THE EFFICIENCY OF *BEMBIDION LAMPROS* (HERBST) (COLEOPTERA:CARABIDAE) AS A PREDATOR OF *HYLEMYA BRASSICAE* (BOUCHÉ) (DIPTERA:ANTHOMYIIDAE) EGGS AND THE EFFECTS OF SEVERAL INSECTICIDES ON THE BEETLE

by

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B.Sc., University of IFE, 1971

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

in the Department
of
Plant Science

We accept this thesis as conforming to the
required standard

THE UNIVERSITY OF BRITISH COLUMBIA

April, 1976

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Date April 1976

ABSTRACT

The efficiency of the carabid beetle, Bembidion lampros (Herbst) as a predator of the eggs of Hylemya brassicae (Bouché) and the effects of the insecticides Dipel, methomyl and chlorfenvinphos on the beetle were studied by introducing some B. lampros into experimental plots of Brussels sprouts and restricting their movements by surrounding the plots with polythene barriers.

More eggs were laid in the first than in the second generation of the cabbage root fly. There was progressive decrease in the number of root fly eggs and the number of B. lampros as the plants matured. During the first generation the untreated control had significantly more eggs than the other treatments. Egg predation by B. lampros resulted in a 45% reduction. In plots containing B. lampros and treated with methomyl, Dipel or chlorfenvinphos, the numbers of eggs were reduced by 35, 44 and 66% respectively.

Laboratory toxicity studies showed that methomyl at 1 g/litre produced 100% mortality of B. lampros one day after treatment. When the rate was reduced to 1/2, 1/4 and 1/8, the mortality of B. lampros dropped to 70, 40 and 20% respectively. Dipel [Bacillus thuringiensis Berliner (16000 IU/mg)] at 1 g/litre and 5 g/litre and chlorfenvinphos at 10 ppm and 40 ppm; produced no mortality three days after treatment. Foliar application of methomyl for aphid control

in the field significantly reduced the *B. lampros* population. There was no significant effect on *B. lampros* when Dipel was applied as a foliar spray to control lepidopterous larvae. Chlorfenvinphos granules applied once early in the season as a subsurface treatment prevented damage by cabbage maggot and was not toxic to *B. lampros*.

Cabbage maggot damage was not severe enough to cause significant reduction in yield at harvest but examination of roots showed that untreated plots had significantly more maggot damage than other treatments. The damage index ranged from 2.5 for untreated plants to 0.0 in plants from plots treated with chlorfenvinphos and containing *B. lampros*. Although differences were not significant, the numbers of overwintering root fly puparia were highest in untreated plots. Significantly more empty puparia, indicating second generation fly emergence, were also found in the untreated plots.

Besides *B. lampros*, other carabids removed from the experimental plots included: *Harpalus affinis* Schr., *Amara* spp., *Calathus fuscipes* Goeze, *Pterostichus melanarius* Ill. and other *Bembidion* spp., in decreasing order of abundance.

B. lampros alone does not give complete protection against root maggot, especially if fly oviposition is very heavy during the first generation when the beetle is most effective. But the beetle will go a long way to suppress part of the population. The use of non-selective insecticides for control of pests of *Brassica* may lead to reduction of *B. lampros* populations and a consequent increase in cabbage maggot attack.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENT

I wish to express my sincere thanks to Dr. D.G. Finlayson, Entomology Division, Research Station, Agriculture Canada, Vancouver for his guidance and supervision throughout this study. His help in preparation of the photographs in the thesis is gratefully acknowledged. I am also indebted to Dr. H.R. MacCarthy, Head, Entomology Division, Research Station, Agriculture Canada, Vancouver for suggesting this topic and for his helpful discussion and encouragement during the field and writing stages of my project. I also thank my faculty supervisor, Dr. J.H. Myers, Institute of Animal Resouces Ecology, U.B.C., for her keen interest and advice on the project.

Thanks to members of my committee, Dr. V.C. Runeckles, Dr. H.R. MacCarthy, Dr. D.G. Finlayson and Dr. J.H. Myers for helpful suggestions and criticisms in the writing of the thesis.

I would like to express my appreciation to Mr. C.J. Campbell, Technician, Research Station, Agriculture Canada, Vancouver for his technical assistance in the field and laboratory studies. His assistance in identifying some of the carabid beetles is gratefully acknowledged. Acknowledgement is also given to Dr. G.W. Eaton, Department of Plant Science, U.B.C., for his advice on statistical analysis. Special thanks go to Mrs. R. Iyer, Technician, I.A.R.E., U.B.C.; Miss O. Piedrahita and Miss K. Fry for their field assistance during the summer of 1975.

I am grateful to the Director, Research Station, Agriculture Canada, Vancouver for permitting my use of the facilities available at the Research Station. The close cooperation of other members of the staff, particularly the library staff at the Station, is gratefully acknowledged.

Finally, I am grateful to the Federal Department of Agriculture, Federal Republic of Nigeria for providing financial aid during the course of this study.

1. INTRODUCTION

The cabbage maggot, Hylemya brassicae (Bouché) is a particularly destructive pest of cabbage, Brussels sprouts, cauliflower, radish, turnip, swede and rutabaga (Lovett, 1913; Paillot, 1914; Schoene, 1916; Brittain, 1927; Smith, 1927). In Canada, in a review by Beirne (1971), it is said to be the most important vegetable pest in Newfoundland and Labrador, the most important single factor limiting turnip production in New Brunswick, one of the main factors limiting high quality rutabaga production in Alberta, and the most serious pest of cabbage and cauliflower in British Columbia where it is a critical factor in the production of early cabbage in the coastal regions.

In certain seasons in North America, as many as 90% of the plants in some brassica crops may be killed (Forbes and King, 1957) and this must surely also be the case in other countries where infestations are severe (Coaker and Finch, 1971). In England and Wales, crop losses of edible brassicas can be as high as 60% but the average estimate, assuming that the crop loss is lower in wet than in dry years, is nearer to 24% (Strickland, 1965). Plants attacked as seedlings or after transplanting are usually severely damaged and they often die because the combination of larval feeding and subsequent rotting destroys the entire root system (Coaker and Finch, 1971). Vigorously growing stem brassicas can support heavy populations of larvae without showing signs of attack but when the larvae directly attack that part of the plant which is used for human consumption, e.g. swede and radish, even a small amount of damage lowers the quality. The presence of larvae within the buttons of Brussels sprouts is a serious problem in crops grown for processing because, even though the incidence of damage is very low, the crop may be rejected (Coaker, 1967).

Certain parasites and predators have been identified and these exert some measure of control by feeding on the immature stages of the cabbage root fly (Wishart et al., 1956; Hughes, 1959; Wright et al., 1960; Read, 1962; Mitchell, 1963a; Coaker and Williams, 1963).

The single-factor approach to insect control, involving sole reliance on insecticides, has the following limitations: 1) selection for resistance in pest populations, 2) destruction of beneficial species, 3) resurgence of treated populations, 4) outbreaks of secondary pests, 5) residue in feeds, foods and the environment, and 6) hazards to humans and the environment (Luckmann and Metcalf, 1975). Strains of cabbage maggots resistant to chlorinated hydrocarbons have already appeared in most countries (Finlayson, 1962; Howitt and Cole, 1962; Harris et al., 1962; Chapman and Pitre, 1963; Coaker et al., 1963). It has also been found that most of the recommended insecticides are toxic to the natural parasites and predators of the cabbage root fly (Morris, 1960; Coaker, 1966; Edwards et al., 1970; Critchley, 1972b; Hassan, 1973). Any reduction in the numbers of parasites and predators, mostly carabids and staphylinids would cause a proportionate increase in survival and numbers of the pest and of the amount of damage on brassica roots (Pickett, 1959; Coaker and Williams, 1963; Coaker, 1965). Luckmann and Metcalf (1975), remark that it is likely that most insect pest-management programs will utilize insecticides, but this use must be compatible with other controls and consistent with the pest-management concept.

The present study evaluated the efficiency of the carabid beetle, Bembidion lampros (Herbst) as a predator of cabbage root fly eggs and gauged the effects of certain insecticides on the beetle with a view to applying an integrated control program for the pest complex of brassica crops.

2. LITERATURE REVIEW

2.1 *Bembidion lampros* (Herbst) (Coleoptera:Carabidae)

2.1.1 Distribution and abundance

Bembidion lampros is a ground beetle in the family Carabidae, a native of Europe and Asia where it is very widely distributed (Hatch, 1953). This species was first recorded in North America in southwest British Columbia in 1946 but the extent of its present distribution in North America is not completely known (Finlayson and Campbell, 1974; Finlayson *et al.*, 1975).

In cabbage plots *B. lampros* occurs in higher numbers on bare ground between the plants than under the plants, and the population of adults found between the plants decreases as the plants increase in size (Mitchell, 1963a). They appear to prefer bare or sparsely covered ground between plants to shaded ground. Mitchell (1963b) showed that the numbers of *B. lampros* were inversely related to the age of each crop, and directly related to the amount of bare ground on each plot.

2.1.2 Life history

The following description of the life history of *B. lampros* is taken from Mitchell (1963a).

Adult males and females are found on the ground during April and May. Copulation occurs between late April and late July and gravid females particularly those ready for oviposition readily move into deep cracks in the soil, a behaviour pattern which is not typical of non-breeding adults except during the winter.

The total number of eggs produced is not known but one batch consisting of about 16 eggs is laid at a time. The eggs are very small with no chorion markings or other external characteristics and measure about 0.55 x 0.34 mm. They hatch after 12 to 15 days at 18°C.

The larvae are found between June and August of the same year and there are three instars. The larvae are slender, about 3 mm long depending on the instar. Pupation takes place at the end of the third instar.

Adults emerge from the pupae between July and September and some adults survive for a year or more. Young adults are pale and usually take a few days to darken. The adults are very small, about 3.5 mm long, black and shiny, with a brassy or aeneous lustre. The legs are pale reddish and prothorax is strongly constricted at the base. Carabids have generally one generation per year and can be conveniently divided into spring breeders which give rise to summer larvae and autumn breeders whose larvae occur during the winter months (Lindroth, 1949). *B. lampros* clearly belongs to the former group (Mitchell, 1963a).

2.1.3 Economic importance

Wright et al., (1956) and Wishart et al., (1956) first recognized the importance of certain species of carabid and staphylinid beetles as predators of the immature stages of the cabbage root fly. Hughes and Salter (1959) and Coaker and Williams (1963) have shown that some carabid and staphylinid beetles commonly found in the soil can be effective predators of cabbage root fly eggs and larvae, and that reduction in their numbers can increase the survival of the pest (Wright et al., 1960; Coaker, 1965).

In Britain, predatory beetles exert a considerable natural check on cabbage root fly populations destroying 90 to 95% of the eggs and larvae produced during the first and second generations (Hughes, 1959). About two-thirds of the mortality occurs in the egg stage and the fewest eggs survived when catches of *B. lampros* were greatest (Coaker, 1965). Wright et al. (1960), in experiments using crops exposed to the first generation of the pest, showed that predatory beetles could markedly reduce cabbage root fly numbers and consequently crop damage. They demonstrated that the numbers of the principal predator trapped, *B. lampros*, were inversely related to the numbers of surviving root fly eggs and larvae. Coaker (1965) used barriers to restrict the movement of adult carabids into and out of plots of brassica crops and also found that the survival of the immature stages of the cabbage root fly was inversely related to the population level of the predatory carabids. After excluding adult carabids almost entirely from the plots, he estimated that they had been responsible for up to one-third of the total egg mortality, although this varied with the species composition of the carabid population.

Van Dinther and Mensink (1971) studied the role that carabid beetles play as predators of the cabbage root fly, using house fly eggs labelled with ^{32}P and exposed under field conditions. Labelled eggs were then used to detect those species out of the many predators encountered in the field, that are predacious on eggs. They found that among the carabids *B. lampros*, *B. ustulatum* and *B. femoratum* were the most important egg-feeders.

2.2 Cabbage maggot, *Hylemya brassicae* (Bouché) (Diptera: Anthomyiidae)

This insect is called the cabbage root fly in the U.K. (Anon., 1947) and the cabbage maggot in North America (Muesebeck, 1942). Although the specific name, *brassicae* has been generally accepted, the generic name has not and there are at present five in regular use. *Hylemya* is used by workers in the United States and Canada. French (Missonier and Stengel, 1966), German (Endrigkeit, 1953) and Russian (Ageeva, 1965) authors used *Chortophila* while others use *Phorbia* (Riedel, 1967), *Hylemyia* (Rygg, 1962; Varis, 1958) or *Delia* (Berte *et al*., 1965). In the U.K. *Delia* has been superseded by *Erioischia* (Kloet and Hincks, 1945) and the pest is designated as *Erioischia brassicae* (Bouché).

This insect has been a destrictive pest in Eastern Canada since about 1855. It is not known when the pest arrived in British Columbia but by 1915 the pest had become well established in the province Gibson and Treherne (1916). It now occurs in vegetable growing areas throughout the country, including the North West Territories (Beirne, 1971).

2.2.1 Generation and life cycle

Depending on climatic conditions, this insect may have one generation per year in the northern U.S.S.R. (Danilevsky, 1961) or four or five in some parts of the U.S.A. (Carlson *et al*., 1947). In Canada, the number of generations ranges from one complete with a partial second in Newfoundland to three in south western Ontario and southern British Columbia (Caesar, 1922; Mukerji and Harcourt, 1970; Forbes, 1962). Smith (1927) used the term generation to describe the cycle starting at the adult and ending at the pupa. Other workers (Miles, 1954; Hughes and Salter, 1959) have used it to describe the cycle starting from the egg and ending with the adult.

Adults of the first generation emerge in late April and early May from the overwintered pupae. After a pre-oviposition period of 6 to 8 days the females begin to lay eggs singly, in crevices in the soil and on the underside of soil crumbs usually within 5 cm of the host plant (Hughes and Salter, 1959). Eggs are laid chiefly around the stems of cruciferous plants but under some conditions, they are laid on the heads of cauliflowers (Smith, 1927) and on Brussels sprouts (Brooks, 1951; Coaker, 1967). The eggs hatch within a week in the field and the larvae move immediately to the plant roots to feed. At the end of a 3 to 4 week intensive larval feeding period, third-instar larvae move away from the roots to pupate in the soil. The next generation of adults emerges from these puparia within two weeks, provided that there has been no induction of pupal aestivation (Missonier, 1960) or diapause (Hughes and Salter, 1959; Zabirov, 1961).

2.2.2 Control

Cultural

These methods include crop rotation, the destruction of infested plants, avoiding growing autumn crops of host plants that encourage large overwintering populations of cabbage root fly, and growing seed crops away from main brassica areas (Schoene, 1916; Bonnemaison, 1965). Most of first-generation flies feed only on the nectar of hedgerow flowers. Removal of these flowers from the vicinity of the host crop may therefore offer a possible method of controlling cabbage root fly (Coaker and Finch, 1971). Finch and Skinner (1971) found that removing hedgerow sites from within 40, 80 or 160 m of plots of brassicas, failed to reduce populations of the cabbage root fly.

Plant resistance

Resistance has been reported among the host plants of the cabbage root fly (Pimentel, 1961; Beck, 1965). Plants can be resistant because they are not attractive to ovipositing adults (Radcliffe and Chapman, 1960; Doane and Chapman, 1962), or because they are capable of tolerating and outgrowing damage when attacked (Matthewman and Lyall, 1966). Doane and Chapman (1962) reported that the cabbage root fly laid eggs on rutabagas and turnips in preference to radish or mustard, cauliflower being the least preferred of the crops tested. In New Brunswick, yields of varieties resistant to cabbage root fly were 30 to 50% higher than susceptible varieties; but the varieties resistant to cabbage root fly were more attractive to bean-seed fly (Pond _et al._, 1962). Swailes (1960) found that resistance could result either because larvae encounter difficulties in becoming established or because the nutritive qualities of the roots are unsuitable for larval growth.

Insecticide

It was not until introduction of the cyclodiene group of organochlorine insecticides, which were highly potent and persistent in the soil, that truly practical and reliable control of cabbage root fly was achieved (Wright, 1954). These compounds were applied either to the soil or to the plant roots before or after sowing or planting, or to the foliage (Forbes and King, 1956; Bonnemaison, 1965). The toxicity of organochlorine insecticides to natural enemies of cabbage root fly (Morris, 1960; Chapman and Eckenrode, 1973), and the development of resistance by this pest to cyclodiene compounds in North America (Finlayson, 1962; Harris _et al_., 1962; Howitt and cole, 1962; McEwen _et al_., 1967), and in England (Coaker _et al_., 1963), Scotland (Osborne, 1968), Norway (Taksdal and Nordby, 1966), Sweden (Heliquist, 1964) and France (Missonier _et al_., 1964) have led to the use of other insecticides.

In Canada and elsewhere alternative insecticides have been found among the organophosphorus and carbamate compounds (Coaker and Finch, 1964; Finlayson and Noble, 1964; Finlayson, _et al_., 1967; Judge _et al_., 1968; Rolfe, 1969) (Appendix Table 11). Of the organophosphorus insecticides tested in the field, chlorfenvinphos, fensulfothion, diazinon and thionazin, the least effective was diazinon. Carbofuran, an organocarbamate had systemic properties (Finlayson, 1969). Similar results have been obtained by Morris (1968) and Read (1970). Finlayson and Campbell (1969) found that split applications, one at seeding and one at 30 days later with chlorfenvinphos, fensulfothion or carbofuran protected cauliflowers from damage until harvest.

Hertveldt et al. (1973) in their experiments on chemical control of cabbage root fly in transplanted Brussels sprouts found that chlorfenvinphos in wettable powder retained a high degree of effectiveness for at least 12 weeks when the insecticide was applied around the base of the transplants at a rate of 100 mg active ingredient per plant.

It has become more difficult in recent years to achieve acceptable levels of control of a number of important pests of vegetables than was the case ten years ago (Gair, 1971; Wright, 1971). There is a strong tendency to blame the present problems on the inadequacies of the new types of chemicals which do not have the persistence for single applications to protect crops throughout their growing season. The very characteristic of persistence, which so favoured the performance of the organochlorine compounds, was the principal reason for their downfall (Wheatley, 1971). Some relatively stable organophosphorus compounds, such as chlorfenvinphos or fonofos, are perhaps one-half to one-fifth as persistent in soil as gamma-BHC, which is one of the least persistent organochlorines (Wheatley, 1971).

The ideally selective chlorfenvinphos, which is probably the best present-day alternative, is less effective than were the organochlorines, despite the large natural enemy-induced mortality that the use of chlorfenvinphos permits (Mowat and Coaker, 1967). Nevertheless, if a high level of control is obtained during the first few weeks after planting, the crops become well established and can then withstand injury without serious reduction in yield. (Coaker, 1969).

Natural

The immature stages of the cabbage root fly are food for many arthropods (Wishart *et al.*, 1956; de Wilde, 1947; Abu Yaman, 1960; Coaker, 1965). Many hymenopterous parasites of the cabbage root fly attack the larval stages but only kill the insect after pupation. Five species of Braconidae, three of Cynipidae and four of Ichneumonidae have been reared from cabbage root fly pupae (Wishart *et al.*, 1957; Hughes and Salter, 1959). The cynipid *Idiomorpha rapae* (Westw.) which lays its eggs on the first or second-stage larvae, is the only hymenopterous parasite of major importance (Wishart *et al.*, 1957). Species of *Aleochara* (Coleoptera:Staphylinidae) are known to parasitize 20 to 30% of cabbage root fly pupae (Read, 1962; Coaker, 1966).

Coaker and Williams (1963) have shown that adult carabid beetles were responsible for about one-third of the egg mortality and the remaining egg mortality was due mostly to predation by adult staphylinid beetles. The carabids that were found to be most important included: *B. lampros* and *Harpalus aeneus* (Fab) which were predominant during April and May; and *Feronia melanaria* (Ill.) (= *P. melanarius*), *Harpalus rufipes* (Deg.) and *Trechus quadristriatus* (Schrank), which became important in

July (Coaker and Williams, 1963; Mitchell, 1963a).

An analysis of the population dynamics of the cabbage root fly in England (Hughes and Mitchell, 1960) showed that no single mortality factor was responsible for maintaining the remarkably constant number of adults that occurred from one generation to the next. Only the direct relationship between the numbers of feeding larvae and the proportion of plants killed could possibly account for this regulation. In a similar analysis, Mukerji (1971) showed that "misadventure" of young larvae is the key factor affecting survival in Canada. Benson (1973) re-analyzed the life-tables for cabbage root fly populations in Canada (Mukerji, 1971) and England (Hughes and Mitchell, 1960). He showed that the key-factor determining population change in Canada is caused by failure of the observed adult females to achieve their potential egg production. This only occurs at the beginning of the second generation each year. In England the key-factor is probably egg predation.

2.3 Other major pests of brassicas (Aphids and Lepidoptera)

Brassica crops are also attacked by other pests of economic importance besides the cabbage root fly. These include the cabbage aphid, *Brevicoryne brassicae* (Linnaeus); green peach aphid, *Myzus persicae* (Sulzer); imported cabbage worm, *Pieris rapae* (Linnaeus); diamond-back moth, *Plutella maculipennis* (Curtis); and cabbage looper, *Trichoplusia ni* (Hübner) (Forbes and MacCarthy, 1959; Banham and Arrand, 1970).

2.3.1 Effectiveness of methomyl on aphids and lepidoptera

The carbamate insecticide, methomyl (Lannate) *S*-methyl-*N*-[(methylcarbamoyl)-oxy] thioacetimidate, formulated as a water-dispersible powder is effective as a foliar spray against a wide spectrum of pests such as cabbage loopers, cabbage worm, diamond-back moth, corn earworm, southern armyworm, tobacco budworm, aphids, leafhoppers and certain beetles (Creighton *et al*., 1971; Green and Workman, 1971). Methomyl has a short residual effect and it is readily metabolized by corn and cabbage plants into harmless products like acetonitrile, carbon dioxide, and methyl-amine which are reincorporated in the plant tissues as carbohydrates or lipids (Hill, 1970; Harvey, 1971). But the insecticide is moderately persistent in soil, from 50 to 75% remaining 30 days after application (Hill, 1970).

2.3.2. Effectiveness of *Bacillus thuringiensis* Berliner on lepidoptera

Bacillus thuringiensis Berliner has been used against the imported cabbage worm, the cabbage looper and the diamond-back moth, by itself or with a chemical insecticide. The bacteria remain active from five to ten days (Tanada, 1956; Fox and Jacques, 1961).

Tests by McEwen and Harvey (1959) showed that good control of the imported cabbage worm could be obtained with *B. thuringiensis* spore dust applied at a rate of 0.3 lbs/acre at a concentration of 10^9 spores/g. Creighton *et al.* (1971) compared *B. thuringiensis* with chemical insecticides. Dipel, a commercial formulation of *B. thuringiensis*, was the most effective of four tested. It was superior to conventional sprays of methomyl and endosulfan plus parathion in protecting cabbage plants.

There has been much documented evidence that *B. thuringiensis* does not directly destroy parasites and predators (Jacques, 1965; Falcon *et al.*, 1968). With the current interest in preventing environmental contamination and the need to develop integrated control and pest management programs, *B. thuringiensis* is one of the few available selective and ecologically safe, insect control agents (Falcon, 1971).

2.4 Toxicity of insecticides to natural enemies of cabbage root fly

2.4.1 Direct effects of insecticides

The mortality caused directly by contact of a natural enemy with a toxicant has been abundantly documented in terms of the reductions in their numbers or in the degree of parasitism or predation which followed insecticide applications in the field. Since one or more stages of a natural enemy must actively search out prey or hosts, it is reasonable to expect that predators and parasites would pick up greater amounts of toxicant and thus suffer greater mortality from residual deposits than would the more sedentary pests occupying the same habitat (Croft and Brown, 1975).

There is considerable evidence which suggest that insecticides, particularly cyclodienes, when applied to soil as a protection against root maggots inadvertently destroy large numbers of predators and parasites resulting, in some cases, in more severe infestation and subsequent damage (Morris, 1960; Read, 1960, 1964; Mowat, 1964; Coaker, 1966; Mowat and Coaker, 1967)). Hassan (1969) studied the effects of organophosphorus (OP) insecticides on carabid and staphylinid beetles during the egg stage of the cabbage root fly using diazinon and chlorfenvinphos granules applied around the base of cabbage transplants. The results showed that diazinon treatments reduced significantly the number of carabid and staphylinid predators in the plots for about eleven weeks. The carabids were found to be remarkably tolerant to chlorfenvinphos.

Edwards and Thompson (175) assessed the effects on carabid predators of some agricultural soil insecticides and concluded that among those tested, fonofos, parathion and phorate were extremely toxic. The beetles were probably killed by the stomach action of the insecticide when they fed on leaf tissues and also, but less likely, on prey containing this insecticide since it is well-known that many species of carabids and staphylinids are not exclusively predaceous and carnivorous but will feed on plant tissues.

A laboratory study of the effects of some soil-applied OP pesticides on carabid beetles showed that higher soil moisture increased the speed of kill in soil treated with thionazin (Critchley, 1972a). In a similar field investigation, Critchley (1972b) found that species of Carabidae affected most by the treatments were small, diurnally active species such as *Bembidion lampros* (Hbst.), *B. quadrimaculatum* (L.) and *Trechus quadristriatus* (Schr.), which were abundant at the time when the treatment was applied. Large species such as *Harpalus rufipes* (deg.), *Pterostichus vulgaris* (L.), *P. madidus* (F.) and *Calathus fuscipes* (Goeze) were also affected but were generally less susceptible, partly because they appeared later in the season when some of the pesticide had disappeared. Bartlett (1964) has generalized that it is in the adult stages that predators are most susceptible to insecticides, and eggs least affected.

2.4.2 Indirect effects of insecticides

Pesticides can affect predators and parasites indirectly through their influence on the pest species which constitute their prey or their hosts, either by eliminating these as a source of food or by leaving them as sources of secondary poisoning (Croft and Brown, 1975). There are numerous reviews which relate to pest resurgence, resulting from the sequence of pest elimination, starvation among the remaining natural enemies, and pest reinvasion before the natural enemies are re-established (Ripper, 1956; Stern *et al*., 1959; Van den Bosch and Stern, 1962).

The effects of sublethal doses of insecticides at levels which cause no mortality in the population or at toxic levels which leave some survivors, have been reviewed by Moriarty (1969). Coaker (1966) reported that a non-selective insecticide, present at concentrations too low to control the cabbage root fly, can increase damage by reducing populations of its natural enemies, particularly predatory beetles. The activity of carabid beetles is greatly increased by the OC insecticides aldrin, dieldrin and DDT and by certain OP compounds, e.g. thionazin (Coaker, 1966; Dempster, 1968; Edwards *et al*., 1970; Critchley, 1972a). With *B. lampros* this behavioural response resulted in increased catches in pitfall traps (Coaker, 1966). *Harpalus aeneus* (= *H. affinis*) when exposed to sublethal levels of insecticides responds by releasing large amounts of a chemical, probably formic acid, which might be sufficient to cause self-annihilation in the confines of its burrows (Critchley, 1972a)

Adult *H. rufipes* when exposed to sublethal deposits of DDT had a reduced feeding rate which may prevent the predator from controlling *Pieris rapae* for some time after spray treatments (Dempster, 1968).

2.5 Prospects for integrated control of brassica pests

The concept of integrated control implies that chemical treatments be used with minimal harm to predatory beetles (Edwards and Thompson, 1975). With recent restrictions placed on OC insecticides, growers have lost some of their most effective pest controls.

2.5.1 Selectivity in insecticides

Expansion of integrated control programs is limited in part by the nature of available control materials. It has been said that the ideal selective treatment is not necessarily one that eliminates all individuals of the pest species while leaving all of the natural enemies (Clausen, 1956; Ripper, 1956; Stern et al., 1959). Use of such a material would force the predators and parasites to leave the treated area or starve. Wright (1956) noticed that plots where DDT, aldrin, or BHC had been used by incorporation into the top 9 cm of soil, sustained more damage from cabbage root fly larvae than those untreated. Root and soil samples revealed larger numbers of cabbage root fly larvae and pupae on treated than untreated plots; apparently the insecticides were selectively more toxic to cabbage root fly predators than to the cabbage root fly itself thus resulting in more damage to the cabbage crop.

In a field study of the effectiveness of certain insecticides in controlling the cabbage root fly and the harm they may cause to parasites, Hassan (1973) found that chlorfenvinphos gave the best protection followed by bromophos, diazinon, dimethoate, Parathion-ethyl and lindane in order of diminishing effectiveness. In similar studies, Mowat (1966) compared the toxicity of dieldrin, an OC, with that of four OP insecticides, to ground beetles which prey on immature stages of the root fly. In medium sandy loam, the most toxic was thionazin. Chlorfenvinphos was of very low toxicity as were also azinphos-methyl and, in dry soil diazinon. Finlayson et al. (1975) also found that the insecticides isophenphos, carbofuran, chlorfen-vinphos and fensulfothion did not affect the populations of predatory beetles. However, the numbers of earthworms were greatly reduced by carbofuran and to a lesser degree by chlor-fenvinphos.

Edwards and Thompson (1975) concluded that chlorfenvinphos tends to be more toxic to dipterans than to other kinds of insects and is thus one of the best insecticides for reducing cabbage root fly and wheat bulb fly. Its success, they added, may be due not only to its toxicity to the pest, but also in part to its lack of toxicity to the predators or even conceivably to increasing their activity and feeding.

The results of tests on cabbage root fly control, in several areas, indicate that a number of compounds provide good control of the pest. Decisions to be made involve a) compounds to use for different cruciferous crops and b) methods of application. For rutabagas, a persistent compound that will give long term protection is required (Read, 1970). For stem crucifers, highly effective control is required only when the plants are small. When the stems become large and woody in texture, they can be quite severely infested without much effect on yield. Thus long term control is not required (Coaker and Finch, 1965; Coaker, 1969; Read, 1970).

2.5.2 Mode of application

One of the most important considerations is the degree of control obtained with various insecticides placed in the row by different methods of application. Furrow treatments with granular or liquid formulations of many materials placed with or near the seed are often phytotoxic, except at very low rates which are usually ineffective (McEwen et al., 1967). Narrow-band placements of effective granular insecticides frequently reduce the plant stand, which in turn can increase maggot feeding injury on individual roots (Eckenrode and Chapman, 1971). Insecticides when broadcast, have detrimental effects on natural predators of the cabbage root fly (Pitre and Chapman, 1964). The root maggots have only limited contact with the soil as they move down between the plant stem and the soil to begin feeding in the roots of the host plant (Read, 1964).

Chapman and Eckenrode (1973) studied the effects of insecticide placement on predator numbers and cabbage maggot control. They found that as bands of granular insecticides were moved away from the seed furrow, phytotoxicity and control of cabbage maggot decreased and more predatory beetles survived. Consequently, with broadcast applications, greater maggot-feeding damage occurred when materials were used which were inefficient (diazinon) or to which the maggot was resistant (aldrin), than if the crop had been left untreated.

One method of control is to band the granular insecticide on the soil surface, incorporate to a depth of about 2.5 cm and then seed in the centre of the band of insecticide. Such treatments are usually followed by one or more spray-band or drench applications applied during the season, as recommended by Finlayson and Noble (1966) and Morris (1968). The drench treatments are required because the single preplanting treatment at a low rate is insufficient to give protection throughout the growing season but will not affect the natural enemies and there will be no high residues left in the soil or the plants at harvest.

Conversely, Read (1970) recommended the use of a surface band application applied at a high rate that would give all-season control of the pest with a single preplanting application. He argued that subsurface applications are less harmful to adult predatory beetles, more economical in terms of labour since the treatment is applied once, and are protected from dispersal by rain and from drying out (Osborne, 1968).

3. MATERIALS AND METHODS

3.1 Description of site and pretreatment cultivation

The experiments were undertaken at the South campus of the University of British Columbia, Vancouver in the spring and summer of 1975. Soil at the site was a sandy loam containing many large stones. The field, free from insecticide residues, was 16 m x 20 m, in an area where brassicas had never been grown. Prior to treatment, the field was harrowed once and most of the larger stones removed.

3.2 Crop and layout of field

The experiments were carried out using one variety of Brussels sprouts, the early F_1 hybrid variety, Jade Cross. The Brussels sprouts were seeded in the greenhouse on 30/1/1975 and transplanted in the field on 10/4/1975. Spacing between the rows was 0.66 m and between plants was 0.5 m. Experimental plots within the field were 4 x 4 m and were arranged in four randomized blocks each plot containing 30 plants in 5 rows of 6 plants.

At the time the field was laid out, it was surrounded by a barrier of polythene sheeting (polyethylene, 4 mil) extending about 10 cm below the soil surface and 15 cm above where it was fastened to wooden stakes. Similarly, plots within the field were separated from one another by polythene barriers (Fig. 1). The outer barrier surrounding the field was to prevent predatory beetles from entering it; the barriers separating the plots were to prevent predatory beetles and *B. lampros* in particular from moving from one plot to the other.

The effect of the barriers on numbers of predatory beetles within the plots was measured by pitfall traps in each plot (Coaker, 1965). There were four pitfall traps in each of the 20 plots. Immediately outside the barriers surrounding the field twenty traps were spaced at equal distances. The outside traps were to help determine the numbers and emergence of new species and the population fluctuations of carabids. The traps were placed on 24/4/1975 as shown in Fig. 2. The pitfall traps were made from new tin cans, 7 cm in diameter x 11 cm deep. A 2 cm hole was cut in the bottom and covered with 40-mesh Lumite screen to allow rain water to drain while retaining the beetles (Finlayson *et al.*, 1975). The tin cans were sunk in the ground so that the rims were flush with the surface. After heavy rain the traps were washed, dried and replaced in the ground.

Figure 1. Layout of experimental field showing some of the plots, the polythene barriers and Brussels sprout transplants at the early stages.

Figure 2. Position of pitfall traps within an experimental plot.

3.3 Design of experiment and treatments

Five treatments, replicated four times in a randomized block design were used to compare the damage caused and the survival of the root-fly eggs subjected to predation by *B. lampros*; the treatments were also used to determine the effects of insecticides on the population of *B. lampros*. The treatments were:

1. Control; untreated with insecticides and without *B. lampros*.
2. Untreated with insecticides but with *B. lampros*. All other carabids were excluded.
3. *Bacillus thuringiensis* Berliner (Dipel, 16000 IU/mg, at the recommended rate of 1 lb/100 gal/acre[1.12 Kg/1123 litre/ha]) with *B. lampros*. All other carabids were excluded.
4. Methomyl (Lannate at the recommended rate of 1 lb/100 gal/acre[1.12 Kg/1123 litre/ha]) with *B. lampros*. All other carabids were excluded.
5. Chlorfenvinphos (Birlane 10G at the recommended rate of 1 oz/1000 ft of row [approx. 1 g/10 m]) with *B. lampros*. All other carabids were excluded.

3.4 Release of root fly puparia

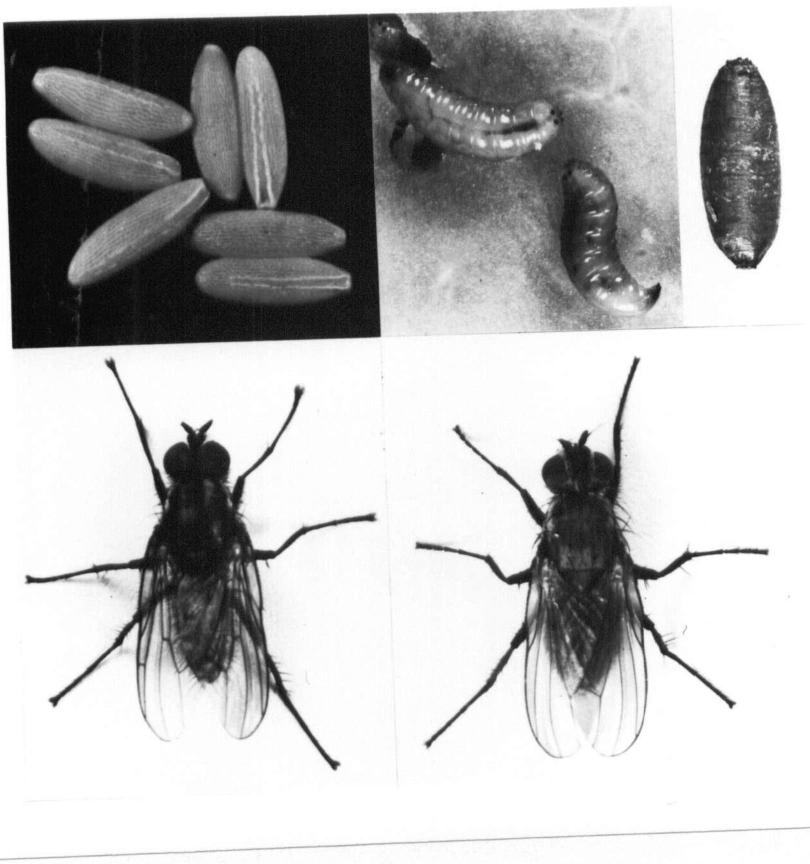
For some time, brassicas had not been cultivated near the site of the experiment. It was therefore assumed that the natural population of cabbage root fly in the area would be low. In order to have enough root flies to work with, about 2,000 puparia, reared at the Canada Department of Agriculture laboratory in Vancouver (Fig. 3) were buried in shallow trenches around the field on May 1, 1975 to give an average of approximately three puparia per plant. These were expected to emerge as adults within 12 to 18 days later. Fig. 4 shows the stages in the life cycle of the cabbage root fly.

Figure 3. Mass rearing of cabbage root fly for field release at Agriculture Canada laboratory, Vancouver.

Figure 4. Stages in the life cycle of the cabbage root fly, *Hylemya brassicae* (Bouché).

From top left: eggs, larvae and puparium

From bottom left: male adult, female adult



3.5 Introduction and sampling of *B. lampros* population

The field was initially sampled to determine the population of *B. lampros* and other carabids present at the start of the experiment. Twenty *B. lampros* were added initially to each plot, except for plots of treatment 1. The beetles had been captured from the experimental sub-station at Abbotsford, B.C. using pitfall traps. More were released in the plots as they became available, for a total of 80 *B. lampros* per plot as follows:

Date	No. of *B. lampros* released per plot
1.5.75	20
6/5/75	10
13/5/75	20
19/5/75	20
28/5/75	10

The adult carabid populations on each plot were sampled every 2 days using four pitfall traps and the numbers recorded. Carabids, including *B. lampros*, trapped from treatment 1 were completely removed but *B. lampros* trapped from other treatments were released within the plots from which they originated after other carabids had been removed. All traps were emptied at the same time each morning and the captives were returned to the plots immediately after sorting. The traps were cleaned and the surrounding soil smoothed daily since the traps quickly become inefficient after heavy rain and during hot dry weather when the soil would crack away from the trap rim. Only carabids known to feed on the immature stages of the cabbage root fly in the field (Fig. 5) (Coaker and Williams, 1963) were used for comparing the beetle populations in the experimental plots. Carabids inside the plots were sampled until harvest but those outside were sampled until the end of September.

Figure 5. The carabid species taken from pitfall traps in the experimental field.
From top left: *Bembidion lampros*, *Bembidion obscurrellum*
From bottom left: *Pterostichus melanarius*, *Harpalus affinis*

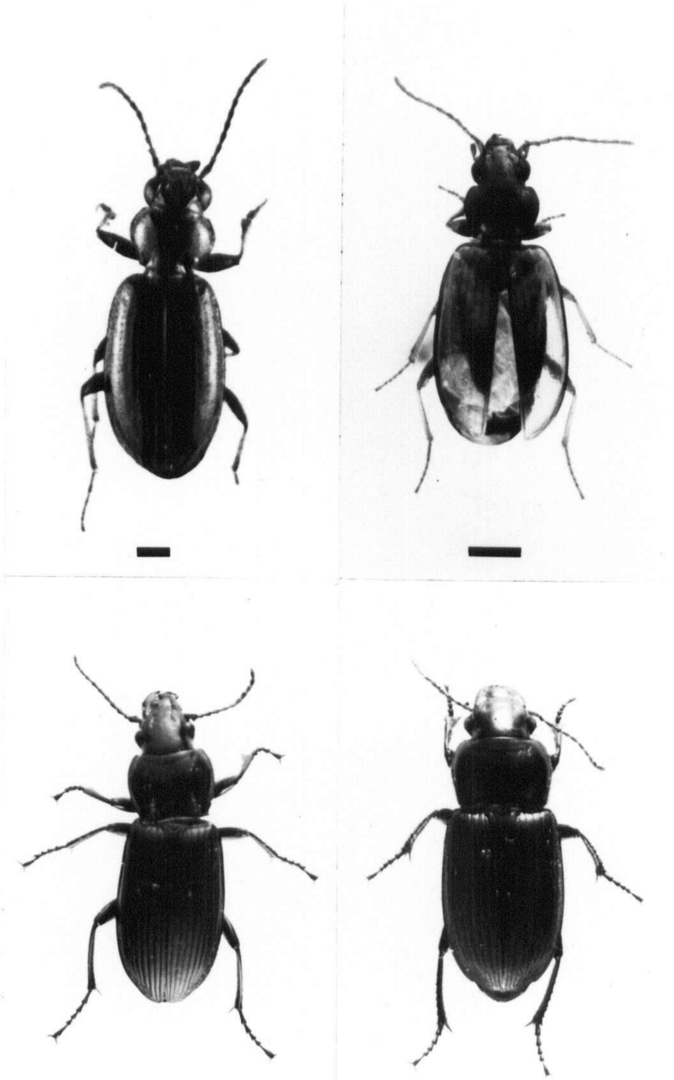
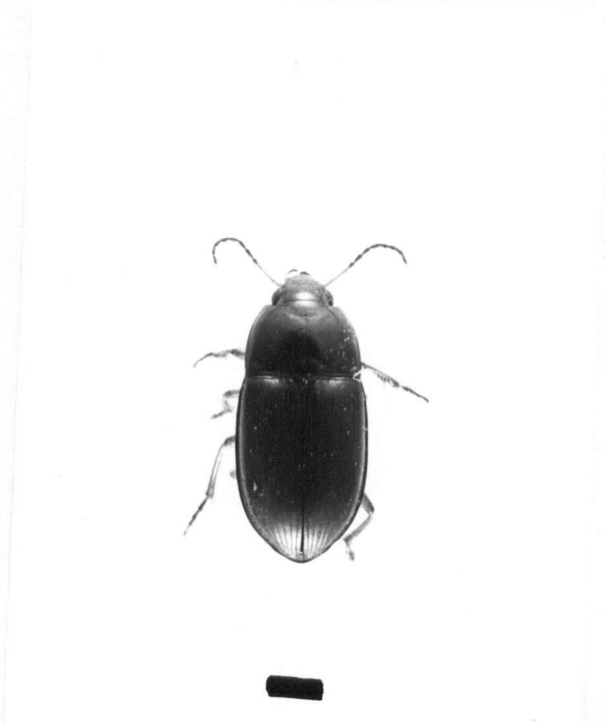


Figure 5. (cont.) From top left: *Calathus fuscipes*, *Clivina fossor*

Bottom: *Amara* spp.



3.6 Egg counts

The start of egg counting was determined by searching for eggs in the soil around young transplants in the control plots as often as possible in late April and early May. As soon as eggs were found (May 5) egg counting began in all five treatments. The same four plants in the middle row of each plot were used for egg counts throughout the cropping season (Fig. 6). The same plants were used for each and for subsequent counts and dead Brussels sprout plants were not replaced. Eggs present around the plant were sampled every 2 days. It is preferable to choose an interval between samples that is shorter than the incubation period of the eggs since this avoids empty shells being counted. Eggs laid near the base of the stem and the first few mm of the top soil around each sampled plant were removed for counting with a moistened camel hair brush (Forbes, 1962).

Figure 6. Counting of *H. brassicae* eggs in an experimental plot.

3.7 Insecticide treatments

B. thuringiensis (Dipel) (treatment 3) was applied at the recommended field rate of 1 lb/100 gal/acre(1.12 kg/1123 litre/ha), five times in the season at approximately three-week intervals (May 28, June 15, July 3, July 22, August 11). The microbial insecticide was applied as a foliar spray mainly for control of lepidopterous larvae.

Methomyl (treatment 4) was applied as a foliar spray five times (May 28, June 15, July 3, July 22, August 11) at the recommended field rate of 1 lb/100 gal/acre (1.12 kg/1123 litre/ha) for control of aphids and lepidopterous larvae.

Chlorfenvinphos (treatment 5) was applied once only, on May 1 at the recommended field rate of 1 oz/1000 ft (approx. 1 g/10 m) of row. The insecticide was incorporated into the soil approximately 1 cm deep in a 10 cm diameter with the plant at the centre of the circle for early protection from damage by root fly larvae.

3.8 Cultural practices

The plots were weeded and irrigated as the need arose. Some of the Brussels sprout plants bolted and went to seed, a process which normally takes two years to complete. Shortly after the seedlings were transplanted, a very heavy frost occurred which probably triggered the plants into flowering and seeding instead of forming sprouts.

3.9 Harvest

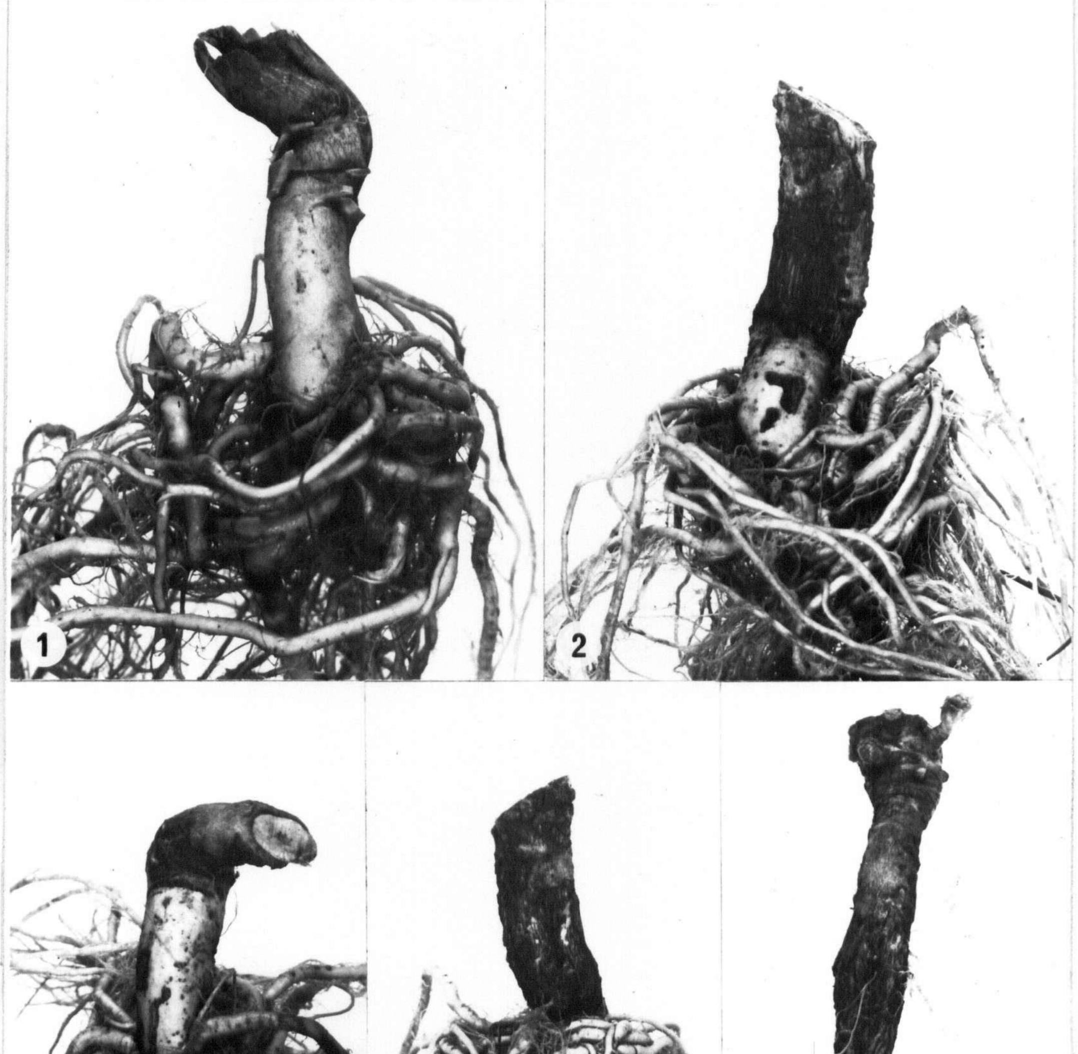
At harvest (September 2-5), the total numbers of living plants were recorded excluding the four plants in each plot used for egg counting. Those which bolted and went to seed were also recorded.

The efficacy of *B. lampros* in decreasing cabbage root fly damage was determined by the number of Brussels sprout plants that were dead or wilted, by the amount of larval damage on the roots, by total fresh weight of the above ground parts and by counting the cabbage root fly puparia in 15 cm cores of soil, 12 cm deep and centering on the main root systems of 5 plants/plot. The plants were cut off at the root-stem junction for the fresh weights to be determined. The weights of the plants that bolted were determined separately from those that formed sprouts. At harvest, 5 plants/ plot were uprooted, the roots washed and the maggot damage assessed visually as 0 (clean), 1 (light), 2 (moderate), 4 (severe) or 8 (very severe) (Fig. 7) (King and Forbes, 1954).

Methods of assessment of cabbage maggot damage based only on the proportion of plants killed or stunted can be misleading, because the numbers vary with both weather conditions and the availability of soil moisture (Hughes, 1960).

Figure 7. Root maggot damage categories in Brussels sprouts.

1. Clean
2. Light
3. Moderate
4. Severe
5. Very severe


1
2
3
4
5

3.10 Puparia counts

Overwintering populations of cabbage root fly were estimated at harvest by the numbers of larvae and pupae found in 5 soil samples per plot. Cores of soil 15 cm diameter by 12 cm deep were taken with the topped plant as the centre of the core using a core sampler. Larvae are usually restricted to the roots of the plants and normally only move a few centimetres away to pupate (de Wilde, 1947), but when populations are high, some move as far as 10 cm (Coaker, 1966). The puparia were extracted from the soil by floatation on water. The puparia were washed from the soil as it passed through a coarse sieve (ten meshes per inch). The sieved soil plus plant remains were spread out on white paper and searched for larvae and pupae. The numbers of full and empty pupae in each soil core were recorded separately. The full pupae were retained to determine possible parasite development of Aleochara bilineata, a staphylinid beetle and the cynipid, Trybliographa rapae.

3.11 Laboratory tests

The microbial insecticide, *B. thuringiensis*, and the insecticides methomyl and chlorfenvinphos were used at the concentrations normally recommended for control of lepidopterous larvae, aphids and cabbage maggot respectively to determine the effects of the three insecticides on *B. lampros*.

Soil from Abbotsford (sandy clay loam) was sieved and oven dried at 95°C to determine the moisture content which averaged 29.6%. Pots of 10 cm diameter were filled with soil to 2.5 cm below the top and each pot was covered with silk screen held in place by an elastic band. Six to 10 mature *Drosophila melanogaster* larvae were added to each pot as food for *B. lampros*. The pots were placed in petri dishes and watered from below.

B. thuringiensis: Dipel was sprayed on the soil to the wet surface. The rate used was equivalent to the recommended field rate of 1 g/litre of distilled water. Five *B. lampros* were added to each of 4 pots after droplets of spray had been wiped dry from the edges of the pot. The mortality was assessed 1, 2 and 4 days after treatment by carefully searching the soil and examining *B. lampros*. In a second experiment, 5 times the original dosage was used.

Methomyl: Lannate at the recommended field rate of 1 g/litre distilled water, was applied as a spray to wet the surface of the soil. Droplets of spray were wiped dry from the edges of the pot. Five *B. lampros* were added to each of 4 pots and pots were examined 1, 2 and 4 days after treatment.

for *B. lampros* mortality. In a second experiment, the rates for methomyl were 1/2, 1/4 and 1/8 of the original dosage. In a third experiment the beetles were added 24 h after treatment using the rates in the second experiment.

Chlorfenvinphos: Similar pots were filled with soil treated with chlorfenvinphos at 10 ppm and 40 ppm oven dry weight respectively. The two treatments were replicated four times. Mortality was assessed 1, 3, 5 and 7 days after 10 *B. lampros* were added to treated soil.

4. OBSERVATIONS AND RESULTS

4.1 Development of cabbage root fly infestation

The data show that egg-laying by the pest started on May 7 and increased rapidly to May 25 and reached a peak about May 28 (Fig. 8). There were two peaks of egg laying, enabling the season to be divided into two periods: May 7 - June 27 and July 11 - August 22. There were variations in the number of eggs laid on plants within the same plot and within treatments. More eggs were laid in the first generation when the plants were young than in the second generation when the plants were mature.

4.2 Occurrence of *Bembidion lampros*

The appearance of *B. lampros* coincided with the main oviposition period of the first generation of cabbage root flies. Thereafter the numbers of eggs laid and of *B. lampros* taken both declined to insignificant numbers. The proportion of *B. lampros* caught in the pitfall traps declined as the plants increased in size. Fig. 9 represents the average number of *B. lampros* taken every two days from pitfall traps in each plot for the various treatments. There was one major generation May 7 to June 18. Although *B. lampros* beetles were added to some of the treatments early in the experiment, there was a natural population present in the untreated control despite their constant removal (Table I).

Figure 8. Oviposition by the cabbage root fly, *Hylemya brassicae* (Bouché): average number of eggs/plant on 52 dates for each treatment, May - August 1975.

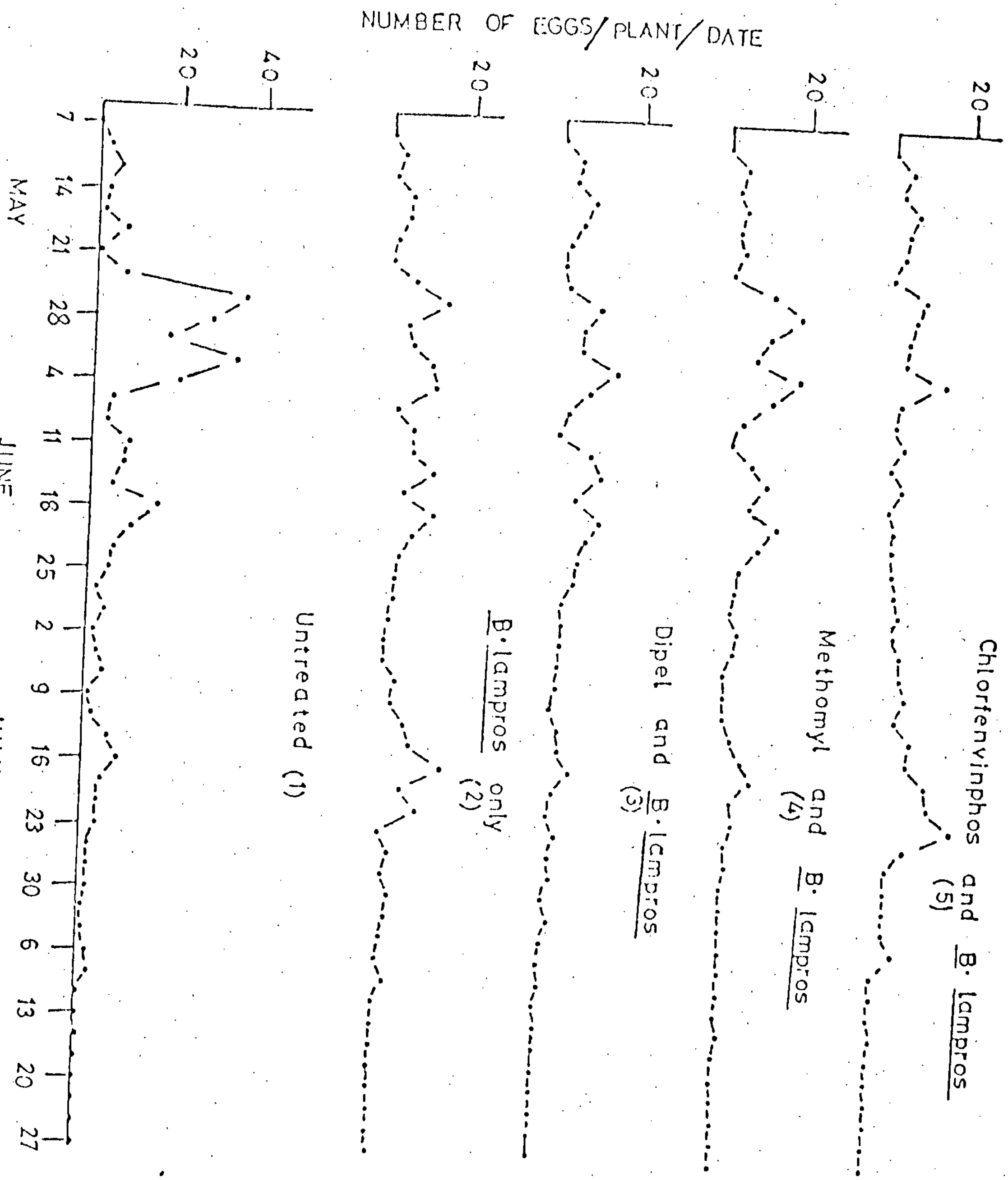

NUMBER OF EGGS/PLANT/DATE
20
40
Chlorfenvinphos and B. lampros (5)
Methomyl and B. lampros (4)
Dipel and B. lampros (3)
B. lampros only (2)
Untreated (1)
7 14 21 28 4 11 18 25 2 9 16 23 30 6 13 20 27
MAY
JUNE
JULY
AUGUST

Figure 9. Population trends of *B. lampros*: average numbers taken every 2 days from pitfall traps in each plot (4 traps/plot) for each treatment May - August 1975.

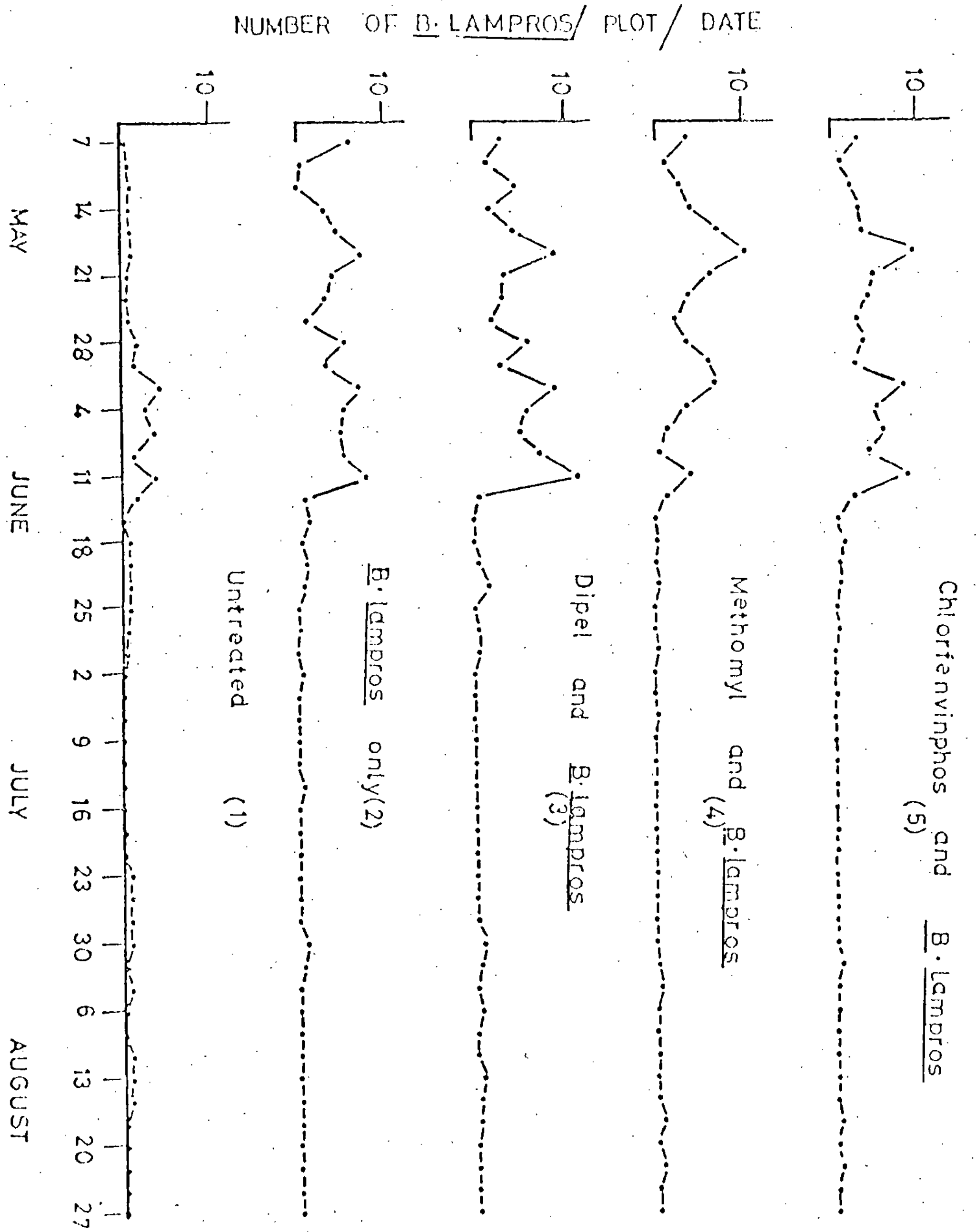

NUMBER OF B. LAMPROS/ PLOT/ DATE
10
Chlorfenvinphos and B. lampros (5)
Methomyl and B. lampros (4)
Dipel and B. lampros (3)
B. lampros only (2)
Untreated (1)
7
14
21
28
4
11
18
25
2
9
16
23
30
6
13
20
27
MAY
JUNE
JULY
AUGUST

TABLE I. Natural population of carabid beetles taken from pitfall traps inside the barrier in the four untreated plots (64 sq m), May to August 1975

Species	May	June	July	August	Total
Bembidion lampros	56	53	7	8	124
Harpalus affinis	10	1	2	6	19
Amara sp.	1	0	5	6	12
Bembidion sp.	5	0	0	0	5
Calathus fuscipes	0	0	2	1	3
Pterostichus melanarius	0	0	2	1	3
Monthly totals	72	54	18	22	166

4.3 Effect of Bembidion lampros on cabbage root fly eggs

Fig. 10 represents the weekly mean of the number of cabbage root fly eggs laid and the corresponding B. lampros population for the various treatments.

The number of cabbage root fly eggs laid in the control was more than double that of any other treatment during the first generation. As the number of eggs increased, the activity of the beetle increased and this resulted in a greater number being trapped. The maximum numbers of beetles occurred a few days after the maximum number of eggs (Appendix Table 3 and 4).

Monthly analyses of the numbers of root fly eggs in the various treatments showed that egg counts from the untreated plots were significantly higher during May and June than in other treatments for the same period (Table II). Treatments which included B. lampros were not significantly different in May but the treatment which had chlorfenvinphos and B. lampros had significantly lower number of eggs than the other treatments in June. There was no significant difference among all treatments in July and August.

There were usually fewer eggs in plots which had B. lampros than in untreated plots during the first generation of the root fly. Analysis of first and second generation eggs of cabbage root fly (Table III) showed that during the first generation the mean numbers of eggs sampled from plots with and without B. lampros differed significantly at the 5% level. This was not so in the second generation when B. lampros had disappeared. The unexpectedly high number of eggs recorded in treatment 5 in the second generation was due to a single plant with consistently higher egg counts.

Figure 10. Occurrence of _Hylemya brassica_ eggs (•— — —•— — —•) and corresponding _Bembidion lampros_ population (•————•————•) (weekly average) in the experimental field. Arrows indicate dates when the insecticides were applied to Brussels sprout plants.

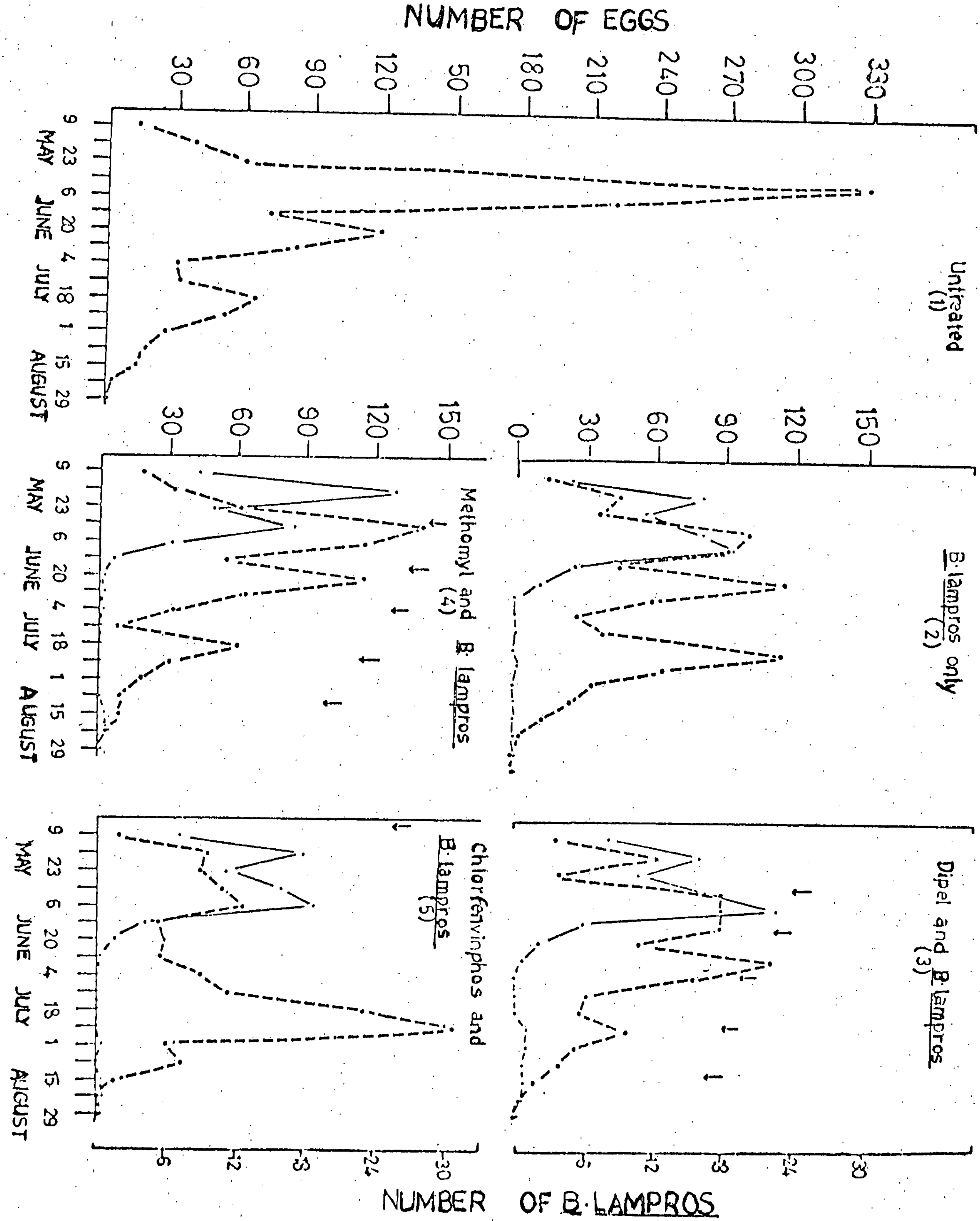

NUMBER OF EGGS
Untreated (1)
B. lampros only (2)
Dipel and B. lampros (3)
Methomyl and B. lampros (4)
Chlorfenvinphos and B. lampros (5)
MAY
JUNE
JULY
AUGUST
NUMBER OF B. LAMPROS

TABLE II. Monthly averages of cabbage root fly eggs in May, June, July and August, 1975*

Treatment	May	June	July	August	Treatment mean
1. Untreated	438a	492a	179 a	54 a	291
2. B. lampros only	196b	312b	264 a	69 a	210
3. Dipel and B. lampros	188b	335b	137 a	41 a	175
4. Methomyl and B. lampros	254b	352b	135 a	37 a	194
5. Chlorfenvinphos and B. lampros	167b	155c	376 a	76 a	193
Monthly mean ± S.D.	248 ± 75.2	329 ± 78.9	218 ± 222.5	55 ± 50.0	213 ± 172.1

* Separation of means in a month is by Student - Newman - Keuls test (S.N.K.), P = 0.05 (Zar, 1974).

Values followed by the same letter are not significantly different (Error degrees of freedom, 12).

There was no significant (P - 0.05) treatment effect on other months according to the F-test of analysis of variance.

TABLE III. The mean number of eggs sampled from plants in the various treatments during the first and second generation of the cabbage root fly in 1975

Treatment	1st generation* May 7 - June 27	2nd generation July 11 - August 22
1. Untreated	930.6a	204.1a
2. *B. lampros* only	509.5b	286.9a
3. Dipel and *B. lampros*	517.4b	146.4a
4. Methomyl and *B. lampros*	606.6b	137.6a
5. Chlorfenvinphos and *B. lampros*	320.2c	406.6a
Grand mean ± S.D.	576.9 ± 32.2	236.3 ± 120.6

* Mean separation was by S.N.K., P = 0.05 (Zar, 1974).

Values followed by the same letter are not significantly different (Error degrees of freedom, 12).

The percentage reduction in the number of eggs due to predation by *B. lampros* during the first generation of the root fly is shown in Table IV. *B. lampros* is shown to have reduced the numbers. The reduction was lowest in methomyl treatments and highest in chlorfenvinphos treatments. Methomyl was toxic to the beetle hence the low percentage egg reduction whereas Dipel and chlorfenvinphos were not toxic to the beetle; moreover chlorfenvinphos was toxic to the cabbage root fly. As a result there was a greater percentage reduction in egg numbers in treatment with chlorfenvinphos and *B. lampros*.

TABLE IV. Percentage reduction in egg numbers due to predation by *B. lampros* for the various treatments during the first generation of cabbage root fly

Treatment	% reduction in eggs*
1. Untreated	0 a
2. *B. lampros* only	45 c
3. Dipel and *B. lampros*	44 c
4. Methomyl and *B. lampros*	35 b
5. Chlorfenvinphos and *B. lampros*	66 d

* Mean separation was by S.N.K., P = 0.05 (Zar, 1974).

Values followed by the same letters are not significantly different (Error degrees of freedom, 12).

4.4 Effects of insecticide treatment on Bembidion lampros

Laboratory test - The results showing the toxicity of insecticide-treated soil to B. lampros are given in Table V. The three insecticides tested differed markedly both in initial and residual toxicity. Only methomyl caused high mortality in B. lampros. When freshly applied to the soil, it was extremely toxic at the recommended field rate of 1 g/litre and adults exposed to treated soil suffered 100% mortality in the first day after treatment. Dipel at the same rate and chlorfenvinphos at 10 ppm gave 0% mortality one day after treatment. The percentage mortality was 70% one day after treatment when the rate for methomyl was halved. Only when the recommended rate was reduced to 1/8 was there no mortality of B. lampros. Increase in the dosage rate of Dipel fivefold and chlorfenvinphos fourfold did not increase the percentage mortality significantly.

TABLE V. Percentage mortality of B. lampros exposed to insecticide-treated soil, sampled periodically after application

Insecticide	Rate (g/liter)	% Mortality days after soil treatment with insecticides 1	2	3	
Dipel*	1	0	7	13	
Methomyl	1	100	-	-	
Untreated	-	0	7	13	
Dipel	5	0	10		
Methomyl	0.5	70	70		
	0.25	40	70		
	0.125	20	40		
Untreated		20	40		
		1	3	5	7
Chlorfenvinphos	10 ppm	0	0	0	0
	40 ppm	5	5	5	5
Untreated		0	0	0	0

* 1.12 kg/1123 litre/ha is rate recommended for brassica crops; 1.12 kg Dipel contains 7.26×10^9 IU.

Dipel and methomyl were applied with a hand sprayer to wet the surface of the soil in the pots.

Field experiments - I investigated the effects of applying Dipel, methomyl and chlorfenvinphos during the attack periods of cabbage maggot, aphids and lepidopterous larvae in the presence of B. lampros.

Monthly totals showed that for June, treatment 5 retained the highest numbers of B. lampros followed by treatments 3, 2 4 and 1 respectively in descending order (Table VI). A significant reduction in the numbers of B. lampros in treatment 4 during the first generation of cabbage root fly resulted in an increase of cabbage root fly egg deposition (Fig. 10). But there was a reduction in the numbers of eggs laid in treatments 2, 3 and 5 where the predator population had not been substantially reduced by insecticide treatments. This is most evident in treatment 5 where the number of eggs was significantly lowest for the first generation of cabbage root fly (Table III).

TABLE VI. Monthly totals of *B. lampros* taken from pitfall traps (4/plot) inside the barrier for the various treatments May - August 1975

Treatment	May	June	July	August	Total
1. Untreated	56	53	7	8	124
2. *B. lampros* only	191	98	5	2	296
3. Dipel an *B. lampros*	208	103	4	9	324
4. Methomyl and *B. lampros*	206	33	1	2	262
5. Chlorfenvinphos and *B. lampros*	213	100	3	3	319
Monthly total of *B. lampros*	894	387	20	24	1325

4.5 Carabid beetles other than *Bembidion lampros*

The number of other carabid beetles taken from inside the barrier during the experiment and their relative abundance in decreasing order are presented in Table VII. A total of 216 carabids was removed from the experimental plots. Outside the barrier, six major species of the family Carabidae were taken, including *B. lampros*. Like those taken from inside the barrier, *Harpalus affinis* was the most abundant. Many more specimens of the same species were caught from outside the barrier than from inside (Tables VII and VIII). However, inside the barrier, *B. lampros* was the most numerous carabid trapped in the untreated control followed in descending order by *H. affinis*, *Amara* sp., *Bembidion* sp., *Calathus fuscipes* and *Pterostichus melanarius* (Table I). There were no significant treatment effects in any month for any species caught inside the barrier (Appendix Table 6). Covariance analysis suggested that the five species did not appear to have influenced the egg counts in any meaningful way since the beetles were constantly being removed from the experimental plots.

TABLE VII. Numbers of carabid beetles other than *Bembidion lampros* taken from eighty pitfall traps in the various treatments from May - August 1975

Species	Untreated	*B.lampros* only	Dipel and *B.lampros*	Methomyl and *B.lampros*	Chlorfen-vinphos & *B.lampros*	Total
Harpalus affinis	19	16	25	19	23	102
Amara sp.	12	4	14	11	7	48
Calathus fuscipes	3	7	11	6	0	27
Pterostichus melanarius	3	6	6	4	5	24
Bembidion sp.	5	6	1	2	1	15
Total carabids	42	39	57	42	36	216

TABLE VIII. Numbers of carabid beetles taken from 20 pitfall traps outside the barrier May - September 1975

Species	May	June	July	August	September	Total
Harpalus affinis	225	30	66	289	116	726
Amara sp.	64	13	21	93	152	343
Calathus fuscipes	42	13	21	72	95	233
Pterostichus melanarius	0	0	19	105	35	159
Bembidion lampros	85	8	4	22	3	122
Bembidion sp.	14	1	0	0	0	15
Total	430	55	131	581	401	1598

4.6 Yield and survival of Brussels sprout plants

The percentage survival and mean weight of fresh Brussels sprout plants at harvest are presented in Table IX. There were no significant differences in the average fresh weights or the percentage survival of plants in the various treatments. Separate analysis of the weights of bolted plants and of those that produced sprouts did not show any significant treatment effects. There was very little loss of plant stand at harvest and the number of plants that bolted to seed varied between treatments and between plots (Appendix Table 8). The percentage survival of plants was very high in all the treatments despite the large numbers of cabbage root fly eggs laid, especially in the untreated plots. These had the lowest percentage survival and treatment 5 with chlorfenvinphos the highest. Root maggot infestation was considered light since less than 5% of the plants untreated were killed.

TABLE IX. Percentage survival and mean weight of fresh Brussels sprout plants at harvest*

Treatment	Average no. of plants /plot that survived	% survival	Mean weight of fresh Brussels sprout plants (kg/plot)
1. Untreated	24.8	95.2	20.8
2. *B. lampros* only	25.5	98.1	19.8
3. Dipel and *B. lampros*	25.5	98.1	19.8
4. Methomyl and *B. lampros*	25.5	98.1	19.8
5. Chlorfenvinphos and *B. lampros*	25.8	99.0	24.1
Grand mean ± S.D.	25.4 ± 0.8	97.7 ± 3.4	20.6 ± 5.2

* There were no significant (P = 0.05) treatment effects on the weight of plants and percentage survival at harvest according to the F-test of analysis of variance; no S.N.K. test (Zar, 1974) was carried out (Error degrees of freedom, 12).

4.7 Cabbage maggot damage

Root examination for cabbage maggot damage showed that on the average, root damage was moderate. The average damage index (Table X) shows that treatments which included *B. lampros* had lower damage indices than untreated controls. Treatment 5 had zero damage index and was significantly different from the other treatments. Some of the roots examined in treatments 1, 2 3 and 4 were found with scars, a sign that they had recovered from early maggot damage. Damage indices for treatments 1 and 4 were not significantly different.

4.8 Effects of treatments on cabbage root fly puparia

The average number of puparia per plant at harvest is given in Table XI. The total number of puparia (empty and full) was highest for treatment 1 and lowest for treatment 5. Treatments 2, 3 and 4 were intermediate. On the whole the number of overwintering puparia averaged 3.2 per plant.

Emergence records of *H. brassicae* puparia collected at harvest revealed 17% pupal parasitism by *Aleochara bilineata*, a staphylinid beetle.

TABLE X. Average index per plant for maggot damage after various treatments (20 plants, 5/plot)

Treatment	Number of roots in each damage category*					Total damage index**	Average damage index per plant***
	clean	light	moderate	severe	very severe		
	0	1	2	4	8		
1	0	7	7	5	1	49	2.5a
2	2	10	7	1	0	28	1.4c
3	0	9	9	2	0	35	1.8bc
4	0	7	9	4	0	41	2.1ab
5	20	0	0	0	0	0	0.0d
Grand mean ± S.D.							1.5 ± 0.7

* Damage category: 0, clean; 1, light; 2, moderate; 4, severe; 8, very severe.

** Sum of the roots per category multiplied by the damage category.

*** Mean separation of damage index is by S.N.K. (Zar, 1974).

Values sharing same letters are not significantly different at 5% level (Error degrees of freedom, 12).

TABLE XI. Average number of cabbage root fly puparia per plant (20 plants, 5/plot) at harvest*

Treatment	Empty puparia**	Full puparia	Average**
1. Untreated	16.3a	3.2 a	9.7a
2. *B. lampros* only	9.3b	4.8 a	7.1a
3. Dipel and *B. lampros*	11.4b	4.4 a	7.9a
4. Methomyl and *B. lampros*	12.4b	2.6 a	7.5a
5. Chlorfenvinphos and *B. lampros*	1.0c	1.0 a	1.0b
Grand mean ± S.D.	10.1 ± 5.1	3.2 ± 4.4	6.6 ± 5/2

* Soil core 15 cm diameter x 12 cm deep with plant as center of sample

** Separation of means is by S.N.K., P = 0.05 (Zar, 1974).
Means followed by the same letter are not significantly different (Error degrees of freedom, 12).

5. DISCUSSION

5.1 Level of oviposition and consequent infestation

The results of this experiment showed that infestation by the first generation of the cabbage root fly is the critical factor in the production of early stem brassicas. The peak of spring egg laying occurs when plants are still small. They may also receive considerable numbers of second generation eggs, but this infestation does not greatly affect production since the plants are by this time nearly mature. This supports the findings of King et al. (1957) who reported that the critical period of damage by root maggots is the 2 to 3 weeks between transplanting and establishment. Coaker and Finch (1965) and Coaker (1969) have confirmed this repeatedly by showing that serious reductions in yield can usually be prevented if the crop is well protected from cabbage maggot damage during the first few weeks after planting.

Egg deposition in the spring was heavier than it was in the summer (Fig. 8). This has also been noted by Gibson and Treherne (1916) and Forbes (1962) in Canada, by Miles (1953) in England, and by de Wilde (1947) and Abu Yaman (1960) in the Netherlands. Miles considers that this is not due to lack of adults but rather to the fact that the environment in summer provides little food to sustain the adults and as a result they do not survive to complete oviposition. De Wilde implicates parasites, predators and weather conditions and Forbes suggests that as the season advances there is a progressively greater acreage of cole crops over which the eggs are distributed so that the number of eggs to be found on a sample of plants is smaller. In this study, there was a progressive decrease in the number of eggs laid especially in the second generation as the plants matured. Coaker (1967) and Hassan (1973) suggest that mature plants may not attract flies for egg laying.

5.2 Effect of weather on oviposition by cabbage root fly

In the experimental field, in spite of the large number of eggs laid, larval populations were not high. There was a great disparity between the numbers of eggs laid and the resulting infestation, particularly in the second generation. The response of the plants to attack depends on the prevailing weather; in warm, wet conditions a plant can survive an infestation of larvae that would kill it in a hot dry period (Hughes, 1960). Weather at the critical times of oviposition, larval penetration and emergence may determine the numbers of cabbage root flies (Coaker and Finch, 1971; Matthewman and Harcourt, 1972). Egg counts and observations in the present study showed that oviposition was greatest on calm, sunny days with intermittent cloud cover. During dry periods, eggs were found under leaves which fell on the soil some centimetres away from the stem rather than immediately around the stem. Because of the prolonged dry period during the summer the plots had to be irrigated. This probably stimulated oviposition.

Beirne (1971) reported that hot weather increases feeding of the adults but decreases egg laying. Moisture was found to have much influence on infestation which tended to be high in wet periods and low in dry ones. The eggs are very susceptible to desiccation, so that up to 90% may fail to hatch in dry weather and the larvae may die from desiccation before they can enter the roots. Adult activity is hindered by cool, wet weather and may be prevented by rainfall, with consequent limitations on egg laying. Mukerji (1971) claims that the newly hatched larva is the critical stage for survival and that death by misadventure at this stage is the key-factor responsible for population change. Benson (1973) concluded that the key-factor determining population change was failure of females to achieve potential egg production.

5.3 Population trend of *Bembidion lampros*

Investigation of the effectiveness of *B. lampros* as a predator of cabbage root fly eggs showed that the beetle was particularly active during the first generation of the root fly but was less common in the second generation (Fig. 10). The sudden drop in the population of *B. lampros* by mid-June could possibly be accounted for by the following: At this time the activity of the beetle had virtually ended. As a result of frequent capture and release, some of the beetles had been killed. The decline in the numbers might be related to the age or coverage of the crop. *B. lampros* caught in cabbage plots by Mitchell (1963b) and Coaker (1965) also declined as the plants increased in size.

The population trend of *B. lampros* (Fig. 9) showed that early emergence of the overwintering population began in late July. These might be a new population which emerged from pupae as suggested by Mitchell (1963a). No attempt was made to study oviposition periods and fecundity in the laboratory by breeding beetles in captivity since the adults are cannibalistic and in cages they usually eat most of their eggs soon after they are laid. Even isolated gravid females have been found to consume their own eggs (Mitchell, 1963a). However, adult predation of eggs and larvae appears unlikely under field conditions, since the eggs are laid in deep cracks in the soil; the larvae live beneath and the adults live on the soil surface (Mitchell, 1963a).

The frequency of the occurrence of ground beetles in monoculture is also known to be greatly influenced by weather and less so by such conditions as density of plant growth and configuration of the ground (Jones, 1969; Skuhravy *et al.*, 1971). The feeding period of B. lampros and some other carabids is known to be affected by temperature (Wishart *et al.*, 1956; van Dinther and Mensink, 1966). The annual feeding cycle of *B. lampros* showed that the gut was empty during the cold months (Mitchell, 1963a). Laboratory experiments have shown that the efficiency of pitfall traps varied directly with dryness of the soil (Mitchell, 1963b; Greenslade, 1964). In this study, it was observed that more *B. lampros* were caught during warm, dry and sunny periods than when the weather was cold, wet and cloudy. The position of the pitfall traps especially later in the season when the plants gave greater coverage than earlier, must have influenced the numbers of *B. lampros* taken.

5.4 Predation of the egg stage of the cabbage root fly by *B. lampros*

Methods for appraising the actual and potential importance of natural eneimies have been reviewed by DeBach and Bartlett (1964), DeBach and Huffaker (1971) and Kiritani and Dempster (1973) who suggested that more than one method of study should be used. In this investigation, addition and exclusion methods were used in which *B. lampros* was introduced into certain plots and excluded from others by means of polythene barriers. This is of great advantage especially for non-flying forms, such as *B. lampros*, which are slow to disperse. The main disadvantage of this technique is that the physical environment is modified by the mechanical barrier. Other workers have used these methods to determine the effectiveness of some carabids as predators of roof fly (Wright *et al*., 1960; Coaker, 1965; Ryan and Ryan, 1973). Hassan (1969) reported that barriers deterred ovipositon by the root fly. This needs further investigation.

The effectiveness of *B. lampros* as a predator of cabbage root fly eggs was demonstrated. Untreated plots had a greater number of eggs than any other treatment and thus had the highest indices of damage and puparia (Table III and X). Although *B. lampros* may prey on any of the immature stages of the cabbage root fly, the relationship between their numbers and the survival of the root fly eggs was the most consistent. The fact that there were no significant differences among treatments which included *B. lampros* in May (Table II), suggests that *B. lampros* was able to reduce considerably the number of eggs laid. It was in fact, after the *B. lampros* population had declined in June (Fig. 10) that treatment 5 had significantly lower egg numbers than other treatments (Table II). This was probably due to the fact that chlorfenvinphos in treatment 5 was still toxic to *H. brassicae* females and this resulted in fewer eggs being laid near the base of the plants. As the number of eggs increased and decreased during the first generation, the number of *B. lampros* responded in a similar way except where methomyl insecticide reduced the population of the beetle. The results also show that during May and June the number of root fly eggs were significantly lower in plots with *B. lampros* than in plots without, but there was no significant treatment effect for July and August, when *B. lampros* population had nearly disappeared (Table II).

A natural enemy may be of great importance in reducing crop damage by the mortality it causes in a given pest generation. The number of empty puparia for each treatment gives an estimate of the number of larvae that penetrated and established themselves in the roots of Brussels sprout plants. Fewer clean roots were recorded in untreated than in treated plots.

Previous workers (Wishart *et al.*, 1956; Coaker and Williams, 1963: Coaker, 1965) have demonstrated the role of predatory and parasitic beetles in reducing populations of immature stages of root fly. Laboratory studies with housefly eggs showed that *B. lampros* consumed fewer eggs as egg density decreased. Feeding did not occur every day. The maximum daily consumption was about 20 eggs (van Dinther and Mensink, 1966). In a field experiment, Hughes (1959) indicated that an average of 42% of the eggs placed around plants were lost every day. In the present investigation the reduction in eggs due to predation by B. lampros was calculated to be 45% during the first generation of root fly (Table IV). It is evident that B. lampros cannot alone give maximum protection against cabbage maggot, but the damage caused by the pest can be reduced significantly by the presence of B. lampros, at least during the first generation. A further reduction of cabbage root fly eggs occurs in the second generation when other carabid species appear (Coaker, 1965).

5.5 Susceptibility of B. lampros to insecticide treatments

The laboratory method used for testing the effect of insecticides on B. lampros in this investigation, has the advantage of providing soil as a substratum. Soil is the natural habitat of the cabbage root fly and its predators and parasites. The studies showed that methomyl was toxic to B. lampros at the recommended field rate. Even when the dosage was halved there was more than 60% kill. B. lampros was remarkably tolerant to both Dipel and chlorfenvinphos (Table V). Methomyl is moderately persistent in soil; about 50 to 75% remains 30 days after application (Hill, 1970; Harvey, 1971). Where high populations of aphids and lepidopterous larvae occur early in the season, treatment with methomyl might be harmful to beetle predators. It has been shown that a decrease in the number of certain predators of the cabbage maggot would cause a proportionate increase in the survival of the pest and in the amount of damage to stem brassicas (Coaker and Williams, 1963; Coaker and Finch, 1964). Information on the critical toxicity of an insecticide and the length of time in which it remains harmful to natural enemies, is of special importance as guidance for integrated control. Short-lived insecticides may be applied to control the pest at times when the useful insects are absent or in a stage of development that is not exposed to the poison.

The application of methomyl (treatment 4) at the peak of egg laying in the first generation significantly reduced the number of B. lampros. Consequently there was an increase in the number of eggs which survived. (Fig. 10). This increase was reflected in the high damage index and the number of empty puparia in methomyl treatments (Tables X and XI). The lower percentage reduction in egg numbers (Table IV) due to predation in methomyl-treated plots, confirmed that methomyl has an adverse effect on B. lampros. Both Dipel and chlorfenvinphos can be applied safely at the recommended field rate since they had no effect on the beetle. The high degree of specificity permits the combination of these two insecticides with macrobial agents in that they may be applied for control of specific pests so as not to interfere with control of other pests by macrobial agents. Similar findings have been reported for Dipel (Jacques, 1965) and for chlorfenvinphos

(Mowat and Coaker, 1967; Falcon *et al.*, 1968; Hassan, 1969).

Adverse effects of insecticides on the natural enemies of cabbage root fly may be even more important with a long term crop, such as Brussels sprouts, in which a high level of control of the first generation attack is probably necessary in order to limit attack by subsequent generations. The increase in the number of eggs in plots treated with chlorfenvinphos during the second generation (Figs. 8 and 10) can be accounted for by the following: At this time *B. lampros* had disappeared and the effect of chlorfenvinphos which was applied on May 1 probably had declined. At the recommended field rate chlorfenvinphos would be effective for 45 days (B.C.D.A. 1976). The results from this study implies that, when necessary, it will be safe to apply supplementary midseason treatments in relation to the time of appearance of the second generation of root fly to which other parasites and predators are tolerant. It is of interest to note that the increase in the number of eggs in chlorfenvinphos-treated plots was due to a single plant. Hawkes (1974) suggested that the odour of host plants is probably a factor in the attraction of females to the crop. Smith (1973) reported that certain chemicals occurring in vapours from cruciferous plants, such as allylisothiocyanate (ANCS), can influence the behaviour of root fly. This needs further investigation.

5.6 Integrated control of insect pests of stem brassicas

The type of insecticide and its mode of application is of vital importance in the control of insect pests of brassica. Attempts to control one pest with an insecticide without an understanding of the other fauna may lead to a chain of reactions. There are documents to support the fact that apart from the problem of resurgence, secondary pests may arise from indiscriminate use of insecticides directed at key pest (N.A.S., 1969; Adkisson, 1971; Reynold, 1971). The dangers of unwise use of insecticides are illustrated by Dunning *et al*. (1975), who found that *B. lampros* and *Feronia melanarius* Ill (= *P. melanarius*) effectively fed upon aphid nymphs on sugar beets, but were reduced by parathion sprays against the aphids. Other workers have demonstrated that carabids prey on aphids (Skuhravy, 1959; Dempster, 1972). The carabid *Harpalus rufipes* Schr. together with other insects and arachnids, particularly *Phalangium opolio* Linnaeus, accounted for at least half of the natural mortality of eggs and larvae of *Pieris rapae* on Brussels sprouts (Dempster, 1967).

The use of an insecticide such as methomyl for the control of aphids and lepidopterous larvae on brassica plots may well have adverse effects on the natural enemies of such insects. The advantage of some protection from aphids, however must be weighed against the disadvantage of almost eliminating predatory beetles. Mowat (1965) reported that staphylinid beetles are at least twice as susceptible to organophosphorus insecticides as the most susceptible carabid species which was *B. lampros*. Use of selective materials and spot applications of broad spectrum insecticide should minimize any adverse effects against natural enemies.

A practical consequence of reducing egg numbers is an increase in yield and this has amounted to as much as 40% in studies in Britain (Wright *et al.*, 1960). Although the egg numbers were reduced in treatments containing *B. lampros* in this study, there was no significant difference in yield among treatments for two probable reasons. First, the crop was well advanced when the root maggots attacked. Second, very few larvae were able to penetrate and get established. The low damage indices appear to support this statement. Most of the plants that were attacked quickly recovered, hence the percentage survival of the plants was high in all the treatments. It seems likely that yield is reduced only when the attack is heavy and occurs at the early stage.

6. SUMMARY AND CONCLUSIONS

The principal finding of this study is that the carabid beetle, *Bembidion lampros* is associated with diminished survival of cabbage root fly eggs. The amount of predation on the eggs may depend on the population density and the activity of the beetle. *B. lampros* alone may not be able to give complete protection to the crop especially when the attack by cabbage maggots is heavy. In the absence of a suitable insecticidal treatment for cabbage maggot control, a reduction of the carabid populations could therefore have undesirable consequences through the survival of the root fly and these could be considerably increased if the populations of predatory and parasitic staphylinid beetles were also reduced.

Egg counts may serve as a warning system for determing the appropriate time for insecticide treatment. It will also provide information on the intensity of attack.

The insecticides tested differed in their toxicity to *B. lampros*. *B. lampros* was tolerant to both Dipel and chlorfenvinphos. Methomyl was toxic and it reduced the *B. lampros* population. Such results as these point to the need for both field and laboratory tests; although laboratory tests may indicate the innate relative toxicities of pesticides, they cannot always predict their impact in field situations. With a fuller knowledge of the toxicity of insecticides to predators, we can plan reliable control measures much more easily.

It is clearly desirable to enhance rather than lessen the effect of *B. lampros* and other carabid predators. In order to protect natural enemies and increase their beneficial effect, more selective chemical control of the insect pests of brassica is needed. Selective chemicals and selective means of application, by timing applications or reducing dosages will go a long way to spare the natural enemies.

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Appendix Table 1. Average number of eggs/plant/date for each treatment at 2 days interval May - August 1975

Date		Untreated	*B. lampros*	Dipel and *B. lampros*	Methomyl and *B. lampros*	Chlorfenvinphos and *B. lampros*
		1	2	3	4	5
May	9	2.4	3.2	4.3	4.4	4.3
	12	5.2	1.6	2.8	2.3	1.8
	14	2.6	5.1	7.6	4.1	6.3
	16	1.6	4.6	5.0	2.6	4.0
	19	6.8	2.2	1.6	3.5	2.9
	21	0.6	0.4	1.0	0.9	0.1
	23	7.4	6.4	2.3	11.2	8.4
	26	35.8	14.1	10.1	17.8	6.4
	28	28.3	5.3	5.7	10.5	4.9
	30	18.0	6.1	5.9	6.8	3.8
June	2	34.5	11.4	14.6	17.8	13.9
	4	20.5	12.1	7.8	11.3	3.2
	6	4.8	2.9	3.4	4.1	2.2
	9	3.9	6.9	1.4	2.4	4.0
	11	9.1	6.9	8.7	7.3	0.6
	13	7.9	11.9	11.3	10.3	4.0
	16	5.4	4.5	5.5	6.0	1.3
	18	16.2	12.3	11.7	12.6	2.2

Appendix Table 1 (cont.)

Date		Treatment 1	2	3	4	5
June	20	10.2	6.9	8.5	7.8	1.4
	23	6.1	4.3	5.5	4.4	2.0
	25	5.1	3.6	5.4	3.9	3.2
	27	1.7	3.3	2.8	2.2	4.4
	30	3.9	2.4	2.8	3.8	2.9
July	2	2.1	1.1	2.5	2.8	4.9
	4	2.5	1.4	3.3	0.6	4.9
	7	4.3	4.4	2.4	0.6	5.6
	9	1.1	3.3	1.3	0.8	4.1
	11	2.0	6.5	3.3	2.6	8.3
	14	5.7	7.6	3.0	5.1	7.2
	16	8.6	15.3	6.0	7.8	12.0
	18	4.8	5.4	2.7	2.6	12.8
	21	4.0	9.9	1.3	3.5	18.8
	23	4.1	1.1	2.8	1.8	7.4
	25	1.8	2.7	1.6	2.4	2.6
	28	2.1	2.2	2.3	0.9	2.7
	30	2.3	3.5	0.9	1.4	2.6

Appendix Table 1 (cont.)

Date	Treatment 1	2	3	4	5
August 1	0.9	2.8	2.0	0.9	3.4
4	0.9	1.9	0.7	0.6	5.3
6	2.2	1.4	0.4	0.8	0.8
8	2.7	2.4	1.4	0.8	0.4
11	0.4	0.0	0.0	0.3	0.2
13	0.1	0.4	0.7	1.0	1.2
15	0.3	0.0	0.0	0.1	0.1
18	0.2	0.0	0.0	0.0	0.1
20	0.0	0.0	0.0	0.0	0.0
22	0.1	0.0	0.0	0.0	0.1
25	0.0	0.0	0.0	0.0	0.0
27	0.1	1.1	0.0	0.0	0.1
29	0.0	0.0	0.0	0.0	0.0

Appendix Table 2. Average number of B. lampros taken from pitfall traps (4/plot) each date at 2 days interval for the various treatments

Date		Untreated 1	B. lampros 2	Dipel and B. lampros 3	Methomyl and B. lampros 4	Chlorfenvinphos and B. lampros 5
May	7	0.5	0.3	4.8	3.0	2.0
	9	0.5	3.5	1.8	4.3	3.5
	12	1.3	4.8	4.5	7.3	3.8
	14	1.3	7.3	8.3	10.5	9.5
	16	0.8	4.3	3.5	6.5	5.0
	19	0.3	3.8	3.5	4.0	4.8
	21	0.8	1.5	1.8	2.3	2.8
	23	1.8	5.8	5.5	3.8	4.0
	26	1.3	3.3	2.8	6.3	2.8
	28	4.5	7.3	8.5	7.0	8.5
	30	2.5	5.5	5.5	3.8	5.0
June	2	3.5	5.3	4.8	1.5	5.8
	4	1.0	5.5	7.0	0.5	4.8
	6	1.5	1.0	0.5	1.3	2.5
	9	1.5	1.0	0.5	1.3	2.5
	11	0.0	1.3	0.0	0.0	0.5
	13	0.5	0.5	0.0	0.3	1.3
	16	0.8	1.3	0.5	0.0	0.8

Appendix Table 2 (cont.)

Date		Treatment 1	2	3	4	5
June	18	0.8	1.0	1.5	0.0	0.8
	20	0.5	0.0	0.0	0.3	0.0
	23	0.5	0.3	0.3	0.0	0.3
	25	0.3	0.0	0.3	0.0	0.0
	27	0.0	0.3	0.0	0.0	0.0
	30	0.0	0.3	0.0	0.0	0.0
July	2	0.0	0.0	0.0	0.3	0.0
	4	0.0	0.0	0.0	0.0	0.0
	7	0.0	0.0	0.0	0.0	0.0
	11	0.0	0.0	0.0	0.0	0.0
	14	0.0	0.0	0.0	0.0	0.0
	16	0.3	0.0	0.0	0.0	0.0
	18	0.0	0.0	0.0	0.0	0.0
	21	0.5	0.0	0.0	0.0	0.0
	23	0.3	0.0	0.0	0.0	1.0
	25	0.3	1.0	1.0	0.0	0.8
	28	0.0	0.3	0.5	0.0	0.3
	30	0.5	0.0	0.0	0.3	0.0

Appendix Table 2 (cont.)

Date	Treatment 1	2	3	4	5
August 1	0.0	0.0	0.5	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0
6	0.5	0.0	0.0	0.0	0.0
8	0.5	0.0	0.5	0.0	0.0
11	0.5	0.0	0.3	0.0	0.0
13	0.0	0.0	0.3	0.5	0.3
15	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.3	0.5	0.3
20	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0

Appendix Table 3. Weekly counts of cabbage root fly eggs on Brussels sprout plants (4 samples/plot) during the growing season May - August 1975

	May				June				July				August					Total
Treatment	9	16	23	30	6	13	20	27	4	11	18	25	1	8	15	22	29	
1	38	150	236	1314	880	284	473	332	122	127	260	206	100	64	51	8	1	4646
2	51	180	145	408	375	177	459	237	107	155	533	262	134	97	46	0	2	3368
3	69	247	77	358	357	215	455	310	128	115	197	108	77	50	36	0	0	2799
4	70	134	250	561	466	221	461	258	134	32	247	126	75	36	34	0	1	3106
5	69	193	182	222	274	109	117	114	194	235	450	635	126	152	28	1	1	3102
Weekly total	297	904	890	2863	2352	1006	1965	1251	685	664	1687	1337	512	399	195	9	5	17021

Appendix Table 4. Number of *B. lampros* taken from pitfall traps (4/plot) in 20 plots inside the barrier each week for the various treatments May - August 1975

	May				June				July				August				Treatment
Treatment	9	16	23	30	6	13	20	27	4	11	18	25	1	8	15	22	29	total
1	3	13	7	33	34	8	8	3	0	0	1	6	2	4	2	0	0	124
2	18	65	44	64	76	11	9	2	0	1	0	4	1	0	0	0	0	295
3	33	65	43	67	91	2	8	2	0	0	0	4	4	2	2	1	0	324
4	35	103	40	68	25	6	1	1	0	0	0	0	1	0	2	2	0	285
5	29	73	46	65	76	17	6	1	0	0	0	0	1	0	1	1	0	316
Weekly total	118	319	180	297	302	44	32	9	1	1	1	14	9	6	7	4	0	1344

Appendix Table 5. Weekly mean of cabbage root fly eggs and the corresponding mean of Bembidion lampros for the various treatments combined*

Date		Nos. of eggs	Nos. of B. lampros
May	9	15.5 hg	5 a
	16	45.2 efg	16.9 b
	23	44.5 efg	9.2 a
	30	143.2 a	15.4 b
June	6	117.6 ab	15.1 b
	13	50.3 efg	2.2 c
	20	98.9 bc	1.6 c
	27	62.6 def	0.5 c
July	4	33.8 efgh	0.2 c
	11	33.2 efgh	0.1 c
	18	84.5 cd	0.1 c
	25	66.9 de	0.7 c
August	1	25.6 fgh	0.5 c
	8	20 gh	0.3 c
	15	9.8 gh	0.4 c
	22	0.4 h	0.2 c
	29	0.3 h	0.0 c
Grand mean ± S.D		50.1 ± 184.1	3.9 ± 0.7

* Values sharing the same letters are not significantly different at the 5% level.

Appendix Table 6. Number of other carabids taken inside the barrier from 80 pitfall traps from May - August 1975

Species	Treatment	May	June	July	August
Amara spp.	1	1	0	5	6
	2	1	0	1	2
	3	3	1	2	8
	4	4	0	3	4
	5	1	0	0	6
	Mean ± S.D.	2 ± 2.4	0.2 ± 0.9	2.2 ± 3.6	5.2 ± 6.2
H. affinis	1	10	1	2	6
	2	3	0	5	8
	3	6	0	6	13
	4	7	1	7	7
	5	7	0	5	11
	Mean ± S.D.	6.6 ± 7.9	0.4 ± 1.2	4.4 ± 4.5	9 ± 9.6
C. fuscipes	1	0	0	2	1
	2	2	0	3	2
	3	2	0	3	6
	4	1	0	0	5
	5	0	0	0	0
	Mean ± S.D.	1.2 ± 1.9	0 ± 0	1.6 ± 2.7	2.8 ± 3.7

Appendix Table 6. (cont.)

Species	Treatment	May	June	July	August
P. melanarius	1	0	0	2	1
	2	0	0	1	5
	3	0	0	1	5
	4	0	0	2	2
	5	0	0	3	2
	Mean ± S.D	0 ± 0	0 ± 0	1.8 ± 2.4	3 ± 3.4
Bembidion spp.	1	5	0	0	0
	2	6	0	0	0
	3	0	1	0	0
	4	2	0	0	0
	5	1	0	0	0
	Mean ± S.D.	2.8 ± 4.5	0.25 ± 0.8	0 ± 0	0 ± 0

* There were no significant treatment differences in any month for any species, P = 0.05 according to the F-test of the analysis of variance, and no S.N.K. test was carried out (Error degrees of freedom, 12).

Appendix Table 7. Weekly totals of carabid species caught outside the barrier from 20 pitfall traps May - September, 1975

	May				June				July				August					September				
Species	9	16	23	30	6	13	20	27	4	11	18	25	1	8	15	22	29	5	12	19	26	Total
Amara spp.	21	28	7	8	2	3	5	3	5	4	5	7	5	26	36	15	11	38	35	43	36	343
B. lampros	24	13	15	33	5	1	1	1	1	1	1	1	2	0	0	0	0	2	1	0	0	102
B. spp.	6	3	5	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17
C. fuscipes	17	12	4	9	1	1	1	0	0	2	7	12	12	18	17	13	12	53	15	21	6	233
H. affinis	77	73	30	45	12	3	8	7	7	9	12	38	34	66	112	59	18	55	22	17	22	726
P. melanarius	0	0	0	0	0	0	0	0	0	2	7	10	9	14	41	25	16	14	5	5	11	159

Appendix Table 8. The numbers and weights (kg) of Brussels sprout plants at harvest

Treatment		No. of bolted plants	No. of plants that formed sprouts	Total no. of plants/plot	Wt. of bolted plants	Wt. of plants that formed sprouts	Total wt. of plants/plot
1	A	2	21	23	0.91	18.57	19.48
	B	4	20	24	2.49	14.50	16.99
	C	2	24	26	1.59	28.31	29.90
	D	3	23	26	2.72	14.27	16.99
2	A	2	23	25	3.62	20.39	24.01
	B	-	26	26	0	17.67	17.67
	C	2	24	26	1.13	16.99	18.12
	D	-	25	25	0	14.27	14.27
3	A	3	23	26	2.95	20.16	23.11
	B	6	20	26	4.98	14.5	19.48
	C	-	25	25	0	16.31	16.31
	D	3	22	25	1.81	18.35	20.16
4	A	4	21	25	2.04	14.95	16.99
	B	3	23	26	2.04	16.54	18.58
	C	-	26	26	0	14.95	14.95
	D	6	19	25	5.66	23.10	28.76
5	A	3	23	26	2.04	18.12	20.16
	B	7	19	26	8.38	19.48	27.86
	C	3	22	25	3.62	21.52	23.14
	D	3	23	26	0.91	22.20	23.11

Appendix Table 9. Root examination and number of cabbage root fly puparia per plant

Treatment	Sample no.	Damage index A	Damage index B	Damage index C	Damage index D	Pupae empty A	Pupae empty B	Pupae empty C	Pupae empty D	Pupae full A	Pupae full B	Pupae full C	Pupae full D
1	1	2	1	2	2	12	24	17	11	0	1	0	5
	2	1	2	4	4	20	18	25	17	2	6	17	3
	3	2	1	4	1	18	9	26	7	4	4	3	2
	4	4	1	2	4	16	19	24	14	3	3	1	2
	5	1	8	1	2	17	10	13	9	2	0	3	2
2	1	2	1	1	1	11	7	5	3	3	16	1	11
	2	1	2	2	2	8	9	16	10	0	6	1	5
	3	0	0	2	4	5	8	8	11	1	0	3	17
	4	1	2	2	1	15	6	7	15	5	4	13	1
	5	1	1	1	1	8	10	6	18	6	1	2	0
3	1	1	1	4	1	9	8	15	11	1	0	4	3
	2	1	2	1	2	5	9	11	13	1	6	2	0
	3	2	2	2	2	7	21	27	12	2	3	26	6
	4	2	1	4	1	24	10	6	6	3	1	17	0
	5	1	1	2	2	8	9	4	12	0	0	1	11
4	1	1	2	4	2	14	17	22	10	14	18	25	15
	2	2	2	1	1	14	7	6	5	18	8	8	5
	3	4	2	2	4	13	8	8	42	19	8	19	43
	4	2	4	2	1	15	13	10	11	18	17	10	11
	5	1	2	1	1	8	8	9	8	10	14	9	10
5	1	0	0	0	0	2	3	0	0	4	0	0	0
	2	0	0	0	0	0	0	4	0	3	0	0	0
	3	0	0	0	0	1	2	1	1	1	1	2	2
	4	0	0	0	0	1	1	2	0	2	1	0	0
	5	0	0	0	0	0	0	1	0	0	0	3	0

* A,B,C,D = plant replicates

Appendix Table 10. Percentage mortality of B. lampros 1, 2 and 4 days after exposure to fresh insecticide-treated soil

Insecticide	Replicates	% Mortality Days after soil treatment with insecticides 1	2	3
1st Experiment				
Dipel	A	0	0	0
1g/	B	0	20	20
(recommended rate)	C	0	0	20
Methomyl	A	100	-	-
1g/	B	100	-	-
(recommended rate)	C	100	-	-
Untreated	A	0	0	20
	B	0	0	0
	C	0	20	20
2nd Experiment				
Dipel	A	0	20	
x 5 above	B	0	0	
Methomyl	A	100	-	
1/2 above	B	40	40	
1/4 above	A	40	40	
	B	40	40	
1/8 above	A	0	40	
	B	0	0	
Untreated	A	40	60	
	B	0	20	

Appendix Table 10 (cont.)

Insecticide	Replicates	% Mortality Days after soil treatment with insecticides 1	3	5	7
Chlorfenvinphos	A	0	0	0	0
10 ppm	B	0	0	0	0
(recommended rate)	C	0	0	0	0
	D	0	0	0	0
40 ppm	A	0	0	0	10
	B	10	10	10	10
	C	10	10	10	0
	D	0	0	0	0
Untreated	A	0	0	0	0
	B	0	0	0	0
	C	0	0	0	0
	D	0	0	0	0

Appendix Table 11. Names of pesticides and chemical definition of compounds used for preventing cabbage maggot damage in Canada and other parts of the world

Common name	Trade name	Chemical definition
azinphos-methyl	Guthion	0,0-dimethyl phosphorodithioate S-ester with 3-(mercaptomethyl)-1,2,4-benzotriazin -4(3H)-one
carbofuran*	Furadan	2,3-dihydro-2, 2-dimethyl-7-benzofuranyl methyl carbamage
chlorfenvinphos*	Birlane	2-chloro 1-(2,4-dichlorophenyl)vinyl diethyl
diazinon *	Basudin	0,0-diethyl 0-(2-isopropyl-6-methyl-4-pyrimidinyl) phosphorothioate
fensulfothion*	Dasanit	0,0-diethyl 0-p-(methyl sulfinyl)phenyl phosphorothioate
fonofos	Dyfonate	0-ethyl-S-phenyl-ethyl phosphonodithioate
menazon	Sayphos	S-[(4,6-diamino-S-triazin-2-yl)methyl] 0,0-dimethyl-phosphorodithioate
phorate	Thimet	0,0-diethyl S-[(ethylthio)methyl] phosphorodithioate
thionazin	Zinophos	0,0-diethyl 0-2 pyrazinyl phosphorothioate
trichlorofon	Dylox Neguvon Dipterex	dimethyl (2,2,2-trichloro-1-hydroxyethyl) phosphonate
trichloronat	Agritox	0-ethyl 0(2,4,5-trichlorophenyl)ethyl-phosphorothioate

* These insecticides are recommended for the control of cabbage maggot in British Columbia (B.C.D.A. 1976).

Appendix Table 12. Names of pesticides and chemical definition of compounds used for the control of aphids and lepidopterous larvae on brassicas

Common name	Trade name	Chemical definition
Aphids		
demeton	Sytox	mixture of 0,0-diethyl S-(and 0)-2-[(ethylthio)ethyl] phosphorothioate
diazinon	Basudin	0,0-diethyl 0-(2-isopropyl-6-methyl-4-pyrimidinyl) phosphorothioate
dimethoate	Cygon	0,0-dimethyl-phosphorodithioate S-ester with 2-mercapto-N-methyl acetamide
endosulfan	Thiodan	1,4,5,6,7-hexachoro-5-norbornene-2,3-dimethanol cyclic sulfite
malathion	Malathion	diethyl mercaptosuccinate S-ester with 0,0-dimethyl phosophorodithioate
methamidophos	Monitor	0,S-dimethyl phosphoroamidothioate
mevinphos	Phosdrin	Dimethyl 2-methoxycarbonyl-1-methylvinyl phosphate
methomyl	Lannate	S-methyl N[(methylcarbamoyl)oxy] thioacetamidate
naled	Dibrom	1,2-dibromo-2, 2-dichloroethyl dimethyl phosphate
Lepidopterous larvae		
chlorphenamidine	Fundal	N-(4-chloro-0-tolyl)-N, N-dimethyl formamidine, hydrochloride
chlorphenamidine	Galecron	N-(4-chloro-0-tolyl)-N, N-dimethyl formamidine, hydrochloride
diazinon	Basudin	0,0-diethyl 0-(2-isopropyl-6-methyl-4-pyrimidinyl) phosphorothioate
Bacillus thuringiensis	Dipel	*Bacillus thuringiensis* (Berliner) contains 25 x 10^9 viable spores/gram

Appendix Table 12 (cont.)

Common name	Trade name	Chemical definition
endosulfan	Thiodan	1,4,5,6,7-hexachloro-5-norbornene-2, 3-dimethanol cyclic sulfite
leptophos	Phosvel	O-(4-bromo-2, 5-dichlorophenyl) O-methyl phenyl phosphorothioate
methomyl	Lannate	S-methyl N[(methyl carbamoyl) oxy] thio-acetimidate
mevinphos	Phosdrin	Dimethyl 2-methoxy carbonyl-1-methylvinyl phosphate
naled	Dibrom	1,2-dibromo-2,2-dichloroethyl dimethyl phosphate
parathion	Parathion	O,O-diethyl O(p-nitrophenyl) phosphorothioate