.6 mg) and 0.06 mg of an anti-

Fig. 1. a) The layout of a pheromone source and cages each containing two male *C. suppressalis* for the experiment of "range of stimulation". ●: Pheromone source, +: Cage. b) The partial layout of pheromone traps and a release point for the experiment of "sampling range". ●: Trap, Δ: Release point. Traps were set at radii of 8, 16, 32, 64, 128 and 256 m from the release point.

oxidant, BHT (butyl hydroxytoluene) were impregnated into a rubber septum (Shin-Etsu Chemical Co. Ltd.). Experiments were conducted in a 70×80 m airy playground with no wild moths on 2, 5 July, 1990 and 1 July, 1991 for the overwintered generation and on 16, 19 August, 1991 for the first. Two male moths of up to 3-day-old were introduced into a stainless screen cage ($5 \times 10 \times 15$ cm). Because, if only a male moth were introduced to avoid a disturbing effect, there was also a risk that no data was available when it disappeared or died by handling troubles under darkness. A pheromone source was placed on a wooden stick at 0.5 m above the ground at 20:00. Then, as shown in Fig. 1-a, the cages were placed directly down wind of the pheromone source (axis O) at 0.1 m above the ground and also on the both sides at an angle of 45° off the direct line (axis A and A'). Intervals between cages were 2 m and 4 m as far as 20 m and 40 m, respectively. The placements were completed within ca. 20 min. Positive behavioral responses used as criteria were as follows: vibration of antennae; walking; walking while wing fanning; continuous flying; intermittent flying. Observations were conducted at 20:50, 21:20 and 21:50 by two persons with red lights for ca. 10 min each. Wind direction and speed were recorded by an automatic recorder which was placed at less than 50 m from the pheromone source. Sunset was at ca. 19:20 and 18:50 for the overwintered and the first generation, respectively.

Sampling range. Sampling range was estimated by trap interaction experiments. Also, marked male moths were released to detect the flight distances. Experiments were conducted in 100×100 m-scale paddy fields with wild moths (ca. 14 ha in total) of Okayama Pref. Agr. Exp. Stn. in 1991. Sticky pheromone traps (Takeda Chemical Co. Ltd.) were placed inside the paddy fields at 0.5 m above the ground at radii of 8, 16, 32, 64, 128 and 256 m from a release point (Fig. 1-b). Four traps were set for each radius. Male moths of up to 3-day-old were marked on their forewings with marking ink. The color was altered for each release. Less than 20 marked moths were introduced into a plastic container (10 cm in radius and 5 cm in depth) with a water-soaked cotton and a folded paper. The container were carried to a release stand at 0.5 m above the ground and were opened carefully after the moths had settled down. Releases were conducted at 19:00 on 2, 6 July for the overwintered generation (132 moths in total) and at 18:30 on 12, 17 August for the first one (427). Numbers of marked and wild male moths captured in each trap were counted on the next day after a release.

RESULTS

Range of stimulation

Estimated ranges of each generation's positive response were plotted against mean wind speeds during each census when the angular dispersion of each axis (A, O, A') from the most frequent downwind direction was within 45° (Fig. 2). A convex curve was obtained. In this analysis both generations were included, because responsiveness of the male to pheromone was not significantly different between generations in a laboratory bioassay (KONDO et al., 1993) and also the maximum response range of each generation obtained in this study was not likely to be different. From the average of the upper 5 points, the maximum downwind range of the pheromone was evaluated to be 36.8 m at a wind speed of 0.36 m/s. This corresponded well to the result that

Fig. 2. The relationship between maximum response distance in male *C. suppressalis* from a pheromone source and mean wind speed. ●: Overwintered generation, ○: First generation.

Fig. 3. Recapture rates of marked male *C. suppressalis* on the next day after a release at various distances from the release point. ●: Overwintered generation, ○: First generation.

the maximum recapture rate of marked male moths in the pheromone trap, when the moths was released 30 cm apart from the trap, was obtained at a wind speed of 0.34 m/s (KONDO and TANAKA, unpubl.).

Sampling range

Figure 3 shows the recapture rates of marked male moths at various distances from a central release point. In the overwintered generation, the maximum recovery was obtained at a distance of 128 m from the release point. Whereas in the first generation, it was at 8 m, the closest to the release point. Moreover, some overwintered male moths were recaptured even at 256 m, but no first generation male moths were

Table 1. Total recovery and mean flight distance of marked male *C. suppressalis* on the next day after a release: comparison between generations

	Overwintered generation	First generation	
Total recovery (%)	14.9 (101) ^a	18.3 (404) ^a	ns ^b
Mean flight distance (m)	112.0	18.8	*** ^c

^a Number of marked male moths which took off the release point.^b $p > 0.05$ (χ^2 test).^c $p < 0.001$ (MANN-WHITNEY's *U* test). Fig. 4. Changes in pheromone trap catches of the wild male *C. suppressalis* with increases in trap intervals. ●: Overwintered generation, ○: First generation. Vertical bars indicate standard errors.

recaptured beyond 64 m. As shown in Table 1, the mean flight distance of marked moths on the next day after a release was significantly longer ($p < 0.001$) in the overwintered generation (112.0 m) than in the first (18.8 m), though the total recovery was not significantly different between the generations ($p > 0.05$).

Captures of wild male moths to a pheromone trap are expected to rise with a decrease in the overlapping degrees of the sampling range. Thus, the trap catches would reach an equilibrium at a certain trap interval if the distribution of the moth population is not clumped. In the case of this study, it was inferred that the moth population was not clumped, because no specific hibernating sites were found within or around the experimental field. If the sampling range is assumed to be a simple circle, half of the trap interval at which the equilibrium is obtained would equal the sampling range. Then, the daily catches of the wild male moths at each trap were plotted against the distances to the nearest trap (Fig. 4). In the overwintered generation, the trap catches increased linearly up to ca. 200 m. Whereas in the first generation, the trap catches gradually increased to reach a maximum at ca. 100 m and did not increase thereafter. Although significant difference between the points of ca. 50 m and 100 m was not found ($p > 0.05$), this may be due in part to the small sampling size ($n=4$). Therefore, the daily sampling range of the trap may be roughly estimated

to be more than 100 m in radius for the overwintered generation and ca. 50 m in radius for the first. This differential tendency between generations coincided with that of the mean flight distance of marked male moths (Table 1).

DISCUSSION

Most of the female *C. suppressalis* of the overwintered generation would colonize in paddy fields after mating outside (TANAKA et al., 1987), whereas the first generation moths emerge from rice plants growing in paddy fields. Thus, the initial virgin ratio of the moth population in the paddy field is expected to be higher in the first generation than in the overwintered one, which may cause greater competition between wild virgin females and the pheromone traps in the first generation (KONDO et al., 1993). In this study, the longer flight distance of marked male moths and the larger sampling range of the pheromone trap were detected in the overwintered generation (Table 1, Fig. 4). Although most female moths mate only once, the males are capable of mating for several nights (e.g. MIYASHITA, 1982). Therefore, most of the overwintered male moths would fly longer distances actively searching for the traps, because the pheromone sources for the male moths would be almost limited to the traps. In the overwintered generation, the recovery of marked male moths in the two traps (8 m and 16 m) close to the release point were remarkably low relative to those in other traps (Fig. 3). The reason for this may be that when male moths at the release point are not within the sampling range of the closer traps due to the conditions of wind directions or wind speeds, they may easily pass by such closer traps in a short time and fly to other distant traps. On the contrary, the first generation male moths would not have to actively search for the traps because of the relatively high density of wild virgin females in the paddy field. This resulted in the shorter flight distance and smaller sampling range in this generation. Since responsiveness to the pheromone and the flight ability of male moths were both not significantly different between generations (KONDO et al., 1993), these remarkable differences in the two generations would be mainly caused by different environmental conditions such as the population density of wild virgin females, which was not estimated in this study, however.

The range of stimulation of the pheromone estimated in a playground was 36.8 m at a wind speed of 0.36 m/s with few differences between the generations (Fig. 2). In the paddy field, the range in the first generation may be smaller because of the competitive effect of virgin females as in the sampling range. However, environmental conditions of the playground may be similar to those of the paddy field in the case of overwintered generation, because the two places are both airy and have few virgin females. Therefore, at least in the overwintered generation the range of stimulation obtained in the playground would not be far off from that in the paddy field.

The range of attraction defined by WALL and PERRY (1987) could not be clarified in this study. NAKAMURA and KAWASAKI (1977) estimated it to be the active space of the sex pheromone of *Spodoptera litura* (F.), which is equal to the range of attraction (WALL and PERRY, 1987), by comparing the results of carefully-timed mark-and-recapture experiments with those obtained from a simulation model. However, this space was very far from the maximum range estimated by observing the continuous flying and intermittent flying of the caged male moths (NAKAMURA, 1976). Thus, to obtain the range of attraction for *C. suppressalis*, experiments should be conducted

by the method of NAKAMURA and KAWASAKI (1977) or by releasing male moths at several points with different distances from a pheromone source and determining the range at which the male moths show significant upwind flights to the source (e.g. ISHII et al., 1981; WALL and PERRY, 1987).

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