DIAMONDBACK MOTH (LEPIDOPTERA: PLUTELLIDAE): PARASITISM BY *COTESIA PLUTELLAE* (HYMENOPTERA: BRACONIDAE) IN CABBAGE

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ABSTRACT

Cotesia plutellae Kurdjumov was evaluated as a potential biological control agent for diamondback moth, *Plutella xylostella* (Linnaeus), in cabbage in spring 1993 and 1994. The parasitoids were reared in a commercial insectary in Texas, delivered overnight via air express, and released 24-48 h after receipt in cabbage fields in Northeast Florida. In 1993, only adult parasitoids were released, but adults and cocoons were released in 1994. The numbers of *C. plutellae* released ranged from 456 per ha per wk in 1993 to 1,334 per ha per wk in 1994. Four consecutive releases were made each year beginning in early February. Parasitism of diamondback moth larvae by *C. plutellae* ranged from 3.6 to 10.9%, and the level of parasitism was related to the total numbers of parasitoids released. *C. plutellae* parasitoids were complimentary to the naturally occurring parasitoid *Diadegma insulare* (Cresson), and the combined mean seasonal parasitism of diamondback moth exceeded 34% in some fields. There was no evidence that *C. plutellae* became established in the general area although > 124,000 parasitoids were released over the 2-year test period.

Key Words: *Plutella xylostella*, biological control, integrated pest management, *Diadegma insulare*

RESUMEN

Cotesia plutellae Kurdjumov fue evaluada como agente potencial de control biológico para *Plutella xylostella* (Linnaeus) en la col, en las primaveras de 1993 y 1994. El parasitoide fue criado en un insectario comercial en Texas, enviado por correo expreso, y liberado a las 24-48 horas de recibido en campos de col del nordeste de la Florida. En

1993 solamente fueron liberados parasitoides adultos, pero en 1994 fueron liberados adultos y capullos. Los números de *C. plutellae* liberados estuvieron en el rango de los 456 por ha por semana en 1993, a los 1,334 por ha por semana en 1994. Cuatro liberaciones consecutivas fueron hechas cada año comenzando a principios de febrero. El parasitismo de *P. xylostella* por *P. plutellae* estuvo en el rango de 3.6 a 10.9%, y el nivel de parasitismo estuvo relacionado con los números de parasitoides liberados. Los parasitoides fueron complementarios del parasitoide natural *Diadegma insulare* (Cresson), y el parasitismo combinado estacional de *P. xylostella* excedió el 34% en algunos campos. No hubo evidencia que *C. plutellae* llegara a establecerse en el área a pesar de que más de 124,000 parasitoides fueron liberados durante los dos años del período de prueba.

The diamondback moth, *Plutella xylostella* (Linnaeus), is a serious pest of cruciferous crops throughout the world. In tropical and subtropical areas, crucifer production has been seriously affected in recent years by populations that have developed resistance to a wide range of insecticides (Talekar & Shelton 1993). Until the mid-1980s in North America, diamondback moth was considered a minor pest, possibly because biological control by natural enemies maintained populations below economically damaging levels. In the United States, increases in the pest have been most severe in southern states, especially Florida, Georgia, North Carolina, and Texas. Insecticide resistance appears to be the most important cause (Leibee & Savage 1992, Leibee et al. 1995). *Bacillus thuringensis*-based pesticides and growth regulators are effective control agents with minimal environmental impact, provided resistance can be avoided (Shelton et al. 1993).

Combining pest control tactics may be the best approach for handling pesticide resistance in diamondback moth. Biever et al. (1994) described the evolution and implementation of a biological control-integrated pest management system for lepidopterous pests of crucifers developed over a period of 24 years. Basically the program consists of three elements: regular scouting of the crop to estimate plant damage and larval infestations; application of pesticides only when needed with reliance upon *Bacillus thuringinesis*-based insecticides; and preservation of natural enemies combined with periodic releases of parasitoids.

Cotesia plutellae Kurdjumov frequently is mentioned as a possible biological control agent for diamondback moth (Talekar & Shelton 1993). There have been sporadic releases of this parasitoid in Florida (Frank & McCoy 1993), but little data are available on its recovery or efficacy. This study reports on the recovery of *C. plutellae* in commercial cabbage fields subjected to conventional pest control practices following inoculative releases of this parasitoid. Data also were collected on the seasonal occurrence and effectiveness of *Diadegma insulare* (Cresson), a naturally-occurring larval parasitoid of diamondback moth. The trials were conducted near Bunnell, Flagler County, Florida during the winter-spring cabbage growing seasons of 1993 and 1994.

Materials and Methods

Parasitoid Source

Cotesia plutellae parasitoids used in this study were purchased from Biofac, Inc., Mathis, TX. The parasitoids were shipped overnight via air express to Gainesville, FL. Adult parasitoids were shipped in 1993 and cocoons were shipped in 1994. The adults

(about 250 ea) were packaged in small cardboard cylinders (12.7 cm long × 3.81 cm diam) capped at both ends. The cylinders were wrapped with old newsprint and bundled in a Styrofoam chest containing packets of ice enclosed in plastic bags (also wrapped with old newsprint) to keep the insects immobile while in transit.

In 1994, cocoons on paper towels (about 1,000 ea) were enclosed in plastic bags, wrapped with old newsprint and inserted in Styrofoam containers for shipping as described for adult parasitoids. Upon arrival, the cocoons were subdivided as required to meet test requirements. Adult parasitoids released in 1994 were received as cocoons and allowed to emerge in the laboratory. The parasitoids were fed a 10% honey-sugar water solution while in confinement.

Adult parasitoids released in 1993 were placed in the field within 48 h after shipment from the insectary in Texas. Adult parasitoids released in 1994 were shipped to Florida as cocoons, allowed to emerge in the laboratory, and placed in the field within 24 h after emergence.

Pesticide Applications

Grower cooperators applied pesticides to the cabbage crop at their discretion.

1993 Field Trials

Parasitoid Release-Adult parasitoids were released in two cabbage fields in 1993 (Fig. 1). Release area 1 (field 1) was 12.1 ha in size and part of a large cabbage field to-

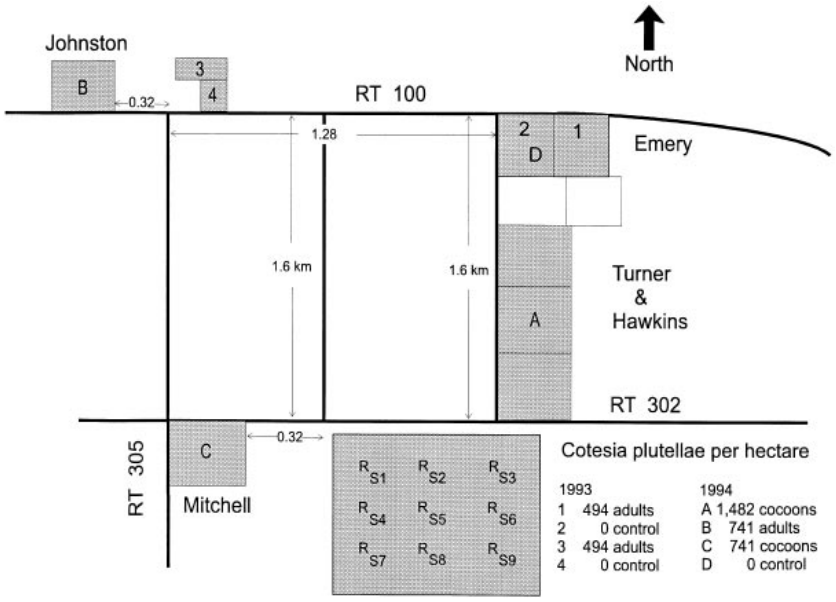

Fig. 1. Schematic of experimental site. Inset shows arrangement of parasitoid release stations and sampling sites (1994 only) in fields A, C, and D. Field B had six release stations and sampling sites (2 rows of 3 each). Bunnell, Flagler County, FL.

taling 24.2 ha, the western half of which was designated as a control area (field 2). The second release area (field 3, 8.1 ha) was located about 1.3 km west of release area 1 (Fig. 1). The second control area (field 4, 4.0 ha) joined field 3 along the southeast edge.

The test fields were located in agricultural areas devoted to the production of cabbage and potatoes. Field 1 was bordered on the eastern edge by wooded swamp, the south by potato fields, the west by the control (field 2), and the north by potato fields. Control field 2 was bordered on the south and north by potatoes and on the west by open pasture land. Field 3 (release area 2) was bordered on the north by wooded swamp, the east and west by cabbage in various stages of maturity, and the south by cabbage (field 4) and fallow crop land.

Cotesia plutellae were released in fields 1 and 3 at a target rate of 494 adults per ha for four consecutive weeks beginning 24 February. This release rate was based upon the recommendation of D. Biever (pers. comm.) from his experiences in developing an integrated management system for pests of crucifers over a 24-year period (Biever et al. 1994). Estimates of actual release rates were made by examining the release containers for dead parasitoids. The sex ratio was approximately 1:1 as determined from examination of representative samples of adults before they were released. The parasitoids were transferred from shipping cylinders into 0.24 liter paper cartons equipped with screened lids for release. A cotton ball in a small plastic cup saturated with 10% honey-sugar water solution provided a food source for the parasitoids. The cartons were placed in the field at the base of cabbage plants and opened to allow the parasitoids to escape. Thirty release sites were established in field 1 (12.1 ha) and 20 were established in field 3 (8.1 ha). The release sites were spaced equidistant throughout the field in either a 5×6 (field 1) or 4×5 grid (field 3). Thus, each release site was near the center of a 0.4 ha block of cabbage.

Sampling procedure-Each parasitoid release field and correspondent control field was systematically sampled weekly throughout the growing season for evidence of *C. plutellae* activity. Each field was divided into four sections nearly equal in size across its width; each section then was subdivided into thirds throughout the length of the field. Timed searches of cabbage plants selected at random were conducted in each of the 12 sections (10 min ea). Thus, each field was scouted for diamondback moth larvae and cocoons or parasitoids for a total of 2 h per wk. The larvae and cocoons collected were returned to the laboratory and held at ambient conditions of 25 ± 2°C, 70-80% RH and under continuous fluorescent lighting for emergence of adult moths or parasitoids. The larvae were held individually in 29.6 ml plastic cups on a modified pinto bean diet (Guy et al. 1985) until emergence of adult moths or parasitoids, or until the larvae died. Diamondback moth pupae and parasitoid cocoons were held separately in 0.24 ml plastic cups until emergence of adults or death.

1994 Field Trials

The location of cabbage fields used in 1994 are shown in Fig. 1. Fields A and D were 12.1 ha in size, field C was 10.5 ha, and field B was 4.8 ha. Field D was the same field used as a control area (i.e., field 2) in 1993. Field A was bordered on the south and north by cabbage, the east by wooded swamp, and the west by a drainage ditch, unpaved county road, and open pasture land. Field B was bordered on the north and east by maturing cabbage fields ready for harvest or that had been harvested but the plant residue had not been destroyed; potato fields bordered the field on the west; and the south side was bordered by a state highway across which was maturing or harvested cabbage fields.

Parasitoid release-Parasitoids were released either as cocoons or adults. Cocoons were released in fields A and C at a target rate of 1,482 and 741 per ha, respectively, and adult parasitoids were released in field B at a target rate of 741 per ha. Estimates

of actual release rates were established later by examining the release containers for dead cocoons or adults a few days after each release. Four releases of adult parasitoids or cocoons were made every two weeks beginning 06 February. The sex ratio as determined from cocoons held in the laboratory for emergence was about 1:1. Release cages, measuring 60 cm long × 38 cm wide × 30 cm high, were partially covered on the sides with 0.32-cm mesh hardware cloth to allow adult parasitoids to exit (Fig. 2). A cotton ball in a plastic cup was saturated with 10% honey-sugar water solution to provide a food source for the adults upon emergence.

Turlings et al.(1989, 1990a and b) conditioned *C. marginiventris* (Cresson) females to search for larval hosts after exposure to odors from plants damaged by beet armyworm [(*Spodoptera exigua* (Hübner)] larvae. They also reported that *C. marginiventris* females were significantly more responsive to the odors after a brief contact experience with host-damaged leaves contaminated with host by-products; but actual encounters with hosts were not required to improve subsequent responses to host-related odors. We obtained similar results with *C. plutellae* females in flight tunnel assays after exposure to cabbage plants damaged by diamondback moth larvae (unpublished). Thus, cabbage plants bearing diamondback moth larvae were placed inside each release cage to condition adult *C. plutellae* parasitoids to search for hosts upon exiting the release station.

The release cages (9 in fields A and C, 6 in field B) were spaced equidistance apart throughout each field (Fig. 1). The cages were mounted on metal conduit poles in drainage ditches so that the bottom of the release station was about 0.5 m above the top of the cabbage plants. Cocoons, still attached to paper toweling, were placed in paper cups and set in the cages next to a potted cabbage plant with feeding diamondback larvae. Adult parasitoids in 0.24 liter paper cups were chilled in a Styrofoam chest for transport to the field. A paper cup containing the requisite number of parasitoids was placed in the release cage adjacent to a potted cabbage plant with feeding diamondback moth larvae.

Sampling procedure-The fields were sampled weekly for host larvae and pupae and cocoons of parasitoids, namely *C. plutellae* and *D. insulare.* Nine sites were sampled in fields A, C, and D and six in field B (Fig. 1, see inset). The sample sites were about equally spaced throughout each field. Initially, all cabbage plants (mean = 65) on 15.2 m of row were examined for larvae, pupae, and cocoons; but as the season progressed and the plants grew in size, the distance was decreased to 3 m per site (mean = 13 plants) the week of harvest.

The diamondback larvae collected were brought into the laboratory where most were dissected to determine if they were parasitized (Day 1994). Some larvae were held on artificial diet as previously described for emergence of moths or adult parasitoids to confirm identifications determined by dissections. Diamondback moth pupae and parasitoid cocoons also were held separately in 0.24 ml plastic cups until they emerged or died.

Statistical analysis-Parasitism of diamondback moth larvae in 1993 was analyzed using unpaired t-tests (Littell et al. 1991). The analyzes compared the combined effects of field and treatment, i.e., field 1 + parasitoid releases vs. field 2 + no parasitoid release; and field 3 + parasitoid releases vs. field 4 + no parasitoid release (Fig. 1). In the 1994 trial, a 1-way analysis of variance (ANOVA) was used with fields as the factor and mean percent parasitism or number of diamondback moth larvae per plant as the response variable. As in the 1993 trial, the analyzes compared the combined effects of field and parasitoid releases (A, B, and C) or field and no parasitoid release (D) (Fig. 1). Differences indicated by significant ANOVA were compared using the Waller-Duncan K-ratio t-test (Littell et al. 1991).

Fig. 2. Release station for *Cotesia plutellae* parasitoids. Cocoons or adult parasitoids were placed in open paper cups and set in the release cage next to a potted cabbage plant infested with diamondback moth larvae.

RESULTS

1993 Release

The number of parasitoids targeted for release was 494 per ha. Examination of the release cartons within 24 h after each release period revealed that only 7.5% of the parasitoids had died. Thus, the actual number of parasitoids released was about 456 per ha. Over the release period, an estimated total of 18,500 *C. plutellae* adults were released in fields 1 and 3 (Fig. 1).

A total of 2,802 diamondback moth forms (1,415 larvae and 1,387 pupae) were collected in the four test fields which yielded 725 parasitoids and 1,246 diamondback moth adults. The remainder died in the holding cups before pupation or eclosion as adults.

Although low, percent parasitism (mean ± s.e.) of host larvae by *C. plutellae* was significantly greater (unpaired t-test, Littell et al. 1991) in release fields 1 and 3 than in the correspondent controls, fields 2 and 4 (Fig. 1): field 1 = 0.76 ± 0.29 vs. field 2 = 0, t = 2.315, 21 d.f., P = 0.031; and field 3 = 2.14 ± 0.76 vs. field 4 = 0, t = 2.384, 17 d.f., P = 0.029.

There also was no significant difference in the percentage of diamondback larvae parasitized by the naturally-occurring *D.insulare* in the parasitoid release fields (1 and 3) versus the control fields (2 and 4): field 1 = 28.51 ± 3.27 vs. field 2 = 25.86 ± 3.14; t = 0.572, 21 d.f., P = 0.573; and field 3 = 24.65 ± 5.42 vs. field 4 = 22.26 ± 4.68; t = 0.316, 17 d.f., P = 0.756. Mean parasitism of host larvae by *D. insulare* in the four fields was 25.68 ± 2.05%.

1994 Release

Examination of the cartons used to release cocoons and adults revealed that > 90% of the parasitoids had survived and escaped the release cage. Thus, the targeted releases of 1,482 and 741 cocoons or adults per ha actually was about 1,334 and 667 cocoons or adults, respectively. Over the release period, an estimated total of 105,840 *C. plutellae* parasitoids were released in fields A, B, and C.

A total of 3,310 diamondback moth forms (2,004 larvae and 1,306 pupae) were collected in all fields in 1994. A total of 653 *D. insulare* and 162 *C. plutellae* also were recovered, most all of which were identified from dissections of diamondback moth larvae (Day 1994). Specimens of a few other species also were noted, but they were not identified.

The seasonal occurrence of diamondback larval populations in fields A-D and the level of larval parasitism in each are shown in Fig. 3. There was no significant difference in the mean (± s.e.) number of diamondback moth larvae per cabbage plant in fields A (0.035 ± 0.010), B (0.016 ± 0.006), C (0.030 ± 0.009), and D (0.030 ± 0.005) when averaged over the season. These results were not surprising as the grower cooperators sprayed their cabbage as frequently as deemed necessary to protect the crop from economic damage.

As expected, the highest mean level of parasitism of diamondback larvae by *C. plutellae* was recorded in field A (10.9%) where the largest number of cocoons were released. However, mean larval parasitism by *C. plutellae* in this field was not significantly different from field C (5.4%) where about 50% fewer cocoons were released (Table 1). Parasitism of diamondback larvae by *C. plutellae* in field B (target of 741 adults per release) and D (no parasitoids released) was 3.6 ± 1.5% and 0%, respectively. The weekly levels of parasitism by *C. plutellae* in each field closely paralleled the release of the parasitoid (Fig. 3). After parasitoid releases were terminated, par-

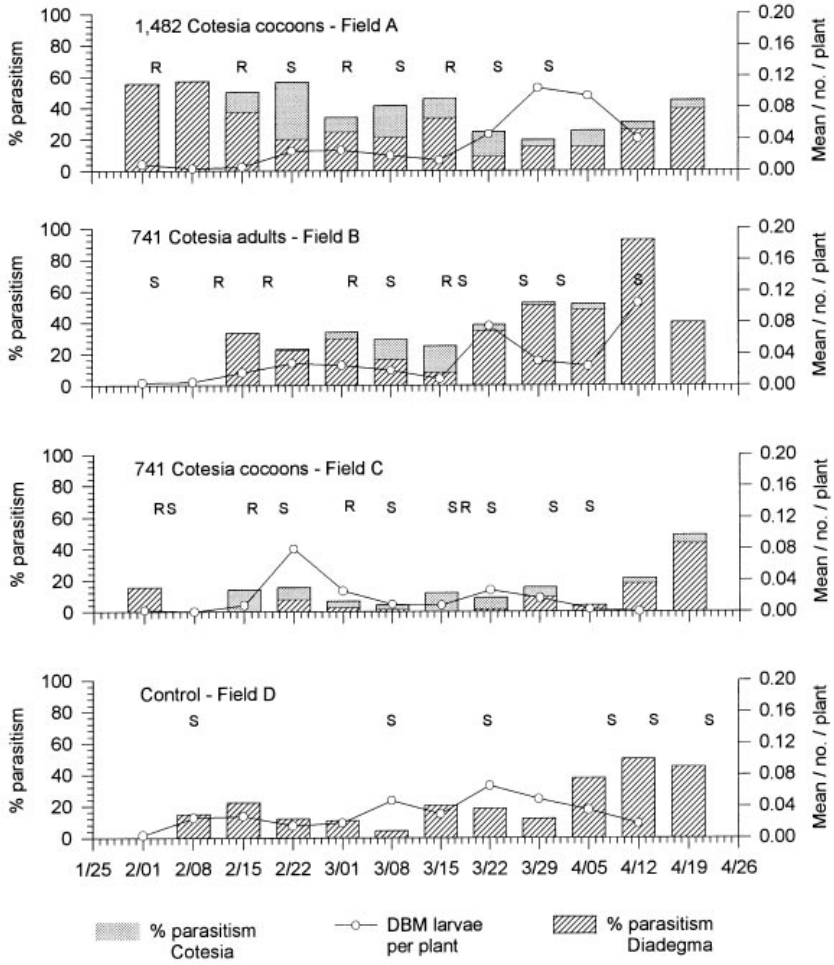

Fig. 3. Seasonal incidence of diamondback moth larval populations and parasitism by *Cotesia plutellae* and *Diadegma insulare* in cabbage. R = date parasitoids were released; S = date field was sprayed with insecticide. Bunnell, FL. 1994.

asitism by *C. plutellae* in fields A, B, and C became progressively less through the remainder of the season.

Mean parasitism over the cabbage-growing season by the naturally-occurring parasitoid *D. insulare* was highest in fields A (29.4%) and B (31.3%); intermediate in field D where no *C. plutellae* were released (20.7%); and lowest in field C (8.6%) (Fig. 3 and Table 1). Mean total parasitism attributed to both *C. plutellae* and *D. insulare* also was highest in fields A (40.3%) and B (34.9%). Mean total parasitism of diamondback larvae in fields C and D was 13.7% and 20.7%, respectively.

There was no evidence that *C. plutellae* survived and became established in the test area following releases made in 1993 or 1994. Growers typically plant the same

fields in cabbage year after year. Thus, we were able to examine the fields in which parasitoids were released in 1993 and 1994 to determine if there was carryover of *C. plutellae* into the following spring cabbage growing season. No *C. plutellae* were recovered in field D in spring 1994 although *C. plutellae* were recovered in this area in spring 1993 following release of adult parasitoids in field 1 (Fig. 1). In spring 1995, cabbage in field A (where parasitoids were released in spring 1994, Fig. 1) and field D were sampled intensely at weekly intervals from February through April and not a single *C. plutellae* parasitoid was recovered. Cabbage in field C, where *C. plutellae* cocoons were released in spring 1994 (Fig. 1) and parasitism of host larvae averaged 5.4% for the season (Table 1), also was sampled intensively at weekly intervals throughout the winter-spring 1995 cabbage growing season. As in fields A and D, no *C. plutellae* were recovered.

In fall 1992, we released a total of 24,981 *C. plutellae* adults in two cabbage fields totaling 12 ha near Zellwood in Central Florida (unpublished). Three releases of about equal numbers of parasitoids (target number per ha = 625) were released at weekly intervals beginning 16 November. These parasitoids also were purchased from Biofac, shipped overnight via air express as described, and released the following morning directly from shipping tubes (250 adults ea) in which they were received. The tubes were evenly spaced throughout each field and placed beneath cabbage leaves for shade. As in the 1993 and 1994 trials, the fields used in 1992 were sprayed heavily,

TABLE 1. RELATIONSHIP BETWEEN RELEASES OF *COTESIA PLUTELLAE* AND THE NATURALLY-OCCURRING PARASITOID *DIADEGMA INSULARE* ON PARASITISM OF DIAMONDBACK MOTH LARVAE IN CABBAGE IN 1994. BUNNELL, FL.

Field	*Cotesia* Released[1] Stage	Number/ha	Mean % Parasitism (± s.e.)[2]
	Parasitism by *Cotesia* (P = 0.0003)		
A	Cocoons	1482	10.9 ± 2.9a
B	Adults	741	3.6 ± 1.5b
C	Cocoons	741	5.4 ± 1.7ab
D	None	0	0c
	Parasitism by *Diadegma* (P = 0.0023)		
A	Cocoons	1482	29.4 ± 4.4a
B	Adults	741	31.3 ± 7.4a
C	Cocoons	741	8.3 ± 3.4b
D	None	0	20.6 ± 4.5a
	Total parasitism (P = 0.0013)		
A	Cocoons	1482	40.3 ± 3.8a
B	Adults	741	34.9 ± 7.0ab
C	Cocoons	741	13.7 ± 3.6c
D	None	0	20.7 ± 4.5bc

[1]The targeted number of parasitoids per release is shown. The actual numbers released, based upon subsequent mortality counts, was about 90% of total shown. Parasitoid releases were made at 2-week intervals on four different occasions starting 06 February.

[2]Means in the same group with different letters are significantly different, Waller-Duncan K-Ratio T test (P-values are shown in parentheses).

TABLE 2. PESTICIDES USED FOR INSECT CONTROL IN CABBAGE FIELDS WHERE THE PARASITOID *COTESIA PLUTELLA* WAS RELEASED IN 1994. BUNNELL, FL.

Date	Material	Rate/ha	Mortality Index[1]
	Field A - 1,482 cocoons/ha		
22-Feb	Monitor	0.71 liter	4
	Xentari	0.24 liter	1
10-Mar	Monitor	0.71 liter	4
24-Mar	Monitor	0.71 liter	4
01-Apr	Phosdrin	0.71 liter	4
	Field B - 741 cocoons/ha		
03-Feb	Monitor 4	0.47 liter	4
08-Mar	Lannate LV	0.47 liter	4
18-Mar	Lannate LV	0.47 liter	4
	Dipel 2X	0.45 kg	1
28-Mar	Lannate LV	0.47 liter	4
02-Apr	Thiodan	0.95 liter	ND
	Dipel	0.45 kg	1
12-Apr	Lannate LV	0.47 liter	4
	Xentari	0.23 kg	1
	Field C - 741 cocoons/ha		
07-Feb	Xentari	0.34 kg	1
21-Feb	Monitor	0.71 liter	4
	Dipel	0.45 kg	1
09-Mar	Dipel	0.45 kg	1
16-Mar	Agree	0.45 kg	1
23-Mar	Phosdrin	0.95 liter	4
31-Mar	Lannate LV	0.71 liter	4
	Xentari	0.23 kg	1
05-Apr	Phosdrin	0.71 liter	4
	Field D - control		
10-Feb	Monitor	0.71 liter	4
	Agree	0.34 kg	1
08-Mar	Phosdrin	0.83 liter	4
	Agree	0.23 kg	1
21-Mar	Asana	0.24 liter	1
08-Apr	Agree	0.23 kg	1
	Dipel	0.23 kg	1

[1]Mortality index for Cotesia adults: 1 = harmless (50%); 2 = slightly harmful (50-79%); 3 = moderately harmful; 4 = harmful (> 99%); ND = no data. All materials sprayed were relatively harmless to Cotesia cocoons. (Kao and Tzeng 1992).

TABLE 2. (CONTINUED)PESTICIDES USED FOR INSECT CONTROL IN CABBAGE FIELDS WHERE THE PARASITOID *COTESIA PLUTELLA* WAS RELEASED IN 1994. BUNNELL, FL.

Date	Material	Rate/ha	Mortality Index[1]
	Lannate	0.95 liter	4
14-Apr	Asana	0.24 liter	1
22-Apr	Asana	0.24 liter	1

[1]Mortality index for Cotesia adults: 1 = harmless (50%); 2 = slightly harmful (50-79%); 3 = moderately harmful; 4 = harmful (> 99%); ND = no data. All materials sprayed were relatively harmless to Cotesia cocoons. (Kao and Tzeng 1992).

and diamondback larval populations were low. Total parasitism of diamondback by *C. plutellae* was < 0.1%; and no *C. plutellae* were recovered in these fields in spring or fall 1993.

DISCUSSION

Numerous attempts have been made to introduce *C. plutellae* into different areas of the world with mixed results (Talekar & Shelton 1993). In the western hemisphere, *C. plutellae* reportedly flourished after introductions into Barbados and Jamaica, and it is credited with affecting significant control of diamondback moths on these and other Caribbean islands (Alam 1992). However, attempts to introduce *C. plutellae* into Honduras, Belize, Costa Rica, and Florida (USA) have not resulted in suppression of diamondback moths (Andrews et al. 1992, Frank & McCoy 1993).

Explanations for establishment of *C. plutellae* in some areas and not others are not readily apparent. *Cotesia plutellae* are numerically responsive to increasing populations of diamondback moths (Ooi 1992, Rowell et al. 1992) and thrive in environments that have not been sprayed with insecticides (Alam 1992). In Florida, cabbage and other cole crops are treated regularly with insecticides to keep pest populations low and prevent damage by diamondback moth larvae (McLaughlin & Mitchell 1993, McLaughlin et al. 1994, Leibee et al. 1995, and Table 2).

In conclusion, *C. plutellae* reproduced in the fields where released, did not survive more than one year, and probably was much less important than the naturally-occurring parasitoid *D.insulare*. There also was no evidence that *C. plutellae* dispersed to other fields nearby. However, in a subsequent study Mitchell (unpublished) found that *C. plutellae* parasitoids spread down wind from the release area but parasitism of diamondback moth larvae on sentinel cabbage or collard plants decreased as the distance from the release area increased up to 800 m.

ACKNOWLEDGMENTS

We appreciate the help of W. Copeland and J. Rye in sampling the fields and preparing the release sites; B. Monroe for constructing the parasitoid release cages; J. Gillet for checking larvae for evidence of parasitism; and J. Leach for compiling the data and preparing the graphics. We extend a special thanks to V. Chew for helpful suggestions on analysis of the data. This article reports the results of research only. Mention of a proprietary product does not constitute an endorsement or the recommendation for its use by USDA.

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