

Diamondback Moth in the Philippines and its Control with *Diadegma semiclausum*

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Abstract

Diamondback moth, *Plutella xylostella* (L.), is the most destructive pest of crucifer crops in the Philippines. Life cycle, population dynamics and biological control with the larval parasitoid *Diadegma semiclausum* have been studied (1988-90) in the mountains of Northern Luzon. One generation of the diamondback moth requires 24.7 days, therefore about 15 generations of the pest may occur during 1 year. The average life expectancy of the females is 16.7 days, during which an average of 233 eggs (maximum 639) are deposited. The continuous monitoring of the diamondback moth field population with light and pheromone traps proved that during the rainy season (June-October) only 5-10 moths/week were found; during population peaks (January and February) almost 3000 moths/week were found. Only one natural enemy — *Cotesia plutellae* (Kurdjumov) has a certain importance in controlling the pest. The parasitism reaches 70% but its efficacy is reduced by hyperparasitism to 80% by a group of six hymenopterans. Starting in March 1989 *D. semiclausum* was imported from Taiwan. The performance of *D. semiclausum* was evaluated in field experiments with screen-covered cabbage plots. The parasitism reached 95%, and in two of three experiments the yield of cabbage was significantly higher than in the control. In an open-field experiment the parasitoid was established with rates of parasitism from 12 to 15% increasing to 64% at harvest time.

Introduction

Crucifer crops like cabbage, *Brassica oleracea* L., Chinese cabbage, *Brassica campestris* (L.) ssp. *pekinensis*, and radish, *Raphanus sativus* L., are the most important vegetables in the Philippines after tomato and eggplant (Bureau of Agricultural Statistics 1988). In 1986 an area of 121,000 ha was planted nationwide with these vegetables (Valmayor and Tiamzon 1988). Cabbage is grown mainly in the mountains of Northern Luzon and is an important source of income for the people.

Diamondback moth (DBM), *Plutella xylostella* (L.) (Lepidoptera: Yponomeutidae), is the most destructive pest of cabbage. DBM ranks above a group of pests with only seasonal importance, e.g. flea beetle *Phyllotreta* sp., aphids *Lipaphis erysimi* (Kalt.) and *Myzus persicae* (Sulz.) (Homoptera: Aphididae), cutworm *Spodoptera litura* (F.) (Lepidoptera: Noctuidae), tomato fruitworm, *Helicoverpa armigera* (Hb.) and cabbage looper *Trichoplusia ni* (Hb.) (Lepidoptera: Noctuidae), and cabbage butterfly *Pieris canidia* L. (Lepidoptera: Pieridae).

In Southeast Asia DBM is highly resistant to most insecticides used for its control (Perng and Sun 1987). In Thailand and Malaysia resistance to synthetic pyrethroids occurred after 1-2 years (Cheng 1988). In the Philippines growth-regulator insecticides (based on teflubenzuron) was successful for about 2 years. A reduced efficacy of even *Bacillus thuringiensis* Berliner is reported from the DBM strain of North Luzon (Theunissen 1981; Kirsch and Schmutterer 1988).

The farmers are using mainly organophosphorus insecticides (triazophos, profenofos, methamidophos), pyrethroids (fenvalerate and deltamethrin) and carbamate insecticides (bendiocarb) for its control. The average number of insecticide sprayings per crop is 12, but could go as high as 20. In some areas farmers are giving up growing cabbage because of their inability to control DBM.

In the Philippines DBM has only one natural enemy of some importance, the larval parasitoid *Cotesia plutellae* Kurdjumov (Hymenoptera: Braconidae). Field parasitism by *C. plutellae* varies over locations, years and seasons from 1 to 70%. Besides the overuse of insecticides as a limiting factor, there is a group of at least six hyperparasitoids limiting *C. plutellae* populations up to 90%. These secondary parasitoids were identified as *Tetrastichus coeruleus* (Bingham) (Hymenoptera: Eulophidae) (LaSalle 1990), *Aphanogmus fijiensis* (Ferriere) (Hymenoptera: Ceraphronidae) (Polaszek 1989), *Diatora* sp. (Hymenoptera: Ichneumonidae) (Fitton 1990a; Horstmann K. pers. comm.) and three species of the genus *Trichomalopsis* (Hymenoptera: Pteromalidae) (LaSalle 1990); these are *T. apanteloctena* (Crawford), *T. ?deplanata* Kamijo & Grissell and *Trichomalopsis* sp. In DBM rearings based on collections from the field the pupa parasitoid *Itopectis* sp. (Hymenoptera: Ichneumonidae) (Fitton 1990) was also found. Occasionally, another larval parasitoid of the genus *Diadegma* (Hymenoptera: Ichneumonidae) was found. This species of *Diadegma* is unknown in Europe and not yet been identified (Horstmann K., pers. comm. 1990).

Diadegma semiclausum plays an important role in the control of DBM in Taiwan (AVRDC 1985) and in Indonesia (Sastrosiswojo and Sastrodihardjo 1986). In March 1989 the Philippine-German Biological Plant Protection Project imported from Taiwan some 100 *D. semiclausum* to evaluate the potential of this parasitoid as a biocontrol agent under Philippine conditions, first in the laboratory, semi-field and then in field experiments. Before working with parasitoids the life cycle, population dynamic, density and occurrence in the course of the year were observed in this region.

Material and Methods

Field observations of the DBM and semi-field experiments were carried out at the experiment farm of the Benguet State University in La Trinidad, Philippines, which is located 250 km north of Manila in the mountains of Northern Luzon (about 1300 m above sea level). *D. semiclausum* was released into the field in La Trinidad Valley, Baguio (about 1500 m above sea level) and Sangan (about 1700 m above sea level).

Laboratory experiment

Six hundred DBM larvae were measured, and their length, width and diameter of the head capsule recorded. On the same day, eggs of DBM laid on 8-week-old cabbage plants were counted. For a period of 15 days, 40 larvae were taken daily, killed and measured. When a sudden increase in the head capsule diameter was observed a molting to the next instar was assumed. For each instar a range in the head diameter was determined and the age of the larvae led to the duration of that instar. The average temperature was 19.5°C (range 15-25°C). The relative humidity was 90% with a range of 70% (day) and 95% (night). To compute the effective thermal total, the threshold of 8.5°C from Yamada and Kawasaki (1983) was adopted.

For laboratory studies on DBM and the parasitoids, glass cages were used. Four-week-old potted cabbage plants were offered to newly hatched single pairs of DBM adults for oviposition. The plants were exchanged daily and the eggs were counted. Unmated pairs were exchanged. The moths were fed with a 30% honey:water solution offered in soaked cotton.

Semi-field and field experiments

Population dynamic of DBM was observed in a 700 m² survey area planted with about 2500 cabbage plants. A light trap and one pheromone trap was placed in this field. The light trap

was an ordinary 100-W bulb. Tests with a special UV black-light produced similar results. Moths were caught from 6 p.m. to 6 a.m. A killing solution of 200 ml 3% formaldehyde was put in a plastic bottle. Every day the bottle was changed and the insects were counted. The sticky insert of the pheromone trap was changed weekly, and the pheromone lure every 2 weeks.

Cabbage was sown in seedbeds and transplanted after 30 days into the field in plots of 1.3 × 5.5 m. Each plot consisted of about 40 cabbage plants in three rows with a planting distance of 35-40 cm. Insect counts were done on six plants/plot taken from the middle row. For semi-field experiments eight plots were covered with nylon screen. The screen was placed 3 days after transplanting. The natural infestation with DBM by that time was sufficient for the experiment. The height of the cages was 2 m. To support the insects two yellow carton papers/cage smeared with a food medium were mounted on the screen at a height of 20 cm.

Release experiment with *D. semiclausum* in the field was conducted from February to May in a broccoli plantation at the Puyat farm in Baguio City. *B. thuringiensis* was sprayed in the first weeks after transplanting.

The degree of parasitism was calculated as follows:

$$\% \text{ parasitism} = \frac{\text{Diadegma cocoons}}{\text{Diadegma cocoons} + \text{Cotesia cocoons} + \text{DBM pupae}} \times 100$$

Results

DBM in Northern Luzon

DBM is closely associated with cabbage. In the valley of La Trinidad, cabbage is grown during the dry season, i.e. from October/November to May/June. No important alternate host plant was observed as a food source for DBM.

Population dynamics

The DBM was present throughout the year (Fig. 1), even during the peaks of heavy rain. In the rainy season it was caught at the rate of 5-10 adults/week in the pheromone trap and 2-3 adults/night in the light trap. During population peaks in January and February 500-700 moths/night were counted in the light trap and 200 moths/week in the pheromone trap.

The DBM population is not primarily suppressed by the reduction of cabbage cultivation in May and June but rather by the rain. The rain induces various mortality factors, such as physical damage by rain drops or fungal infection due to high humidity.

The changing importance of the two traps with respect to the number of moths they caught is caused by weather changes. The effectiveness of a light trap depends very much on the temperature during the night. In the mountains of northern Luzon the coldest period of the year is November-January. Night temperature goes as low as 0°C. The light trap catches shown in Fig. 1 constitute the weekly average. During the rainy season both traps caught more moths of the cutworm *S. litura*.

Life cycle

The developmental time for each instar and the head sizes of the larvae are shown in Table 1. These data correspond well with the findings of Yamada and Kawasaki (1986). Regarding fitness and multiplication, the Philippine conditions with 20°C and 90% RH are very favorable for DBM. Dusk – some 30 min between 6.30 p.m. and 7.30 p.m. – is the adults' most active time for mating and oviposition. In this period the thermohydrograph recorded 20-21°C and 90-95% RH. These are the optimum conditions for DBM. The total development time of 23.7 days suggests, in theory, 15.4 generations/year are possible. However, considering the range

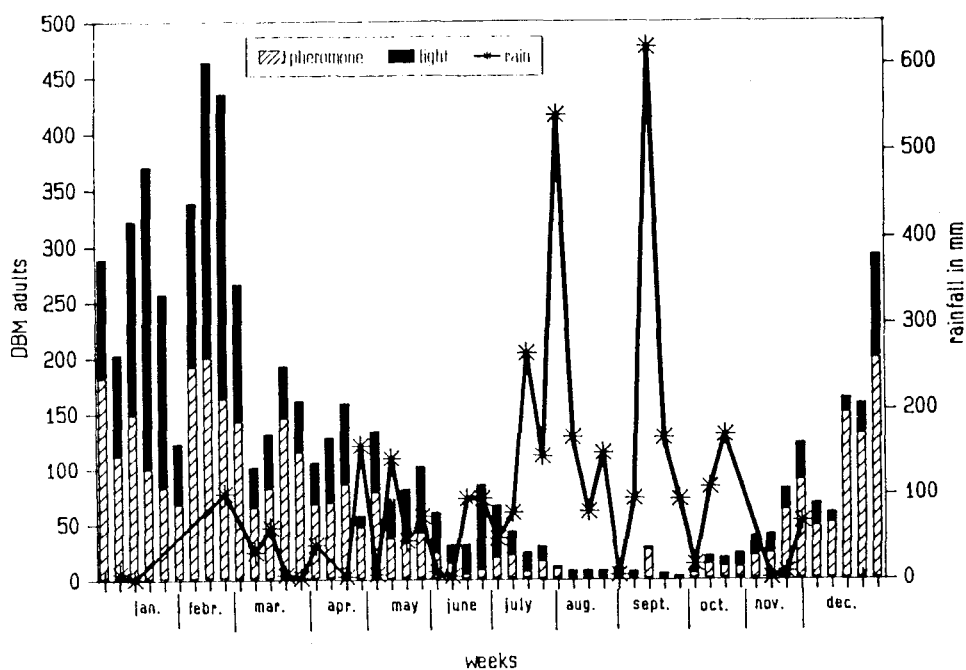


Fig. 1. Monitoring of DBM population by light trap and pheromone trap and rainfall for one year. La Trinidad (Philippines), 1989. Light trap data were taken daily, pheromone trap data weekly.

Table 1. Life cycle of DBM in Northern Luzon (Philippines)^a.

Observations	Development stage							
	Egg	Larval stages				Prepupa	Pupa	Adult
		L1	L2	L3	L4			
Head capsule ^b (mm)	—	0.14 (0.10-0.18)	0.23 (0.20-0.30)	0.42 (0.33-0.48)	0.57 (0.50-0.65)	—	—	—
Life span ^c (days)	4.17 ±0.95	4.18 ±0.57	1.83 ±0.45	3.81 ±0.54	3.33 ±2.09	1.17 ±0.94	5.16 ±0.78	16.10 ^d ±9.43
Time to reach this stage (days)	—	4.17	8.35	10.18	13.99	17.32	18.49	23.65
Day-degree °C ^e	46	46	20	42	37	13	57	Σ=261 ^f

^aField observations (temp.: 19.5°C, RH: 90%); ^bmean (range); ^cmean ± standard deviation; ^dlife expectancy of females (laboratory observation); ^ethreshold temp.: 8.5°C; ^fsum of all developmental stages.

of especially the last three instars (4th, instar larvae, prepupa and pupa) expressed here in standard deviation it becomes obvious that generations overlap. After two generations the individuals found on the plants in the field cannot be accurately assigned to a certain generation. The head capsule sizes are almost the same as those measured by Harcourt (1986). The measurements of length and the width of the larval bodies are useless because of its wide range. The measurements overlap from the 2nd to the 3rd and from the 3rd to the 4th instar.

A female DBM can lay 233 eggs in 12 days. The peak of oviposition is the 2nd day, and after 6 days 90% of the total number of eggs are deposited. The longevity of the females and their fecundity are positively correlated ($R^2 = 0.74$). The results shown in Table 2 are similar to those of Ho (1965) who found an average of 230 eggs/female and Bhalla and Dubey (1986) with 243 eggs/female. However, the maximum number of eggs/female is less in the other studies except Salinas (1986).

Control of DBM with *D. semiclausum*

The pest populations of *D. semiclausum* treated plots and of control plots are given in Fig. 2. The initial pest population was the same in all eight plots. Twenty days after the first release the cocoons of the F₁ generation of *D. semiclausum* were found. Parasitism increased continuously reaching 95%.

An important growth stage for cabbage regarding yield is the period of early head formation. Protecting the plants against pest attack in this span from 45 to 65 days after transplanting can prevent later yield losses. Using *D. semiclausum* it was possible to keep the DBM infestation in this critical time (57 days after transplanting) as low as 5-7 larvae/plant.

Table 2. Reproduction and fecundity of DBM in laboratory observations.

Observations	Mean	Range
Pre-oviposition period (days)	0.3 ± 0.68	0-2
Oviposition period (days)	11.8 ± 6.21	4-20
Post-oviposition period (days)	4.6 ± 4.90	0-16
No. of eggs per female	232.7 ± 193.94	38-639
No. of eggs per female per day	15.9 ± 7.70	2-30
Max. No. of eggs per female per day	66.2 ± 31.36	26-130
Life expectancy of females (days)	16.7 ± 9.43	4-27

(n = 10; Temp.: 19.5°C; RH: 90%)

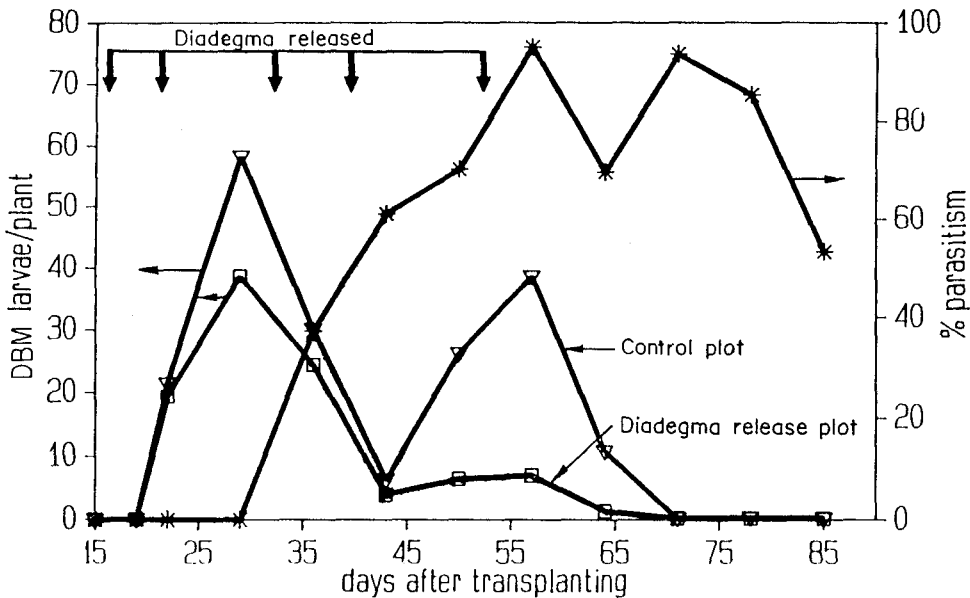


Fig. 2. Population of DBM in control plot and *D. semiclausum* released plots. Both plots were under screen cages in a cabbage field. Swamp, La Trinidad (Philippines), 1990.

The plants in the control plots, however, had up to 40 larvae/plant. This difference is significant (DMRT, $P = 0.05$) and is responsible for the differences in the harvest as given in Table 3. The mean number of larvae/plant over all 10 counts is 18.7 in the control and 9.8 in *D. semiclausum* plots (DMRT $P = 0.05$)

A field release of *D. semiclausum*, with close monitoring of the population, was conducted from February to May 1990 in Baguio. One hundred and fifty pairs of *D. semiclausum* were released 22 days after transplanting in a broccoli garden surrounded by hedges and bushes. DBM pupae and *Diadegma* cocoons were counted to compute parasitism. Fifteen days after release the cocoons of the F_1 generation were found. The parasitoid was established and parasitism reached 64% at harvest time (Fig. 3). This experiment was done under special conditions, since the pest pressure did not compare to other crucifer plantations in Baguio or La Trinidad at that time.

Comparing cabbage under *Diadegma* release with untreated cabbage the weight/cabbage head was higher and, thus, the yield/plot. The single plant weight was recorded after cleaning the cabbage to a marketable condition. The difference in the attributed weight/head results directly from the pest attack and indirectly by removing the damaged cover leaves. Each head of cabbage was classified but usually all plants of a treatment were in the same quality class. The three classes of quality — A, B and C — applied in the vegetable market of the Philippines are reflected in a return difference of 1-2 Pesos (4-8 US cents)/kg.

Table 3. Harvest of three control experiments where *Diadegma* was used for DBM control in cabbage (La Trinidad, Philippines, 1989-90).

Crop attribute	Experiments (location)		
	Balili 1	Balili 2	Swamp
Yield (kg/plot)			
<i>Diadegma</i>	5.59 a	21.60 a	27.28 a
Control	2.45 a	9.30 b	8.60 b
Weight of cabbage (kg/head)			
<i>Diadegma</i>	0.41 a	0.81 a	0.87 a
Control	0.35 a	0.46 a	0.56 b
Quality of cabbage (class) ^a			
<i>Diadegma</i>	B	A	A
Control	B	B	C

Data followed by the same letter are not significantly different (LSD $P = 0.05$). ^aClasses of quality: A = no damage, B = 3 to 5 leaves are removed, C = 5-10 leaves are removed.

Conclusions and Prospects

DBM was successfully controlled with the release of *D. semiclausum*. If it were possible to produce and release the necessary numbers of *D. semiclausum* this system could be transferred to the complete vegetable area of northern Luzon. But the sole import and release of some thousands of *D. semiclausum* to establish this new species is not sufficient. *D. semiclausum* is quickly included in the balance of the ecosystem. It is attacked by the same group of hyperparasitoids as *C. plutellae*. In Baguio a few weeks after release of *D. semiclausum*, 30% of secondary parasitoids emerged from collected *Diadegma* cocoons. It is uncertain whether the established populations of the beneficial species such as *Diadegma* and *Cotesia* are able to suppress the pest population to an acceptable level without any insecticides. But monitoring the pest and the beneficial species could reduce insecticide application. The natural balance of DBM and beneficials could work to a certain level of pest infestation; beyond this level insecticide application will be necessary.

It is shown that the cycle of the DBM generations is never broken throughout the year. If farmers could adjust their rotations not to grow cabbage or other crucifer crops for a certain

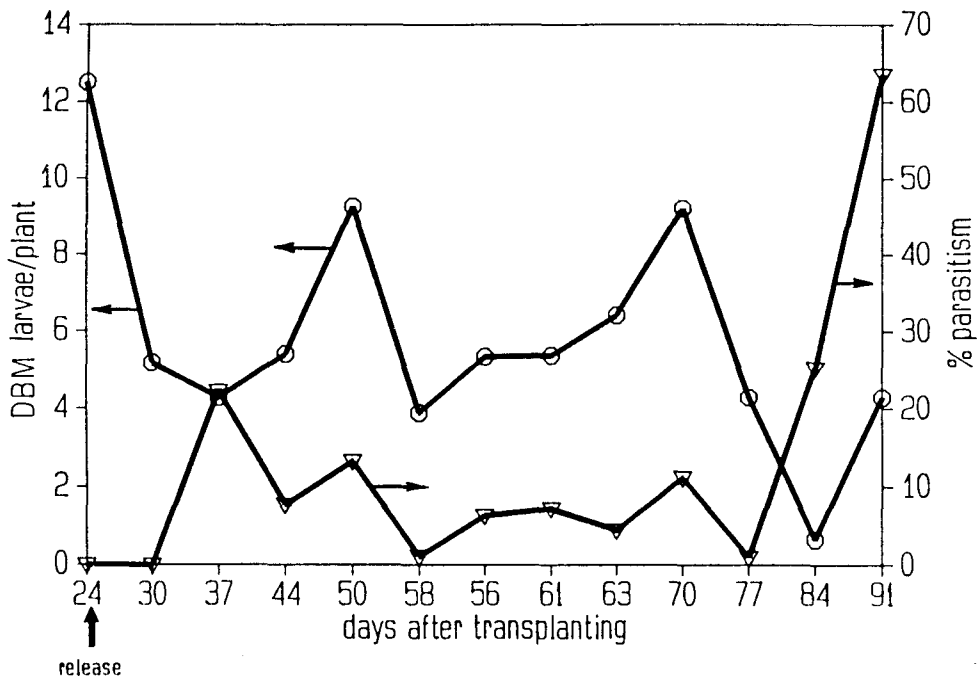


Fig. 3. Population of DBM and parasitism by *D. semiclausum* in open field. Puyat, Baguio City (Philippines) 1990.

time in the year during the rainy season for instance the DBM population cycle would break down. A new immigration and population increase of the pest should be attacked by a release of the parasitoids to accelerate the buildup of the initial population of these beneficials.

Other activities, like threshold spraying, adjusted crop rotation, destruction of plant residues after harvest and the use of selective insecticides are necessary. Nevertheless, the beneficials would be more effective if they were better protected and supported. Sowing flowering plants such as flowering pechay around the plot some weeks before transplanting the cabbage could be one way to attract and feed the beneficials.

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