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Communication Disruption for Control of the Beet Armyworm, Spodoptera exigua (Hübner), with Synthetic Sex Pheromone

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Abstract
The feasibility of synthetic sex pheromone as a communication disruption agent for the control of the beet armyworm, *Spodoptera exigua* (Hübner), was examined by dispensing a 7:3 mixture of (Z, E)-9, 12-tetradecadienyl acetate and (Z) -9-etradecen-1-ol. When the pheromone was dispersed into a 155 ha field, attraction of male moths to sex pheromone traps was completely inhibited and densities of egg masses and young larvae were reduced to 6% and 1%, respectively, relative to those in an untreated field about 9 km away. Follow-up studies enabled to estimate that the rate of mating inhibition in the treated field was ca. 97%. When the pheromone was dispersed into 0.07-0.13 ha greenhouses, the larval density was drastically reduced within 1 month, while the density increased to about 9 time of the initial density in the untreated greenhouse. Treatment with 500 dispensers in a 0.02 ha greenhouse reduced the estimated mating ratio in females to 20-50%, whereas mating rate was 95% without treatment. When sex pheromone treatment was combined with the use of light trap, the mating rate was reduced to 2-3%. These results indicated the efficacy of synthetic sex pheromone in controlling S. exigua population both in open fields and in greenhouses.

Discipline: Insect pest
Additional key words: Welsh onion, greenhouse, (Z, E)-9, 12-tetradecadienyl acetate, (Z)-9-tetradecen-1-ol, mating delay

Introduction

The beet armyworm (BAW), *Spodoptera exigua* (Hübner), (Lepidoptera: Noctuidae), is a serious pest of okra (*Abelmoschus esculentus* Moench), onion (*Allium ascalonicum* L.) and asparagus (*Asparagus officinalis* L.) in Southeast Asia, especially in Thailand (Jee-rajunya, personal communication). This insect has attacked Welsh onion (*A. fistulosum* L.) in Kochi and Kagoshima Prefectures since the early 1980's[3,8]. The effectiveness of most of the insecticides used (including methomyl and EPN) has declined. Insecticides were certainly effective in the early 1980's[9], but this species appears to have the potential to rapidly acquire resistance[5,9]. The development of a new technique aside from insecticide spraying was necessary to control this insect.

Brady & Ganyard[1] identified one of the sex pheromone components of BAW as (*Z,E*)-9,12-tetradecadienyl acetate (Z9E12-14:Ac). Mitchell & Doolittle[6], however, reported that this compound showed no attractant activity by itself. Tumlinson, Mitchell & Sonnet[11] who reexamined the sex pheromone components, identified 11 compounds from virgin female secretions, and revealed that (*Z*)-9-tetradecen-1-ol (Z9-14:OH) was also an essential component for male attraction. Mitchell, Sugie &

This review is based on the original articles[8-10,12-17].

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Tumlinson[7] developed an effective formulation: a mixture of 0.1 mg of Z9E12-14:Ac and 0.01 mg of Z9-14:OH on a rubber septum. In Japan and Taiwan, this formulation was found to be effective for male attraction[2,12], and to be useful for monitoring seasonal occurrence.

Communication disruption in open onion fields

Experiments were conducted in two areas in Kochi Prefecture of Japan in 1987. The treated area covered about 155 ha of which Welsh onion plots comprised about 24 ha. This area was considered to be isolated from other agricultural areas. The untreated area was 9 km away from the treated one.

The sex pheromone dispensers were supplied by Shin-Etsu Chem. Co., Ltd.; a sealed polyethylene tube 20 cm long and containing 80 mg (AI) of a 7:3 mixture of Z9E12-14:Ac and Z9-14:OH and an aluminum wire. Dispensers were distributed evenly in the 24-ha Welsh onion fields at the rate of 1,000 dispensers/ha. Other parts of the treated area (about 130 ha) including rice fields, orchards and forests, were treated with 320 dispensers/ha. In the fields, each release point had three dispensers attached to the top of a 60-cm plastic stick. Forest and orchard trees had dispensers directly attached, at 1 to 1.5 m above the ground. The total number of dispensers was 66,000, and the total net amount of sex pheromone used was about 5.3 kg. Sex pheromone dispensers were set on July 16 and 17, and removed on September 17 and 18.

1) Effects of communication disruption

BAW moths were captured with the light trap in the treated area throughout the treatment period (Fig. 1), indicating that adults emerged in the treated area throughout the treatment period. Conversely, trap catch with sex pheromone trap was as low as with empty traps during the treatment period, indicating that communication disruption was certainly effective throughout the period.

The mating ratio of the females caught with the light trap increased during the treatment period (Table 1): 40–60% in late July and early August, 70–80% in mid and late August, and 70–90% in early and mid-September. However, considering that the capturing efficiency of virgin females was about 25% of that for mated females, the real mating rate in

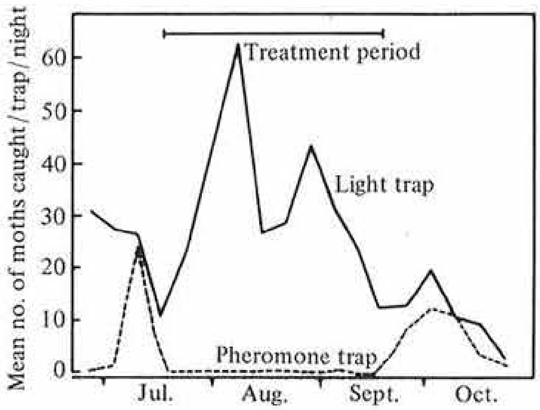

Fig. 1. Catches of BAW with sex pheromone traps and light trap in the area treated with synthetic sex pheromone (1987, Kochi)

Table 1. Catches of BAW moths with light trap in the area treated with synthetic sex pheromone (1987, Kochi)

Date	No. of individuals caught				Mating ratio[b] (%)	Sex ratio[c] (%)
	Female		Male	Unknown[a]		
	Mated	Virgin				
7/24–7/30	16	24	134	9	40	23
7/31–8/06	59	43	97	8	58	51
8/07–8/13	28	7	79	2	80	69
8/14–8/20	21	7	77	2	75	27
8/21–8/27	35	15	33	2	70	60
8/29–9/03	93	36	121	7	72	52
9/04–9/10	35	5	62	3	88	39
9/11–9/17	27	11	47	6	71	45
— Removal of pheromone dispenser —						
9/18–9/24	42	4	31	5	91	60
9/25–10/01	58	0	45	9	100	56

a): due to lack of abdomen.
b): {(no. of females mated)/(no. of females caught)} × 100.
c): {(no. of females caught)/((no. of females) + (no. of males))} × 100.

the field population was estimated to be 20–50% in the treatment period[15]. This estimation seemed too high to account for the reduction of the field population density. It is thus necessary to take the effect of mating delay into consideration as described below.

2) Effects on BAW population

Onions were planted on about 1 m wide ridges in the plots (5–10 a) which were scattered in the experiment areas. Damaged leaves were collected and dissected to identify the instar and to count the number of larvae. Farmers sprayed insecticides such as methomyl, EPN, permethrin and fenvalerate-dimethoate against BAW independently of the experiment. However, these insecticides were ineffective[9] and not considered to have any effect on population density. In the treated area, the egg mass density was less than 0.5/100 hills throughout the period. Conversely, in the untreated area, mean egg mass density reached peaks twice, followed by peaks of the young instar larvae (Fig. 2) and then of the old instar larvae.

3) Follow-up experiments in 1988

In 1988, sex pheromone was released at a higher rate into a smaller area than in 1987 to confirm the population suppression effect. Treated area was the northern one third (about 50 ha) of the treatment area of 1987, where Welsh onion plots comprised

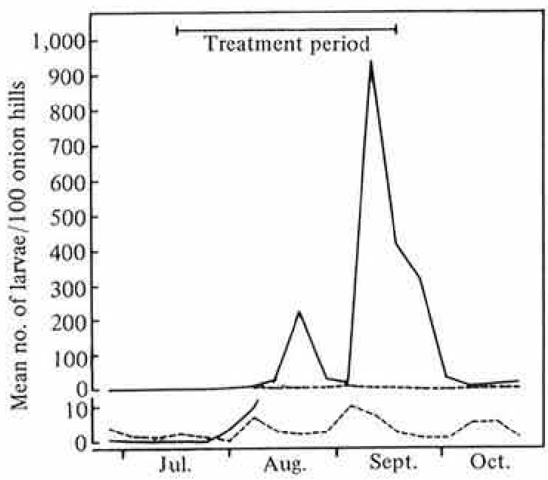

Fig. 2. Population density of 1st and 2nd instar larvae of BAW in areas treated (broken line) and not treated (solid line) with synthetic sex pheromone (1987, Kochi)
Lower inset is a magnification emphasizing the population trend in the treated area.

about 24 ha. Dispensers were set evenly in Welsh onion plots and other cultivated plots at the rate of 1,500 and 600 tubes/ha, respectively. Sex pheromone dispensers were set on July 6 to 8 and removed on September 30. In the treated area, BAW population was suppressed at a very low level, and the infestation was less than 0.2% throughout the treatment period. Conversely, in the untreated area, population density gradually increased until late August, and rapidly increased in early September. The maximum density of young larvae exceeded 400 individuals/100 hills. The mean infestation rate of hills increased to more than 50% in mid-September. It was confirmed again that treatment with synthetic sex pheromone successfully reduced the field BAW population.

Communication disruption in greenhouse

1) Preliminary experiment in farmers' greenhouses

BAW has been a severe pest also in greenhouse cultivation of Welsh onion. The greenhouses were covered with a polyvinyl sheet but the lateral sides with a net (3 × 4 mm mesh). BAW repeated generations there, since Welsh onion was continuously cultivated.

Two greenhouses for Welsh onion cultivation were treated with 500 dispensers/10 a: house A, 579 dispensers/11.6 a; house B, 330 dispensers/6.6 a, and one greenhouse at the rate of 100 dispensers/10 a: house C, 66 dispensers/6.6 a. One greenhouse was used as a control: house D (13.2 a). These greenhouses were at least 1 km apart from each other. Light traps (lamp: BLB 20W) were set in and out of the house A.

The larval density decreased drastically in the treated houses A and B (500 dispensers/10 a), whereas it increased rapidly during the treatment period in the untreated house D (Table 2). The mating rate of females captured in the treated house A was very low as compared with that of females trapped out of the greenhouse (Table 3). These data indicate that treatment with synthetic sex pheromone reduced the mating rate and resulted in the decrease of the larval population density.

However, the light trap captured so many BAW moths that it seemed to affect the population density. Therefore, follow-up experiments were considered to be necessary to confirm the effect of pheromone in greenhouses.

Table 2. Densities of BAW larvae in greenhouses treated with synthetic sex pheromone (1987, Kochi)

Date	No. of larvae/20 m^2			
	House A[a)]	House B	House C	House D
7/30	74 (1.00)	63 (1.00)	450 (1.00)	36 (1.00)
8/12	21 (0.28)	68 (1.08)	333 (0.74)	167 (4.64)
8/19	1 (0.01)	23 (0.35)	333 (0.74)	325 (9.10)
9/02	0 (0.00)	0 (0.00)	–[b)]	–[b)]

a): For the treatment of the greenhouses, see text. Pheromone dispensers were set on July 22 and removed on September 22. Values in parentheses represent the relative densities (1.00 on 7/30).

b): All the crops had been harvested.

Table 3. Catches and mating ratios of BAW moths with light traps in and out of the greenhouse treated with synthetic sex pheromone (1987, Kochi)

Date	No. of moths caught			
	In greenhouse		Out of greenhouse	
	Male	Female	Male	Female
7/30	14	9 (0)	39	13 (0.77)
7/31–8/02	162	188 (0.005)	144	84 (0.54)
8/03–8/06	231	131 (0.069)	172	124 (0.41)
8/07–8/09	120	110 (0.064)	175	76 (0.76)
8/10–8/12	22	18 (0)	53	23 (0.78)
8/13–8/19	38	15 (0.13)	37	41 (0.58)

Values in parentheses represent mating ratio of females.

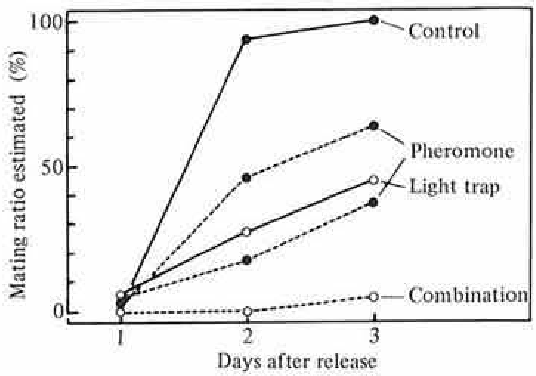

Fig. 3. Mating ratio of BAW females released together with males in greenhouse when synthetic sex pheromone and/or light trap were used or not used (September 1988, Kochi)

2) Evaluation of effects of pheromone and light trap

A series of experiments were conducted to evaluate the effect of synthetic sex pheromone and light trap on BAW population in Kochi in September, 1988. Marked BAW moths were released into a greenhouse (2 a) where synthetic sex pheromone and/or light trap were used or not used. In the greenhouse, Welsh onion and egg plants were cultivated together.

When the greenhouse was not treated with pheromone, the mating ratio of BAW reached about 95% by the 2nd night (Fig. 3). This indicates that most of the females mated in the 1st night of release, since mating of BAW moths starts after midnight and continues until around dawn[13] so that the mating ratio in the sample of the 2nd night should reflect the mating ratio in the 1st night.

When the greenhouse was treated with synthetic sex pheromone, the mating ratio of BAW was 20–40% in the 2nd night and 40–60% in the 3rd night (Fig. 3). These results show that even a higher dose of synthetic pheromone dispenser (25,000 dispensers/ha) than the open field application (1,000 disp./ha) was insufficient to inhibit the BAW mating completely.

When the light-trap was set from the 1st night but not permeated with pheromone, the mating ratio was 25% and 42% in the 2nd and 3rd nights, respectively. The light-trap captured ca. 70% of males in the 1st night of release and 85% by the 2nd night. Removal of male moths from the population should have resulted in the decrease of the mating ratio.

When pheromone treatment was combined with

Table 4. Influence of delayed mating on reproduction of BAW females (mean ± S.D)

Age (d)	Mating ratio (N)	No. of eggs laid	No. of eggs hatched	Hatchability	Relative fecundity
1	100 (10)	991 ± 323	899 ± 372	0.910	92
2	90 (10)	1,165 ± 248	981 ± 433	0.850	100
3	100 (10)	992 ± 271	873 ± 354	0.856	89
4	100 (10)	655 ± 217	465 ± 258	0.714	47
6	90 (10)	549 ± 204	227 ± 274	0.341	23
8	60 (10)	342 ± 252	97 ± 167	0.171	10
10	30 (10)	105 ± 148	3 ± 9	0.019	0

Females with different ages were paired with a 2-d-old male, respectively.

the use of a light trap, mating ratio was less than 5% even by the 3rd night, reflecting the combined effect of communication disruption by pheromone and mass trapping of male moths by light trap. The results suggest that this combined effect was certainly responsible for the population reduction observed in the preliminary experiment (Table 2).

Influence of delayed mating

In the open field experiment in 1987, we observed a mating ratio of 50–80% in the females caught with the monitoring light trap in spite of the drastic reduction in the field population density. Considering that the capturing efficiency of virgin females was about 1/4 of that of mated females, the real mating rate in the field population was tentatively estimated to be 20–50% [15]. This estimated ratio seemed to be too high to account for the reduction of the field population density.

1) Effect of mating delay on BAW reproduction

One to 10 days old BAW females were allowed to mate with 2-d-old males. The numbers of eggs laid and hatched are shown in Table 4. Three-d-old or younger females laid more than 900 eggs and more than 85% of the eggs hatched. Four-d-old or older females laid fewer eggs and their hatchability decreased remarkably. The number of unfertilized eggs laid before pairing increased in 4-d-old and older females. Mating ratios decreased in 8-d-old or older females. The mean longevity of unmated female was 9.9 d after emergence in a separate investigation. Delayed mating apparently resulted in decreased reproduction of BAW.

2) Simulation of reproduction under communication disruption

According to Kiritani & Kanoh[4], cumulative percentage of mated females and realized expected reproduction (RER) were calculated assuming that there was a difference in the mating inhibition (Table 5). These suggest that when the daily mating inhibition was less than 70%, the reduction in cumulative mating ratio would be 5% or less and consequently the RER would be reduced only by 30% or less. A reduction of more than 90% of daily mating inhibition would be necessary to expect more than 70% reduction of reproduction. In the 1987 experiment, although the BAW population was remarkably reduced in the fields (Fig. 2), the real mating rate was estimated to be 20–50%, based on the difference in the trapping efficiency between mated and virgin females[15]. Application of these estimates to the simulation depicted in Table 5 indicated that the daily inhibition of mating would have been more than 90% throughout the treatment period. In this simulation, removal of females caused by death or dispersal is not considered, which would result in the overestimation for both daily inhibition and RER. Therefore, it is estimated that BAW

Table 5. Cumulative ratio of mated females and realized relative expected reproduction in a hypothetical BAW population

Daily mating inhibition	Cumulative ratio of mated females	Cumulative realized expected reproduction
0.00	1.00	92
0.20	1.00	93
0.40	1.00	90
0.60	0.99	80
0.70	0.95	71
0.80	0.85	56
0.90	0.59	33
0.95	0.33	18
0.98	0.15	8
0.99	0.08	4

mating should have been reduced by 95% or more in the 1987 experiment.

Conclusion

The control effect of the synthetic sex pheromone as a communication disruption agent against BAW population was confirmed both in open field and in greenhouse experiments. The sex pheromone formulation has already been registered as a pest control agent by the Ministry of Agriculture, Forestry and Fisheries of Japan. BAW sex pheromone was used over about 600 ha of Welsh onion, green pea, water melon, and Japanese yam in open field (1,000 dispensers/ha), and over about 60 ha of ornamental flowers in greenhouse (5,000 dispensers/ha) in 1993 (Mochizuki, personal communication). Although the use of BAW pheromone is limited at present, it may be one of the potent tools for integrated pest management program.

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