Use of Osmia cornifrons for Pollination of Apples in Aomori Prefecture, Japan

Norio SEKITA and Masateru YAMADA

Plant Protection Division, Aomori Apple Experiment Station (Kuroishi, Aomori, 036-03 Japan)

Abstract
A mite, Chaetodactylus nipponicus, invades nests of Osmia cornifrons to feed on pollen which has been stored by the bees in the nests for their offspring. The mite also adversely affects the flight of the bees by clinging to their bodies. Two methods of control of the mite were developed. In the first one a selective insecticide was used. Egg mortality from the mite decreased markedly by supplying the bees with nest sources treated with 60 ppm endosulfan. Furthermore, by spraying the nest entrance two to three times every second or third day during the flying period, the mite could be controlled without any lethal effect on the bees. In the second method, differential mortality from high temperatures was used, as pre-pupae of O. cornifrons are resistant to high temperatures due to the diapause while during this period, the mites are still reproducing and are sensitive to high temperatures. Most orchards require the application of insecticides in late April. To avoid the exposure of the bees to insecticide sprays, emergence from nests is delayed by storing the nests at 0-5°C from early to late April. Even though the period of storage exceeds 20 days, the activity of the bees is normal.

Discipline: Horticulture
Additional key words: cold storage, control of Chaetodactylus nipponicus, life history, mortality factors, pesticide application

Introduction
Aomori Prefecture is located in the northern tip of Honshu, Japan. It is the leading apple-producing region in Japan with annual yields averaging approximately 500,000 t or nearly one half of the total production in Japan. The area of apple production in Aomori Prefecture has fluctuated around 25,000 ha over the past 30 years (Fig. 1).

Hand-pollination was first recommended to growers as early as in the 1930s. The effects of hand-pollination were extensively studied in the 1950s. In 1959 approximately 50% of all the apple trees in the Prefecture were hand-pollinated and this level was maintained until the beginning of the 1970s.

Studies on the use of the honey bee, Apis mellifera L. in Aomori apple orchards started in 1961. In 1978, 40% of the total area cultivated with apple was pollinated by honey bees. By 1981, this proportion had decreased to less than 20% and the decline is still continuing.

Studies on the biology of the species of Osmia bees were initiated in the 1960s. Life histories, types of foraging plants and distribution were investigated. Since the 1970s, studies have been concentrated on the methods for establishing Osmia cornifrons (Radoszkowski) in apple orchards as pollinators\(^1\). The use of O. cornifrons has steadily increased since 1981 and over 60% of the total area cultivated with apple was pollinated by this species in 1990.

Osmia bees in Aomori Prefecture

Three species of Osmia bees occur in Aomori Prefecture\(^6\), i.e. O. orientalis Benoist, O. taurus Smith and O. cornifrons (Radoszkowski). Each of these species has only one generation per year. Adults appear in spring and lay eggs which develop into adults in fall. The adults remain in their
The Osmia bees occupy a variety of nesting sites including nail holes, holes bored in logs, hollow stems, drinking straws, etc. Although most apple growers in Aomori Prefecture supply the bees with hollow stems of reed plant as the nest sources, artificial nests such as plastic tubes are also used.

In this paper the term “nest tubes” refers to hollow stems and artificial tubes.

**Foraging flight of *O. cornifrons***

Fig. 2 shows the periods of adult emergence from the nests, foraging flight and nest construction of *O. cornifrons* in relation to the blooming periods of various host plants and to the weather conditions. Male emerges earlier than the female. The emergence from the nest as well as the foraging flight is strongly affected by the temperature conditions. At temperatures lower than 16°C, the bee cannot fly and stays in the nest. From the point of view of the use of wild bees as pollinators, synchronization of foraging flights to apple bloom is particularly important. Since *Osmia cornifrons* displays the optimum synchrony, it has been most extensively studied.

**Mortality factors in the nest***

In order to determine the factors which are important for the survival of *O. cornifrons* in the nest, life tables were constructed for 27 populations. Three typical life tables are presented in Table I to indicate the kinds of mortality factors which operate on the species and the factors that are important from an applied point of view. In population A, the mortality in each stage was relatively low and...
more than 90% of the individuals survived to the adult stage. In population B, the highest mortality occurred in the larval stage. The proportion of individuals that survived to the adult stage was 78%. In population C, the mortality was highest in the egg stage, due to the parasitism of a mite, Chaetodactylus nipponicus Kurosa. Only 31% of the individuals emerged as adults. This mite invades the O. cornifrons nests to feed on the pollen which has been stored by the bee in the nest for its offspring. The mite also adversely affects the flight of the bees by clinging to their bodies. It is not unusual to see hundreds of mites clinging to a single bee.

Fig. 3 shows the total mortality in the nest in relation to the egg mortality caused by the mite, C. nipponicus. Mortality rates were converted to k-values\(^2\). More than 80% of the variation in the total mortality was attributed to the egg mortality caused by the mite, suggesting that the development of control measures for the mite will be important to maintain large populations of O. cornifrons.

Control of the mite, C. nipponicus

Three methods are recommended to control the mite affecting O. cornifrons in Aomori Prefecture\(^3\). The first and most reliable method is to cut each nest tube lengthwise and select healthy cocoons. The drawback to this method is that many nests are destroyed and the process is time-consuming. The other two methods are as follows.

1) Control with insecticides

The use of pesticides to control the mite is difficult because the margin between the lethal dosage to the mite and the toxic dose to O. cornifrons is very small. Three typical examples are shown in Table 2\(^5\).

Dioxabenzofos is one of the most popular insecticides used for the control of major apple insect pests. It is toxic to the mite but is also toxic to O. cornifrons. Most insecticides showed similar toxicities to those of dioxabenzofos.

Cyhexatin is an acaricide used worldwide until the
Table 1. Three sampled life tables for *O. cornifrons*<sup>3</sup>

<table>
<thead>
<tr>
<th>Stage</th>
<th>Mortality factor</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>100 l&lt;sub&gt;x&lt;/sub&gt;&lt;sup&gt;0&lt;/sup&gt;</td>
<td>100 q&lt;sub&gt;x&lt;/sub&gt;&lt;sup&gt;0&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Egg</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>C. nipponicus</em>&lt;sup&gt;a&lt;/sup&gt;</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Fungi + Unknown</td>
<td>4.5</td>
<td>0.1</td>
</tr>
<tr>
<td>Total</td>
<td>4.9</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>Larva</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fungi + Unknown</td>
<td>95.1</td>
<td>99.2</td>
</tr>
<tr>
<td><strong>Pre-pupa</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>M. osmiae</em>&lt;sup&gt;b&lt;/sup&gt;</td>
<td>93.3</td>
<td>83.2</td>
</tr>
<tr>
<td>Fungi + Unknown</td>
<td>0.3</td>
<td>0.0</td>
</tr>
<tr>
<td>Total</td>
<td>0.5</td>
<td>2.6</td>
</tr>
<tr>
<td><strong>Pupa</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fungi + Unknown</td>
<td>92.8</td>
<td>81.0</td>
</tr>
<tr>
<td><strong>Adult in cocoon</strong></td>
<td>92.7</td>
<td>80.7</td>
</tr>
<tr>
<td><em>A. verbasci</em>&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.0</td>
<td>1.3</td>
</tr>
<tr>
<td>Fungi + Unknown</td>
<td>0.0</td>
<td>1.9</td>
</tr>
<tr>
<td>Total</td>
<td>0.0</td>
<td>3.2</td>
</tr>
</tbody>
</table>

**Emerged adults**

|                |            |            | 92.7 | 78.2 | 30.7 |

a): *Chaetodactylus nipponicus* (Acarina, Chaetodactylidae); mite.
b): *Monodontomerus osmiae* (Hymenoptera, Torymidae); parasite.
c): *Anthrenus verbasci* (Coleoptera, Dermestidae); predator.
d): 100 l<sub>x</sub>; Percentage of individuals which survived until the beginning of stage x.
e): 100 q<sub>x</sub>; Percentage of individuals which died during the stage interval x.

---

Fig. 3. Relationship between the egg mortality caused by the grain mite, *C. nipponicus*, and the total mortality from egg to adult stages in *O. cornifrons*.

Mortalities are expressed as k-values (Varley and Gradwell<sup>2</sup>).

latter part of the 1980s. It is not toxic to *O. cornifrons* but its toxicity to the mite was too low. Most fungicides and miticides showed similar toxicities to those of cyhexatin.

Endosulfan is an insecticide registered for the control of aphids in Japan. It is, however, not recommended for use in apple orchards in Aomori Prefecture because of its high toxicity to aquatic organisms. Endosulfan is not toxic to *O. cornifrons* and is highly toxic to the mite. Further tests showed that (1) by supplying the bees with nest sources treated with 60 ppm endosulfan, the egg mortality from the mites could be reduced to a negligible level, and (2) by spraying the nest entrance two to three times every second or third day during the flying period, the mite could be controlled without any lethal effect on *O. cornifrons*.

Large amounts of insecticide are needed to treat entire orchards. For such uses, highly toxic insecticides such as endosulfan should be avoided. In contrast, since dipping and/or spraying of the nests...
Table 2. Mortalities of *O. cornifrons* and *C. nipponicus* from three insecticides

<table>
<thead>
<tr>
<th>Pesticide</th>
<th>Concentration (ppm)</th>
<th>% mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td><em>O. cornifrons</em></td>
</tr>
<tr>
<td>Dioxabenzofos</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>94</td>
</tr>
<tr>
<td></td>
<td>12.5</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>6.3</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td>Cyhexatin</td>
<td>250</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>125</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>62.5</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>31.3</td>
<td>0</td>
</tr>
<tr>
<td>Endosulfan</td>
<td>300</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>150</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>0</td>
</tr>
</tbody>
</table>

requires only a minimum amount of insecticide, endosulfan has been recommended for the control of the mite.

2) **Use of differential mortality from high temperatures**

After feeding on pollen, the larvae of *O. cornifrons* spin silken cocoons in late June and become pre-pupae. Pre-pupae are resistant to high temperatures due to the diapause. During the period when the bees are in the diapause, mites are still reproducing and are sensitive to high temperatures.

A large number of nests which were contaminated with mites were stored at 30–31°C and 70% RH (Fig. 4). After removal from storage, the tubes were opened to determine the level of mortality of the mites and to collect the cocoons. The cocoons were kept under natural conditions for later evaluation of adult emergence. The survival of *O. cornifrons* exceeded 80% regardless of the duration of storage. In contrast, the mite survival declined as the period of storage increased. Storage for 9 weeks completely eradicated the mites. Other tests showed that the storage time could be shortened at higher temperatures.

Apple growers and grower's co-operatives have storage facilities for dehiscing pollen which can be adapted to the heat treatment of *O. cornifrons* nests to kill the mites. Tests using these facilities gave satisfactory results when the nests were kept at 30–32°C for 30–40 days.

**Avoidance of pesticide applications**

Under natural conditions, the bees emerge from their nests from mid to late April and the flight activity continues until late May. Most orchards require the application of an insecticide in late April
### Table 3. Management schedule for use of *O. cornifrons* as an apple pollinator in Aomori Prefecture

<table>
<thead>
<tr>
<th>Month</th>
<th>Phenology of apples</th>
<th>Life cycle of <em>O. cornifrons</em></th>
<th>What to do</th>
</tr>
</thead>
<tbody>
<tr>
<td>November</td>
<td>Dormant</td>
<td>Dormant</td>
<td>Prepare nest tubes, shelters, etc.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Remove cocoons from nest tubes.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Important if nests have been reused for 2-3 years in order to remove natural enemies from nests.</td>
</tr>
<tr>
<td>April</td>
<td>Early</td>
<td>Complete dormancy, remains within cocoons</td>
<td>Store cocoons/nest tubes at 0 to 5°C.</td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td></td>
<td>Dip-treat nest tubes to prevent contamination from the mite, <em>Chaeodactylus nipponicus</em>.</td>
</tr>
<tr>
<td></td>
<td>Late</td>
<td>10 days after bud break</td>
<td>Set up nest shelters + place nest tubes in shelters.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2-3 days later</td>
<td>* Spray to control insect pests on apples. (Leaf rollers hibernating as larvae, leaf miners, etc.)</td>
</tr>
<tr>
<td>May</td>
<td>Early</td>
<td>Blooming</td>
<td>Place nest tubes / cocoons in shelters.</td>
</tr>
<tr>
<td></td>
<td>Full-bloom</td>
<td>Adult emergence from nest</td>
<td>To control the mite, spray nest entrance 2-3 times every 2nd or 3rd day.</td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>Visit of flowers (Nest construction)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Late</td>
<td>Petal-fall</td>
<td>* Spray to control insect pests on apples. (Apple tortrix, etc.)</td>
</tr>
<tr>
<td></td>
<td>10 days after petal-fall</td>
<td>Discontinuation of flight</td>
<td></td>
</tr>
<tr>
<td>June</td>
<td>Early</td>
<td>Pre-pupal stage</td>
<td>Store under natural conditions.</td>
</tr>
<tr>
<td>July</td>
<td>Early</td>
<td></td>
<td>High temperature treatment.</td>
</tr>
<tr>
<td>August</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>September</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>October</td>
<td>Dormant</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Each arrow indicates transfer of nest tubes and/or cocoons from one place to another.

To control the summer fruit tortrix, *Adoxophyes orana fasciata* Walsingham which hibernates as larvae and two species of leaf miners, *Phyllonorycter ringoniella* (Matsumura) and *Lyonetia prunifoliella malinella* Matsumura. To avoid the exposure of the bees to insecticide sprays, emergence from the nests should be delayed until the spray applications are over. Storage of the bees at 0-5°C from early April to late April is recommended. Nests should be placed in storage just before the normal occurrence of adult emergence from the cocoons as evidenced by the ticking sounds from the adults chewing on their cocoons. A few days after the last spray, the nests should be transferred to nest shelters in orchards. Even though the period of storage exceeded 20 days, the activity of the bees was normal.

Apple growers and grower's co-operatives normally possess cold storage facilities to store apples. Space
in these facilities is typically available for storage of *Osmia* nests by this time, and thus the cold storage method is widely practiced.

In addition to the summer fruit tortrix which hibernates as larvae, there are other leaf rollers which hibernate as eggs, i.e. *Archips fuscocupreanus* Walsingham and *A. xylostea*us (L.). Larvae of these species have hatched by the pre-bloom stage and spraying at this time affords the best control. Spraying, however, is usually delayed until 10 days after petal-fall in order to avoid the toxicity to pollinating insects.

**Summary of *Osmia* bee management**

The procedures mentioned above are summarized in Table 3 in relation to the phenology of apple trees and the seasonal life history of *O. cornifrons*. Although this management program is currently recommended in Aomori Prefecture, some problems remain to be solved, of which, the control of leafrollers hibernating as eggs is particularly important.

As mentioned earlier, even though optimum control can be achieved by a pre-bloom spray, the application is delayed until 10 days after petal-fall. As the use of *O. cornifrons* becomes more popular, the leaf roller problems are becoming more serious in many orchards. Fig. 5 shows that a pre-bloom spray of dioxabenzofos immediately destroyed a whole colony of *O. cornifrons*. In contrast, BT application was absolutely safe for the bee (Sekita, unpublished data). Accordingly, various BT compounds were tested from the 1970s to the 1980s. BT compounds, however, have never been recommended for use due to the insufficient control of leafrollers.

Recently some IGR compounds such as chlorfluanuron and flufenoxuron have been found to be less toxic to *O. cornifrons* but still reasonably toxic to leaf rollers. Studies using these compounds are currently in progress.

**References**


(Received for publication Oct. 12, 1992)