Undersowing rutabaga with white clover: impact on *Delia radicum* (Diptera: Anthomyiidae) and its natural enemies[1]

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The Canadian Entomologist **136**: 427 – 442 (2004)

Abstract—The cabbage maggot, *Delia radicum* (L.), is a serious pest of cruciferous crops in temperate regions of North America and Europe. The effects of undersowing rutabaga, *Brassica napus* L. subsp. *rapifera* Metzg. (Brassicaceae), with white clover, *Trifolium repens* L. (Leguminosae), on second-generation cabbage maggot and its natural enemies were studied in Newfoundland in 1997 and 1998. In 1997, totals of 1311 and 724 eggs were recovered from bare and undersown plots, respectively. More eggs were present in bare plots than undersown plots on various specific dates. In 1997, rutabagas from bare plots weighed more than those from undersown plots, although damage ratings were similar, suggesting that competition, not cabbage maggot feeding, caused the yield differences. In 1998, there were few cabbage maggots present and little damage or yield reduction in either treatment. Similar numbers of cabbage maggot pupae were extracted and reared from each treatment in each year. In 1997, of the pupae reared from undersown plots, 48% produced cabbage maggot flies, 14% produced parasitic Hymenoptera, and 8% produced *Aleochara bilineata* Gyllenhal (Coleoptera: Staphylinidae); 19% of the pupae from bare plots produced cabbage maggot flies, 8% produced parasitic Hymenoptera, and 36% produced *A. bilineata*. More *A. bilineata* were captured in pitfall traps in bare plots than in undersown plots. The effect of clover on carabid beetles was species specific. There were more *Bembidion lampros* (Herbst) and *Amara bifrons* (Gyllenhal) in bare plots in 1997, and more *Pterostichus melanarius* (Illiger) in undersown plots in both years. Despite consistently lower egg numbers in undersown plots than in bare plots, the numbers of pupae in the two treatments were similar at the end of the season. We speculate that this may be due to differential, density-dependent mortality of immature stages of cabbage maggot caused by predators and parasitoids.

Dixon PL, Coady JR, Larson DJ, Spaner D. 2004. Effets d'un sous-semis de trèfle blanc dans des cultures de rutabagas sur *Delia radicum* (Diptera : Anthomyiidae) et ses ennemis naturels. *The Canadian Entomologist* **136** : 427–442.

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Résumé—La mouche du chou, *Delia radicum* (L.) est un ravageur important des cultures de crucifères dans les régions tempérées de l'Amérique du Nord et de l'Europe. Nous avons étudié les effets de sous-semis de trèfle blanc, *Trifolium repens* L. (Leguminosae) dans des cultures de rutabagas, *Brassica napus* L. subsp. *rapifera* Metzg. (Brassicaceae) sur des mouches du chou de seconde génération et leurs ennemis naturels à Terre-Neuve en 1997 et 1998. En 1997, nous avons récolté un total de 1311 oeufs dans les parcelles sans sous-semis et 724 oeufs dans celles avec sous-semis. Il y avait plus d'oeufs dans les parcelles sans sous-semis que dans celles qui en avaient, et ce à plusieurs dates spécifiques d'ensemencement des sous-semis. En 1997, les rutabagas provenant des parcelles sans sous-semis étaient plus lourds que ceux des parcelles sans sous-semis, bien que les cotes d'endommagement aient été semblables, ce qui laisse croire que c'est la compétition, et non l'alimentation de la mouche du chou, qui explique les différences de rendement. En 1998, il y avait peu de mouches du chou et il y a eu peu de dommage ou de réduction de rendement dans les deux types de conditions expérimentales. Nous avons extrait et mis en élevage un nombre semblable de pupes de la mouche du chou dans les deux types de parcelles au cours des deux années. En 1997, quarante-huit pour cent des pupes provenant des parcelles avec sous-semis ont produit des mouches du chou, 14 % des hyménoptères parasites et 8 % des *Aleochara bilineata* Gyllenhal (Coleoptera : Staphylinidae); 19 % des pupes des parcelles sans sous-semis ont produit des mouches du chou, 8 % des hyménoptères parasites et 36 % des *A. bilineata*. Des pièges à fosse ont récolté plus d'*A. bilineata* dans les parcelles sans sous-semis que dans celles avec sous-semis. Les effets du trèfle sur les carabes variaient selon l'espèce. Il y avait plus de *Bembidion lampros* (Herbst) et d'*Amara bifrons* (Gyllenhal) dans les parcelles sans sous-semis en 1997 et plus de *Pterostichus melanarius* (Illiger) dans les parcelles avec sous-semis au cours des deux années. Malgré le nombre toujours inférieur d'oeufs dans les parcelles avec sous-semis par comparaison aux parcelles sans sous-semis, le nombre de pupes était semblable dans les deux situations à la fin de la saison. Nous posons en hypothèse que ce phénomène s'explique par une mortalité différentielle dépendante de la densité des stages immatures de la mouche du chou causée par les prédateurs et les parasitoïdes.

[Traduit par la Rédaction]

Introduction

The cabbage maggot, *Delia radicum* (L.) (Diptera: Anthomyiidae), is one of the major pests in commercial production of cruciferous crops in the temperate regions of North America and Europe. In Newfoundland it is the single most important economic pest of vegetables (Morris 1983) and the limiting factor in the production of rutabaga (*Brassica napus* L. subsp. *rapifera* Metzg. (Brassicaceae)) and cole crops such as cabbage (*Brassica oleracea* L. var. *capitata* L. (Brassicaceae)) and broccoli (*Brassica oleracea* L. var. *italica* Plenck (Brassicaceae)) (Morris 1960; Coady and Dixon 1997). One complete generation and a partial second generation develop each year in Newfoundland (Morris 1959, 1960; Coady and Dixon 1997). Cabbage maggot larvae feed on root tissue and, when abundant, can stunt or kill seedlings and young transplants of both cole crops and rutabaga. Vigorous, well-established cole crops can tolerate heavy populations of larvae and, for cole crops, the first generation of cabbage maggot is of most concern. When larvae directly damage the part of the plant used for human consumption (*e.g.*, rutabaga, turnip), feeding can severely disfigure the fleshy roots and lower the quality (Morris 1959). For these crops, the second generation of cabbage maggot is the most critical.

Adequate control of *D. radicum*, particularly of the second generation, is a challenge (Finch and Collier 2000). Also, the number of insecticides available for *D. radicum* control has steadily decreased and continues to decline. In Atlantic Canada, chlorpyrifos is the only insecticide currently registered and recommended for cabbage maggot in cole crops (Anonymous 1999). Of the four products recommended for cabbage maggot in rutabaga, two are for early-season use (Anonymous 1999) and are ineffective against the second generation. As well, terbufos is being withdrawn at the end of 2004, and the others (chlorpyrifos, chlorfenvinphos, and phorate) are organophosphates and are under review. There are few alternatives to insecticides for the successful control of cabbage maggots (Vernon and Mackenzie 1998). One potential option is diversification of the agroecosystem through intercropping.

Intercropping is the agronomic practice of growing two or more crops simultaneously on the same field; undersowing is a type of intercropping that combines an economically important crop with a living mulch that is not harvested (Costello 1994). Many pest insect species occur at lower population levels in undersown crops than in monocultures. Cruciferous vegetables have been well studied in this respect (Hooks and Johnson 2003), and numerous studies have indicated that increased plant diversity often reduces the number of cabbage maggot eggs found around host plants. Many hypotheses have been proposed to explain the reduced infestation by cabbage maggot in undersown crops, including resource concentration (Root 1973), effects on natural enemies (Root 1973), and altered host-plant quality (Theunissen 1994). Recent research, however, has indicated that the theory of "appropriate/inappropriate" landings (Finch 1996*a*; Finch and Collier 2000) is the most likely explanation. This theory is based on the disruption of host-finding behavior by the female cabbage maggot fly in intercropped or undersown situations, which leads to reduced oviposition.

In addition to directly reducing oviposition, undersowing can affect the cabbage maggot indirectly through its natural enemies. The major parasitoids of *D. radicum* in Newfoundland are *Aleochara bilineata* Gyllenhal (Coleoptera: Staphylinidae) and *Trybliographa rapae* (Westwood) (Hymenoptera: Figitidae) (Coady and Dixon 1997). *Aleochara bilineata* adults eat cabbage maggot eggs and larvae (Finch *et al.* 1999; Hartfield and Finch 2003), and beetle larvae develop as parasitoids within cabbage maggot pupae, overwintering in the first instar. Carabid beetles also have been implicated as predators of cabbage maggot eggs and larvae (Finch and Skinner 1988; Finch and Elliott 1994).

Much of the previous undersowing research on cabbage maggot in brassicas focussed on the first generation of *D. radicum*. Often, the undersown crop was planted several weeks before the brassicas to ensure sufficient ground cover, and competition between the two plant species caused unacceptable yield loss. The focus of our research was the second generation of *D. radicum*, as it is the most important generation in rutabaga production in Newfoundland. We tried to minimize competition between clover (*Trifolium repens* L. (Leguminosae)) and rutabaga by sowing clover when the rutabaga was transplanted, rather than earlier. The general objective of this study was to assess the applicability of the appropriate/inappropriate landings theory as it applies to second-generation cabbage maggot with its complex of natural enemies. Specific objectives were to assess the effects of undersowing of rutabaga with white clover on (*i*) numbers of eggs laid by female cabbage maggot flies, (*ii*) numbers of cabbage maggot pupae, (*iii*) abundance of predators and parasitoids of the cabbage maggot, and (*iv*) rutabaga yield and quality.

Materials and methods

Field sites

Field studies were conducted in 1997 and 1998 in a sandy loam soil at the Atlantic Cool Climate Crop Research Centre of Agriculture and Agri-Food Canada in St.

John's, Newfoundland and Labrador (47°51′N, 52°78′W). The experimental design was a randomized block with four blocks. Each block consisted of one plot of rutabaga, *B. napus* subsp. *rapifera* cv. Laurentian, grown in bare soil and one plot of rutabaga undersown with white clover (*T. repens* cv. Sonja). In 1997, each plot was 4.5 m × 6.0 m with five rows of 20 rutabaga plants/row, or 100 plants per plot. In 1998, each plot was 6.0 m × 10.0 m, arranged in 11 rows of 35 rutabaga plants/row, or 385 plants per plot. Plots were enlarged in 1998 because of possible interplot interference in 1997. The 1998 study site was adjacent to the 1997 plots; the same area could not be used in both years because overwintering cabbage maggot might have emerged under the row covers. Each year, before planting, all plots were fertilized with 8:16:8 N–P–K + 2% boron at a rate of 1500 kg/ha. No pesticides were used, and foliage-feeding caterpillars and weeds within plots were removed by hand. Weeds between plots and on plot edges were rotovated. Clover was not cut in either year and plots were irrigated when necessary.

All rutabaga was grown from seed in size 48 plastic flats (Kord Products Inc, Brampton, Ontario, Canada) in Promix®. After germination, the flats were placed in an environment-controlled greenhouse and watered as required. A water-soluble fertilizer (20:20:20, N–P–K) at 75 g per 100 L was used until plants were 6 weeks old; thereafter, plants were hardened off outside under a fabric row cover (Reemay®, BBA Fiberweb, Nashville, Tennessee) to prevent infestation by first-generation cabbage maggot. Rutabaga was transplanted on 19 June 1997 and 15–16 June 1998. In undersown plots, rutabaga was transplanted and clover was broadcast immediately at 7.5 kg/ha using a handheld broadcast spreader (Ev-N-Spred®, Model No. 2700A, EarthWay Products, Bristol, Indiana). Clover was inoculated with the appropriate strain of *Rhizobium* sp. prior to sowing. As the research focussed on the second generation, it was essential that first-generation cabbage maggot were excluded from the plots. Therefore, Reemay® row covers were placed over all plots immediately after planting and left until first-generation emergence was complete, approximately 4 weeks after transplanting. The decline of the first generation was determined using the degree-day model modified for Newfoundland (Coady and Dixon 1997) and by collecting adults in yellow pan traps. When row covers were removed, and weekly thereafter, clover cover was estimated visually in two 0.25-m^2 quadrat samples in each plot. Quadrat samples were photographed as well; clover cover and height relative to the rutabaga were estimated from the photographs. In addition, when row covers were removed, the soil around four or five rutabaga plants in each plot was examined for cabbage maggot eggs.

Flies

Flies were collected using 22.5 cm diameter metal cake pans sprayed with yellow Tremclad® rust paint. Two traps were placed randomly in a rutabaga row in each plot (excluding guard rows) and filled with soapy water. Because the clover was broadcast, it was present both within and between rows, and traps in undersown plots were actually in clover. Twice weekly, flies were removed, the pans were cleaned, and the water was replaced. Samples were taken from 1 August to 10 October 1997 and from 14 July to 26 October 1998.

Eggs

Oviposition by cabbage maggot flies was monitored by *in situ* examination of the stem, upper root, and surrounding soil for eggs. In both 1997 and 1998, nine randomly chosen plants per plot were monitored twice weekly. The same plants were monitored during the entire experiment, and eggs were destroyed as they were counted to ensure that the same egg was not counted more than once. Sampling began on 1 August in 1997 and on 14 July in 1998 and continued until 19 September and 25 September, respectively. We assumed that all eggs were *D. radicum* even though small numbers of *Delia platura* (Meigen) and *Delia florilega* (Zetterstedt) were present in the study area. Other species of Anthomyiidae that oviposit on rutabaga (*e.g.*, *Delia floralis* (Fallen) and *Delia planipalpis* (Stein)) are not known to occur on the island of Newfoundland (Griffiths 1991).

Pupal rearing

Soil and rutabaga samples were used to assess percent parasitism of cabbage maggot pupae by *A. bilineata* and Hymenoptera. In November, 20 root balls and a volume of soil surrounding the roots in a radius of 7.5 cm and to a depth of 7.5 cm were taken at random from each plot. Plants that were in guard rows or that had been sampled for eggs were not used for pupal samples. The number of cabbage maggot pupae extracted from each sample was recorded. Pupae were placed in groups of up to 50 in dampened fine vermiculite and kept at 4 °C for 21 weeks before being incubated at 20 °C, 70% RH, and 16L:8D. Insect emergence was recorded every 24 h and percent parasitism calculated.

Pitfall trapping

Two pitfall traps were placed randomly in each plot to determine the activity-density of *A. bilineata* and ground beetles (Coleoptera: Carabidae). Each trap consisted of a 500-mL clear plastic container (12 cm × 7 cm) within a 13 cm diameter plastic flower pot placed in the soil with the top at ground level. Propylene glycol (250 mL) was added and replaced as needed, usually every third week. A flat, square, wooden cover, with a 10-cm nail at each corner acting as a leg, was positioned about 3 cm above the trap opening to exclude rain and debris. Captured material was removed weekly and traps were operated from 1 August to 26 November 1997 and from 17 July to 23 October 1998. Staphylinids other than *A. bilineata* were identified to family only.

Damage assessment and yield

The 20 rutabaga root samples taken from each plot for pupal counts (see previous section) also were used for damage and yield assessments. The same number of roots was used each year for consistency, although plots were larger in 1998 than in 1997. Rutabaga damage was assessed using the King and Forbes (1954) rating scale and by harvest (pretrimmed) and trimmed root masses. For the rating scale, each bulb was washed and assigned a rating of either 0, 1, 2, or 4. A rating of 0 or 1 indicated a marketable rutabaga that was clean (0) or had slight damage that could be trimmed (1). A rating of 2 meant that one-quarter to one-half of the root was damaged but marketable, and a rating of 4 meant that the rutabaga was severely damaged and not marketable. The washed rutabagas were weighed to determine total root yield. Damaged portions were trimmed with a knife and each rutabaga was reweighed to determine trimmed root yield.

Data analysis

Data for most measured traits were analysed with analyses of variance procedures to determine differences between bare and undersown treatments (SAS Institute Inc 1989). Where intraplot variance was high, the Wilcoxon's signed-ranks test was used to determine differences (Sokal and Rohlf 1995). This nonparametric test is a distributionfree analysis where treatment ranks rather than means are compared. Cabbage maggot pupal data were analysed and presented separately by year because of large environmental differences between the years. A significance level of $P < 0.05$ was used for all analyses. In 1998, so few flies were caught that data were not separated by sex. Least squares means are presented throughout (Steele and Torrie 1980). The intervals between sampling dates varied; thus, all data were standardized by dividing the mean number per count or trap by the monitoring interval. Means are presented with standard errors (Sokal and Rohlf 1995).

Results

In both years, the soil surface between plants within rows, as well as between rows, was >95% covered by clover in undersown plots when row covers were removed. Throughout the experiment, the clover cover was even, had few weeds, and was approximately one-half to three-quarters of the height of the rutabaga plants. The bare plots were virtually weed-free during the study. Pan trap monitoring data and the degree-day model indicated when the first generation of cabbage maggot flies was declining and when to remove row covers. No eggs were found when the soil around several rutabagas in each plot was examined at the time of row cover removal.

The spring of 1998 was warmer and drier than that of 1997, and the 780–800 degree days (>4.4 °C) required for second-generation emergence (Coady and Dixon 1997) were accumulated 10 days earlier (1 August versus 11 August). For unknown reasons and although the sampling period was longer in 1998, fewer flies or eggs were collected in 1998 than in 1997.

Flies

More flies were captured in 1997 (1046) than in 1998 (188). In 1997, the first flies were captured on the first sampling day (1 August) and the last were captured on 26 September (Fig. 1*a*). In 1998, the first flies were collected on 14 July (Fig. 1*b*) and the last were collected on 12 October (data not shown). In 1997, the mean number of flies per pan trap per day peaked in the bare plots on 8 August (6.9 flies) and in the undersown plots on 1 August (7.2 flies) (Fig. 1*a*). In 1998, the mean number of flies per pan trap per day was highest in the bare plots on 13 August (0.7 flies) and in the undersown plots on 14 July (2.1 flies). In both years, more flies were trapped in undersown plots than in bare plots on the majority of sampling dates (1997: 9 of 15 dates; 1998: 18 of 22 dates) (Fig. 1). Overall in 1997, more female than male flies were captured in bare plots on 9 of 15 sampling dates, and this difference was significant on 12 August (Fig. 2*a*). Trap catches of males were highly variable, especially in undersown plots (Fig. 2*b*).

Eggs

Totals of 2035 and 65 eggs were collected in 1997 and 1998, respectively. In 1997, the first cabbage maggot eggs were observed on 7 August (Fig. 3), 1 week after the first flies were trapped. The last date on which eggs were observed was 18 September. There were differences between treatments, with more eggs in bare plots than in undersown plots on 10 of 13 sampling dates. Peak oviposition occurred in both treatments on 19 August; the mean number of eggs per plant was 2.2 ± 0.5 in bare plots and 1.4 ± 0.3 in undersown plots. The total number of eggs in 1997 was 1311 in bare plots and 724 in clover plots. When sampling dates were examined individually, both parametric and nonparametric analyses indicated that there were more eggs in bare plots

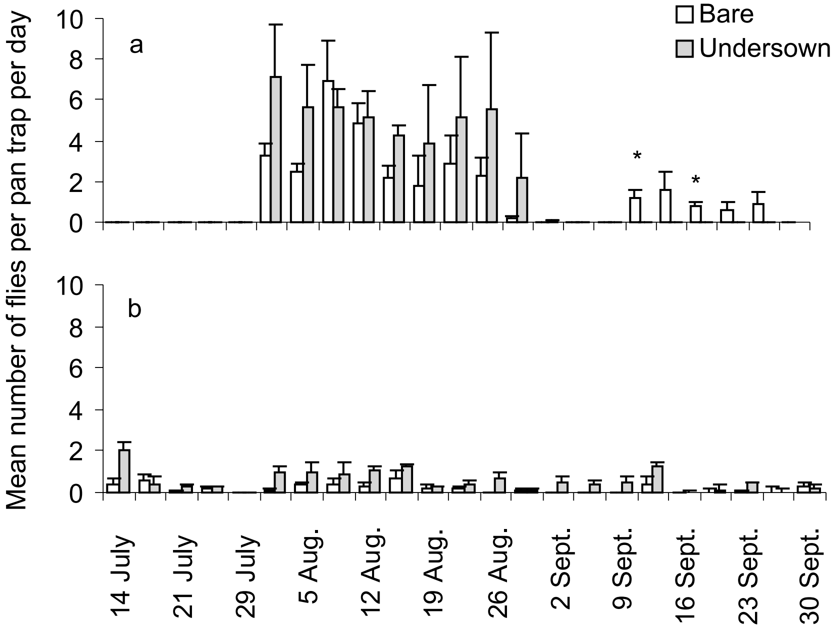

FIGURE 1. Mean number of *Delia radicum* flies per pan trap per day from *Brassica napus* subsp. *rapifera* cv. Laurentian grown in bare soil or undersown with *Trifolium repens* in 1997 (*a*) and 1998 (*b*). Asterisk indicates treatment differences at $P < 0.05$.

than in undersown plots on 7 and 28 August and 1 and 5 September. In 1998, few eggs were collected on any date and data are not shown. Sampling started on 14 July and the first eggs were observed on 31 July. The highest mean number of eggs per plant in 1998 was 0.10 ± 0.06 for bare plots (31 July) and 0.08 ± 0.05 for undersown plots (28 August), and treatments did not differ statistically on any collection date.

Pupal rearing and parasitoids

Numbers of cabbage maggot pupae extracted and reared from each plot did not differ between treatments in either year (Table 1). In 1997, 48% of the pupae reared from undersown plots produced cabbage maggot flies, 14% produced parasitic Hymenoptera, 8% produced *A. bilineata*, and from 31% there was no emergence; in bare plots, 19% of the pupae produced cabbage maggot flies, 8% produced parasitic Hymenoptera, 36% produced *A. bilineata*, and from 39% there was no emergence. Most (>90%) of the parasitic Hymenoptera were *T. rapae*. The rest were sent to the Canadian National Collection in Ottawa, Ontario, but could not be identified because of a lack of systematists. Overall in 1997, the percent parasitism of pupae from bare plots by *A. bilineata* and parasitic Hymenoptera was double (44%) that of pupae from undersown plots (22%). In 1998, few pupae were extracted from soil samples and treatments did not differ in any measured trait (Table 1).

The total number of staphylinids (not including *A. bilineata*) in pitfall traps did not differ between treatments in either year (Table 2). The total number of *A. bilineata* recovered in pitfall traps in 1997 (301) was similar to that in 1998 (322) (Table 2). Overall, more *A. bilineata* were captured in bare plots than in undersown plots: in 1997, 237 in bare plots compared with 64 in undersown plots and in 1998, 211 in bare plots and 111 in undersown plots (Table 2). In 1997, there were more beetles in pitfall traps

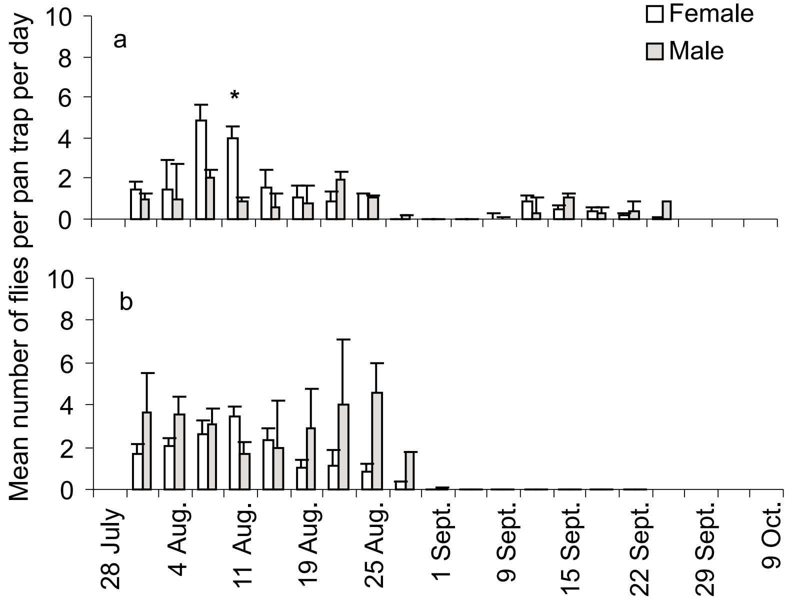

FIGURE 2. Mean number of female and male *Delia radicum* flies per pan trap per day from *Brassica napus* subsp. *rapifera* cv. Laurentian grown in bare soil (*a*) or undersown with *Trifolium repens* (*b*) in 1997. Asterisk indicates treatment differences at $P < 0.05$.

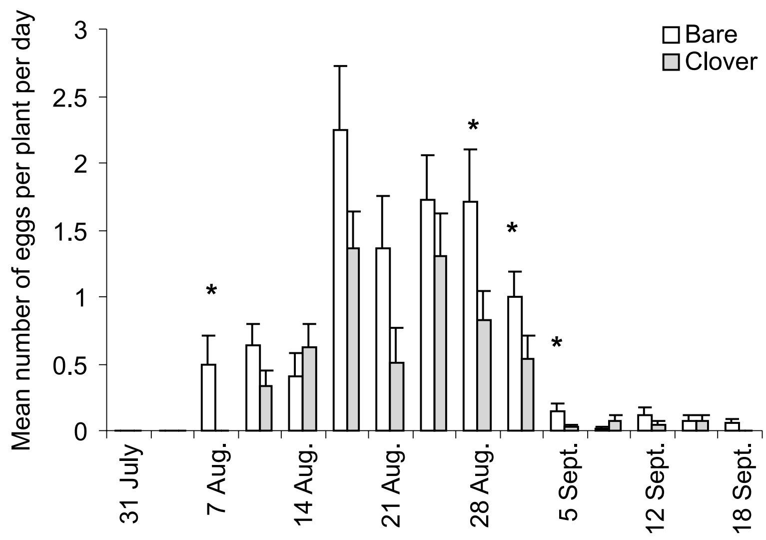

FIGURE 3. Mean number of *Delia radicum* eggs per plant per day from *Brassica napus* subsp. *rapifera* cv. Laurentian grown in bare soil or undersown with *Trifolium repens* in 1997. Asterisk indicates treatment differences at $P < 0.05$.

in bare plots than in undersown plots through August and early September (Fig. 4*a*). In 1998, numbers in the two treatments were similar except on two dates in September when there were more beetles in bare plots (Fig. 4*b*).

Table 1. Mean number of *Delia radicum* pupae per plot collected from *Brassica napus* subsp. *rapifera* cv. Laurentian grown in bare soil or undersown with *Trifolium repens* in 1997 and 1998, and mean numbers of *D. radicum* flies, *Aleochara bilineata*, and Hymenoptera per plot that emerged from those pupae after completion of diapause.

Year		Treatment	Mean number per plot				
			Pupae	Flies	*A. bilineata*	Hymenoptera†	No emergence‡
1997		Bare soil	142	27	51	12	55
		T. repens	155	74	12	22	48
	F test		NS	**	*	NS	NS
	SE		13	3.6	8.6	6.7	16.2
1998		Bare soil	11	4	4	0	3
		T. repens	13	4	4	1	4
	F test		NS	NS	NS	NS	NS
	SE		4.3	1.8	2.3	0.8	1.1

Note: NS, treatment effects not significant ($P \geq 0.05$); *, significant at $P < 0.05$; **, significant at $P < 0.01$; SE, standard error of the difference of two least squares means.

† Parasitic wasps, approximately 90% *Trybliographa rapae* and 10% unidentified species.

‡ No emergence, unidentified mortality.

Carabidae

Fifteen species of ground beetles were collected (Table 2), only two of which are native species (Morris 1983). Captures of just three species differed between treatments in at least one year and only these are considered further. *Bembidion lampros* (Herbst) and *Amara bifrons* (Gyllenhal) were trapped in higher numbers in bare plots than in undersown plots in 1997 but generally were uncommon in 1998. *Pterostichus melanarius* (Illiger) was more abundant in undersown plots than in bare plots in both years and in 1998 was the most abundant species captured overall (Table 2).

Damage assessment and yield

Rutabaga damage ratings were similar for undersown and bare plot treatments in both years (Table 3). Rutabagas from bare plots weighed more than those from undersown plots in 1997 but not in 1998 (Table 3). A smaller proportion of each rutabaga from the bare plots had to be trimmed to remove damage (8.6% compared with 14.3% for undersown plots) in 1997. In 1998 there was little damage or yield reduction in any plot, and treatments did not differ in any measured yield parameter (Table 3). About 2% of each rutabaga in both treatments had to be trimmed to remove damage in 1998.

Discussion

Undersowing rutabaga with white clover was effective in reducing the numbers of cabbage maggot eggs in 1997, when appreciable numbers of eggs were present. The appropriate/inappropriate landings theory (Finch 1996*a*; Finch and Collier 2000) explains the often observed reduction in oviposition in mixed plantings through differences in colonization by female flies. When brassicas are grown in bare soil, a gravid female avoids the soil and lands on a green plant (an appropriate landing); when brassicas are grown with another green crop, the female cannot distinguish between the two green plant species, and if she lands on the non-host (an inappropriate landing), she often leaves without laying eggs. In our experiment, eggs were destroyed as they were

TABLE 2. Total numbers of *Aleochara bilineata*, unidentified Staphylinidae, and ground beetles (Coleoptera: Carabidae) of various species caught in pitfall traps in plots of *Brassica napus* subsp. *rapifera* cv. Laurentian grown in bare soil or undersown with *Trifolium repens* in 1997 and 1998.

		Number of individuals					
		1997			1998		
Family	Species	*T. repens*	Bare soil	Total	*T. repens*	Bare soil	Total
Staphylinidae	*Aleochara bilineata* Gyllenhal†	64	237	301‡	111	211	322‡
	Unidentified species	196	134	330	30	28	58
Carabidae	*Bembidion lampros* (Herbst)†	75	124	199‡	7	10	17
	Pterostichus melanarius (Illiger)†	125	66	191‡	463	328	791‡
	Amara bifrons (Gyllenhal)†	53	102	155‡	5	27	32
	Clivina fossor (L.)†	44	64	108	6	16	22
	Agonum muelleri (Herbst)†	35	20	55	55	20	75
	Harpalus rufipes (De Geer)†	10	10	20	12	12	24
	Amara littoralis Mannerheim	4	15	19	1	1	2
	Carabus nemoralis Müller†	10	7	17	2	5	7
	Amara apricaria (Paykull)†	0	7	7	0	0	0
	Notiophilus biguttatus (F.)†	1	4	5	1	5	6
	Amara aulica (Panzer)†	2	2	4	23	5	28
	Amara familiaris (Duftschmid)†	2	1	3	0	0	0
	Pterostichus strenuus (Panzer)†	2	0	2	0	0	0
	Harpalus affinis (Schrank)†	0	1	1	0	0	0
	Amara patruelis Dejean	0	1	1	0	0	0

† Introduced (after Morris 1983).
‡ Treatments differ at $P < 0.05$.

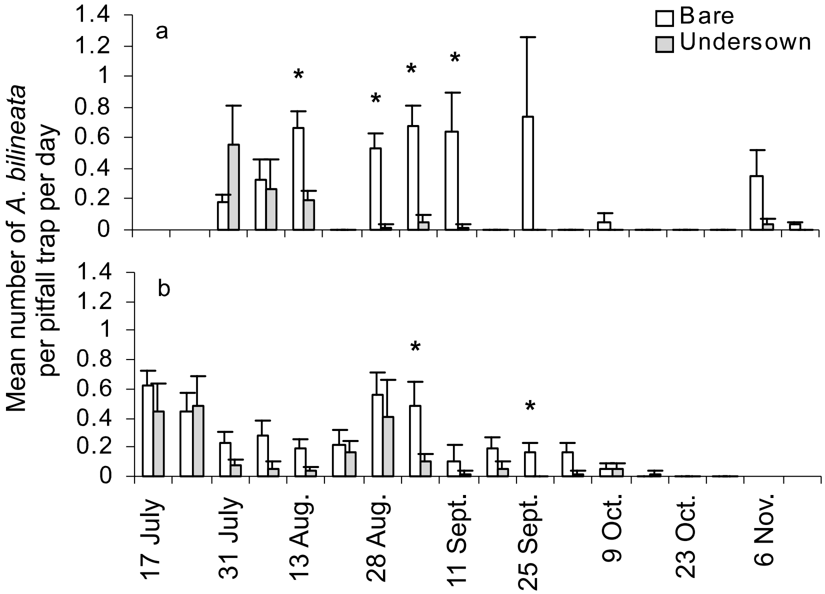

FIGURE 4. Mean number of *Aleochara bilineata* per pitfall trap per day from *Brassica napus* subsp. *rapifera* cv. Laurentian grown in bare soil or undersown with *Trifolium repens* in 1997 (*a*) and 1998 (*b*). Asterisk indicates treatment differences at $P < 0.05$.

counted. This ensured that eggs were counted just once, but it may have skewed the results if the presence of eggs stimulates oviposition by conspecifics (De Jong and Städler 2001).

Our results show the importance of considering the sex of flies in this type of study. Although there were more flies in pan traps in the clover, most of these were males. Finch (1995) noted that most cabbage maggot females are trapped over bare soil, whereas males are stimulated to land by green backgrounds. It makes intuitive sense that diverse plant backgrounds will affect males and females in different ways, as they respond to different behavioral cues to find landing sites. Also, the colour of the background affects the numbers of flies caught in pan traps (Kostal and Finch 1996), and our data may have been influenced by placing pans in bare plots on bare soil and those in undersown plots in clover. Differences in numbers of cabbage maggots between the two years probably reflect population densities but also that plots were larger in 1998, with almost four times as many host plants available.

The two most important parasitoids in this study were *A. bilineata* and *T. rapae*. Their relative abundance was similar to that in earlier Canadian reports (*e.g.*, Wishart 1957; Turnock *et al.* 1995), with *A. bilineata* more common than *T. rapae*. In 1989, Turnock *et al.* (1995) recorded 74% parasitism of cabbage maggot by *A. bilineata* but 0% by *T. rapae* in untreated plots of rutabaga at St. John's, Newfoundland. In the early 1950s, levels of parasitism near the current study sites were 34% by *A. bilineata* and 5% by *T. rapae* (Wishart 1957).

We were concerned that white clover would impede host finding by the natural enemies of the cabbage maggot. *Aleochara bilineata* was monitored by pitfall trapping and pupal rearing, both of which indicated that it was more prevalent in bare plots than in undersown plots, similar to other reports (*e.g.*, Langer 1996). The impact of egg predation by *A. bilineata* is probably minimal. Adults take a wide variety of food and although they will eat up to 12 cabbage maggot eggs per day, 85% or more of eggs are

TABLE 3. Mean total and trimmed root yield and *Delia radicum* damage rating for *Brassica napus* subsp. *rapifera* cv. Laurentian grown in bare soil or undersown with *Trifolium repens* in 1997 and 1998.

Year		Treatment (n = 80)	Total root yield ($g{\cdot}plant^{-1}$)	Trimmed root yield ($g{\cdot}plant^{-1}$)	Number of rutabagas in damage grade[†]				Overall damage rating[†]
					0	1	2	4	
1997		Bare soil	714	652	0	1	42	37	2.91
		T. repens	624	535	0	1	44	35	2.86
	F test		*	*					NS
	SE		47	46					0.16
1998		Bare soil	746	730	32	21	20	7	1.11
		T. repens	724	709	25	20	30	5	1.25
	F test		NS	NS					NS
	SE		45	25					0.18

NOTE: Total root yield is the mass after washing and before trimming; trimmed root yield is the mass after damaged tissue is removed. NS, treatment effects not significant ($P \geq 0.05$); *, treatment effects significant ($P < 0.05$); SE, standard error of the difference of two least-square means.

[†] Damage grades and damage rating (average of damage grades) after King and Forbes (1954); see text for details.

laid below the soil surface and *A. bilineata* will eat only those on the surface (Finch *et al.* 1999). Adults do eat larvae, and it has been estimated that the release of two beetles per plant is sufficient to control cabbage maggot larvae on cabbage (Hartfield and Finch 2003). Our results may, in part, reflect a density-dependent response of adult *A. bilineata* to higher numbers of cabbage maggots in bare plots; to find their prey, beetles use the chemical cues released by larvae when feeding (Hartfield and Finch 1999). The percent parasitism by *T. rapae* was not significantly different between treatments. *Trybliographa rapae* is a highly specific parasitoid, synchronized to attack the three larval instars of cabbage maggot (Soroka *et al.* 2002). Previous research has shown that the response of *T. rapae* to habitat diversification is inconsistent (Langer 1996; Hartfield *et al.* 1999). In the rearing part of this study, a high percentage of pupae apparently were nonviable, as in several other studies where a large proportion of cabbage maggot pupae produced neither flies nor parasitoids (Morris 1960; Finch and Collier 1984; Turnock *et al.* 1995). In these reports, most dead pupae were from heavily parasitized populations and the authors speculated that multiparasitism and superparasitism probably killed many parasitoids in the pupae. In our case, the numbers of nonviable pupae in the two treatments were similar and although there was a higher percent parasitism by *A. bilineata* in the bare plots compared with undersown plots, this was not so for *T. rapae*.

The other natural enemies monitored were ground beetles, which were able to move freely between treatments, particularly in 1997, when plots were smaller. We interpret the catches as general indicators of the activity-density of each species and, as such, there were obvious species-specific differences between treatments. Although ground beetles differ in their response to dense vegetation, most species are opportunistic feeders. In a European study, twice as many carabid and staphylinid predators were trapped on intercropped plots compared with bare plots, but similar reductions in cabbage maggot egg numbers occurred when the predators were excluded (Tukahirwa and Coaker 1982).

With the exception of *P. melanarius*, in the current study most carabids were captured in bare plots. *Pterostichus melanarius* was most frequently captured in undersown plots and was numerically dominant even in 1998 when few cabbage maggots were present. This large species is not an effective predator of cabbage maggot eggs or first-instar larvae (Finch 1996*b*), although it may eat older larvae and pupae. *Bembidion lampros* and *A. bifrons* were most common in bare plots. In a laboratory study, *B. lampros* and *A. bifrons* ate an average of 12 and 58 cabbage maggot eggs/beetle per day, respectively (Finch 1996*b*). Predators were monitored by pitfall trapping, which measures relative abundance and activity rather than absolute population density, and without direct assessment of predation, it is difficult to interpret catch data. Nevertheless, clear differences occurred in the numbers of these predators in the two treatments, although these differences caused no measurable effects on rutabaga damage.

In cole crops such as cabbage and broccoli, control is directed towards the first generation of cabbage maggot. To achieve the 60% minimum ground cover required to reduce fly oviposition (O'Donnell and Coaker 1975), an undersown crop is planted 4–6 weeks before the main crop, which often results in unacceptable competition. In our experiment, clover was sown at the same time as the rutabaga was transplanted. When peak second-generation activity was expected, the clover had covered more than 95% of the soil surface. Yield reduction in 1997 in the undersown plots likely was due in part to direct competition with the clover, as cabbage maggot damage ratings in bare and undersown plots were similar. However, cabbage maggot damage was a factor too, as a smaller proportion of each rutabaga from the bare plots, compared with the undersown plots, had to be trimmed to remove damage. Whether the level of yield loss is acceptable depends on a number of factors including the associated reduction in economic and environmental costs of pest control. Weed suppression and the availability of nitrogen from the clover for the following crop also are important considerations (Armstrong and McKinlay 1997). In addition, because Laurentian rutabaga is highly susceptible to cabbage maggot damage, it was an appropriate choice for distinguishing treatment differences. A more tolerant cultivar would suffer less yield loss.

Despite consistently lower cabbage maggot egg numbers in undersown plots, the numbers of pupae in the two treatments were similar at the end of the season, indicating differential mortality of immature stages of the pest. Previous studies reported a reduction in numbers of pupae (Tukahirwa and Coaker 1982; Langer 1996), larvae (Ryan *et al.* 1980), and eggs in undersown crops. We do not know how pupal density correlated with larval density. Cabbage maggot numbers may have been affected indirectly through the influence of undersowing on natural enemies such as *A. bilineata*, *A. bifrons*, and *B. lampros*, which were more prevalent in bare plots than in undersown plots and may have responded to higher numbers of cabbage maggot eggs or larvae in a density-dependent manner.

In conclusion, the appropriate/inappropriate landings theory was relevant to second-generation cabbage maggot in that egg numbers were significantly lower in undersown plots than in bare plots. Unfortunately, the reduction in oviposition was negated by a decrease in parasitism and possibly predation, resulting in no net reduction in numbers of overwintering pupae or reduction in damage. The causes of mortality of cabbage maggot larvae — in particular, the impact of natural enemies — need to be further investigated in undersown systems.

Acknowledgements

This study was conducted in partial fulfillment of an MSc degree by J Coady at the Memorial University of Newfoundland. It was funded by the Agriculture and Agri-Food Canada Matching Investment Initiative and Science Horizon programs. We thank J Coombes and B George for technical assistance, C Williams for sowing the clover, and D McKenzie for advice on choice of the undersown crop. We thank two anonymous reviewers for their suggestions on earlier versions of this manuscript.

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(Received: 6 July 2003; accepted: 13 January 2004)