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

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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 pollinator[3–5]. 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[3)], 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

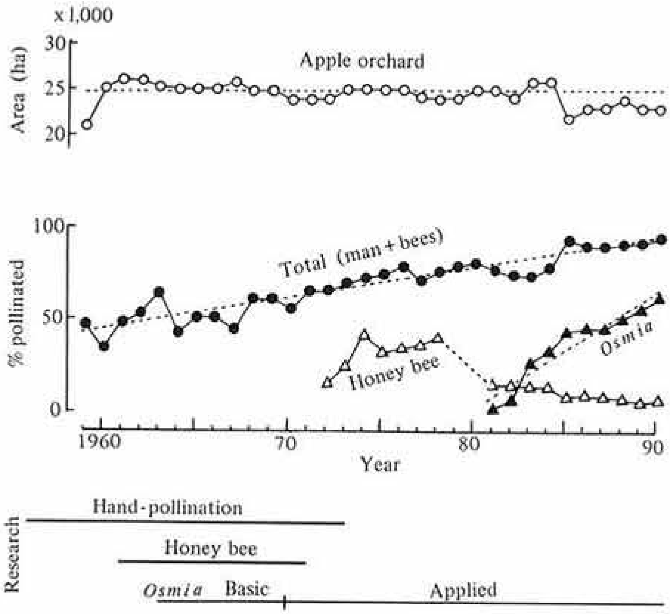

Fig. 1. Land area devoted to apple cultivation in Aomori Prefecture; percentages of apple trees pollinated by different methods, and research on history of the pollination of apples in Aomori Apple Exp. Sta.

Source: Annual reports of Aomori Apple Exp. Sta. and guide books published annually from Dept. Agri. & For., Aomori Pref.

cocoons until the next spring. *O. orientalis* nests in snail shells. The population density of this species is low in general and its foraging period lags behind the period of apple blooming. *O. taurus* is restricted to mountainous areas. Although it appears later than *O. cornifrons*, the foraging periods of the two species partly overlap. Of these three species, *O. cornifrons* is the most widely distributed in the Prefecture.

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[3]. 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[3]. Three typical life tables are presented in Table 1 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

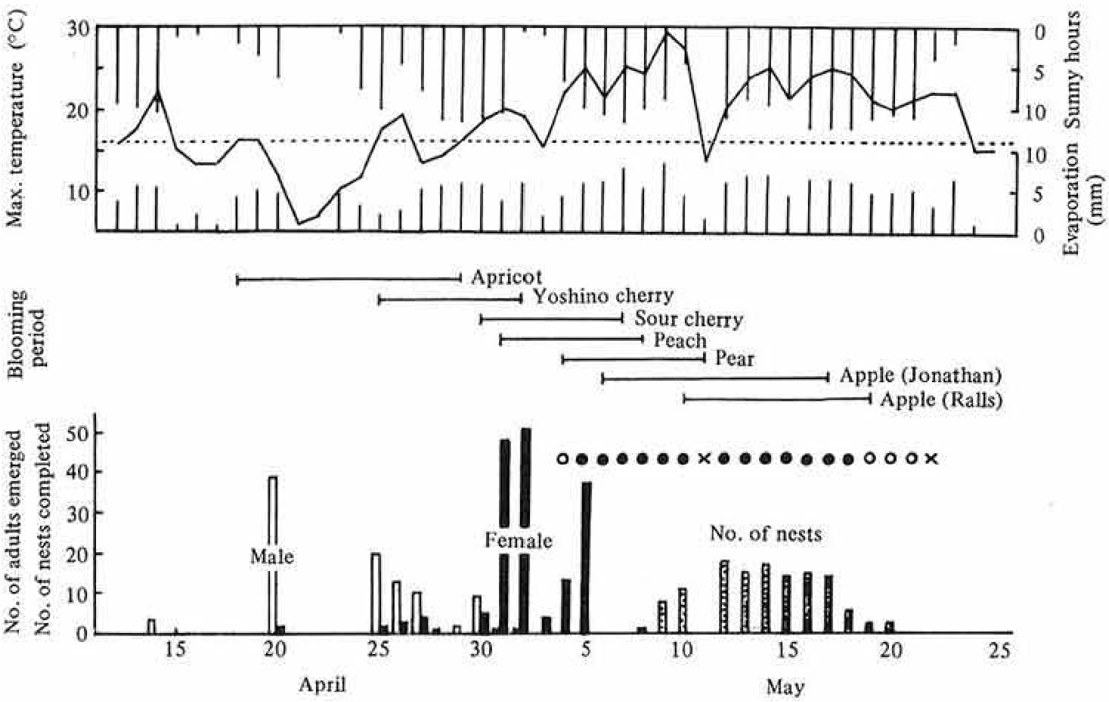

Fig. 2. Emergence of adults from nests, foraging flight and nest construction for *O. cornifrons* in relation to blooming periods of host plants and to weather conditions[3]
Foraging flight: ●; Active, ○; Not active, ×; No flight.

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[1]. 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*[3)]

Stage	Mortality factor	Population					
		A		B		C	
		100 l_x [d)]	100 q_x [e)]	100 l_x	100 q_x	100 l_x	100 q_x
Egg		100		100		100	
	C. nipponicus[a)]		0.4		0.7		64.2
	Fungi + Unknown		4.5		0.1		5.1
	Total		4.9		0.8		69.3
Larva		95.1		99.2		33.7	
	Fungi + Unknown		1.9		16.1		0.0
Pre-pupa		93.3		83.2		33.7	
	M. osmiae[b)]		0.3		0.0		0.0
	Fungi + Unknown		0.2		2.6		3.0
	Total		0.5		2.6		3.0
Pupa		92.8		81.0		32.7	
	Fungi + Unknown		0.1		0.3		0.0
Adult in cocoon		92.7		80.7		32.7	
	A. verbasci[c)]		0.0		1.3		4.6
	Fungi + Unknown		0.0		1.9		1.5
	Total		0.0		3.2		6.1
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_x; Percentage of individuals which survived until the beginning of stage x.
e): 100 q_x; Percentage of individuals which died during the stage interval x.

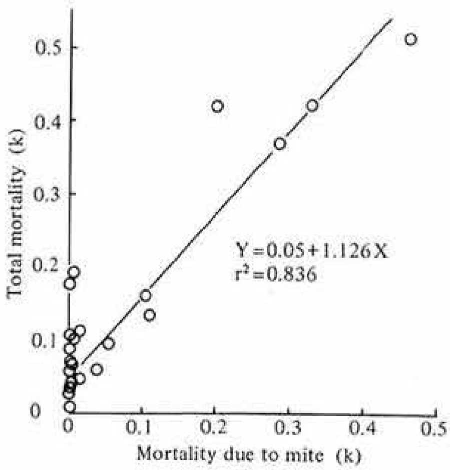

Fig. 3. Relationship between the egg mortality caused by the grain mite, *C. nipponicus*, and the total mortality from egg to adult stages in *O. cornifrons*
Mortalities are expressed as k-values (Varley and Gradwell[2)]).

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[5)]

Pesticide	Concentration (ppm)	% mortality	
		O. cornifrons	*C. nipponicus*
Dioxabenzofos	50	100	
	25	94	100
	12.5	17	98
	6.3	10	96
	3.2		29
Cyhexatin	250	0	22
	125	0	24
	62.5	0	6
	31.3	0	0
Endosulfan	300	0	
	150	0	
	75	0	
	60	0	100
	30	0	94
	15	0	72
	8	0	4

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[5)].

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.

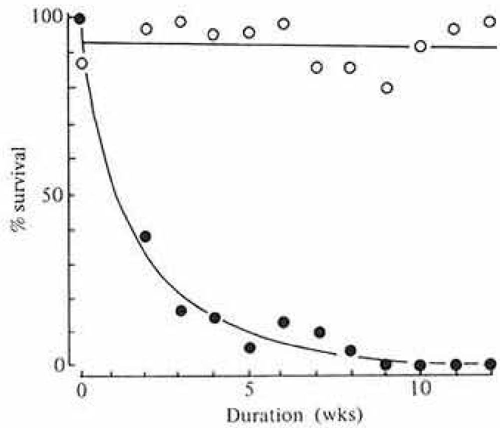

Fig. 4. Differential effects of high temperature on *O. cornifrons* (○) and the grain mite, *P. nipponicus* (●)[5)]
The nests of *O. cornifrons* were stored at 30–31°C and 70% RH.

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[1]

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

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[4] 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. xylosteanus* (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[1], some problems remain to be solved, of which, the control of leafrollers hibernating as eggs is particularly important.

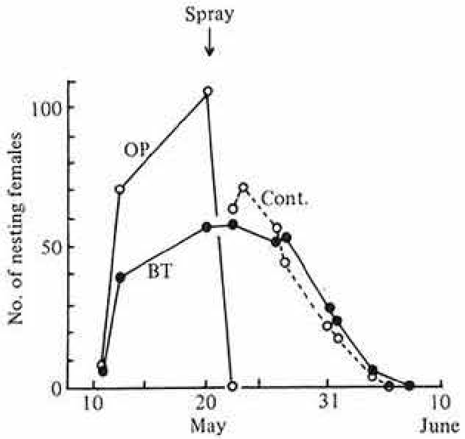

Fig. 5. Effect of OP insecticide on the colony of *O. cornifrons*
Dioxabenzofos (OP) and *Bacillus thuringiensis* (BT) were sprayed at the full-bloom stage of apple trees.
Cont.: unsprayed control.

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 chlorfluazuron 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.

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