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A Comparison of Cultural, Biological, and Chemical Control of *Pieris Rapae* (L.) On Cabbage and Cauliflower

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A COMPARISON OF CULTURAL, BIOLOGICAL, AND CHEMICAL CONTROL OF *PIERIS RAPAE* (L.) ON CABBAGE AND CAULIFLOWER

By

Resham B. Thapa

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ABSTRACT

A COMPARISON OF CULTURAL, BIOLOGICAL, AND CHEMICAL CONTROL OF *PIERIS RAPAE* (L.) ON CABBAGE AND CAULIFLOWER

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Cultural, biological, and chemical controls of *Pieris rapae* (L) were tested. On cabbage, *Bacillus thuringiensis* (B.t.) Berliner provided good control of *P. rapae* (92% control and 97% damage reduction). It also gave the highest yield. A mixture of malathion and carbaryl gave very good control and also produced better yield than the other treatments except B.t. On cauliflower, B.t. and the chemical treatment provided 96% and 99% damage reduction, respectively. On both cabbage and cauliflower, chemical treatment based on economic thresholds and weekly sampling was less effective than either B.t. or the weekly insecticide treatment. Hand removal was the least effective on both cabbage and cauliflower, and would not be economical in controlling *P. rapae* in the U.S.

DEDICATION

This thesis is dedicated to my mother.

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INTRODUCTION

The family cruciferae includes many important vegetables and weeds worldwide. The most important species and varieties are cabbage (Brassica oleracea var. capitata L.), cauliflower (Brassica oleracea var. botrytis L.), brussel sprouts (Brassica oleracea var. gemifera DC.), broccoli (Brassica oleracea var. italica Plenck), kholrabi (Brassica oleracea var. caulorapa DC.), turnip (Brassica campestris L. ssp. rapifera (metzg) Sinsk), mustard (Brassica campestris L.), and radish (Raphanus sativus L.) as well as many weed species, such as yellow rocket (Barbarea vulgaris R. Br.), hoary alysum (Berteroa incana L.), indian mustard (Juncea L.) and black mustard (Brassica nigra L.).

Cabbage and cauliflower are two of the major vegetables among crucifers. They originated on the coast of England and Wales, the Channel Islands and Southern Europe. An Arab writer in the twelfth century mentioned "Flowering Syrian Cabbage," today called cauliflower, growing at the eastern end of the Mediterranean Sea (McDonald 1971). Perhaps the original home was the Island of Rhodes and its cultivation spread from the Mediterranean region throughout Europe.

Both cabbage and cauliflower are the leading vegetable crops in many countries of the world (McCollum 1975). They are grown as spring and summer vegetables in temperate climates and winter vegetables in the tropics. In Nepal, they are major winter vegetables. Cabbage and cauliflower world production figures are given in Appendix I (FAO 1980).

In the U.S., the annual return from fresh market cabbage is 40-60 million dollars, from 156,000 to 195,000 acres of land (Mack et al. 1956). Cabbage ranked ninth in acreage and seventh in value among 22 principle vegetable-growing states in 1973. In 1977, total harvest of 101,920 acres valued at about $12 million (McCollum 1980). New York ranked first in cabbage production for sauerkraut with 1979 total harvest of 3402.6 acres valued at $2.54 million (Anonymous 1979). Among cabbage-producing states, Michigan ranks eleventh for its $3,229,000 cabbage crop. In 1981, 2,900 acres of commercial cabbage yielded 46,400 cwt (hundred-weight) for fresh market and processing (Michigan Food Facts 1982). About 90% of the cabbage produced goes to the fresh market. Generally, 32,000 to 35,000 acres of cauliflower are grown annually. It ranked eighth in acreage and sixth in value among vegetable-growing states in 1977. The Michigan cauliflower crop almost doubled in 1981 (Appendix 2), ranking seventh nationally.

Cabbage has long been thought to have medicinal value (McDonald 1971). For example, in Rome every illness had just one remedy--cabbage: crushed cabbage for wounds and dislocated joints, raw cabbage for gout, cabbage juice for deafness, and cooked cabbage for warts and weak eyes. Cabbage was also used to prevent drunkenness.

Cabbage and cauliflower play an important role in nutrition in developing countries. Their nutritional value as greens claims priority among the first foods of infants as their diet needs to be supplemented (Oomen and Grubben 1977). In developing countries, where animal sources of protein are very expensive, vegetables are available and dependable sources of protein. Legumes and other vegetables are the only affordable and readily available source of many required nutrients for vegetarians.

Duckworth (1966) listed the quantities of amino acids in vegetable crops. Of the 20 different amino acids, eight are essential ones that must be provided in the diet. The remaining 12 amino acids can be synthesized in the body. The essential amino acids present in leafy and other vegetables are given in Appendix 3 (Duckworth 1966, in Arthey 1975).

Cabbage and cauliflower contain much sulfur, and when eaten raw are rich in vitamins A, B, and C (Appendix 4). Vitamin C alone is 30-60 mg/100 gm cabbage and, even after storage or fermentation, it is high compared to that of most vegetables. They are also rich in iron and calcium. In addition, raw cabbage provides needed roughage to the diet (Becker and Dickson 1982) (Appendix 5).

Grading of cabbage and cauliflower is done on the basis of maturity, color, head size, and condition. Kramer and Twigg (1970) classified quality characteristics of cabbage and cauliflower into:

1. Quantitative - including yield and net weight.
2. Hidden - including nutritional value and
3. Sensory - including appearance (color, size, flavor and texture).

In the U.S., the Food and Drug Administration controls the quality of various agricultural products. The Agricultural Marketing Service has defined the required qualitative as well as quantitative characteristics for cabbage and cauliflower (CFR 1982). The Runciman Committee (1957) reported the horticultural marketing that stressed the importance of acceptability.

Quality is one of the most important aspects in marketing cabbage and cauliflower in developed countries such as the U.S.A., Europe, and the U.K. (Arthey 1975). However, there are no market standards for these vegetables in developing countries, such as Nepal or India. Simple visual inspection is given at the time of harvest to separate severely damaged heads. Outer leaves are removed from solid heads giving a better appearance and convenience in handling. Quality control and market price are often directly related. Therefore, even some improvement in quality standards in developing countries would result in better prices for producers and better produce to consumers.

Twenty-one different orders of insects, including 92 families and 186 genera, occur in cabbage field (Weives and Chiang 1973). At least 60 species of invertebrates (insects, mites, and gastropods) are injurious to cabbage and cauliflower (Safaryan 1972). Diseases, nematodes, and weeds also affect cabbage and cauliflower production. The primary insect pests in Michigan are the cabbage maggot (Hylemya (= Delia) brassicae Bouche), imported cabbage worm (Pieris rapae L.), cabbage looper (Trichoplusia ni Hbr.), and diamondback moth (Plutella xylostella L.). Other insects may also cause considerable damage. As a result of insect pest attacks, yield and/or market value may be reduced. Of the major insect pests, P. rapae is the most important one (Cass 1961, Pimentel 1961, Hirata 1963, Prasad 1963, Weires and Chiang 1973).

P. rapae

P. rapae is widely distributed throughout the world (Commonwealth of Entomology 1952). It is more common than P. brassicae (L) in Rumania (Niculescu 1963). In Australia and New Zealand, Bartholemeu (1911) reported only the presence of P. rapae. Shapiro (1975) calculated 4% loss of a dozen crops throughout its world range. In the USSR, P. rapae and P. brassicae both are common and cause up to 50% loss in white cabbage (Voltukhov 1975). In the Krasnador region in the USSR, P. rapae caused more damage than P. brassicae.

1. Oviposition

The female lays eggs individually over the host plant leaves, 70% of which are laid on the lower leaf surface (Harcourt, 1962, 1969). She prefers large but not too old plants (Jones and Ives 1979). Richard (1940) reported that the adult female lays 300-400 eggs. Generally she deposits eggs on uninfested hosts or ones with low infestation. There is a significant correlation between the density of eggs and larvae of P. rapae (Prasad 1961). Border rows tend to have a higher density of eggs. This is the function of host discovery (Harcourt 1962, 1969). The eggs hatch in 5-7 days (Demin 1965). Egg biology is referred to Hinton (1982).

Ovipositional preference is the most important factor determining the susceptibility of cabbage to P. rapae (Latheef and Irwin 1979). Plant size, age and varietal characteristics significantly affect egg laying. Mustard glucosides serve as a larval feeding stimulant and also as an adult ovipositional stimulant. Rainey (1936) reported that P. rapae prefered mustard glucosides and presented the glucoside content of 24 cruciferous varieties. Radcliffe and Chapman (1966) tested varietal resistancy of cabbage to P. rapae oviposition preferences. Red cabbage variety was least susceptible to early season oviposition. Chalfant and Brett (1967) studied 37 cabbage varieties and found Mammoth Red Rock and Savoy Perfection Drumhead were the most resistant varieties. Copenhagen Market 36 and Stein's Flat Dutch proved highly susceptible. Leaf water content is another phenotypic characteristic associated with oviposition by P. rapae (Wolfson 1980). Terofol (1965) concluded, on the basis of tests of 50 food plants, that P. rapae and P. brassicae had similar preferences.

2. Larvae

P. rapae larvae are voracious feeders. They feed on the lower epidermis just after hatching and slowly move to the central part. In general, larvae feed from 8 a.m. to 4 p.m. but are most active from noon to 4 p.m. (Stepanova 1962). However, on warm days, they may feed from 4 a.m. to noon and 4 p.m. to midnight. They do not migrate except at very high densities (Harcourt 1961).

Larval development starts at 50°F. Growth rate is limited by availability of nitrogen in the food plants (Slansky and Fenny 1977). Larvae adjust their feeding rate to maximize the nitrogen accumulation rate, since amino acids are necessary for the development and growth of immature stages (Abdel Mageed 1973).

Weather and natural enemies are the major mortality factors for the larvae. Harcourt (1966) reported 3 natural mortality periods for *P. rapae* in early and late cabbage:

1. Between hatching and second moult (primarily rainfall).
2. Third instar to fifth instars (primarily predators and parasitoids).
3. Pupal stage (primarily parasitoids).

Hirta (1963) reported 50% mortality in the egg or first instars and 50% of the surviving larvae failed to pupate.

Late transplanted cabbage may suffer more damage than early transplanted ones (Prasad 1962). Late season infestation reduced weights of marketable heads by 125, 142, and 539 gm/plant, infested at 4, 7, and 9 weeks, respectively, with two larvae/plant. Jackson and Scott (1980) found a highly negative correlation between larval numbers and yield.

3. Pupae and Diapause

The pupal period lasts 8-14 days. Long daily photoperiod and high temperature result in continuous development (Matinyan 1966). Pupae enter diapause after exposure of larvae to photoperiods of less than 11 hours/day (Barker 1963, Barker et al. 1963, Baker and Cohen 1965). However, there is variation in the incidence of diapause in different geographic locations. Pupae may overwinter on tree trunks, fences, plant remains, or other vegetation (Stepanova 1962, Baker et al. 1963, Demin 1965).

4. Adult Activity

Adults emerge in spring from overwintering pupae (Southerland 1966). Generally, they have 3 generations in a year (Harcourt 1961, Kelsey 1964), but may have as many as 6-8 generations (Oatman 1966, Avidov and Harpaz 1969, Saunders 1982). Adults can fly 1¼-3 miles a day and flying speed is 3-6 miles an hour. They prefer to fly 15 cm above the vegetation (Nikolaus 1974).

Predators and Parasitoids of *P. rapae*

1. Predators

About 26 species of birds feed on pierids. Weires and Chiang (1973) reported seven different species of birds occurring in cabbage fields. However, only English sparrow (*Passer domesticus* L.) was common. Dempster (1967, 1969) reported 12 different arthropod predators including five species from Coleoptera alone. Among the predators, the most important were *Harpalus rufipes* (Dig) and *Phalangium opilio* (L.). Feltwell (1982) reports seven species of Hymenoptera and Hemiptera, and three species of Diptera predaceous on pierids. Some species of Orthoptera, Heteroptera, and Dermaptera also are predaceous on pierid larvae. Pimentel (1961) rpeorted spiders as very effective predators of P. rapae.

2. Parasitoids

Parasitoids are more host-specific than predators (Stehr 1975). Both primary and secondary (hyperparasitoids) are known from P. rapae. A few species are facultative hyperparasitoids, attacking both the host and its primary parasitoids. Both solitary and gregarious parasitoids attack P. rapae.

Apanteles rubecula (Marshall) is an early solitary endoparasitoid of P. rapae larvae (Puttler et al. 1970). Trichogramma evanescens (Westwood) attacks P. rapae eggs (Parker 1970). A very common gregarious larval parasitoid of P. rapae is Apanteles glomeratus (L), which can be reared easily in the laboratory (David and Gardiner 1952, Gardiner 1978). Parker (1970) reported A. glomeratus as a major factor keeping P. rapae population at low levels. It parasitizes all stages of P. rapae, but develops best on first and second instars (Moisecva 1960). Ho (1962) reported only 0.33% larval parasitism by A. glomeratus. There are about 45 Apanteles larvae/host (Moss 1933). High rates of A. glomeratus parasitism on P. rapae suppress tachinid parasitoids (Bisset 1934).

Management

1. Cultural

Various pest management options have been used in cabbage and cauliflower to reduce damage in terms of quality and quantity. Some of the oldest practices, still in use today, are methods in which numbers are reduced through cultural practices (Watson 1979, Sill 1982). In the USSR, cultural methods have been used to increase the effectiveness of natural enemies (Ennis 1979). In the

Philippines, tomato grown close to cabbage provides good control for diamond-back moth (Sill 1982). Trap crop or decoy crop is used to control the club root of cabbage incited by Plasmodiophora brassicae (MacFarlane 1952). The trap crop induces the resting fungal spores to germinate but is actually resistant to fungus. Intercropping with repellent crops or enhancer crops has been successful in reducing damage on cabbage and cauliflower (Hart 1979, Brewer and Ball 1978).

Direct traditional cultural practices have been used by farmers for many years. Handpicking of pests is even today practiced in backyard gardens. Cultural practices also have been used in combination with chemical treatment. This practice may be less profitable for the short term; however, in the long run, it may be far more advantageous when considering the side effects of chemical use alone (Watson 1979).

2. Biological

Some very serious pests have been managed by biological methods using natural enemies. Many predators feed on pierids, including various species of birds, spiders, and many orders of insects (Marshall 1909, Collenette 1935, Witherby et al. 1938, Michel 1947, Speyer 1956, Gyory and Reichart 1965, Singh et al. 1976). Cole crop insect parasitoids are listed in Appendix 7 (Pimentel 1981).

The use of microbial control has developed into a more important part of biological control in recent years. The over 1000 microbes known are probably only a part of the total number of pathogens infecting insects (Maddox 1975). The National Academy of Science list of insect pathogens (1969) includes 90 species of bacteria, 260 species of virus and rickettsiae, 460 species of fungi and 255 species of protozoa. Although the first record of the use of microbes for insect control was in the eighteenth century, much of the work was carried out by the middle of the nineteenth century (Feltwell 1982).

Among bacteria that infect insects, the best known is Bacillus thuringiensis var. thuringiensis Berliner (B.t.). B.t. was first discovered in diseased silkworms by a Japanese scientist in 1902. It was rediscovered in 1915 by the German scientist Berliner, in the province of Thuringia. The resting spore of B.t. produces a proteinaceous endotoxin, toxic to lepidopterous caterpillars but with little or no effect on other species (Krieg and Herbs 1963). Its production by American companies has grown to over 900 metric tons (2 million lbs.) per year, including 375 isolates.

The advantages of B.t. are:

1. There is no chemical residue problem.
2. It is somewhat specific and not hazardous to many beneficial insects or humans.
3. Commercial preparation can be made easily and economically.
4. Low doses can suffice in control work.
5. It is compatible with most insecticides and application techniques.

3. Chemical

Insecticides were apparently used before recorded history. Fronk (in Pfadt 1971) noted that sulfur was used by the Greeks against pests about 3000 years ago and the Romans used asphalt fumes to rid their vineyards of insect pests. The Chinese used arsenic compounds against garden pests before 900 A.D.

Before the 1940s, only 2 major categories of insecticides (inorganic and botanical) were used. Paris green (arsenical) was the first insecticide to be used on a large scale in the U.S. After the discovery of DDT by Paul Miller in 1939, a revolution in insecticide control occurred, with the majority (about 90%) of currently used pesticides being synthetic organics.

4. Threshold

Stern (1959) proposed the terms "Economic injury level" and "Economic threshold level." Economic injury level refers to the density of a particular pest species that will cause a loss equal to the cost of an insect control measure. Economic threshold is a density of insect species lower than the economic injury level. It is the pest level where something must be done to avoid reaching the economic injury level. Plant damage is expressed as visible foliage damage to leaves, fruits, or both.

According to these terms, insects are of 2 types: economic and non-economic. Non-economic species are always below the economic threshold. Of many species in a particular crop, only a few occur at densities above the economic injury level, where control measures should be considered.

Objectives

The main objective of this study was to compare different control methods in terms of effectiveness, costs and benefits. The goal was to select an economically desirable combination of control methods for managing cabbage worm complexes in Michigan. In addition, since cabbage worm complexes are prevalent in many countries where cabbage and cauliflower are grown, this study may supply basic information for using management tools in other countries.

Nepal is primarily an agro-based country where 93% of the people are dependent on agriculture (TRAS No. 14, 1980). Legumes and vegetables are the main source of protein in Nepal. Since cabbage and cauliflower are major winter vegetables, pest management is very important to protect these crops. Serious cabbage worm complex problems occur in government research farms and farmers' fields. For example, the cabbage crop was totally destroyed on a farm in Rampur due to severe attacks of insect pests and nematodes (Tereda, IAAS/Rampur, 1978). It was not possible to go there and study this problem in Nepal due to the short time and costs. This study in Michigan will provide problem-oriented information for Nepal where:

1. Farmers are unaware of the potential problems of toxic chemicals. Only 19% of the total population are literate, including government officials, teachers, students, and workers. Most of the farmers can hardly read or write. Therefore, they are not aware of serious hazards of using chemicals such as insecticides, herbicides, and fungicides.
2. Farmers have little experience in chemical use and handling. They are aware of the fact that insect pests and diseases are serious problems in vegetable production, but pest management is largely unknown. It is important here to focus on the safe use of chemicals for pest management. In addition, the use of safe chemicals will reduce problems by lowering the adverse effects on the crop and the environment. Kitchen gardening is common in Nepal; hence, the potential adverse effects on house pets, animals, and humans is high when pesticides are used because of the everyday close contact with them.
3. There are no cold storage facilities for vegetables in Nepal. Many fresh green vegetables may lose their flavor, have their color fade, and undergo rapid decay due to lack of storage facilities. Therefore,

daily fresh vegetable selling and consumption as well as everyday fresh-picked vegetable uses by farmers is a common practice in Nepal. For this reason, chemicals with no waiting days or minimum waiting days after application have advantages over chemicals with long waiting days.

Materials and Methods

This experiment was conducted at the M.S.U. Department of Entomology, Collins Road Farm. The field was selected on the basis of soil type and irrigation availability for growing cabbage and cauliflower (Anonymous 1982). The plot (Fig. 1) was fallow in 1980. During the summer of 1977, the plot had been planted in potatoes for Colorado potato beetle study. The same plot was used in a small plot vegetable study during 1978 and 1979 with various vegetable crops. Cabbbage and cauliflower were planted for experimental study in summer, 1981. Fertilizer (Anonymous 1970, Warnke and Christenson 1981), irrigation (Kaoli and DeVera 1977, Vitosh 1977), weed control (Barrett and Meggitt 1983, Zandstra and Putnam 1983), and maggot control (Wells 1979, Grafius et al. 1981, Lyon et al. 1981) were done as recommended.

Cabbage (var. sanibel) and cauliflower (var. self-blanche) were used in this study. Minge (1968) summarizes varietal characteristics. Self-blanche variety was a self-wrapping variety from M.S.U. (Honma 1973) and sanibel from Wisconsin (Williams and Walker 1968).

Cabbage and cauliflower seeds were sown in vermiculite in the green house on May 20 and watered as needed. Six week old seedlings were transplanted into the field on June 30. A plot consisted of 48 plants spaced one foot apart in 6 rows (3 rows cabbage and 3 rows cauliflower) with 2.5 ft between rows (Fig. 1). A uniform walking space of 4 feet was left between each plot.

Plots were arranged in a randomized block design. The center 4 rows of each plot were treated, leaving one border row on each side to reduce the border effect and provide sources of beneficial insects. There were five treatments including a control. Each treatment was replicated four times. Treatments consisted of:

1. Hand removal (a traditional cultural practice). Hand removal of larvae on cabbage and cauliflower was done weekly. Larvae were removed or smashed on the leaves. No chemical or synthetic biological treatments were used.
2. *Bacillus thuringiensis* (B.t.) (biological method of pest management). *Bacillus thuringiensis* (Dipel) was sprayed at ½ lb. per acre weekly until the crop was harvested. Spraying was done with a low volume 3 gallon (12 liter) backpack sprayer. Spray drift or border effect was minimized with the guard rows, and by selecting spray time for low wind velocity and optimal wind direction (perpendicular to the rows). Each plant in the center 4 rows was covered evenly.
3. Chemicals (chemical method of pest control). The safest available insecticides, malathion and carbaryl, were used in this treatment. They were applied at a rate of 2 pt./A and 1½ lb./A, respectively, in approximately 125 gal. water/A. Treatments were applied weekly.
4. Threshold spray (threshold level of pest management). The same concentration of malathion and carbaryl were used in this treatment. Treatment was applied when the population exceeded an average of one larva per plant.

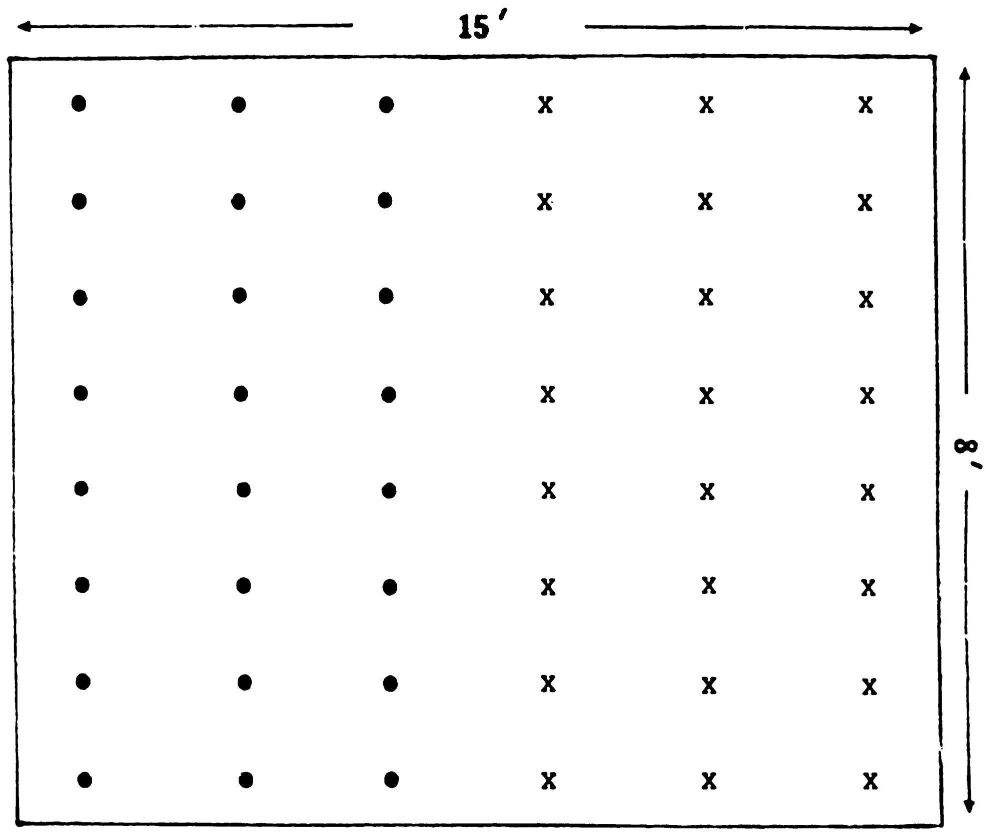

Figure 1. Individual plot

Cabbage (●) and Cauliflower (X).

5. Control (untreated). This was provided to compare the above 4 treatments as well as to observe the pest population trend during the growing season on late cabbage and cauliflower.

The following observations on the center 4 rows in each plot were recorded weekly:

1. Insect counts. The number of eggs, small (1st, 2nd instars), medium (mostly 3rd, a few 4th), and large (4th, 5th instars) larvae per plant in each plot were recorded weekly. P. rapae was the major pest. A few cabbage loopers (Trichoplusia ni) were observed during the growing period. Aphids and white fly numbers were also recorded. The abundance of other insect pests was extremely low. Diamondback moth (Plutella xylostella) was not observed during the study.

   For P. brassicae, a European relative, large larvae consume about 10 times as much as small larvae and medium larvae consume about 5 times as much (Chlondy 1967). Larval numbers of P. rapae were converted into small larva equivalents using these factors, and converted into insect degree days (Ruppel 1982). This made it easier to compare treatments like chemical and B.t. in which only small larvae were present, with the controls and hand removal, where larval size varied.

2. Feeding damage. Holes per plant were recorded weekly. The size of hole is important to plant recovery. Also, hole size is related to the size of the larva. Holes were recorded as small (less than 7 mm) and large (greater than 7 mm). Fifty leaf samples were collected from mid-season growing plants and small and large holes measured on

them, gave the average ratio of 1:10. Large holes were converted into small hole equivalents for comparison between treatments. Only small holes were observed in the chemical and B.t. treatments.

3. Predators and parasitoid counts: In the weekly observations, predators were counted in each plot. Cocoon number of the gregarious braconid, *Apanteles glomeratus*, was counted. Tachinids were present in very low numbers and were not quantitatively sampled.

4. Yield records. Cabbage and cauliflower yields were recorded at harvest. Cabbage heads were graded into 4 categories:

   i. A grade. No holes, no insects, no frass.

   ii. B grade. Wrapper leaves with a few small holes, no insects, no frass.

   iii. C grade. Wrapper and 1-2 inner leaves with small holes, no insects, no frass.

   iv. D grade. Wrapper and more than 2 inner leaves with holes (small or large), presence of frass and insect larvae.

   Cauliflower was harvested almost 3 weeks later than cabbage. No insects or frass were observed in the heads at either of the two harvest dates. All heads were marketable.

5. Adult activity. Pherocon Ic* traps with commerical pheromone caps (Zoecon Corp.) were set up next to the field for cabbage looper adult monitoring. Counts of *P. rapae* adults active in the experimental area were made each week before noon.

6. Weather records. Weather data was recorded at the M.S.U. Horticulture Farm, 2 km south of the Entomology Farm. Temperature data

were converted into degree days using a base 50°F and the technique of Baskerville and Emin (1969).

Results and Discussion

I. EGGS

1. Pieris rapae (L) eggs on cabbage: Eggs were first observed on cabbage leaves on July 31, a month after transplanting, but they must have been present in small numbers earlier since larvae were first found a week earlier. Early cabbage in an adjacent plot was already infested by P. rapae larvae. The mean egg number ranged from 0.58 to 0.84 per plant in the control and the chemical treatments, respectively (Table 1). There were no significant differences in mean numbers of eggs per plant in any treatments. However, block differences occurred. Lower egg numbers were observed in the central blocks. Differences in egg numbers were observed between dates during the growing season. The highest numbers of eggs were observed on August 6, approximately six weeks after transplanting (Fig. 2). The early and late egg laying trends for each treatment were similar.

2. Pieris rapae eggs on cauliflower: Similar results were found in cauliflower. However, the highest egg numbers occurred on hand removal treatment (0.53) and fewest eggs on control (00.4) and differences were not statistically significant (Table 2). More eggs were laid per plant on cabbage than on cauliflower, in agreement with the results of Hart (1979).

II. LARVAE

1. Pieris rapae larvae on cabbage: Cabbage was not infested by first generation P. rapae, as the plants were transplanted in late June. Second

Table 1

Mean *Pieris rapae* eggs and larvae (small equivalents)/ plant on cabbage averaged for all sampling dates.[1]

Treatment	Eggs	Larvae (small eqvt.)
chemical	0.84 a	0.04 a
threshold	0.73 a	0.43 a
control	0.58 a	4.30 c
hand removal	0.22 a	3.61 b
Bt	0.80 a	0.34 a

[1]Means followed by the same letter are not significantly different ($P > 0.05$) by SNK test.

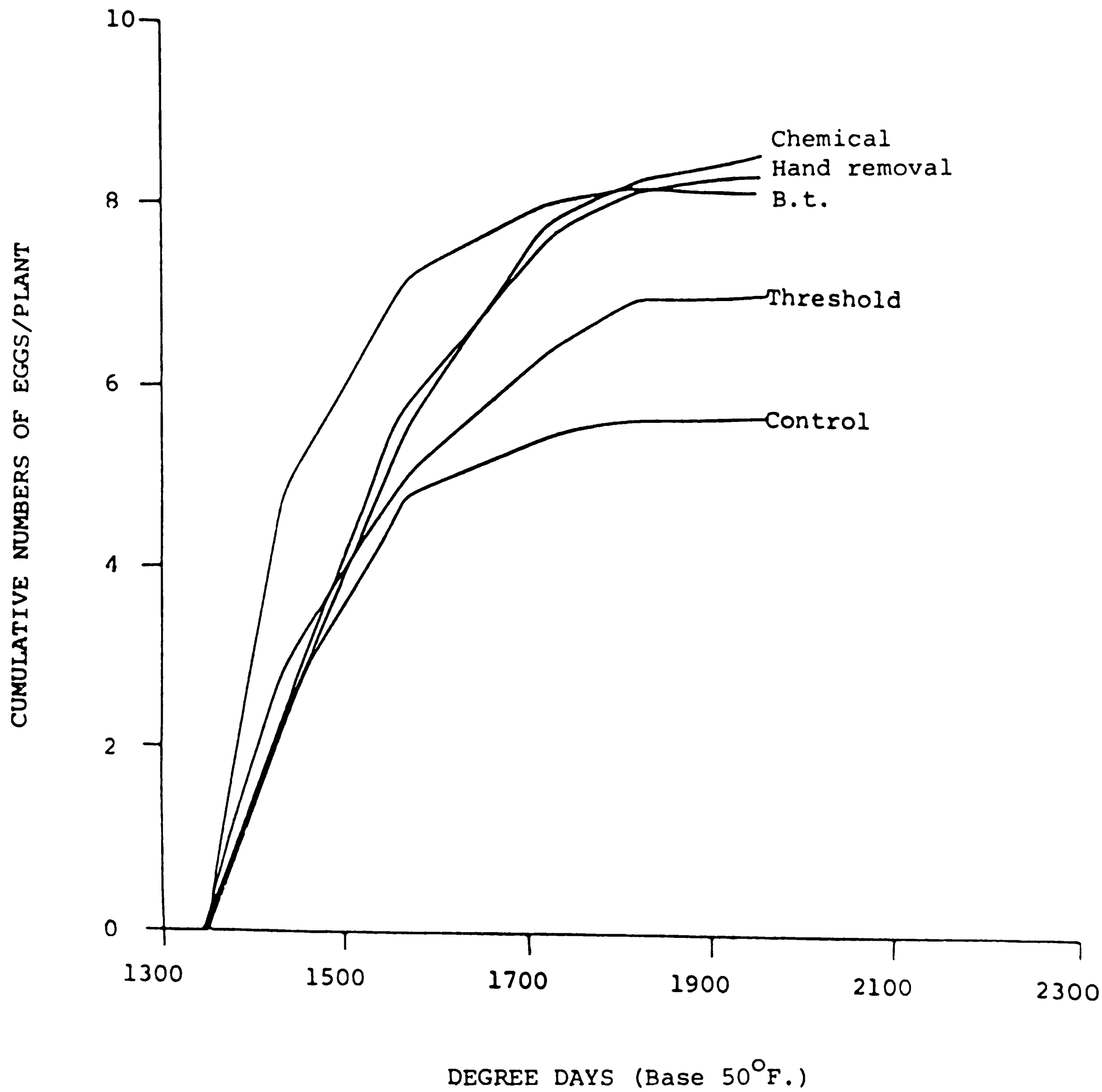

Figure 2. *P. rapae* eggs on cabbage.

generation P. rapae larvae were first noticed in the third week of July (Table 3). Peak numbers were observed in the middle of August.

The mean density of P. rapae larvae (small equivalents) ranged from 0.04 to 4.30 per plant in chemical treatment and control, respectively, during the growing season. Larval density in the control plots was significantly higher than in the other treatments. Chemical, threshold, and B.t. treatment did not differ from each other (Table 1). Treatment and date interaction showed significant differences between dates and treatments (Table 3).

The mean P. rapae larval density (small equivalent) for each date and treatment was converted into insect degree days and plotted against degree days $DD_{50}{}^{o}F$ (Ruppel 1982). A sigmoid trend was observed in hand removal and control while the rest of treatments did not show such a trend (Fig. 3). The chemical treatment reduced insect degree days to the lowest level.

2. Pieris rapae larvae on cauliflower: Similar results were observed for cauliflower as occurred on cabbage. The mean larval number (small equivalent) per plant during the growing season ranged from 0.02 in chemical to 2.62 in hand removal treatment (Table 2). Mean larval densities were lower in cauliflower than in cabbage. Date x treatment interaction was similar to results for cabbage (Table 4).

III. ADULTS

P. rapae adult activity on field: Butterflies were observed on the day of transplanting of cabbage and cauliflower. Their number peaked on July 31, a month after transplanting (Fig. 4). Thereafter, P. rapae adults decreased, and no adults were observed after the third week of September.

Table 2

Mean *Pieris rapae* eggs and larvae/
plant on cauliflower averaged for all sampling dates.[1]

Treatment	Eggs	Larvae (small eqvt.)
chemical	0.45a	0.02a
threshold	0.43a	0.23a
control	0.40a	2.17b
hand removal	0.53a	2.62b
Bt	0.49a	0.13a

[1]Means followed by the same letter are not significantly different ($P > 0.05$) by SNK test.

Table 3

Mean Pieris rapae Larvae (small equivalents) / Plant

During the Growing Season on Cabbage.[1]

Date / Trt.	7/24	7/31	8/6	8/14	8/21	8/29	9/6
chemical	0.0Aa	0.14Aa	0.19Aa	0.03Aa	0.02Aa	0.03Aa	0.0Aa
threshold	0.0Aa	0.59Aa	0.33Ba	2.45Ca	0.06Ba	0.27Aa	0.55Aa
control	0.27Ac	2.25Ac	8.95Ab	18.52Aa	10.40Ab	2.03Ac	0.5 Ac
hand removal	0.5 Ab	3.23Ab	8.47Aa	10.89Ba	8.73Aa	2.94Ab	1.33Ab
Bt	0.0Aa	0.33Aa	1.13Ba	1.03Ca	0.81Ba	0.14Aa	0.0 Aa

[1] Means followed by the same letter (capital in row and small in column) are not significantly different (P > 0.05) by Tukey's multiple range test.

Table 4

Mean *Pieris rapae* Larvae (small equivalents) / Plant during the growing season on cauliflower.[1]

Date / Trt.	7/24	7/31	8/6	8/14	8/21	8/29	9/6
chemical	0.0Aa	0.06Aa	0.09Az	0.02Aa	0.0Aa	0.03Aa	0.0Aa
threshold	0.39Aa	0.06Aa	1.39ABa	0.0 Ba	0.25Ba	0.64Ba	0.0 Aa
check	0.14Ad	0.61Acd	3.31ABc	9.81Aa	6.7 Ab	2.69Bcd	0.89Acd
hand removal	0.23Ad	0.80Ad	4.09Abc	7.98Aa	8.06Aa	6.28Aab	2.09Acd
Bt	0.02Aa	0.17Aa	0.75Ba	0.39Ba	0.22Ba	0.0 Ba	0.0 Aa

[1]Means followed by the same letter (capital in rows and small in columns) are not significantly different (P > 0.05) by Tukey's multiple range test.

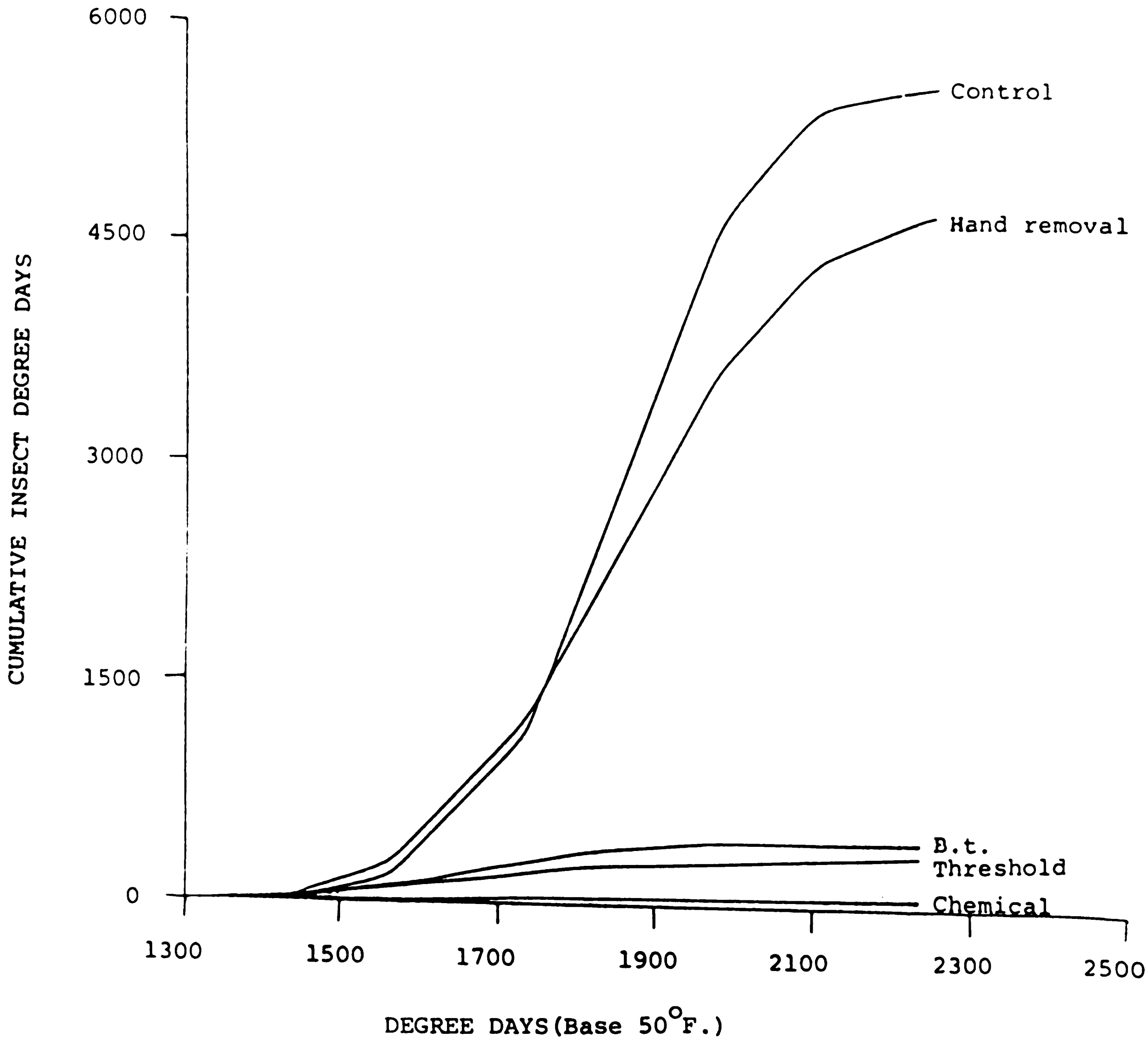

Figure 3. P. rapae larvae(small equivalents)on cabbage.

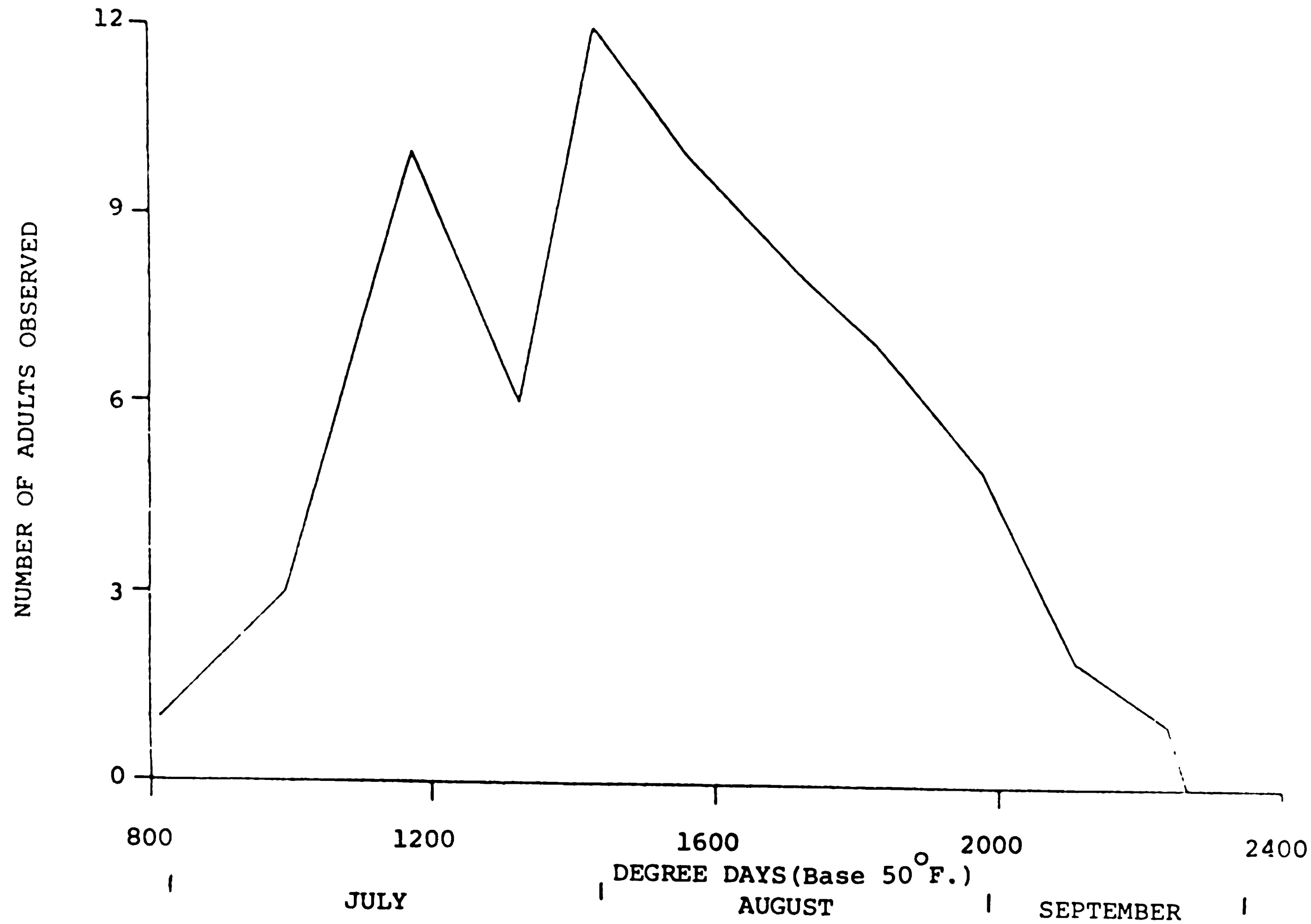

Figure 4. Adult butterflies in field.

IV. PREDATORS

1. Predator activity on cabbage: The first coccinellid predator was observed on July 30. Coccinellid and *Chrysopa* spp. were observed feeding on aphids on cabbage leaves. Very low numbers of predators were observed, ranging from 0.002 to 0.012 per plant in chemical and hand removal, respectively (Table 5). Perhaps the low number of predators in cabbage was due to the low aphid populations which were present during the growing period (0.38 to .74 per plant in chemical and B.t., respectively). Predator numbers were slightly higher on B.t. and hand removal treatments than chemical and threshold treatments.

2. Predator activity on cauliflower: They occurred the same time as in cabbage, and results were similar to results in cabbage (Table 6). Similar numbers of predators were present on cauliflower than on cabbage (0.004/plant in chemical treatment to 0.012/plant in hand removal treatments).

IV. PARASITOIDS

1. Parasitoid activity on cabbage: *Apanteles* cocoons were noticed early in the first week of August and adult *Apanteles* were first observed on August 10. Most parasitoids observed in this study were *Apanteles glomeratus*, ranging from 5-50 per affected host. A few larvae were parasitized by tachinid flies; generally three emerged per affected pupa. Mean percent parasitism ranged from 3.85 in chemical treatment to 0.84 in hand removal (Table 5). Parasitoids in B.t. treatment were lower than hand removal or control, probably due to the the low number of hosts rather than an adverse effects of the B.t. treatment.

2. Parasitoid activity on cauliflower: Pimilar parasitoid activity on cauliflower was similar to that on cabbage (Table 6). Percent parasitism ranged

Table 5

Predators and parasitoids / plant during growing season on cabbage.[1]

Treatment	Mean numbers of predators/ plant	Mean numbers of parasitisized larvae/plant[1]	% Parasitism
chemical	0.002	0.002a	3.85
threshold	0.005	0.003a	0.86
control	0.011	0.040b	2.55
hand removal	0.012	0.011a	0.84
Bt	0.008	0.005a	1.35

[1]Means followed by the same letter are not significantly different ($P > 0.05$) by SNK test.

Table 6

Predators and parasitoids / plant
during growing season on cauliflower.

Treatment	Predators/ Plant	Number of parasitisized larvae/plant[1]	% Parasitism
chemical	0.004	0.0 a	0 a
threshold	0.007	0.0 a	0 a
control	0.010	0.014b	2.25b
hand removal	0.012	0.008a	0.86b
Bt	0.008	0.004a	3.03a

[1]Means followed by the same letter are not significantly different ($P > 0.05$) by SNK test.

from 3.03 in B.t. treatment to 0.86 in hand removal. There were no parasitoids observed in chemical and threshold treatments. Parasitoid numbers were slightly lower in cauliflower than in cabbage.

VI. DAMAGE

1. Holes on cabbage: Chemical and B.t. treatments provided the best control in terms of damage reduction. B.t. provided a 92% reduction of P. rapae larvae and 97% damage reduction and 2-3 times as many marketable heads compared with the control on cabbage (Table 7). Chemical treatment reduced both P. rapae larvae and damage by 99% (Table 7). The mean number of holes (small equivalent) ranged from 0.22 to 43.69 in chemical and control, respectively (Fig. 5). Hand removal was significantly better than control. Both hand removal and control were significantly worse, in terms of damage reduction, than the other treatments. Chemical, critical, and B.t. treatment did not differ significantly from each other.

Analysis of date x treatment interaction showed no differences between dates and treatment for B.t. and chemical treatment. The other treatments differed significantly from each other (Table 9).

2. Holes on cauliflower: Similar results occurred in cauliflower (Table 10). The mean number of holes was lower in cauliflower than in cabbage in the respective treatments, as the result of P. rapae's ovipositional preference for cabbage. Treatment x date interaction showed no differences between B.t. and chemical treatments. The rest of the treatments differed significantly between dates (Table 11).

Table 7

P. rapae and damage reduction in cabbage.

Treatment	Larval reduction %	Damage Reduction %
chemical	99.0	99.5
threshold	90.1	82.5
hand removal	16.0	52.3
Bt	92.0	97.5

Table 8

Effect of treatments on damage reduction on cabbage.

Treatment	Holes/Plant[1] (small equivalents)	Marketable Heads (in %) U.S.	Nepal
chemical	0.22 a	90.6[2]	96.9
threshold	7.69 a	57.1	76.2
control	43.69 c	30.5	44.1
hand removal	20.83 b	36.5	60.3
Bt	1.10 a	96.9	100.0

[1]Means followed by the same letter are not significantly different ($P > 0.05$) by SNK test.

[2]Some heads not marketable due to small size.

Table 9

Mean Number of Holes (small equivalents)/Plant on Cabbage.[1]

Trt. \ Date	7/24	7/31	8/6	8/14	8/21	8/29	9/6
chemical	0.17Aa	0.37Ca	0.78Ca	0.19Ca	0.58Ca	0.12Ba	0.0 Aa
threshold	8.66Ab	3.64Cb	32.02Ba	3.0 Cb	6.05Cb	16.53Ba	6.73Ab
check	15.64Ae	48.25Ad	87.52Ab	141.0 Aa	69.03Ac	55.95Acd	4.48Ae
hand removal	9.33Ac	28.97Bb	46.00Ba	60.44Ba	46.69Ba	13.47Bbc	3.44Ac
Bt	0.70Aa	2.2 Ca	3.39Ca	2.95Ca	1.39Ca	0.36Ba	0.0 Aa

[1] Means followed by the same letter (capital in rows and small in columns) are not significantly different (P > 0.05) by Tukey's multiple range test.

Table 10

Effect of treatments on damage reduction and yield for cauliflower

Treatment	Holes/Plant[1] (small equivalents)	Yield (cwt/A)
chemical	0.17 a	237 a
threshold	2.57 b	264 a
control	13.70 c	257 a
hand removal	12.94 c	260 a
Bt	0.62 a	300 a

[1]Means followed by the same letter are not significantly different ($P > 0.05$) by SNK test.

Table 11

Mean Number of Holes (small equivalents)/Plant on Cauliflower.[1]

Date / Trt.	7/24	7/31	8/6	8/14	8/21	8/29	9/6
chemical	0.0 Aa	0.22Ba	0.41Ca	0.56Ba	0.7 Ba	0.16Ca	0.0 Ba
threshold	1.67Ab	0.92Bb	11.83Ba	0.73Bb	1.39Bb	13.8Ba	0.6 Bb
check	1.94Ae	14.77Ad	34.27Ab	42.39Aa	38.41Aab	24.17Ac	8.52Ad
hand removal	1.59Ae	9.95Ad	33.22Ab	39.67Aab	44.03Aa	20.67ABc	6.11ABde
Bt	0.37Aa	1.53Ba	2.44Ca	1.84Ba	1.06Ba	0.33Ca	0.0 Ba

[1] Means followed by the same letters (capital in rows and small in columns) are not significantly different ($P > 0.05$) by Tukey's multiple range test.

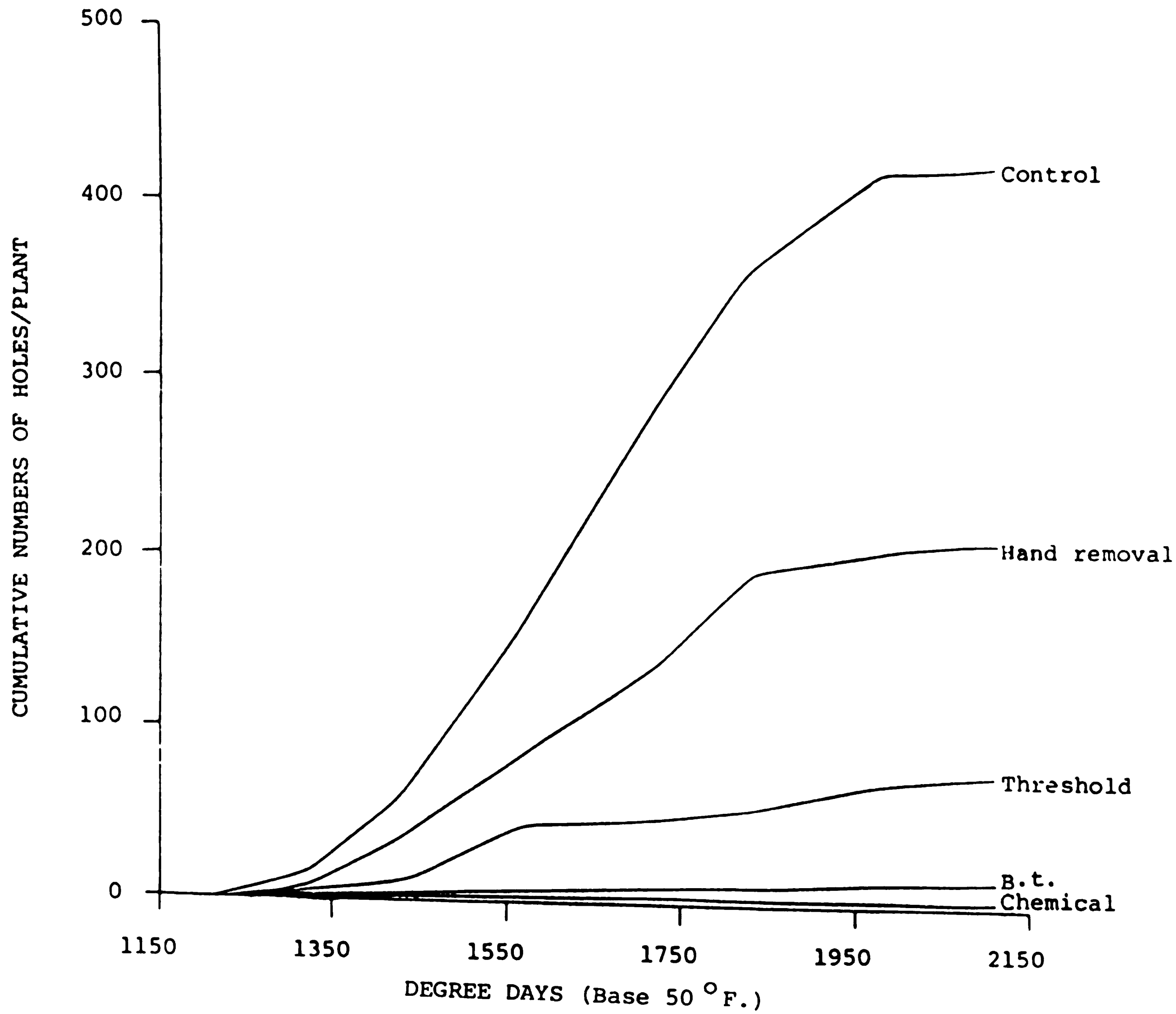

Figure 5. Holes(small equivalents) on cabbage.

VI. <u>YIELDS</u>

1. Yield in cabbage: Qualitative or marketable grades of cabbage were separated for U.S. and Nepal conditions (Table 12). B.t. was the best treatment, producing the highest U.S. marketable yield. However, it did not differ statistically with chemical treatment in U.S. or Nepal market condition. Hand removal was the least effective treatment, producing very low marketable heads under U.S. conditions. The U.S. marketable grade yields averaged from 138 cwt/A to 607 cwt/A in hand removal and B.t. treatment, respectively. However, under Nepal market conditions, yields ranged from 240 cwt/A in control to 631 cwt/A in B.t. treatment (Table 13). Threshold treatment produced slightly lower marketable yields than chemical treatment under Nepal conditions.

2. Yield in cauliflower: First harvest of cauliflower was three weeks later than cabbage and second harvest a month later. *P. rapae* larval populations were extremely low due to cold weather. Also, cauliflower was less preferred for oviposition. Therefore, all cauliflower heads escaped damage or contamination and all heads were marketable. No significant difference in yield was found between the treatments, although B.t. treatment produced slightly higher yields than the rest of the treatments (Table 10).

VIII. Cost-benefit analysis of different control measures on cabbage.

The threshold of larvae on cabbage has been suggested as 0·1 cabbage looper larvae/plant (Green 1972), 1-3 damage rating (Shelton et al. 1982), 1-2 holes/plant (Chalfont et al. 1979), and 1-4 head damage rating (Simonet and Morisak 1982). Andolaro et al. (1982) suggested threshold level on the basis of larval units such as 0·8, 1·0, 1·6, and 2·5 for early preheading, late preheading,

Table 12

Cabbage yield by grade.[1]

Treatment	(A)	U.S. marketable (A+B)	Nepal marketable (A+B+C)	Total (A+B+C+D)
chemical	44.25b	46.10b	48.975bc	51.075a
threshold	20.225a	25.70a	39.30b	50.175a
control	12.125a	16.975b	21.40a	54.850a
hand removal	6.225a	12.475a	24.475a	49.125a
Bt	46.275b	55.80b	57.925c	57.925a

[1]Pounds per plot, means followed by the same letters are not significantly different ($P > 0.05$).

Table 13

Marketable Cabbage Yield[1]

Treatment	U.S. marketable		Nepal marketable	
	cwt/A	$ value	cwt/A	$ value
chemical	502	3494	533	1455
threshold	294	2046	449	1223
control	188	1308	240	653
hand removal	138	960	271	739
Bt	607	4225	631	1720

[1]Dollar value based on 1981 market price for U.S. and 1974-76 for Nepal.

early head formation, and late head formation, respectively. Hoy (1982) provided codes 1-5 for damage rating and larval number per plant on the basis of his sampling technique for cabbage.

Studies have been done on plant growth stages of cabbage, as well as cabbage insect biology. These two critical factors are important means for optimizing sampling and for making control decisions (Chalfant et al. 1979, Harcourt 1962 and 1969, Ladd et al. 1981, Green 1972, Shepard 1973, Simonet and Morisak 1982). The same data still has to be worked out under Nepal conditions based on market standard requirement.

The benefit/cost ratio and net benefit (benefit minus cost) approaches are two common criteria for choosing the best method for pest management (Howitt and Edens 1979). Headley (1972) discussed the economics of pest management as functions of productivity in pest control. The economics of production lie in achieving maximum net return per unit produced. The difference in yield with and without control measure is the marginal benefit of the control method.

Treatment costs and yield recorded at harvest for each treatment are given in Table 13 and 14. The market value of cabbage at harvest was calculated for U.S. marketable grades (Table 13). C and D grade did not meet U.S. market standards. Grades A, B, and C are easily marketable in Nepal. Market value is given in Table 13. Prices for insecticides are estimated for U.S. and Nepal conditions (Table 14).

B.t. and chemical treatments gave higher marketable yields in both U.S. and Nepal market conditions. B.t. was the best control method for U.S. as well as Nepal conditions on the basis of economic analysis (Table 15). It gave the highest net return ($2802 and $999 under U.S. and Nepal conditions, respective-

Table 14

Treatment Cost dollars / acre.[1]

Treatment	U.S.	Nepal
chemical	60	33
threshold	32	14
hand removal	175	17
Bt	115	68

[1]Price calculation based on 1981, labor and chemical costs for U.S., and 1972-76 farming book Rapti model farm.

Table 15

Marginal Return/Acre.[1]
(marginal revenue - marginal cost)

Treatment	U.S.	Nepal
chemical	2126	769
threshold	706	556
hand removal	-523	69
Bt	2802	999

[1]Value in dollars.

ly). B.t. exceeded the net return of the chemical treatment by \$676 under U.S. and \$230 under Nepal conditions.

The second best alternative in both the U.S. and Nepal was the chemical treatment. Chemical treatment gave a slightly higher net dollar value compared to the threshold treatment in Nepal marketable yields, but much higher net return under U.S. conditions. This difference was due to grade standard differences between Nepal and the U.S. Economic thresholds are related to the marketable yield produced; therefore, different grade standards for different countries may alter economic thresholds.

In this study, treatments and sampling were done on a weekly basis. P. rapae densities were far above economic threshold levels on certain dates. The peak period coincided with the critical heading of cabbage which resulted in reduced cabbage head quality, thereby reducing marketable yields.

Hand removal was the least effective method and was not profitable at all under U.S. conditions. In fact, marketable yield and net return were less than the control. Under Nepal market conditions, hand removal gave some net return. It would also provide some employment to farmers. However, it is only practical in small-scale production. Other cultural practices, such as the use of wood ashes, companion crops, and intercropping, may be better alternatives to this method (Brewer and Ball 1978, Ives 1978, York and Guin 1981).

IX. Other insect pests.

Pieris rapae was the most important pest in this study. Other insect pests may also have severe effects on cabbage and cauliflower when they are abundant. In this study, cabbage looper, cabbage aphids, and white flies were also monitored.

Many authors have reported cabbage looper as a major pest in cabbage (Kennedy and Putnam 1976, Wyman and Oatman 1977 in California; Creighton and McFadden 1975 in South Carolina; Hostettler et al. 1979 in Columbia, South America). Similarly, severe injury has been reported on cabbage and broccoli from aphids (Oatman and Planter 1969, Kennedy and Oatman 1976). White flies can cause considerable damage when present in large numbers.

There were few cabbage loopers observed (Tables 16 and 17). Simonet and Morisak (1982) also observed large numbers of P. rapae and only a few cabbage loopers on cabbage in Ohio. Cabbage loopers were first found in early July and continued to late September. Cabbage loopers (small larval equivalents) during the growing season are given in Tables 16 and 17.

Aphid populations were also low. Mean numbers per plant were very low throughout the growing season (Tables 16 and 17). Densities did not differ between cabbage and cauliflower and never reached damaging levels. Chemical and threshold treatments were significantly better than the other treatments in reducing aphid populations in cabbage. However, only chemical treatment was better than the others in cauliflower (Table 17).

Whiteflies can cause considerable damage when present in large numbers. However, they were present only in low numbers and therefore did not differ between treatments. Means per plant averaged during the growing period ranged from 0.37 to 0.51 in chemical and control, respectively, on cabbage (Table 16). Numbers were slightly higher on cauliflower, possibly because of the long growing period (Table 17).

Table 16

Cabbage loopers (small larvae equivalents), aphids, and whiteflies on cabbage $\bar{x}$ number / plant.[1]

Treatment	CL Larvae (small equivalents)	Aphids	Whiteflies
chemical	0.02a	0.38a	0.37a
threshold	0.15bc	0.54b	0.46a
control	0.34d	0.71c	0.51a
hand removal	0.21c	0.68c	0.46a
Bt	0.06ab	0.74c	0.47a

[1]Means followed by the common letters are not significantly different ($P > 0.05$) by SNK test.

Table 17

Cabbage loopers (small larvae equivalents), aphids, and whiteflies on cauliflower $\bar{x}$ number / plant.[1]

Treatment	CL Larvae (small equivalents)	Aphids	Whiteflies
chemical	0.01a	0.30a	0.48a
threshold	0.03a	0.49b	0.60a
control	0.14a	0.62b	0.67a
hand removal	0.07a	0.56b	0.51a
Bt	0.01a	0.64b	0.70a

[1]Means followed by the common letters are not significantly different ($P > 0.05$) by SNK test.

Summary and Conclusions

Cultural, biological, and chemical methods were compared for the control of P. rapae (L.) on cabbage and cauliflower.

Bacillus thuringiensis (Berliner) provided excellent control of P. rapae (L.) with 92% larval reduction and 97% damage reduction on cabbage. It provided the highest marginal returns: 419 cwt/A increase due to treatment for the U.S. market conditions, and 360 cwt/A increase for Nepal market conditions. B.t. was also the best method on the basis of cost benefit analysis with $2802 and $999 net benefit, respectively, under U.S. and Nepal conditions. In addition, B.t. can be used by farmers without any harmful effects on beneficial insects (honey bees, predators, parasitoids) or human health.

The combination of malathion and carbaryl also provided excellent control with 99% P. rapae larval reduction and 99% damage reduction on cabbage. It provided marginal returns of 314 cwt/A and 293 cwt/A under U.S. and Nepal market conditions, respectively (slightly less than the B.t. treatment).

The threshold spray provided 90% reduction of P. rapae larvae and 82% damage reduction. It was better under Nepal market conditions (209 cwt/A increase) than under U.S. conditions (106 cwt/A increase due to treatment). This difference was due to the differences in grading in U.S. and Nepal.

Hand control provided only 16% larval reduction of P. rapae, with 52% damage reduction. it was not affordable under U.S. conditions, being more expensive and providing unsatisfactory control. It produced a 31 cwt/A yield increase under Nepal market condition. It would provide some employment for workers under Nepal conditions. However, the only possibility of using this method for P. rapae control is in kitchen gardens, farmers using their leisure hours, or in places where no alternative methods are available.

On the basis of overall effect on P. rapae control, damage reduction, marketable yield increases, and the economic analysis, Bacillus thuringiensis (Berliner) was the best control measure on cabbage. The malathion and carbaryl mixture was the second best method. Hand removal resulted in high costs and the least control obtained. It did not produce sufficient U.S. grade cabbage increases to cover labor costs.

Threshold sprays did not produce enough marketable cabbage because sampling was not done frequently enough to treat before damage occurred. More frequent sampling is needed on cabbage beginning with pre-heading stages (Simonet and Morisak 1982).

This study shows that B.t. is the best method for P. rapae management. Use of the B.t. program in Nepal will provide the following benefits:

1. It eliminates the potential problem of toxicity and poisoning to beneficial insects, animals, growers, and consumers.

2. Even the least experienced farmer can handle it easily. Insecticide and herbicide handling is more critical.

3. B.t. facilitates daily fresh vegetable consumption due to no time limit from spray to harvest.

4. B.t. solves the problem of poisoning and toxic effects on household pets, animals, and human beings. It is best for kitchen or backyard gardening.

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Appendix 1

Cabbage and Cauliflower World Production for 1980 (FAO 1981).

Region	Area harvested (1000 HA)		Yield (1000 MT)	
	Cabbage	Cauliflower	Cabbage	Cauliflower
World	1628	341	35139	4535
Africa	25	7	640	146
N. C. America[1]	95	23	1847	264
U.S.A.	72	17	1551	195
South America	23	5	571	73
Asia	783	176	15401	1746
Europe	320	126	8032	2183
Oceania	5	4	109	114
USSR	377*	2*	8540*	9*

*Data estimated.

1 includes Antiqua, Barbados, Bermuda, Canada, Costa Rica, Cuba, Dominican Republic, El Salvador, Guadelope, Guatemala, Haiti, Honduras, Jamaica, Martinique, Mexico, Nicaragua, Panama, Puerto Rico, Trinidad Tob. and USA.

Appendix 2

Vegetable production and value in Michigan (Michigan Dept. of Ag. 1982).

Crop	Year	Acres		Production		Price Received (Dollars/ cwt)	Value of Production (1,000 Dollars)
		Planted	Harvested	Per Acre (cwt)	Total (1,000 cwt)		
Cabbage	1977	3,600	3,200	164	526	6.28	3,302
	1979	3,300	3,000	163	489	6.56	3,207
	1981	3,200	2,900	160	464	6.96	3,229
Cauliflower	1977	1,100	1,000	50	50	16.60	831
	1979	1,200	1,100	70	77	27.70	2,132
	1981	1,200	1,000	62	62	37.90	2,350

Appendix 3

Essential amino acid contents in vegetables
(Duckworth 1960).
Amounts gm/100 gm protein

	Leafy Vegetables	Other Vegetables
Lysine	3.1 - 7.5	1.5 - 5.8
Methionine	0.9 - 2.0	0.5 - 2.6
Tryptophan	0.9 - 2.1	0.6 - 1.6
Leucine	3.7 - 9.3	2.7 -11.9
Isoleucine	2.4 - 6.3	1.5 - 5.1
Phenylalanine	1.9 - 6.4	1.4 - 4.5
Threonine	2.2 - 5.5	1.5 - 5.0
Valine	1.8 - 7.1	2.2 - 6.4

Appendix 4

Vitamin Content in Cabbage and Cauliflower
(Lorenz and Maynard 1980).

Amounts/100 gm					
Vegetable	Vit A (IU)	Thiamin (mg)	Riboflavin (mg)	Niacin (mg)	Ascorbic Acid (mg)
Common Cabbage	130	0.05	0.05	0.3	47
Savoy Cabbage	200	0.05	0.08	0.3	55
Cauliflower	60	0.11	0.10	0.7	78

Appendix 5

Nutritional Values of Cabbage and Cauliflower (Lorenz and Maynard 1980).

	Amounts/100 gm									
	Water (%)	Energy (kcal)	Protein (gm)	Fat (gm)	Carbohydrate (gm)	Ca (mg)	P (mg)	Fe (mg)	Na (mg)	K (mg)
Common Cabbage	92	24	1.3	0.2	5.4	49	29	0.4	20	233
Savoy Cabbage	92	24	2.4	0.2	4.6	67	54	0.9	22	269
Cauliflower	91	27	2.7	0.2	5.2	25	56	1.1	13	295

Appendix 6

Amount and dollar value of BT used at the farm level (USDA 1976).

Year	Amount (Kg)	Value (Million $)
Before 1970	11,350	0.4
1970	136,200	2.7
1971	295,100	5.9
1972	363,200	7.2
1974	454,000	9.0

Appendix 7

Parasitic Insects Introduced as Biological Control Agents for Arthropod Pests on Cole Crops.
(Luck in Pimentel 1981).

Pest	Crop	Problem Location		Parasite	Order/ Family	Source	Estab- lished	Success	Ref.*
Bravicornyne brassicae (L) (Cabbage aphid)	Cabbage	Australia	1.	Unnamed sp.	Hymenoptera	Ceylon, 1907	yes	P	1
			2.	Diaeretiella rapae (McIntosh)	Hymenoptera Braconidae	Queensland, New South Wales, 1902	yes	None	2
Murgantia histrionica (Hahn) (Harlequin cabbage bug)	Veg.	U.S. (California)	1.	Trissolcus murgantiae (Ashmead)	Hymenoptera Scelionidae	U.S. (Mississippi) 1941-1942	yes	?	2
		U.S. (Hawaii)		Ooencyrtus johnsoni (Howard)	Hymenoptera Encyrtidae	U.S. (California) 1940	yes	?	2
			2.	T. murgantiae (Ashmead)	Hymenoptera Scelionidae	U.S. (California) 1946	yes	?	2
		Bermuda		O. johnsoni (Ashmead)	Hymenoptera Encyrtidae	U.S. (Hawaii) 1953	no	-	2
Pieris rapae (L) (Imported cabbage worm)	Crucifer	U.S.	1.	Apanteles glomeratus (L)	Hymenoptera Braconidae	Germany, 1881;	no	-	2
						England, 1884, 1889	yes	N	2
			2.	Trichogramma evanescens (Westwood)	Hymenoptera Trichogramma-tidae	Europe, 1965-1967	?	?	2
			3.	A. rubecula (Marsh)	Hymenoptera Braconidae	Canada, 1967 (British Columbia)	yes	?	2
		U.S. (Hawaii)	1.	A. glomeratus (L)	Hymenoptera Braconidae	U.S., 1898, 1923 Japan, 1923	yes	?	2
			2.	Pteromalus puparum (L)	Hymenoptera Pteromalidae	U.S., 1898-1919	yes	?	2
		New Zealand	1.	P. puparum (L)	Hymenoptera Pteromalidae	England, 1932-1933	yes	S	2
			2.	A. glomeradus	Hymenoptera Braconidae	England, 1932-1934;	no	-	2
						U.S., 1938-1939	yes	S	2

Appendix 7 Continued

Pest	Crop	Problem Location	Parasite	Order/ Family	Source	Estab- lished	Success	Ref.*
		Australia	1. P. puparum (L)	Hymenoptera Pteromalidae	New Zealand 1941	yes	S	2
			2. A. glomeradus (L)	Hymenoptera Braconidae	Canada, 1942; England, 1943-1944	yes	S	2
			3. A. rubecula (Marsh)	Hymenoptera Braconidae	Switzerland 1949	yes	S	2
		Philippine Islands	1. A. glomeradus (L)	Hymenoptera Braconidae	U.S., 1934	no	-	2
			2. P. puparum (L)	Hymenoptera Pteromalidae	U.S. (Hawaii) 1934	no	-	2
Plutella xylostella (L) (Diamondback moth)	Crucifer	New Zealand	1. Diadegma cerophaga (Grav.)	Hymenoptera Ichneumonidae	England, 1936	yes	S	2
			2. Diadromus collaris (Grav.)	Hymenoptera Ichneumonidae	England, 1937	yes	S	2
Pieris rapae (L) (Imported cabbage worm) (continues)	Crucifer	Australia	1. Diadegma fenestralis (Holmar)	Hymenoptera Ichneumonidae	New Zealand 1938	no	-	2
			2. D. cerophaga (Grav.)	Hymenoptera Ichneumonidae	New Zealand 1946-1947	yes	P-S	2
			3. D. tibialis (Grav.)	Hymenoptera Ichneumonidae	Italy, 1951	no	-	2
			4. Diadromus collaris (Grav.)	Hymenoptera Ichneumonidae	New Zealand 1947	yes	P-S	2
			5. A. plutellae (Kurdjumov)	Hymenoptera Braconidae	Italy, 1951	yes	P-S	2
		Indonesia	1. Diadegma cerophaga (Grav.)	Hymenoptera Ichneumonidae	Holland, 1928; New Zealand 1950	yes	S	2
		Fiji	1. Diadromus collaris (Grav.)	Hymenoptera Ichneumonidae	New Zealand 1943,1945	no	-	2
			2. Diadegma cerophaga (Grav.)	Hymenoptera Ichneumonidae	New Zealand 1943,1945	no	-	2

Appendix 7 Continued

Pest	Crop	Problem Location		Parasite	Order/ Family	Source	Estab- lished	Success	Ref.*
		Tongo	1.	Diadromus collaris (Grav.)	Hymenoptera Ichneumonidae	Fiji, 1943	no	-	2
		Antigua	1.	D. collaris (Grav.)	Hymenoptera Ichneumonidae	Canada, 1949	no	-	2
			2.	Diadegma cerophaga (Grav.)	Hymenoptera Ichneumonidae	Canada, 1949	no	-	2
		Hong Kong	1.	Macromalon orientale (Kerr)	Hymenoptera Ichneumonidae	India, 1968	?	-	3
			2.	Tetrastichus sokolowskii (Kurdj)	Hymenoptera Eulophidae	India, 1968	?	-	3
		Barbados	1.	Diadromus collaris (Grav.)	Hymenoptera Ichneumonidae	Canada, 1949	no	-	2
			2.	Diadegma cerophaga (Grav.)	Hymenoptera Ichneumonidae	Canada, 1949	no	-	2
		Jamaica	1.	Diadromus collaris (Grav.)	Hymenoptera Ichneumonidae	Canada, 1949	no	-	2
		South Africa	1.	Nythobia cerophaga (Grav.)	Hymenoptera Ichneumonidae	England, 1936	yes	?	4

Appendix 7 Continued

Pest	Crop	Problem Location	Parasite	Order/ Family	Source	Estab- lished	Success	Ref.
Hylemya spp. (Root maggot)	Crucifer	Canada	1. Aleochara bilineata (Gyltenhal)	Coleoptera Staphylinidae	Switzerland 1949-1954	?	-	2
			2. A. bipustulate (L)	Coleoptera Staphylinidae	Switzerland 1949-1954	?	-	2
			3. Phygadeuon trichops (Thoms)	Hymenoptera Ichneumonidae	Switzerland 1949-1954	?	-	2
			4. Tribliographa rapae (Westwood)	Hymenoptera Cynipidae	Switzerland 1949-1954	?	-	2
			5. Aphaereta sp.	Hymenoptera Braconidae	Japan, 1953	?	-	2

[1]Laing and Hawai 1976. [2]Clausen 1978. [3]Rao et al. 1971. [4]Jaques 1974.