
Control of the Beet Armyworm, *Spodoptera exigua* (HÜBNER) (Lepidoptera: Noctuidae), Using Synthetic Sex Pheromone

I. Effect of Communication Disruption in Welsh Onion Fields

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(Received March 24, 1989)

The feasibility of synthetic sex pheromone as a communication disruption agent for the control of the beet armyworm, *Spodoptera exigua*, was examined by dispensing a 7:3 mixture of (Z,E)-9,12-tetradecadienyl acetate and (Z)-9-tetradecen-1-ol into a 155 ha field containing scattered Welsh onion, *Allium fistulosum* L., plots (total area: 24 ha). Attraction of male moths to sex pheromone traps in the treated area was completely inhibited throughout the period of the treatment. Densities of egg masses and the 1st and 2nd instar larvae were reduced to 6% and 1%, respectively, relative to those in an untreated area about 9 km away. The maximum density of the 4th and 5th instar larvae was reduced to 4% of that in the untreated area. Consequently, crop damage was drastically reduced. In the treated area, the density of the larvae increased after the removal of the pheromone dispenser in mid-September, contrasting to a decrease of population density in the untreated area. These results showed the efficacy of synthetic sex pheromone in controlling field populations of *S. exigua*.

INTRODUCTION

The beet armyworm, *Spodoptera exigua* (HÜBNER), has been a serious pest of the Welsh onion, *Allium fistulosum* L., fields in Kochi and Kagoshima prefectures since the early 1980’s (HORIKIRI, 1986; TAKAI 1988a). The effectiveness of almost all of the insecticides used (including methomyl and EPN) has declined. Insecticides were certainly effective in early 1980’s (TAKAI, 1988b), but this species appears to have the potential to rapidly acquire insecticide resistance (TAKAI, 1988b; MEINKE and WARE, 1978). The development of a new technique aside from insecticide spraying was necessary to control this insect. We therefore intended to study the feasibility of disrupting communication using synthetic sex pheromone.

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BRADY and GANYARD (1972) identified one of the sex pheromone components of S. exigua as \((Z,E)\)-9,12-tetradecadienyl acetate (Z9E12-14:Ac). MITCHELL and DOOLITTLE (1976), however, showed that this component had no attractant activity by itself. TUMLINSON et al. (1981) reinvestigated 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 et al. (1983) reported 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, this formulation was revealed to be effective for male attraction (WAKAMURA, 1987), and to be useful for monitoring seasonal occurrence (KITAMURA, personal comm.).

In the case of the common armyworm, S. littura, male moths are able to fly more than 5 km during 1 night (Oyama and WAKAMURA, 1976; WAKAMURA et al., unpublished). Females have equal flight potential (NODA and KAMANO, 1988). Sex pheromone permeation of a field certainly inhibited mating behavior but often resulted only in a slight reduction of larval population, possibly because of immigration of mated females from outside of the treated area (Oyama et al., 1978; KITAMURA et al., 1985; KITAMURA and KOBYASHI, 1985). Since no information was available on the dispersal distance of adult S. exigua, we assumed that it has flight potential equaling that of adult S. littura. We attempted to permeate as large an area as possible with the largest possible amount of synthetic sex pheromone.

MATERIALS AND METHODS

Experiment area. Experiments were conducted in 2 areas, Nii and Kitahara, Tosa city, Kochi prefecture, Japan, in 1987. The treated area (Nii) was ca. 155 ha of which Welsh onion plots comprised ca. 24 ha. This area was regarded as isolated from other agricultural areas (Fig. 1); the west side of this area faces forest and the north-west side faces a river bordered by forest. To the south of the field is a small residential area bordered by the ocean. The untreated area (Kitahara) was 9 km from the treated area.

Synthetic sex pheromone. The dispensers used were supplied by Shin\'etsu Chem. Co., Ltd.; a sealed polyethylene tube 20 cm long and containing 80 mg of a 7:3 mixture of Z9E12-14:Ac and Z9-14:OH and an aluminum wire. Purity of Z9E12-14:Ac and Z9-14:OH was 85\% and 96\%, respectively. The main impurity in Z9E12-14:Ac was the \((Z,Z)\)-isomer whose content was ca. 10\%. Synthetic sex pheromone permeates through the polyethylene layer and evaporates from the surface into the air.

Twenty-four thousand dispensers were set evenly in the Welsh onion fields at the rate of 1,000 dispensers/ha. In other parts of the treated area (ca. 130 ha) such as rice fields, greenhouses, orchards, home gardens and forests, ca. 42,000 dispensers were set at the rate of 320 dispensers/ha. In the open Welsh onion or rice fields, each release point had 3 dispensers attached to the top of a 60-cm plastic stick with vinyl adhesive tape. Forest trees and greenhouses had dispensers directly attached, at 1 to 1.5 m above the ground. The total number of dispensers was 66,000, and the total amount of sex pheromone used was ca. 5.3 kg.

Treatment period. In 1986, a large peak of trap catches of adult S. exigua was observed in September in sex pheromone and light traps (Fig. 2). This peak was preceded by an increase of severe crop damage by larvae (TAKAI, 1988a). The seasonal fluctuation of the trap catch is thought to reflect the field density of S. exigua moths.
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Fig. 1. Map showing treated area with synthetic sex pheromone in 1987 (Nii, Tosa city, Kochi prefecture, Japan). Treated area (155 ha) is indicated by the thick solid line. A and B represent the central and peripheral parts for the population survey, respectively. Hollow and solid circles indicate the locations of sex pheromone traps for Spodoptera exigua and S. litura, respectively, and “x” indicates that of a light trap.

In the present experiment, sex pheromone dispensers were set on July 16 and 17 in order to reveal their effect onto the larval population from late August to early September, and removed on September 17 and 18 in order to investigate whether the population density would increase after the removal.

Estimation of the evaporated dose of the synthetic sex pheromone. The volume of the liquid in dispensers was measured once a week to estimate the evaporated amounts. Qualitative changes of the sex pheromone components in the dispensers were analyzed using liquid chromatography and a gas chromatograph-mass spectrometer at the Research and Development Laboratory of Shin’etsu Chem. Co., Ltd.

Sex pheromone trap and light trap. Water-pan type of sex pheromone traps (30×24×15 cm, Takeda Chem. Ind., Ltd.) were set 1 m above the ground at 4 locations in the treated area (Fig. 1), and at 2 locations in the untreated area in order to evaluate the effect of communication disruption. Each trap was baited with a rubber septum impregnated with a 7:3 mixture of Z9E12-14:Ac and Z9-14:OH (Wakamura, 1987), and filled with 3 l of water containing 100 ml of 10% benzalkonium chloride solution. Each trap in the treated area was accompanied by another trap 10 m away in which no lure was baited, in order to offset chance male catches (that is, catches not by attraction). A light trap (lamp: FL-6) was set at the center of the treated area. Each trap was checked daily and captured S. exigua moths were stored in 70% ethanol. Females were dissected to investigate the spermatophore in the bursa copulatorix.
Survey of field density. Larval field density was surveyed in every 5 or 6 plots in the central and marginal parts of the treated area (Fig. 1), and in the untreated area once a week from 3 weeks before the placement of dispensers (June 26) to 6 weeks after removal (October 30). Onion hills were planted on ca. 1 m wide ridges in ca. 5–10 a plots scattered in the experiment fields. Plots and ridges were arbitrarily selected where onion plants were 30–60 cm high.

Surveys were conducted on all of the 400 to 500 hills on 10 m of ridge of each plot. Most larvae were inside of hollow leaves. Damaged leaves were collected and dissected to recognize the instar and to count the number of larvae. The instar was identified by the size of the head capsule. When the density became higher, less hills were sampled to save time and labor.

Farmers sprayed insecticides such as methomyl, EPN, permethrin and fenvalerate-dimethoate against *S. exigua*, both in the treated and untreated areas, independently from the experiment. However, these insecticides were ineffective (Takai, 1988b), and not considered to have an effect on population density.

Tethered female. Two-day-old females were tethered on tops of sticks arranged in the onion fields in treated and untreated areas as in Oyama (1974). On the evening of August 27, 20 females were tethered in each of the 2 plots in the treated area, and 25 females in the untreated area. They were recovered the next morning and investigated for spermatophore. Individuals which had died by the times of recovery were omitted from mating rate calculations. In order to protect the females from predation by birds, they were covered with small net cages through which males were able to pass.

Evaluation of the effects on the *S. litura* population. The common armyworm, *Spodoptera litura*, is also a severe pest on the Welsh onion. The major component of *S. exigua* sex pheromone, Z9E12-14: Ac, is a minor but important component of *S. litura* sex pheromone (Tamaki et al., 1973). Although the mating of *S. litura* has been inhibited...
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![Graph showing the number of moths caught over time](image)

Fig. 3. Catches of *Spodoptera exigua* with sex pheromone traps (SP) and light trap (L) in the area treated with synthetic sex pheromone (1987, Nii).

by the evaporation of Z9E12-14: Ac (Yushima et al., 1975; Oyama, 1977), its effect on the field population was not clear (Oyama et al., 1978).

For the evaluation of the effect of the treatment against *S. litura*, 2 dry pheromone traps (box type, Takeda Chem. Ind., Ltd., Sato et al., 1978) were set in both the treated (Fig. 1) and untreated areas. An empty trap with no lure was also set 10 m from each trap in the treated area. In order to evaluate the effect on the field population of *S. litura*, the number of egg masses and larvae of *S. litura* were also recorded during *S. exigua* field population surveys.

**RESULTS AND DISCUSSION**

**Effects of communication disruption**

*S. exigua* adults were captured with a light trap throughout the treatment period (Fig. 3). This indicates that adults were in the treated area throughout the experimental period. Conversely, mean trap catch of sex pheromone traps was as low as that of empty traps throughout the treatment period. Sex pheromone traps caught 10–20 males per night before and after the period (Fig. 3). These results showed that the effect of communication disruption certainly continued throughout the period.

The results of the dissection of the females caught with the light trap are shown in Table 1. The mating rate was observed to increase throughout the treatment period: 40–60% in late July and early August, 70–80% in mid- and late August, and 70–90% in early and mid-September. After removal of the dispensers, the mating rate exceeded 90%. The mating rates of the tethered females were 0% (0/18 = no. of females mated/no. of females recovered alive) and 17% (3/18) in the treated area, and 92% (23/25) in the untreated area. Therefore, some females were thought to be able to mate even in the treated area.

The volume of the liquid in the dispenser decreased gradually; simple regression was observed between the exposed period (X weeks) and the reduction rate of "length"
Table 1. Catches of adult *Spodoptera exigua* with light traps in the area treated with synthetic sex pheromone (1987, Nii)

<table>
<thead>
<tr>
<th>Date</th>
<th>No. of individuals caught</th>
<th>Mating rate (%)</th>
<th>Sexual ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Female</td>
<td>Male</td>
<td>Unknown&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>7/24-7/30</td>
<td>16</td>
<td>134</td>
<td>9</td>
</tr>
<tr>
<td>7/31-8/6</td>
<td>59</td>
<td>97</td>
<td>8</td>
</tr>
<tr>
<td>8/7-8/13</td>
<td>28</td>
<td>79</td>
<td>2</td>
</tr>
<tr>
<td>8/14-8/20</td>
<td>21</td>
<td>77</td>
<td>2</td>
</tr>
<tr>
<td>8/21-8/27</td>
<td>35</td>
<td>121</td>
<td>7</td>
</tr>
<tr>
<td>9/4-9/10</td>
<td>35</td>
<td>62</td>
<td>3</td>
</tr>
<tr>
<td>9/11-9/17</td>
<td>27</td>
<td>47</td>
<td>6</td>
</tr>
</tbody>
</table>

---removal of pheromone dispenser---

<table>
<thead>
<tr>
<th>Date</th>
<th>No. of individuals caught</th>
<th>Mating rate (%)</th>
<th>Sexual ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/18-9/24</td>
<td>42</td>
<td>31</td>
<td>5</td>
</tr>
<tr>
<td>9/25-10/1</td>
<td>58</td>
<td>45</td>
<td>9</td>
</tr>
</tbody>
</table>

<sup>a</sup> due to lack of abdomen.

<sup>b</sup>({(no. of females mated)/(no. of females caught)} × 100.

<sup>c</sup>({(no. of females caught)}/[(no. of females) + (no. of males)]) × 100.

Table 2. Amount of sex pheromone remaining in dispenser

<table>
<thead>
<tr>
<th>Date</th>
<th>Liquid &quot;length&quot; (mean±S.D.)</th>
<th>Remaining amount&lt;sup&gt;a&lt;/sup&gt; (mg/dispenser)</th>
<th>Z9E12-14: Ac</th>
<th>Z9-14: OH</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/17</td>
<td>175.7±3.2 mm</td>
<td>52</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>7/24</td>
<td>169.1±1.6</td>
<td>39</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>7/31</td>
<td>157.0±4.1</td>
<td>28</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>8/7</td>
<td>149.7±0.5</td>
<td>28 (20%)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>8/14</td>
<td>142.1±2.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8/21</td>
<td>133.7±3.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8/28</td>
<td>127.4±4.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9/4</td>
<td>120.5±6.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9/11</td>
<td>117.5±3.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9/17</td>
<td>111.2±3.9</td>
<td>13 (40%)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>13</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> YAMAMOTO (unpublished data).

<sup>b</sup> percentage of decomposition of Z9E12-14: Ac.

The release rate of the pheromone gradually decreased throughout the treatment period. The analysis of the contents of the dispenser showed that the amount of the major compound, Z9E12-14: Ac, was reduced from 52 mg to 13 mg during the 2-month exposure, and that its decomposition rate reached 20-40% towards the end of the period. From these data, evaporating rates were estimated to have gradually decreased: 0.68 g/ha/day in mid- and late July, 0.52 g/ha/day in August, and 0.37 g/ha/day from late August to mid-September (YAMAMOTO, unpublished data). The evaporation rate seemed inversely proportional to the mating rate of the females caught with light traps.
Effects on density of S. exigua eggs and larvae

The mean densities of egg masses, 1st and 2nd instar larvae, and 4th and 5th instar larvae are shown in Fig. 4. In the treated area, the egg mass density was less than 0.5 masses/100 hills, both in the middle and peripheral plots throughout the period. Conversely, in the untreated area, mean egg mass density reached peaks twice; 1.1 masses/100 hills in mid-August and 6.9 masses/100 hills in early September. These
peaks were followed by peaks of the 1st and 2nd instar larvae both in treated and untreated areas. They appeared 1 week after those of egg masses. In the treated area, the maximal density was ca. 10 individuals/100 hills. In the untreated area, density was more than 900 individuals/100 hills in early September, and egg mass density was thought to have been reduced in the treated area.

All of the egg masses collected in both treated and untreated areas were observed to hatch normally. This suggests that hatchability was not reduced in the treated area.

The infestation rate of hills is shown in Fig. 5. Apparently, population density (Fig. 4) and infestation rate were reduced in the treated area. Infestation rate of hills and population density of 4th and 5th instar larvae (which increased 1 or 2 weeks later than those of 1st and 2nd instar larvae) were observed to increase simultaneously, both in treated and untreated areas.

It is therefore apparent that the chance for the females to mate was reduced by the large amount of sex pheromone dispersed into the test area, which resulted in a decrease of density of egg masses and 4th and 5th instar larvae.

It is interesting that egg mass density was remarkably reduced in the treated area in spite of the high mating rate (40–80%) of the females caught with the light trap. An examination is necessary of the physiological condition of these females, and this is one of the objectives of works to follow.

It has been reported that communication disruption experiments were successful against several fruit tree and tea pests in Japan (OHTAISHI, 1986; FURUNO, 1986; SATO, 1986). Subsequently, some pest control agents have been developed. Communication disruption experiments of which aimed to control noctuid species have been reported for S. litura (KITAMURA et al., 1985; OYAMA et al., 1978), S. littoralis (KEHAT et al., 1983, 1986) and Heliothis virescens (TINGLE and MITCHELL, 1982). In these cases, even though the
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**Fig. 6.** Catches of *Spodoptera litura* males with sex pheromone traps in treated (broken line) and untreated (solid line) areas.

**Fig. 7.** Density of *Spodoptera litura* larvae in Welsh onion fields. Broken and dotted lines indicate the densities in central and peripheral parts of treated area, respectively. The solid line indicates the untreated area.

Mating rate was certainly reduced, field density and crop damage was not significantly decreased. The present study, in which the field population of *S. exigua* was remarkably suppressed, is the first case of successful control of noctuid species using sex pheromone.

**Immigration of mated females**

Although the communication disruption of *S. litura* was successful in reducing the mating rate, the reduction of population density was unclear because of possible immigration of mated females from surrounding untreated fields (Kitamura et al., 1985; Oyama et al. 1978). In the present study, if mated females had immigrated into
the treated area, the density of eggs and larvae would have been higher in the marginal part than in the central part. There was, however, no remarkable difference in the densities of eggs and larvae between the marginal and central parts (Fig. 4). Therefore, immigration of females was considered to be negligible in the present experiment. The treated area was thought to be well-separated from the neighboring agricultural area.

Effects of Z9E12-14: Ac on S. litura

The trap catches of S. litura are shown in Fig. 6. In the treated area, trap catches were apparently less than those in the untreated area: 1–15% from late July to early August and 13–30% from mid-August to mid-September (Fig. 6). The field density of the larvae in the treated area seemed to be suppressed in late July and early August (Fig. 7). This suppression was possibly caused by the intensive spray of insecticide against S. exigua in the treated area. The field density of larvae in the treated area was not remarkably decreased in comparison with that of the untreated area (Fig. 7). In the present experiment, the effect of communication disruption with Z9E12-14: Ac, a minor component of S. litura sex pheromone, is thought to have been insufficient for reduction of the S. litura field population.

ACKNOWLEDGEMENT

We wish to sincerely thank Dr. Juro Koyama of the Shikoku National Agricultural Experiment Station (currently of the National Institute of Sericultural and Entomological Science) for his useful and helpful advice throughout the experiment and critical review of the manuscripts, Dr. Takeshi Yushima of the Tokyo University of Agriculture for useful advice on the experiment, Dr. Akira Yama-

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