UNDERSOWING RUTABAGA (Brassica napus L.) WITH WHITE CLOVER (Trifolium repens L.): EFFECTS ON THE CABBAGE ROOT MAGGOT (Delia radicum (L.)) AND ITS PARASITOID/PREDATOR (Aleochara bilineata GYLL.)

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by

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ABSTRACT

The cabbage root maggot *Delia radicum* (L.) (Diptera: Anthomyiidae), particularly the second generation, is the most serious insect pest of rutabaga in Newfoundland. Cabbage root maggot larvae feed on the developing root and leave unsightly scars that reduce marketability. Undersowing rutabaga with white clover (*Trifolium repens* L. var. Sonja) was tested to determine the effects on cabbage root maggot adults, oviposition, rutabaga yield and marketability, carabid beetles and the root maggot predator/parasitoid *Aleochara bilineata* Gyll. (Coleoptera: Staphylinidae).

Results of this study show that undersowing did have significant effects on the factors studied. The bare plots had more *D. radicum* females and eggs, *A. bilineata* (measured by both pitfall trapping and rate of parasitism), and some carabid species (*Clivina fossor* and *Bembidion lampros*). The undersown plots had higher total numbers of *D. radicum* of which most were males, and more of some carabid species (*Pterostichus melanarius* and *Amara bifrons*). There was a significant yield reduction in undersown compared to bare plots in 1997, and no rutabaga were marketable from either treatment. In 1998 when there was less pest pressure, yields were similar and a small percentage of rutabaga were marketable from both treatments.

The rate of parasitism by *A. bilineata* was lower in the undersown plots, as observed by other researchers. An incubator study of fall-collected *D. radicum* pupae found peak *D. radicum* emergence occurred at 172 degree days (DD) and peak *A. bilineata* emergence occurred at 421 DD, above a base threshold of 4.4°C. Survey collections showed that *A. bilineata* is present in all major growing areas of Newfoundland.

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I wish to dedicate this thesis to the memory of a very inspirational, intelligent and special person - Mr. Charles Coady (1912-1999).

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1.0 Introduction

The demand for high quality produce has resulted in a reliance on chemical pesticides. Pressure from consumers has meant that growers have to provide flawless produce for market. This means that there is little tolerance for damaged products. Thus, farmers are constantly seeking reliable control methods to ensure that they meet the demands of the market. While chemical pesticides are one method of providing this, there are many alternatives.

Pesticides, including insecticides, not only kill targeted pests, they disrupt the predator/prey relationship by killing natural enemies. Increased awareness of environmental issues in the agricultural industry has resulted in a desire to limit the usage of pesticides. The United States (US) is presently in the process of limiting many of the pesticides available on the market and this will undoubtedly affect other countries - particularly Canada - as the number of insecticide options decreases. In 1996, The US government passed a new Act, the "Food Quality Protection Act" (FQPA), which established a health-based safety standard for pesticide residues in foods and has led to a review of all pesticides (K. Ryan, pers. comm.). The impact of the FQPA on pesticide availability is not yet clear but it is certain that some products will be withdrawn (K. Ryan, pers. comm.).

Rachael Carson's book Silent Spring (1962) did much to inform the public of the negative effects of pesticides. She questioned the implications of the unrestrained use of pesticides on human health and the well-being of all organisms on earth. This resulted in a rapid increase in the understanding of the dangers associated with the release of these chemicals into the environment.

Scientists have been researching alternative farming methods for a number of years. Integrated Pest Management (IPM), the integration of a variety of pest management techniques, has been adopted widely by the agricultural industry. The United Nations Food and Agriculture Organization describes IPM as: "A pest management system that, in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains the pest populations at levels below those causing economic injury" (Poincelot, 1986). IPM makes use of forecasting, monitoring, available control methods and careful planning to help achieve an acceptable level of control.

The research presented here was undertaken to determine if undersowing could be used as part of an IPM program in Newfoundland. The goal was to determine if undersowing rutabaga, *Brassica napus* L. subsp. *rapifera* Metzg., with clover, *Trifolium repens* L. cv. Sonja, would lower pest infestations of *Delia radicum* (L.) (Diptera: Anthomyiidae) and increase the incidence of the naturally occurring predator and parasitoid *Aleochara bilineata* Gyll. (Coleoptera: Staphylinidae). Factors investigated include *D. radicum* oviposition, populations and parasitism; rutabaga damage and yield; and populations of possible predators and parasitoids.

1.1 Rutabaga

1.1.1 History

Rutabaga, *Brassica napus* L. subsp. *rapifera* Metzg., is a biennial plant of the Cruciferae or mustard family and is also known as swede or Swedish turnip (Munro and Small, 1997). Rutabagas arose through the chance hybridization between summer turnip, *Brassica rapa* L., and cabbage, *Brassica oleracea* L. (Shattuck and Proudfoot, 1990). Rutabaga originated in Northern Europe in 1620 and was first recorded in American gardens in 1806 (Nonnecke, 1989; Munro and Small, 1997).

Rutabagas have a characteristic edible tuberous root of various shapes with the cultivated types usually round or globular. Their flesh colour is either white or yellow with the latter being the most frequently grown. The root and leaves of the rutabaga have been grown for use as a table vegetable and as a fodder crop for livestock. Today, rutabagas are still used in Europe, parts of the former Soviet Union and in New Zealand as a feed for livestock (Shattuck and Proudfoot, 1990). Although at one time they were used for livestock feed in North America, due to high production costs they are now grown here only as a table vegetable. The reduction in fodder rutabagas has led to a decline in the total area in commercial production in North America. Today, 2% of the value of fresh vegetable markets are represented by rutabaga (Munro and Small, 1997).

Most North American production is in the cool, short-season regions of Canada. In 1998, the farm value of rutabagas in Canada was 15.5 million dollars with the production on a total of 5945 acres (Anon., 1998a). Production is concentrated in

Ontario, Quebec and the Atlantic provinces. Canadian production is based on the fresh vegetable trade although a small portion of the crop is cubed and sold frozen. Young rutabaga leaves are also eaten as "greens". Rutabagas are used in soups, salads and boiled dinners.

Rutabagas are cool climate crops that are stored at low temperatures and high humidities like other root crops. Exposure to early fall frosts gives the rutabaga its flavour peak. They are left in the field until late October or early November. Marketed rutabagas are usually waxed to prevent drying.

A number of rutabaga cultivars have been developed in North America. The first was "Laurentian" which was developed early this century in Quebec and which by the late 1930's had become the standard table cultivar due to its resistance to the disease club root (*Plasmodiophora brassicae* Woronin) (Shattuck and Proudfoot, 1990). Laurentian is still the most widely grown cultivar. However, it is very susceptible to attack by the cabbage root maggot, *Delia radicum* (L.) (Diptera: Anthomyiidae).

1.1.2 Production in Newfoundland

Rutabagas have always been a popular vegetable for the people of Newfoundland both for the root and the greens. Production of this crop is spread across the major growing areas of the province. Acreage of rutabaga has been in slight decline over the past number of years. In Newfoundland in 1998, a total of 400 acres of commercial rutabaga produced $1.56 million in farm cash receipts (Anon., 1998b). Many home gardeners and hobby farmers also grow rutabaga.

1.1.3 Pests

Like most crucifers, rutabagas are affected by a variety of insects and diseases. There are several diseases that affect production in Newfoundland. Club root has been a major problem in several areas of the province. This soil-borne fungus induces galling and deformity of the root system that may lead to the death of the plant. Proper management techniques, including a minimum five-year rotation, will help keep club root in check (Nonnecke, 1989). Other diseases, referred to as storage diseases, include black rot (*Xanthomonas campestris* (Pammel)), and black leg (*Phoma lingam* (Tode: Fr.) Desmaz). Damping off of seedlings is caused by *Pythium* sp. Most of these diseases can also be prevented through proper farm practices. Brown heart is a nutritional deficiency that occurs when there is a lack of boron (Nonnecke, 1989).

The major limiting factor for commercial growers of crucifers in Newfoundland is insects. A number of leaf-feeding Lepidoptera including the purple-backed cabbage worm, *Evergestis pallidata* (Hufnagel) (Lepidoptera: Pyralidae), and the cabbage white butterfly, *Pieris rapae* (L.) (Lepidoptera: Pieridae), are common pests usually requiring management. The diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), is thought to be carried into Newfoundland by weather systems from the mainland and the eastern United States and thus is unpredictable and not present every year. The most serious insect pest of crucifers in Newfoundland is the cabbage root maggot, *Delia radicum* (L.) (Diptera: Anthomyiidae).

1.2 *Delia radicum* (L.) (Diptera: Anthomyiidae)

Delia radicum occurs throughout Canada. It causes significant damage and loss to cruciferous crops when the larval stage feeds on the root system. When numerous, tunneling by larvae can destroy young plants or result in lower yields, stunted growth and reduced quality. Feeding results in wilting and death in stem crucifers like broccoli and cabbage, and loss in rutabagas as the edible/marketable part of the plant receives direct damage by tunneling maggots (Howard *et al.*, 1994).

In most parts of Canada there are two to three generations of root maggot, depending on the weather and soil conditions. In the Province of Newfoundland there are generally two generations (Coady and Dixon, 1997). The emergence, life cycle development and activities of root maggot are governed by weather conditions. Each generation requires a certain number of "heat units" (degree days). As each Province and growing region have different climates, so too do they have different numbers of *D. radicum* generations. Thus, because of the climate, Newfoundland usually has two full generations or one and a partial second (Coady and Dixon, 1997).

1.2.1 History

Delia radicum is restricted to the temperate zone of the Holarctic region (35-60°N) (Coaker and Finch, 1971). It is a widespread pest of crucifers in northern Europe, Scandinavia, the former Soviet Union and North America. It is thought to have been introduced into North America from Europe early in the 19th century, probably in soil used as ballast in ships before the 1830's (Pederson and Eckenrode, 1981). Dumping the ballast in the ocean was prohibited so it was unloaded on land, along with any incidental insect stowaways! (Morris, 1983). *Delia radicum* was described by Bouché in 1833 as *Anthomyiidae brassicae* and it has undergone frequent name changes since that time. North American literature referred species of *Delia* to *Hylemya* until quite recently. Griffiths (1991) divided the "*Delia-brassicae*-group" to which *D. radicum* was referred by Henning, into the *D. radicum* subsection.

1.2.2 Taxonomy

Linnaeus first described the cabbage root maggot, *Delia radicum* (L.) in 1758 (Griffiths, 1991). The taxonomy of *D. radicum* is as follows:

Phylum Arthropoda

Class Insecta

Order Diptera

Suborder Cyclorrhapha

Division Schizophora

Section Calyptratae

Family Anthomyiidae

Subfamily Anthomyiinae

Genus *Delia*

Species *radicum*

1.2.3 Life Cycle

Adults

The adults begin to emerge from the overwintering pupae in the spring when the accumulated degree days reach approximately 200 (base 4.4°C) (Coady and Dixon, 1997)(see section 1.2.5 for explanation). The grey-brown flies are similar in appearance to, but slightly smaller than, house flies. The male flies are smaller than the females, have a more broadly rounded abdomen and are more bristly.

Eggs

Female flies produce white oblong eggs that are approximately 1.0 mm in length and 0.3 mm wide at the middle (Neveau *et al.*, 1997). Eggs have a finely sculptured pattern that is important in distinguishing the eggs of various *Delia* species (Brooks, 1951). Females begin to lay eggs the day following mating (Coaker and Finch, 1971). The typical oviposition site is on the plant stem at soil level, or in the soil immediately surrounding the stem of the host plant (Hughes and Salter, 1959). The female lands on a leaf, walks down the stem and begins oviposition.

Larvae

Eggs hatch within about a week depending on temperature, and the emerging larvae move to the roots of the plant to feed (Coaker and Finch, 1971). There are three larval instars and mature larvae are approximately eight millimetres in length. The white, legless, cylindrical maggots feed on root hairs and roots and may tunnel into fleshy parts of roots. The larvae feed for a period of three to four weeks (Coaker and Finch, 1971).

Pupae

The late third instar larvae complete feeding and leave the roots to pupate in the soil near the roots, usually at depths of 4-8 cm (Royer *et al.*, 1998). The puparia are brown or reddish brown in colour and barrel shaped. During the summer, the pupal stage lasts for approximately two to three weeks. If diapause is induced, the development of the insect ceases and the pupa overwinters. *Delia radicum* overwinters in the pupal stage.

1.2.4 Damage

Cabbage root maggot feed on the roots of host plants. This feeding, particularly when larvae are numerous, can have devastating effects on the plant. Feeding affects the ability of the plant to absorb water and nutrients and this in turn may result in stunted growth, reduced yield and reduced marketability. This feeding is particularly damaging to transplants and new crops, however mature crops may be able to withstand some feeding (Coaker and Finch, 1971). First generation maggot damage results in rough areas or scar tissue. Second generation damage includes tunnels on or near the root surface. Some larvae also chew their way into the bulb of the plant. This feeding not only seriously reduces quality but causes storage problems as well.

Some plants such as cabbage, broccoli and Brussels sprouts may still be marketable since it is the above ground portion of the plant that is sold and the damage is contained on the stem or non-edible part of the plant. These plants can tolerate feeding in small amounts.

Plants such as rutabaga, turnip and radishes cannot sustain much damage. In cruciferous root crops, such as rutabaga, where the underground portion of the plant is marketed, slight damage may render the plant unmarketable (Howard *et al.*, 1994). This is true because the larvae tunnel into the stem and tissue of the edible part of the plant.

Marketability is therefore reduced significantly as even a slight amount of damage is not tolerated by consumers.

1.2.5 Control Options

Adequate control of *D. radicum* infestations has been a problem for growers and researchers for many years. In the Atlantic Provinces, research on control methods was conducted as early as 1919 in Truro, Nova Scotia (Brittain, 1920). In Newfoundland, early work focussed on management with chemical insecticides (Morris, 1960). More recent research involves forecasting, monitoring and undersowing. Researchers have also studied control of the pest through the use of such methods as exclusion fences (Vernon and Mackenzie, 1998), collars (Skinner and Finch, 1986) and row covers (Hough-Goldstein, 1987). Sticky traps have been explored as another control option (Tuttle *et al.*, 1988).

Control through the use of chemical insecticides is very complex. Not only does optimum control through insecticides require the farmer to be familiar with the life cycle of the pest they are trying to control, they should forecast and monitor its emergence. Currently, growers use insecticides formulated as granules and drenches. In order to protect young seedlings and transplants, it is necessary to successfully maintain first generation root maggot control for all crucifers. Since insecticides target young larvae, timing is critical. Second generation control programs have involved overhead sprays (drenches) of insecticides that may not be effective if the crop canopy prevents the spray from reaching the target. Drenches must be applied with a high water volume to reach the larvae in the soil (Coady and Dixon, 1997). This requires proper insecticide application equipment and the correct nozzles to direct the spray towards the plant base.

The number of registered chemical insecticides available for *D. radicum* control has steadily decreased and with the possibility of organophosphates being phased out in the USA, there will be even fewer control options. In Newfoundland, the insecticides of choice for control are organophosphates such as chlorpyrifos (Lorsban), azinphos-methyl (Guthion, Sniper and APM) and chlorfenvinphos (Birlane) (K. Ryan, pers. comm.).

Integrated Pest Management for *Delia radicum* includes a variety of control methods. Cultural control includes plowing of infested fields during the fall which exposes the overwintering pupae to weather conditions and predators and will reduce pest populations. Exclusion attempts through the use of row covers reduce pest populations while maintaining favourable growing conditions for the plants. Variation of planting date is another method of pest control. This method helps the plant avoid the first generation egg laying period. While these separately produce different results, they can be considered together for IPM programs.

The key to success with IPM is to be aware of the pest, its life cycle and population trends in the specific area. When it is necessary to have insecticides as part of the management program, monitoring and forecasting the timing of pest attacks are vital to achieving adequate control.

Monitoring of *Delia radicum* activity is achieved through the use of a variety of trapping methods. Yellow pan traps, egg traps and soil counts for eggs can provide details of *D. radicum* activity in the area being monitored (Howard *et al.*, 1994; Bligaard *et al.*, 1999).

Forecasting is a very useful tool in determining pest emergence. Through the use of degree day (DD) accumulations, it is possible to predict *D. radicum* emergence. There is a direct relationship between temperature and the rate at which an insect develops. Each stage in the life cycle requires a certain number of DD to develop. The DD are determined by accumulating the number of daily heat units above a base threshold. The base threshold temperature, the temperature below which insect development does not occur, is 4.4°C for *D. radicum* in the United Kingdom (Finch and Collier, 1986), and in Newfoundland (P. Dixon, pers. comm.). The DD for a particular date are calculated by subtracting the base temperature from the average daily temperature (minimum plus maximum temperature divided by two). Field research in Newfoundland resulted in the estimation that peak emergence of first generation flies from overwintering pupae occurs at about 200 DD and the second generation at 780 DD (Coady and Dixon, 1997). Subsequent laboratory studies showed the DD requirements to be 10-30 DD lower than the field estimates (Dixon, unpublished).

Timing of insecticide application can be achieved either by forecasting *D. radicum* oviposition using degree days or by the less-accurate "calendar method". The calendar method involves application of pesticides the same time each year. This will not ensure adequate control as the dates of occurrence of optimum DD differ each year.

Many growers in Newfoundland have related first generation cabbage root maggot emergence to the bloom of *Amelanchier* sp. (chuckley pear) as both require a similar number of degree days.

There are naturally occurring parasitoids and predators that can kill the cabbage root maggot. The major parasitoids of *D. radicum* are a cynipid wasp, *Trybliographa rapae* (Westwood) (Hymenoptera: Cynipidae) and the staphylinid beetles *Aleochara bilineata* Gyll. and *Aleochara bipustulata* Grav. (Coleoptera: Staphylinidae) (Finch, 1989). Each of these has been shown to occasionally infest relatively high proportions of overwintering *D. radicum* pupae (Finch, 1996), although parasitism can vary tremendously between years, crops, sites and generations or with pesticide history (Langer, 1996). *Aleochara bilineata* and *A. bipustulata* regularly parasitize 20-30% of cabbage root maggot pupae in the United Kingdom (Finch and Collier, 1984), and from 10-79% in Canada (Turnock *et al.*, 1995). *Aleochara bipustulata* is not known from Newfoundland and *T. rapae* is uncommon here (Morris, 1960; P. Dixon, pers. comm). In Newfoundland, the major natural enemy of the cabbage root maggot is *Aleochara bilineata*.

1.3 *Aleochara bilineata* Gyll. (Coleoptera: Staphylinidae)

Parasitism and predation of *D. radicum* by various species of *Aleochara* are very common. *Aleochara bilineata* adults (Figure 1.1) feed on eggs and larvae of the cabbage root maggot and the larvae develop as parasitoids within *D. radicum* puparia (Royer and

Figure 1.1: *Delia radicum* pupa (top) and *Aleochara bilineata* adult (bottom), (magnification = 15x).

Photo courtesy of Dr. Guy Boivin, Horticulture Research and Development Centre, St. Jean-sur-Richelieu, PQ.

Boivin, 1999). *Aleochara bilineata* presumably entered North America with its host from Europe (Morris, 1983).

Most of the members of the family Staphylinidae are beneficial as both the larval and adult stages are predators. They are important in the control of Diptera pest species (Klimaszewski, 1984). *Aleochara bilineata* adults have been shown to consume approximately ten *D. radicum* eggs or first-instar larvae each day in a laboratory experiment (Hertveldt *et al.*, 1984). Females of *A. bilineata* oviposit in the soil close to the plant roots. Royer and Boivin (1999) found *A. bilineata* to have host discrimination that is based on chemical cues rather than the presence of visual or tactile cues such as maggot entrance holes.

1.3.1 Taxonomy

With over 32,000 described world species, the Staphylinidae is one of the largest families of beetles. Most staphylinid beetles have elongate, slender bodies that are tapered at each end. A distinguishing characteristic of most species of this family are short, truncate elytra which leave over half of the flexible abdomen exposed (Moore and Legner, 1979). The taxonomy of *Aleochara bilineata* is as follows:

Order Coleoptera

Family Staphylinidae

Subfamily Aleocharinae

Tribe Aleocharini

Genus *Aleochara*

Subgenus *Coprochara*

Species *bilineata*

1.3.2 Life Cycle

The adult *Aleochara bilineata* female lays her eggs in close proximity to a *Delia radicum* puparium. On emergence, the first instar larva searches for the host. It chews an entrance hole that is typically on the dorsal surface of the puparium on the caudal end, a process lasting 12 to 36 h (Royer *et al.*, 1998). Once the entrance is complete, the parasitoid overwinters as a first instar larva (Figure 1.2). After spending three larval instars as an ectoparasitoid, the beetle larva pupates within the fly puparium, then re-

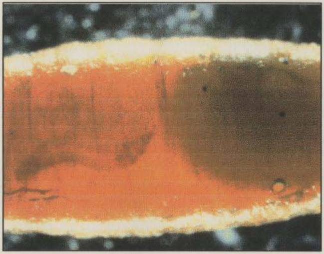


Figure 1.2: Parasitized *Delia radicum* pupa (note *Aleochara bilineata* larva on inside left, and *A. bilineata* entry hole on bottom right) (magnification = 35x).

Photo courtesy of Dr. Guy Boivin, Horticulture Research and Development Centre, St. Jean-sur-Richelieu, PQ.

enters the soil as an adult beetle. Turnock *et al.* (1995) recorded 74% parasitism of the puparia of *D. radicum* by *A. bilineata* in Agriculture and Agri-Food Canada Research Centre plots at St. John's, Newfoundland in 1989.

Although *A. bilineata* has been found to be a good candidate for biological control of *D. radicum*, the beetles emerge after first generation damage occurs and thus can only control further generations of the pest. As the focus of this research was on second generation root maggot damage on rutabaga, the intent was to determine the effectiveness of controlling this damage by *A. bilineata*.

1.4 Predators

Predatory beetles of the families Carabidae and Staphylinidae can aid in reduction of pest infestations. Predators are opportunistic feeders and feed on the resources available to them. Several species of carabid beetles are known to consume eggs of *Delia radicum*. Early research concluded that carabid and staphylinid beetles consumed approximately 95% of the eggs and early larval instars of *D. radicum*. However, recent studies indicate that this result was affected by other factors such as pesticide levels in the soil. Finch and Skinner (1988) found that *Aleochara bilineata* consume approximately 30% of the eggs laid around plants in the field; in laboratory experiments, it was found that the adults consumed approximately ten fly eggs or first instar larvae each day.

1.5 Undersowing

The planting of two or more crop species in the same field is known as undersowing or intercropping. The main principle behind undersowing is that increasing diversity in the agro-ecosystem provides a more stable cropping system and generally supports lower populations of pests (Theunissen *et al.*, 1992). Increased vegetation diversity in an undersown field may alter the interaction between the crop, pests and beneficial insects within the system.

Undersowing has been used in IPM systems in various crops including carrots (Rämert, 1996), cabbage (Theunissen and Schelling, 1992; Finch and Edmonds, 1994; Langer, 1996; Lotz *et al.*, 1997), and other brassicas (Dempster and Coaker, 1974; O'Donnell and Coaker, 1975; Theunissen and den Ouden, 1980; Finch and Kienegger, 1997). In brassica crops, a cover of 60% is necessary to reduce *Delia radicum* occurrence in an undersown field (O'Donnell and Coaker, 1975). Furthermore, the undersown crop must be present at periods of critical *D. radicum* activity and be actively growing or it will not reduce pest insect infestations (Finch and Kienegger, 1997).

Many authors have found that undersowing causes a reduction in *D. radicum* oviposition (Tukahirwa and Coaker, 1982; Langer, 1992; Theunissen and Schelling, 1992; Finch and Edmonds, 1994; Kostal and Finch, 1994), probably due to a decrease in host finding ability.

The currently most widely accepted theory, termed "appropriate/inappropriate landings" (Kostal and Finch, 1994), provides an explanation of the behavior of *Delia* *radicum* in undersown situations. Firstly, crucifers emit secondary plant chemicals with a characteristic odor and flavor that identify them to insect species (McKinlay, 1994). These secondary plant chemicals attract the females, who are in flight, to the general area of the host plant. When the female fly is in close proximity to the plants, she uses visual stimuli to actually find the host. She is attracted to the green colour of the plant and will be stimulated to land on only these "appropriate" objects (Finch, 1996). Since the undersown crop is also green, the female may land on the "inappropriate" object (undersown crop). The observed landing behavior of the fly is to carry out a spiral flight above the host plant after she has landed on a brassica plant and then land again on the plant to oviposit. However, when the female lands on a plant other than the host, for example clover, it is uncommon for the female to then attempt to land on the host plants nearby. Rather, she often leaves the area to search for a suitable oviposition host in another area. In a bare soil situation, females perform the spiral flight but if they land on the soil they then make short hops to seek out host plants.

Since the female is searching for an appropriate oviposition site, when she lands on clover the stimuli are not sufficient for her to remain in the area and seek out the host plant. This in turn should result in fewer female flies and fewer eggs in the clover plots as the female will not expend her resources searching the area for a suitable oviposition site. Kostal and Finch (1994) found that female flies landed on brassicas grown in bare soil four times as often as those grown in various undersown situations and that background has a significant effect on host-plant selection and oviposition of the female.

Studies indicate visual stimuli have a greater effect than chemical or mechanical barriers on the deterrence of egg laying by *Delia radicum* in undersown brassica plants. The flies laid eggs on the brassica plants as opposed to the undersown crop whereas with no undersowing, the flies laid similar numbers of eggs alongside all brassica plants irrespective of plant background or plant size (Kostal and Finch, 1994).

Undersowing studies in Europe have concentrated solely on cabbage and management of first generation *Delia radicum*. In this case, clover must be planted six to eight weeks before the brassica crop to ensure sufficient ground cover, and this inevitably causes problems with reduced yield due to competition.

1.6 Objectives

The objective of this study was to investigate the use of undersowing and naturally occurring predators and parasitoids as possible biological control options for second generation *Delia radicum* in rutabaga. While several studies exist on these separate topics, it was considered important to develop an experimental design to test the possibility of using these control approaches for Newfoundland conditions. While there has been significant work on undersowing other crops such as cabbage (eg. Finch *et al*, 1999; Finch and Edmonds, 1994; Langer, 1992; Langer, 1996; Lotz *et al*., 1997), there has been very little work on undersowing rutabagas and none on undersowing rutabaga for second generation cabbage root maggot management. The second generation was chosen for study as it is the most damaging to crops of rutabaga, and therefore of greatest concern to commercial growers.

It was thought that clover could be sown at the same time as rutabagas were transplanted, reducing competition, and that any yield reduction which did occur might be beneficial as small to medium size rutabaga are more marketable than large ones. This research will help to determine if undersowing can be used in a commercial setting for growers and whether it might ultimately reduce pesticide reliance by providing alternative pest control measures.

2.0 Materials and Methods

2.1 Study Area

Field studies were conducted in the summers of 1997 and 1998 at the Atlantic Cool Climate Crop Research Centre, Agriculture and Agri-Food Canada, Brookfield Road, St. John's, Newfoundland (47° 51' N 52° 78' W). The soil was a loam with low organic matter content. The presence of weeds would have been undesirable as they might have affected the experiment. Thus, weeds were removed on a regular basis as required using a rotovator between plots and on plot edges but within plots weeding was by hand. Care was taken, particularly in the undersown plots, not to remove clover with the weeds, and to disturb the clover as little as possible. When necessary, irrigation was applied. Other crops planted in the area in 1997 and 1998 included potatoes (*Solanum tuberosum* L.), cabbage (*Brassica oleracea* L.), rutabaga and forage. Previous to 1997, the site had been sown to carrots (*Daucus carota* L.) (1996), potatoes, rutabaga and cabbage (1995) and potatoes (1994). No herbicides, fungicides or insecticides were used in the field experiments.

2.2 Experimental Design

2.2.1 General

A randomized block experimental design with four blocks was used. A block consisted of one plot of rutabaga not undersown and one plot of rutabaga undersown with white clover (*Trifolium repens* L. cv. Sonja) (Figure 2.1). In 1997, each plot was 4.5

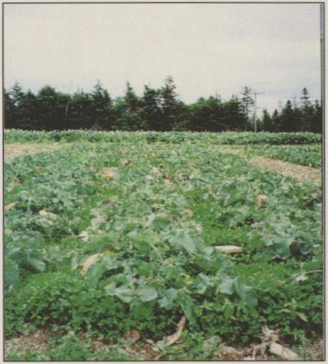


Figure 2.1: Field site at Agriculture and Agri-Food Canada Research Centre showing rutabaga plots undersown with clover.

metres by 6.0 metres and consisted of five rows of rutabagas with 20 rutabagas per row for a total of 100 plants per plot. In 1998, each plot was 6.0 metres by 10.0 metres and consisted of 11 rows with 35 plants in each row for a total of 385 plants per plot. In all plots in both years, rows were 0.75 meters apart and plants within rows were 0.15 metres apart. Before planting in each year the plots were fertilized with 8-16-8 (N-P-K plus Boron) at a rate of 1.5 kg/10 m^2. The site used in 1997 was adjacent to the 1998 site. The same plots could not be used in both years due to the possibility of overwintering cabbage root maggot emerging under the row covers.

2.2.2 Rutabaga Transplants

Rutabaga, cultivar Laurentian (Vesey's Seeds, PEI), was seeded in size 48 plastic flats (K1020 flat and K806 insert) on April 25, 1997, and April 18, 1998, in commercial Promix®. Seedlings were thinned after germination to one plant per cell. The flats were placed in an environment-controlled greenhouse where they remained until seedlings reached the true-leaf stage. A small amount (unmeasured) of fertilizer (20-20-20 (N-P-K)) mixed in water, was applied to each plant at a rate of 75g/100L every third day. When plants were six weeks old, they were "hardened off" by placing the flats outside during the day for one week after which they were kept outside during both night and day. The flats were placed outside under a fabric row cover (Reemay®) to prevent infestation by first generation flies. Once hardened off, the plants were ready for transplanting in the field.

Rutabaga were transplanted on June 19, 1997 and June 15 and 16, 1998. Reemay® row covers were placed over the plots immediately after planting was completed (Figure 2.2). The row covers remained on the plots for approximately four weeks or until the majority of first generation cabbage root maggot flies had emerged. This was determined by predicting first and second generation *D. radicum* fly emergence using the degree day model modified for Newfoundland (Coady and Dixon, 1997) and collecting adults in yellow pan traps. Row covers were used in this experiment to exclude first generation cabbage root maggot as the research was focused on damage by second generation cabbage root maggot feeding.

All plots were planted the same day in 1997. In 1998, this was not possible due to the increased number of plants. In that year, bare plots were planted one day and clover plots were planted the next day. Plots were planted one at a time and were immediately covered with Reemay®. Bare plots were planted and covered first before undersowing plots were started. This was to ensure clover was seeded in the clover plots only. Rutabaga were transplanted first and then clover was sown. Clover seeds were inoculated with the appropriate strain of *Rhizobium* bacteria prior to sowing to ensure N-fixation. Using a hand-held Even Spreader (EV-N-SPRED®, Model No. 2700A), the clover was sown at a rate of 7.5 kg/ha. Once seeded, the plot was immediately covered with Reemay® to exclude cabbage root maggot adults.

Figure 2.2: Plots at the Agriculture and Agri-Food Canada Research Centre showing row covers to exclude first generation cabbage root maggot damage.

2.3 *Delia radicum* Adults

Flies were collected using yellow pan traps. Metal cake pans of 22.5 cm diameter were hand painted with yellow paint ("Tremclad" yellow rust paint). This color was used because it is attractive to root flies (Finch and Skinner, 1974). One pan trap was placed in each plot, positioned on the soil surface. The location of each pan trap in each plot was randomly selected using Minitab (1994). Each rutabaga in each plot was assigned a number (guard rows and edge plants were excluded), and the pan trap placed in the rutabaga row nearest the plant chosen by the Minitab program. Pans in bare plots were placed on bare soil and those in undersown plots were placed in clover. The traps were filled with soapy water (five milliliters of Sunlight liquid dish detergent per two litres of water) to reduce the surface tension, which resulted in the drowning of flies entering the pans.

Two times per week, the pans were cleaned and refilled with soapy water. The flies were removed from the traps, placed in sampling jars and returned to the laboratory where they were placed in ethyl acetate for at least two hours to stiffen the wings. This treatment was necessary as wing venation is a critical characteristic in identification. After removal from the ethyl acetate, samples were dried, pinned, labeled, identified and separated by sex using a binocular microscope and the keys of Brooks (1951) and Griffiths (1991). Small numbers of flies of two other *Delia* species (*D. florilega* (Zetterstedt) and *D. platura* (Meigen)) were present in the pan traps but these were not considered in the analysis as they are saprophages and not primary pests of rutabaga. Sampling took place between August 1 and October 10, 1997 and July 14 and October 26, 1998.

2.4 Ovipositional Preference of *Delia radicum*

In both 1997 and 1998, nine plants per plot for a total of 72 plants for the experiment were monitored for number of eggs laid by female *D. radicum*. All plants used in monitoring were randomly selected from the rows that were not used as guard rows. The rows on each end and the first two plants in each row were considered guards and to avoid an edge effect, were not used for monitoring. In 1997, monitoring was conducted on nine plants per plot, three from each of the inner three rows. In 1998, the nine plants used for monitoring were selected randomly, one from each of the nine inner rows. The same plants were used for monitoring during the entire experiment.

Delia radicum oviposition was monitored using the following methods: two times each week, the 72 plants were examined in situ for cabbage root maggot eggs. The stem and upper root of each rutabaga was examined as well as the surrounding soil, and eggs destroyed as they were counted. By carefully pulling away the soil around the base of the plant, the small white eggs were easily visible to the naked eye. Soil was disturbed as little as possible and returned when the eggs were retrieved to ensure minimal disruption to the clover, the rutabagas and the surrounding soil. Sampling began on August 1 in 1997 and on July 14 in 1998 and continued until September 19 and

September 25 in 1997 and 1998 respectively.

The assumption was made that all eggs were *D. radicum* even though small numbers of *D. platura* and *D. florilega* were often present in the study area. Other species of root maggots which oviposit on rutabaga, for example *Delia floralis* (Fall.) and *Delia planipalpis* (Stein) are not known to occur on the island of Newfoundland, although *D. floralis* has been collected in Labrador (Griffiths, 1991).

2.5 Pitfall Traps

Pitfall traps were used to determine Coleoptera activity in the plots. Two pitfall traps were placed in each plot with positions chosen randomly using a Minitab (1994) program in a manner similar to that used for the yellow pan traps (see section 2.3). The traps were constructed by placing a 500 mL clear plastic salad container (12 cm diameter x 7 cm high) within a 13 cm diameter plastic flower pot. The traps were placed in holes in the soil so that the top was at ground level. Two hundred and fifty milliliters of propylene glycol was placed in each trap to kill and preserve specimens. The propylene glycol was replaced as needed (usually every three weeks). A wooden cover was placed approximately one inch over the top of the opening of each trap to shelter it from rain. Arthropods collected in these traps were removed once per week by sieving through a 1.0 millimetre mesh strainer. The propylene glycol was returned to the pitfall trap. The specimens were removed from the strainer, placed in dry containers immediately and brought back to the laboratory. Beetles in the families Carabidae and Staphylinidae were retained in vials of 70% ethanol until they were pinned; others were discarded. All carabids were identified to species using Lindroth (1974) and Forsythe (1987). The collected staphylinids were sorted, and *Aleochara bilineata* identified using the key of Klimaszewski (1984) and other species recorded as "other Staphylinidae". Sampling took place between August 1 and November 26, 1997 and July 17 and October 30, 1998.

2.6 Rutabaga Sampling

Rutabaga were sampled for two purposes: 1 – cabbage root maggot pupae were extracted from the soil around the rutabagas for assessment of percent parasitism by *A. bilineata* and distribution; and 2 –to quantify damage to rutabaga by cabbage root maggot larvae.

2.6.1 *Aleochara bilineata* Distribution

Plots (10 metres by 10 metres) on 50 commercial farms were marked off using white wooden pegs in early spring 1997. Farmers planted rutabaga or cabbage but did not use pesticides on these plots. In November, 20 root balls and the surrounding soil were taken from each plot at the Research Centre and from the farms for extraction of cabbage root maggot pupae. Samples were collected by discarding the leaves from the rutabaga and harvesting the rest of the plant. Each sample consisted of a plant and a volume of soil surrounding the roots to a radius of 7.5 centimeters and 7.5 centimeters deep. Each sample was placed in a separate bag and kept in a dark room at about 4°C until it could be examined in the laboratory.

In the laboratory, the plants were washed to remove puparia from the roots and the surrounding soil. The soil samples were wet sieved using a Canada Standard Sieve Series No.14 sieve (mesh size 1.4 mm), (W.S. Tyler Company), and running tap water to retrieve all the puparia. The number of cabbage root maggot puparia collected for each sample was recorded. Using a microscope, puparia were visually separated as either parasitized or non-parasitized. All puparia with a visible entrance hole or a visible *Aleochara bilineata* larva were classified as parasitized by *Aleochara bilineata*. Numbers of each were recorded and pupae placed in groups of up to 50 in plastic rearing containers (11.25 centimetres square) with moist vermiculite. They were held in a growth chamber (Conviron - Model #I25L) at 4°C for 21 weeks (Collier and Finch, 1985) to allow completion of diapause. The pupae were then removed from the containers and placed in individual vials. These vials were replaced in the growth chamber and the temperature increased to 20°C. The number of emerging flies, *Aleochara bilineata* adults and degree days (DD) were recorded daily. Percent parasitism by *Aleochara bilineata* of pupae extracted at the Research Centre and from the commercial farms, was calculated.

2.6.2 Damage Assessment

Damage was assessed using a damage rating scale (King and Forbes, 1954) and rutabaga weights. A sample of 20 randomly-chosen rutabagas was harvested from each plot, for a total of 160 rutabagas. The same number of plants was used each year for consistency even though plots were larger in 1998. For the damage rating, each bulb was washed, visually inspected and assigned a damage rating that ranged from 0 to 4. Rating the rutabaga involved visually dividing the bulb into four equal longitudinal sections. Those rated 0 had no damage and would be marketable. A rating of 1 meant that the bulb had sustained damage on up to ¼ of its surface and was mildly damaged. These could be used as a marketable rutabaga and the minor damage trimmed. For a rating of 2, damage had to be on ¼- ½ of the plant that was deemed moderately infested. A rank of 4 meant that the rutabaga was severely damaged and was not marketable. The ranking scale does not include the number 3.

The washed rutabagas were weighed to determine the "harvest weight". Damaged portions were then removed using a knife and each rutabaga re-weighed to determine the "trimmed weight".

2.7 Data Analysis

A significance level of $p \leq 0.05$ was used for all analyses. The analyses were conducted using SAS/STAT (SAS Institute Inc., 1989) and Minitab (Minitab Inc, 1994) statistical programs. Analysis of variance (ANOVA) was used to determine differences in the amount of activity and damage by *Delia radicum* between the two treatments (Sokal and Rohlf, 1995). ANOVA was also used to evaluate differences in yield in bare plots versus plots undersown with clover, and differences in the activity of *A. bilineata* and other potential predators between treatments. In situations where high intraplot variance of the count data occurred, Wilcoxon's signed-ranks test was used to determine significance of the distribution of the variates (Sokal and Rohlf, 1995). This non-parametric test is a distribution free analysis where treatment ranks are compared rather than actual data (Sokal and Rohlf, 1995).

The intervals between sampling dates varied for egg counts, adult *Delia radicum* in pan traps and beetles in pitfall traps. Thus, all data were standardized by dividing the mean number per count or trap by the monitoring interval. However, where adult fly data are separated by sex, the data are not divided by the number of days in the sampling interval but reflect captures in pans on the sampling day. Means are presented with standard errors (SEM) (Sokal and Rohlf, 1995).

3.0 Results

Nineteen ninety-seven and nineteen ninety-eight were very different in terms of insect activity, probably due to the weather conditions. Nineteen ninety-eight was a much warmer year and the second generation of *D. radicum*, and thus sampling, began earlier than in 1997. The required DD for peak emergence of second generation *D. radicum* is 780-800 at a base of 4.4°C (Coady and Dixon, 1997). These accumulated DD were reached on August 11 in 1997 and August 1 in 1998. While there were more monitoring dates in 1998, the results were more variable and very low numbers of flies, eggs and beetles were collected. In both years the cabbage root maggot was the main insect pest present; very few lepidopteran pests (cabbage white butterfly, diamondback moth, purplebacked cabbageworm) or brassica-feeding aphid species were observed.

3.1 *Delia radicum* Adults

Unless stated otherwise, all data are for males and females combined.

1997

The first fly captures in pan traps occurred on the first day of monitoring, August 1, and the last flies were trapped on September 26 (Figure 3.1). It is possible that the start of the second generation was missed although trapping began as soon as row covers were removed. A total of 1056 flies were captured. Of these, 435 were trapped from the bare plots with a daily mean of 1.8 (range 0 – 6.9). A total of 621 flies were collected from the clover plots, with a daily mean of 2.5 (range 0 – 7.2). Overall, peak fly capture

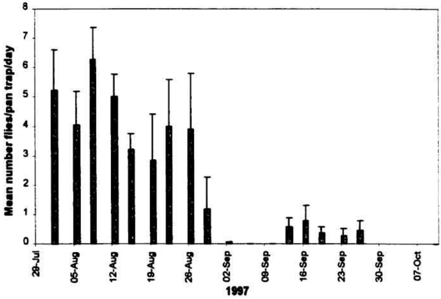


Figure 3.1: Mean number and Standard Error of Mean (SEM) of *Delia radicum* flies per pan trap per day in 1997 (n = 8; rutabaga undersown and bare combined).

occurred on August 8 when the mean number of flies per day was 6.9 $\pm$ 2.0 for the bare and 5.7 $\pm$ 0.9 for the clover (Table 3.1 and Figure 3.2). The highest number of flies caught in the clover plots was on August 1 and in the bare plots the highest number was trapped on August 8. There was generally a higher mean fly capture in the clover plots from the start of trapping until September 2 (Figure 3.2) but late in the season, September 13-26, flies were captured only in the bare plots. However, using a parametric test (ANOVA), which assumes homogeneity of variance, there were significant differences between the treatment means on just two dates: September 16 and 19. Using distribution-free statistics not affected by differential variance, (Wilcoxon's signed-ranks test) there were significantly more flies captured in the clover versus the bare plots in nine of the fifteen monitoring dates (or 60%). The reasons for the few captures between August 29 and September 10 are unclear. There was no apparent relationship between temperature or precipitation, and low numbers of flies (unpublished data).

Non-parametric tests showed that undersowing had a significant but different, effect on both females and males. There were more females collected in the bare plots on 9 of the 14 monitoring dates (significant on 12 August and 13 September) when flies were present (Figure 3.3) and more males were collected in the clover plots on 9 of the 11 monitoring dates when flies were present (Figure 3.4).

Table 3.1: Mean number and SEM of *Delia radicum* flies per pan trap per day (x 10) in clover or bare plots, 1997. (* = significantly different at $p \leq 0.05$)

Date (1997)	Mean # *D. radicum*/trap/day (x10)	
	Bare	**Clover**
August 1	32.5 ± 6.0	71.7 ± 25.0
August 5	24.4 ± 4.3	56.3 ± 21.0
August 8	69.2 ± 20.2	56.7 ± 9.0
August 12	48.8 ± 9.7	51.3 ± 12.9
August 15	21.7 ± 5.7	42.5 ± 5.5
August 19	18.1 ± 15.0	38.8 ± 28.8
August 22	28.3 ± 13.9	51.7 ± 29.4
August 26	23.1 ± 8.2	55.0 ± 37.7
August 29	1.7 ± 1.0	21.7 ± 21.7
September 2	0	0.6 ± 0.6
September 6	0	0
September 10	0	0
September 13	11.7 ± 4.0*	0
September 16	15.8 ± 8.5	0
September 19	7.5 ± 2.8*	0
September 23	5.6 ± 4.1	0
September 26	9.2 ± 6.0	0
October 10	0	0

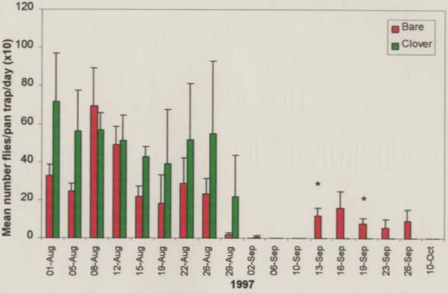


Figure 3.2: Mean number and SEM of *Delia radicum* flies per pan trap per day in clover or bare plots, 1997. (* = significantly different at $p \leq 0.05$), ($n = 4$).

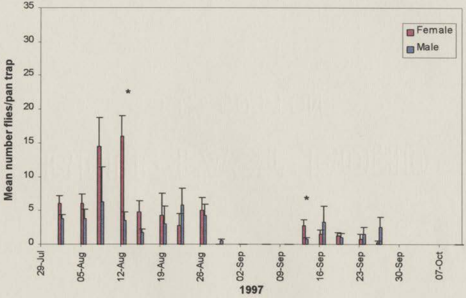


Figure 3.3: Mean number of male and female adult *Delia radicum* per pan trap in rutabaga not undersown with clover (bare plots), 1997. (* = significantly different at $p \leq 0.05$), ($n = 4$).

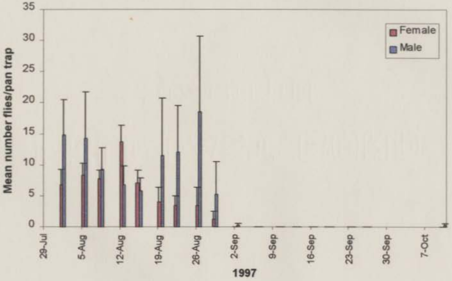


Figure 3.4: Mean number of male and female adult *Delia radicum* per pan trap in rutabaga undersown with clover, 1997, (n = 4).

1998

Flies were collected from the pan traps beginning on July 14 and the last *D. radicum* were trapped on October 12 (Table 3.2 and Figure 3.5). The data were variable and the numbers captured were small (total flies captured = 235) Of these, 84 were in the bare plots and 151 in the clover plots. Data were not separated by sex as so few flies were trapped. Flies were captured only in the clover plots on August 25 and September 1, 4 and 8, and flies were captured only in the bare plots on October 9 and 13. The mean number of flies per plot was significantly higher (Wilcoxon's signed-ranks test) for the clover plots on 18 of the 22 monitoring dates (or 82%) when flies were present.

1997 versus 1998

Analysis of variance showed that there were significantly more flies captured in 1997 than 1998 with 1056 and 195 respectively, a ratio of 5.4:1 between the two years. It is interesting to note that the peak number of flies for 1997 was 122 whereas for 1998 the peak was 12. In both years, there were a high proportion of sampling dates with more flies in the clover (1997 - 9/15 and 1998 - 18/22).

3.2 Ovipositional Pattern of *Delia radicum*

1997

Plants were checked for eggs beginning on August 1, 1997. Eggs were not identified using a microscope due to time constraints and it is possible that a small

Table 3.2: Mean number and SEM of *Delia radicum* flies per pan trap per day (x 100) in clover or bare plots, 1998.

Date (1998)	Mean # *D. radicum*/trap/day (x100)	
	Bare	**Clover**
July 14	41.7 ± 25.0	208.3 ± 31.5
July 17	58.3 ± 28.5	41.7 ± 31.5
July 21	6.3 ± 6.3	31.3 ± 6.3
July 24	16.7 ± 9.6	25.0 ± 8.3
July 28	0	0
July 31	8.3 ± 8.3	100.0 ± 28.9
August 4	37.5 ± 12.5	93.8 ± 48.3
August 7	41.7 ± 25.0	83.3 ± 61.6
August 10	33.3 ± 13.6	108.3 ± 16.0
August 13	66.7 ± 36.0	125.0 ± 9.6
August 17	18.8 ± 18.8	25.0 ± 0
August 20	16.7 ± 9.6	41.7 ± 16.0
August 25	0	70.0 ± 28.7
August 28	8.3 ± 8.3	8.3 ± 8.3
September 1	0	43.8 ± 29.5
September 4	0	41.7 ± 21.0
September 8	0	50.0 ± 25.0
September 11	41.7 ± 31.6	125.0 ± 16.0
September 18	3.6 ± 3.6	14.3 ± 14.3
September 22	12.5 ± 12.5	43.8 ± 21.3
September 25	0	0
September 29	31.3 ± 31.3	18.8 ± 18.8
October 2	16.7 ± 16.7	41.7 ± 16.7
October 6	6.3 ± 6.3	12.5 ± 7.2
October 9	33.3 ± 33.3	0
October 13	8.3 ± 8.3	0
October 16	0	0
October 20	0	0

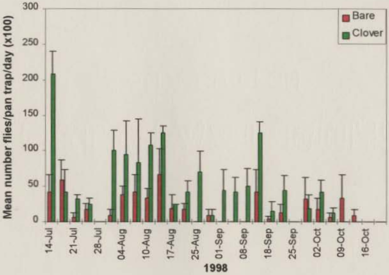


Figure 3.5: Mean number and SEM of *Delia radicum* flies per pan trap per day in rutabaga undersown with clover or bare, 1998, (n = 4).

proportion may have been deposited by other species of *Delia*. No eggs were observed on August 1st or 5th (Table 3.3 and Figure 3.6). The first eggs were observed during the second week of monitoring on August 8, one week after the first flies were trapped. The last date on which eggs were observed was September 19. There were more eggs in the bare plots than the clover plots on ten of the thirteen days when eggs were present (77% of the monitoring days). Peak oviposition occurred on August 19 with a mean number of eggs per plant of 2.24 ± 0.49 on the bare plots and 1.37 ± 0.28 for the clover.

Analysis of variance showed there were significantly more eggs in the bare plots on August 8, August 29, September 2 and September 6 (Figure 3.6). Wilcoxon's signed-ranks test showed there were significantly more eggs in the bare plots on 10 of the 13 dates.

The overall mean number of eggs per plant per date was 0.67 for the bare plots (range 0 – 2.24) and 0.38 for the clover plots (range 0 – 1.37). The cumulative mean egg count per plant for 1997 was 998 for the bare plots and 573 for the clover plots (Figure 3.7).

1998

Sampling started on July 14 in 1998. Females began egg laying on July 31, approximately one week earlier than in 1997 (Table 3.4 and Figure 3.8). The first occurrence of eggs was fifteen days after first collection of adults. More eggs were collected from the bare plots for four of the seven sampling dates when eggs were present

Table 3.3: Mean number and SEM of *Delia radicum* eggs per plant per day (x 100) in clover or bare plots, 1997. (* = significantly different at $p \leq 0.05$)

Date (1997)	Mean # Eggs/Plant/Day (x100)	
	Bare	**Clover**
August 1	0	0
August 5	0	0
August 8	49.1 $\pm$ 21.0*	0
August 12	63.2 $\pm$ 17.0	34.0 $\pm$ 11.0
August 15	40.7 $\pm$ 17.0	62.0 $\pm$ 17.6
August 19	224.3 $\pm$ 49.0	136.8 $\pm$ 17.7
August 22	136.1 $\pm$ 39.0	50.9 $\pm$ 25.6
August 26	172.9 $\pm$ 33.0	129.9 $\pm$ 32.5
August 29	171.3 $\pm$ 38.0*	83.3 $\pm$ 20.3
September 2	100.0 $\pm$ 18.0*	54.2 $\pm$ 16.5
September 6	14.6 $\pm$ 6.0*	2.8 $\pm$ 2.2
September 10	1.4 $\pm$ 1.0	6.9 $\pm$ 5.0
September 13	11.1 $\pm$ 7.0	4.6 $\pm$ 3.0
September 16	7.4 $\pm$ 4.0	7.4 $\pm$ 4.6
September 19	5.6 $\pm$ 3.0	0

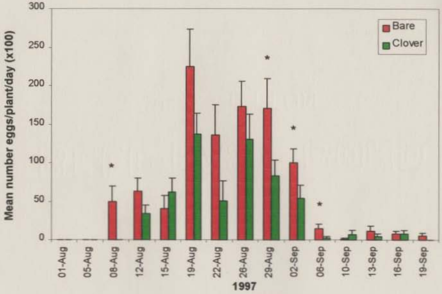


Figure 3.6: Mean number and SEM of *Delia radicum* eggs per plant per day on rutabaga undersown with clover or bare in 1997. (* = significantly different at $p \leq 0.05$), ($n = 36$).

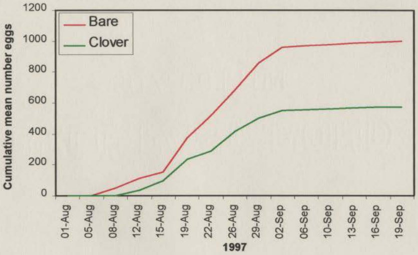


Figure 3.7: Cumulative mean number of eggs 1997.

Table 3.4: Mean number and SEM of *Delia radicum* eggs per plant per day (x 100) in clover or bare plots, 1998.

Date (1998)	Mean # Eggs/Plant/Day (x100) Bare	Clover
July 14	0	0
July 17	0	0
July 21	0	0
July 24	0	0
July 28	0	0
July 31	10.2 ± 6.3	0
August 4	0	0
August 7	5.6 ± 4.7	3.7 ± 3.7
August 10	1.9 ± 1.9	2.8 ± 2.8
August 13	0	0
August 17	0	0
August 20	4.9 ± 3.6	0.9 ± 0.9
August 25	3.3 ± 2.0	4.4 ± 3.2
August 28	6.5 ± 3.5	8.3 ± 5.4
September 1	0	0
September 4	0.9 ± 0.9	0
September 8	0	0
September 11	0	0
September 18	0	0
September 22	0	0
September 25	0	0

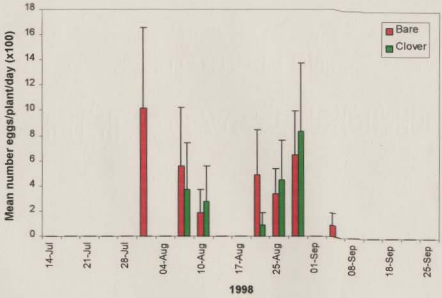


Figure 3.8: Mean number and SEM of *Delia radicum* eggs per plant per day on rutabaga undersown with clover or bare in 1998, (n = 36).

(57% of the monitoring days). Unlike 1997, there was no pattern between plots as the numbers of eggs were highly variable. Overall there were fewer eggs laid compared to 1997 with the highest mean number of eggs per plant on any monitoring date 0.10 ± 0.06 SEM for the bare plots and 0.08 ± 0.05 SEM for the clover plots.

In 1998, there was no significant difference between numbers of eggs in the bare and clover plots. The overall mean per plant per date was 0.02 for the bare plots (range 0 – 0.10) and 0.01 for the clover plots (range 0 – 0.08). Wilcoxon's signed-ranks test showed a significant difference over the season between the bare and clover plots, with more eggs in the bare on four of the seven dates when eggs were collected.

The cumulative mean egg count per plant for 1998 was 33.19 for the bare plots and 20.19 for the clover plots (Figure 3.9).

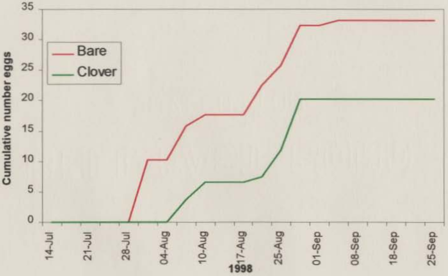


Figure 3.9: Cumulative mean number of eggs 1998.

3.3 Pitfall Trap Catches

3.3.1 Staphylinidae

1997

The majority of the staphylinids captured were *Aleochara bilineata* (Figure 3.10). The majority of *A. bilineata* were captured in the bare plots (5 out of 6 monitoring days) with the first capture occurring on the first monitoring day – August 1 (Figure 3.11). There were significantly more *A. bilineata* captured in the bare plots on August 15, 29, September 6, and 13.

The majority of the "other Staphylinidae" were also captured in the bare plots.

1998

As with 1997, the majority of the staphylinids captured in 1998 were *Aleochara bilineata* (Figure 3.12) with more being retrieved from the bare plots (7 out of 9 monitoring days) (Figure 3.13). The majority of the "other Staphylinidae", were again captured in the bare plots but only by a slight margin. Again the *A. bilineata* were active when monitoring began on July 17 (Figure 3.13). There were significantly more *A. bilineata* captured in the bare plots on September 4 and September 25.

Although the total number of *A. bilineata* recovered were similar in both years, few "other Staphylinidae" were trapped in 1998 compared to 1997 (Figures 3.10 and 3.12).

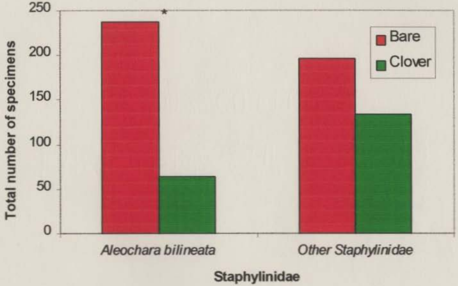


Figure 3.10: Total numbers of *Aleochara bilineata* and "other Staphylinidae" from pitfall traps in rutabaga undersown with clover or bare between August 8 and November 26, 1997. (* = significantly different at $p \leq 0.05$).

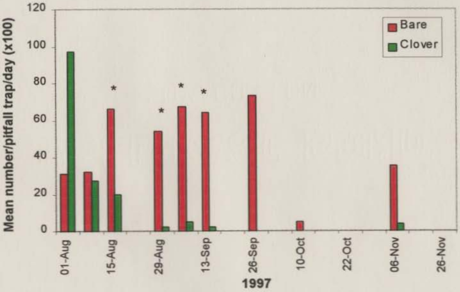


Figure 3.11: Mean numbers of *Aleochara bilineata* per pitfall trap per day in rutabaga undersown with clover or bare, 1997. (* = significantly different at $p \leq 0.05$), ($n = 8$).

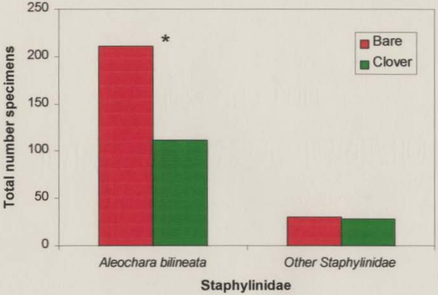


Figure 3.12: Total numbers of *Aleochara bilineata* and "other Staphylinidae" from pitfall traps in rutabaga undersown with clover or bare between July 17 and October 30, 1998. (* = significantly different at $p \leq 0.05$).

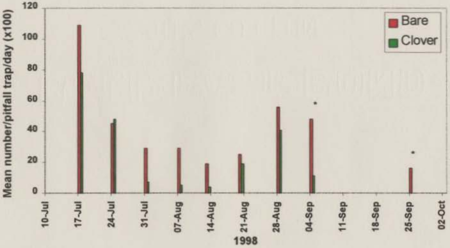


Figure 3.13: Mean numbers of *Aleochara bilineata* per pitfall trap per day in rutabaga undersown with clover or bare captured between July 17 and October 30, 1998. (* = significantly different at $p \leq 0.05$), ($n = 8$).

3.3.2 Carabidae

1997

There were 15 carabid species captured during the monitoring period. The total number of specimens captured over the entire monitoring period was higher in the bare plots for most species (bare 8/15; clover 5/15; bare = clover 2/15). The most abundant carabids were *Bembidion lampros* Herbst. and *Pterostichus melanarius* Illiger. *Bembidion lampros* captures were significantly more abundant in traps in the bare plots; of a total of 199 individuals captured, 124 were from the bare rutabaga. *Pterostichus melanarius*, however, was significantly more abundant in traps in the clover plots (125 of 191 individuals captured, Figure 3.14).

Only four of the 15 carabid species captured had a total specimen count of more than 100 per season (Figure 3.15). These four from most to the least abundant, were *Bembidion lampros*, *Pterostichus melanarius*, *Amara bifrons* Gyll. and *Clivina fossor* L. Five *Amara* species were captured other than *A. bifrons*, but these were infrequent. The captures of *A. bifrons* were significantly higher in the bare plots.

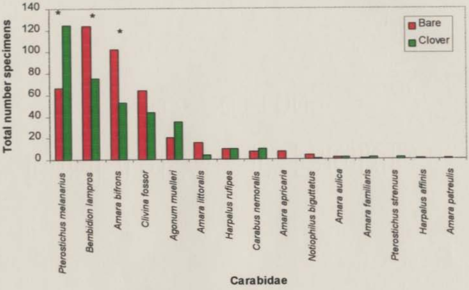
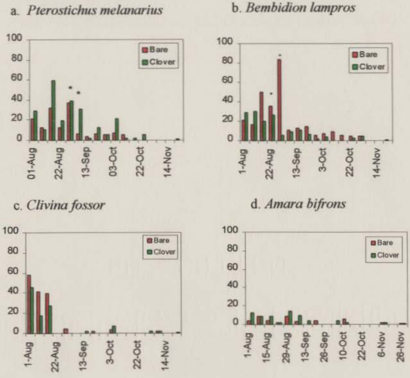


Figure 3.14: Total numbers of various species of Carabidae collected in rutabaga undersown with clover or bare between August 8 and November 26, 1997. (* = significantly different at $p \leq 0.05$)



1997

Figure 3.15: Mean number individuals per pitfall trap in rutabaga undersown with clover or bare (a=*Pterostichus melanarius*; b=*Bembidion lampros*; c=*Clivina fossor*; d=*Amara bifrons*), 1997. (* = significantly different at $p \leq 0.05$).

1998

Ten carabid species were captured in 1998, all of which were also present in 1997 (Figure 3.16). Overall, more species were captured in the bare plots (9) than the clover plots (8). *Pterostichus melanarius* was the most abundant carabid with the majority (463/791; 59%) caught in the clover plots (Figure 3.17). It was also the only species with more than 100 specimens in 1998 (Figure 3.16). The total number of *P. melanarius* captured was much higher in 1998 than in 1997 (790 vs. 190).

The next most-frequently captured carabid was *Agonum muelleri* Herbst. with a total of 75 individuals (Figure 3.16). The only genus with more than one species was *Amara* with three species including the third most frequently trapped carabid, *A. bifrons*.

3. 4 *Aleochara bilineata* Parasitism and Degree Day Study - 1997

Delia radicum pupae were collected in the fall from the eight plots at the Research Centre. An average of 144 pupae per plot from the bare treatment and 153 pupae per plot from the undersown were reared through diapause (Table 3.5). Almost half the pupae in each treatment were dead and a small number were parasitized by hymenoptera. *Delia radicum* emerged from 18% of the pupae from bare plots and 58% of the pupae from undersown plots. *Aleochara bilineata* emerged from 37% of the pupae from bare plots compared to 9% from undersown plots. Degree-days for *Aleochara bilineata* emergence were calculated using 4.4°C, the developmental threshold for *Delia radicum,* as the base threshold temperature for *A. bilineata* has not been determined.

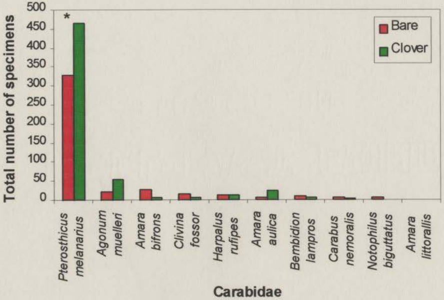


Figure 3.16: Total numbers of various species of Carabidae collected in rutabaga undersown with clover or bare between July 17 and October 30, 1998 (* = significantly different at $p \leq 0.05$).

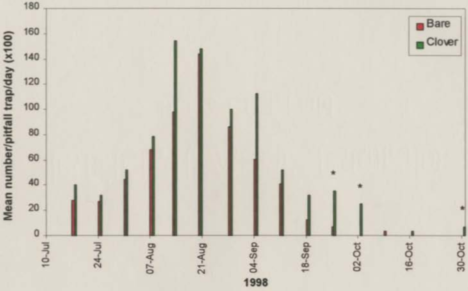


Figure 3.17: Mean number of *Pterostichus melanarius* per pitfall trap in rutabaga undersown with clover or bare, 1998. (* = significantly different at $p \leq 0.05$), ($n = 8$).

Table 3.5: Percent *Delia radicum* and *Aleochara bilineata* emergence from *D. radicum* pupae collected in 1997 and reared in the incubator study.

Treatment	**N Pupae Reared/Plot**	**% *Delia radicum***	**% *Aleochara bilineata***	**% Other†**
Bare	144 ± 8	18 ± 3	37 ± 6	46 ± 7
Clover	153 ± 5	58 ± 5	9 ± 3	44 ± 5

† = Other includes dead *D. radicum* pupae and those parasitized by Hymenoptera

In the incubator study, emergence of overwintered *Aleochara bilineata* began at 374 DD and ceased at 530 DD (Figure 3.18) (N = 254). Peak emergence was at 421 DD. Peak emergence of *Delia radicum* reared at the same time occurred at 172 DD (N = 401).

3.5 Distribution Across the Province

Of the 1715 *D. radicum* pupae collected in the fall of 1997 from across the island, *A. bilineata* was present in all areas sampled and appears to be distributed widely within Newfoundland and Labrador.

3.6 Damage assessment

1997

There was no significant difference between undersown and bare rutabaga (Table 3.6) in damage as scored by King and Forbes scale (1954). According to the rating scale, no marketable rutabagas were harvested, however, there was a significant difference between the bare and undersown plots in terms of harvest yield, marketable yield and trimming loss.

Rutabaga from bare plots were significantly heavier than those from undersown plots with an average pre-trimmed weight per rutabaga of 714 $\pm$ 32 g (bare) and 624 $\pm$ 34 g (clover), P=0.0179 (Table 3.6). The marketable yield in the bare plot was significantly higher (652 $\pm$ 31) than the clover (535 $\pm$ 36) (P=0.0487). A significantly smaller

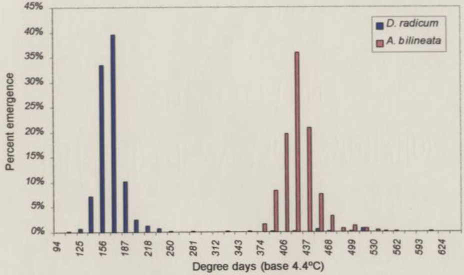


Figure 3.18: Degree days required for *Delia radicum* and *Aleochara bilineata* post-diapause emergence, calculated using a base threshold of 4.4°C.

Table 3.6: Damage assessments for rutabaga collected in 1997 and 1998 from bare plots or plots undersown with clover. Note: the pre-trimmed yield is the weight after harvesting and washing, the marketable yield is the weight after damaged tissue is removed and the difference between the two gives the percent trimming loss.

Year	Treatment	N	Mean Pre-Trimmed Yield (g)	Mean Marketable Yield (g)	Mean Trimming Loss %	Mean Damage Rating† (0-4)
1997	Bare	160	714 $\pm$ 32*	652 $\pm$ 31*	8.6	2.91 $\pm$ 0.11
	Clover	160	624 $\pm$ 34	535 $\pm$ 36	14.3*	2.86 $\pm$ 0.11
1998	Bare	160	746 $\pm$ 31	730 $\pm$ 30	2.3	1.11 $\pm$ 0.13
	Clover	160	724 $\pm$ 33	709 $\pm$ 33	2.1	1.25 $\pm$ 0.12

* = Significantly higher at $p \leq 0.05$
† = The damage rating - King and Forbes scale (1954)

proportion of each rutabaga from the bare plots had to be trimmed to remove damage (8.6% compared to 14.3 % for the clover).

1998

The damage rating scale showed no significant differences between undersown and bare rutabaga (See Table 3.6). According to the rating scale, some of the rutabagas harvested were marketable. There were no significant differences with respect to the two treatments in terms of harvest yield, marketable yield or trimming loss.

Rutabaga from bare plots had an average pre-trimmed weight per rutabaga of 746 g, compared to 724 g in the clover plots (Table 3.6). The mean marketable yield in the bare plots was 730 g and 709 g in the clover plots. A smaller proportion of each rutabaga from the clover plots had to be trimmed to remove damage (2.1 % loss in the clover plots compared to 2.3 % loss in the bare plots).

4.0 Discussion

4.1 *Delia radicum* adults and oviposition

When sexes were combined there were more flies captured in the clover plots than the bare plots for both years, although the mean number of adults captured per pan trap per treatment was highly variable especially in 1998. Late in the season no flies were captured in the clover plots. Finch and Edmonds (1994) showed that second generation flies seemed to avoid clover plots. Perhaps the bare plots were more attractive to the *D. radicum* during the latter part of the season; it has been shown that the response of several *Delia* species to color varies depending on crop developmental stage and background color (Vernon and Broatch, 1996).

There were more flies in the clover in 1997 when populations were large, but this was due to a high proportion of males. The number of female flies was actually higher in traps in the bare plots. It seems essential that sexes be considered separately, as undersowing apparently affects each sex differently. The results support the "appropriate/inappropriate landings" theory of Kostal and Finch (1994), which focuses on the ability of female *D. radicum* to find oviposition sites. Since there were fewer females in the undersown plots, the clover does appear to have reduced their ability to find oviposition sites.

It is possible that the differences in fly captures between the two years may be at least partly due to population dilution in 1998. The ratio of flies captured was 5.4:1 in 1997 and 1998 but the ratio of plot areas was 1:3.9 because of the increase in plot size in

1998. This may have contributed to population dilution although the number of pan traps was the same in both years. Also, as the plots were covered with Reemay to exclude first generation root maggot, all flies in both years must have originated outside the plot area.

In 1997, females laid eggs around rutabaga growing in bare soil over most of the monitoring period. Since there were more eggs laid around rutabaga growing in bare soil, the findings indicate that undersowing brassicas with clover results in lower oviposition rates by *Delia radicum*.

4.2 Natural enemies – Predators and Parasitoids

Predators

Undersowing with clover has been found generally to result in increases in the number of carabids captured in pitfall traps (O'Donnell and Coaker, 1975; Tukahirwa and Coaker, 1982; Theunissen *et al.*, 1992; Armstrong and McKinlay, 1997). However, with the exception of *Pterostichus melanarius* in the current study, most carabids were captured in the bare plots. *P. melanarius* was one of the most frequently captured carabid species in both 1997 and 1998 and was most common in the undersown plots in both years. Other studies have reported collecting more *P. melanarius* in undersown plots (Dempster and Coaker, 1974; O'Donnell and Coaker, 1975).

There are at least three possible explanations for the differences in species abundance in pitfall traps in undersown and bare plots: beetle abundance/activity, habitat preference and the reproductive condition of the carabids. Firstly, pitfall traps measure both the activity and population density of beetles (Luff, 1975) and results must thus be interpreted with caution. Factors that may influence activity and thus captures include hunger, temperature, humidity and readiness for mating (Wheater, 1991). A hungry beetle, for example, may actively be searching for food and thus be more likely to encounter a pitfall trap and be captured than a satiated beetle. It is possible that captures reflect population density directly but without an absolute sampling method, population density cannot be separated from activity. Secondly, vegetation cover may influence both activity and population density. Some species of ground beetles prefer habitats with vegetation cover whereas others prefer bare areas (Lindroth, 1974). Undersown plots have denser vegetation where the clover cover shades the soil surface and results in a damp, shaded habitat.

The majority of the species collected in the rutabaga field are species usually found in open, dry areas with short vegetation rather than in forest or on wet soils (Lindroth, 1974). Additionally, pitfall traps are not as effective in capturing small species, like *Bembidion lampros*, as large beetles, like *Pterostichus melanarius*.

There are two categories of carabids recognized as either adult hibernators or larval hibernators. Adult hibernators, such as *Bembidion lampros*, are most abundant and active in the spring or early summer whereas larval hibernators, like *Pterostichus melanarius*, have a peak abundance in the middle of the summer (Wallin, 1985). Thus, the dominance of *P. melanarius* in the pitfall traps may reflect the life history patterns more than the abundance of carabid species in the plots.

Many (60-100) species of carabid and staphylinid beetles are considered important predators of eggs and larvae of *Delia* spp. (Finch, 1989). Predation was not studied in the current experiment, but as most species captured are generalist predators, it is possible that some predation of immature stages of *D. radicum* did occur. In 1997, *Bembidion lampros*, *Amara bifrons* and *Agonum muelleri* were among the most-frequently trapped carabids. In a study of carabid beetles as predators of *D. radicum* eggs, the most notable egg predators were species of *Bembidion*, *Amara* and *Agonum* (Finch, 1996).

Although *Aleochara bilineata* is a specific natural enemy of *Delia* spp, most of the species of predatory ground beetles collected are polyphagous and opportunistic in terms of prey choice. Undersowing probably affects many invertebrates, some of which might be eaten by ground beetles if encountered. The effects of undersowing on other species in the agro-ecosystem were not studied, but could indirectly affect pitfall trap catches if these other species are eaten by ground beetles. The ground beetles might then be less hungry, less active and thus under-represented in trap catches.

Parasitoids - *Aleochara bilineata*

There were no significant differences between the number of *Delia radicum* pupae per plant in rutabaga undersown or bare, but there were significantly lower rates of parasitism by *A. bilineata* in undersown plots. Langer (1996) found that cabbage undersown with white clover had fewer *D. radicum* pupae per plant and less parasitism by *A. bilineata* than cabbage grown in bare soil. More *A. bilineata* were collected in pitfall traps in the bare plots, also supporting the idea that *A. bilineata* was actually more abundant in the bare plots. This may also indicate that there were differences in *A. bilineata* oviposition or in larval success at finding a *D. radicum* puparium.

One consideration with *A. bilineata* and IPM of *Delia radicum* is that the beetle parasitizes the pupae of the pest, after larval feeding has been completed. The life cycle of the beetles is well synchronized with that of the cabbage root maggot, as the adult beetles emerge from overwintered root maggot pupae two to three weeks later than the emergence of the first generation of *D. radicum*. The degree day study showed that peak *A. bilineata* emergence was at 420 DD above a base of 4.4°C. At the time of *A. bilineata* emergence, many first generation *D. radicum* will have completed the larval stage and there will be pupae available for *A. bilineata*. The beetle remains present to parasitize second generation pupae. *Aleochara bilineata* emerges too late to reduce damage by first generation *D. radicum* larvae in any single season, but it is still a beneficial species: in the short-term it reduces the number of flies emerging in the second generation, and in the longer-term it may reduce populations year to year. One goal of this study was to determine if undersowing rutabaga with clover would increase parasitism by *A. bilineata* of second generation root maggot. In fact, undersowing significantly reduced parasitism.

4.3 Damage Assessment

There is usually a yield reduction in undersown crops due to competition between the crop and the intercropped species (Theunissen and den Ouden, 1980). However, in the case of rutabaga a slightly lower yield is acceptable, as consumers prefer smaller rutabaga. In terms of marketability, the ideal Laurentian rutabaga weighs 700g and has a circumference of 10-12 centimetres (Nonnecke, 1989). While there were no marketable rutabaga produced in the experimental plots in 1997 according to the damage rating scale, the mean yield was close to this 700 g ideal weight (closest was bare soil, 714 g, Table 3.6). There were some marketable rutabagas in 1998, and the mean yield in that year was also close to ideal in bare and clover plots.

Rutabaga are graded under the Fresh Fruits and Vegetables Products Regulations that falls under the Canada Agricultural Products Act. The Canada No. 1 rutabaga must meet specified standards set out in the Act which ensure that rutabagas are of consistent quality with regard to size, appearance, quality and packaging. Canada No. 1 rutabaga must not be trimmed "on the upper half of the root, or deeply into the flesh on the lower half of the root so as to alter the general shape of the root or to materially affect the appearance of a rutabaga" (Anon, 1999). Thus, the extent of trimming required on the rutabaga from the current study would mean that most were unmarketable.

The trim loss percent and the damage rating index both assess damage to the rutabaga by *D. radicum*. The rating index relies on a visual surface assessment of the rutabaga, whereas the trim loss takes into account the depth of damage in the rutabaga. The trim loss percent, while more labour intensive, seemed to be more accurate and provided more information on the damage to the rutabaga. The rating scale was not as effective.

The difference in yields between the bare and undersown plots may be due to *Delia radicum* feeding and not competition from the clover, especially as 1997 and 1998 were very different both in terms of assessed damage, yields and pest populations. In 1997, there were high populations of *D. radicum* and significant differences between treatments in yields and trimming percentage. However, in 1998 there were low fly populations and no significant difference between treatments in damage or yield. If competition between the rutabaga and clover had been a major factor, there should have been differences in yield in 1998 as well as 1997.

Clover undersown in stem brassicas like cabbage, cauliflower and broccoli has to be cut to reduce competition with the main crop (Finch and Kienegger, 1997). In these crops, protection is directed against the first generation of *Delia radicum*. Clover must cover at least 60% of the inter-row spaces to be effective, and therefore, must be planted four to six weeks before the crop (O'Donnell and Coaker, 1975). A drawback with planting the clover early is that it becomes too competitive with the main crop and has to be mowed (Finch, 1996). In this experiment, the clover was sown at the same time the rutabagas were transplanted. By the time second generation *D. radicum* activity was expected and the row covers removed, the clover had covered more than 95% of the soil between the rows but was not high enough to require cutting.

While researchers in the UK and elsewhere have had positive results with undersowing cabbage, broccoli and similar brassicas with clover, these crops are damaged indirectly by *D. radicum*. In the present study, however, a less tolerant crop, rutabaga, was used. As *D. radicum* attacks the edible part of the rutabaga, the damage threshold is very low and undersowing may not be appropriate in this crop.

Concerns with differences between the yield of rutabaga undersown with clover and those grown in bare soil could be addressed by harvesting the undersown plot later. This would result in increased yields. However, it appears that most of the yield loss observed in this experiment was due to *Delia radicum* and not to competition with the clover.

4.4 Summary

It is clear that undersowing affects the insect fauna of the rutabaga crop in different ways. Of the nine parts of the crop system which were studied, species which were collected in higher numbers in the undersown plots include adult male *Delia radicum*, *Pterostichus melanarius* and *Amara bifrons*. Species collected in higher numbers in the bare plots were adult female *D. radicum* and eggs, *Aleochara bilineata* (measured by both pitfall trapping and rate of parasitism), *Bembidion lampros* and *Clivina fossor*. *Delia radicum* pupae were present in bare and undersown plots in approximately equal numbers.

According to the theory of "appropriate/inappropriate landings" (Kostal and Finch, 1994), more eggs would be expected in the bare plots, as was found in this study. However, the numbers of *D. radicum* pupae were approximately equal in bare and undersown plots, possibly indicating a higher mortality of eggs or larvae in the bare plots. *Aleochara bilineata* and *Bembidion lampros* are known to eat eggs and early-instar *D. radicum* larvae, and both were captured in higher numbers in bare plots. Although predation was not quantified in this study, it is possible that these beetles fed on eggs and larvae as has been observed in other studies (Finch, 1996; Hartfield and Finch, 1999). *Pterostichus melanarius* was found most frequently in undersown plots and although it will eat *D. radicum* eggs and larvae, it generally takes larger prey (Hagley *et al*., 1982) so may not have had a significant impact on mortality of immature stages of *D. radicum*.

While undersowing did not increase the rate of parasitism by *A. bilineata* as expected, it did decrease the numbers of *D. radicum* adult females and eggs. Although fewer *D. radicum* eggs, and presumably fewer larvae were present in undersown plots, in 1997 when insect pressure was high, no rutabaga were marketable. Undersowing may have a place in an integrated pest management system for the cabbage root maggot. However, further research is needed before it is an option for growers, particularly for use in a crop with a low damage tolerance such as rutabaga.

4.5 Future Research

Although undersowing rutabaga with clover reduced the rate of parasitism by *A. bilineata*, it may still be possible to incorporate the use of this beetle in an IPM program in brassicas. The concept of controlling *D. radicum* by annual releases of large numbers of laboratory reared *A. bilineata* in an inundative biological control program has been discussed for many years (Whistlecraft *et al.*, 1985; Hartfield and Finch, 1999) but has not been tested in the field. Previous scenarios involved releasing *A. bilineata* to coincide with *D. radicum* oviposition, as *A. bilineata* was considered a voracious predator of root maggot eggs. It has recently been shown that "*A. bilineata* does not have the impressive egg destroying capability that it was credited with by the earlier researchers" (Hartfield and Finch, 1999). However, in cage studies, *A. bilineata* released at a rate of two adult beetles per plant, was able to control *D. radicum* by preying on root maggot larvae (Hartfield and Finch, 1999). Thus, if released early enough, *Aleochara bilineata* might aid in the control of first and second-generation *Delia radicum* by feeding on larvae and parasitising pupae.

One advantage of using *A. bilineata* in a mass-release program is that although not a native species, it has been present in Newfoundland for many years (Morris, 1960); the current study showed that it is in fact distributed across the province. If large numbers are released, the environmental impact should be less than if a new species is introduced. The release program will, however, have to take into account the life cycle of

Delia radicum. Also, it has been suggested that while *A. bilineata* is the most appropriate parasitoid to rear and release against *D. radicum* in an inundative biological control program, this is only true in areas where the wasp *Trybliographa rapae* is uncommon (Finch, 1995). Competition between the two parasitoids is biased heavily in favor of the wasp (Reader and Jones, 1990). Since *T. rapae* was found in low numbers in this experiment and is known from previous studies to be rare in Newfoundland (Morris, 1960), it should not adversely affect the use of *A. bilineata* in a release program in this province. A release program is still probably in the distant future: questions of mass-producing beetles and grower acceptance would have to be addressed, and field tests would need to be conducted to determine whether results of the cage studies would be similar in the field.

Another interesting avenue for future research might be to test rutabaga varieties which are tolerant or resistant to root maggot. The cultivar "Laurentian", which is highly susceptible to *D. radicum*, was intentionally used in the current study and although there were fewer eggs laid in the undersown plots, all rutabaga were damaged to such an extent that none were marketable. Birch (1988) found that when both resistant and susceptible varieties of swede turnips were used, feeding by *D. radicum* larvae on resistant cultivars was restricted to surface root tissue only, and tunnels on the susceptible cultivars were much deeper. The combination of undersowing and a resistant variety might be an effective control method.

4.6 Conclusion

In conclusion, *Delia radicum* has been studied for many years in many countries and yet it remains a very difficult pest to manage. As agriculture moves into the 21st century, one thing seems certain: the cabbage root maggot will continue to be the focus of intense study as researchers attempt to develop integrated pest management systems which rely less and less on chemical insecticides.

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