Suitability of felt traps to monitor oviposition by cabbage maggot (Diptera: Anthomyiidae)[1]

PL Dixon,[2] RJ West,[3] KB McRae,[4] D Spaner[5]

Atlantic Cool Climate Crop Research Centre, Agriculture and Agri-Food Canada, PO Box 39088, St. John's, Newfoundland, Canada A1E 5Y7

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Abstract—The effectiveness of felt egg traps to detect oviposition by the cabbage maggot, *Delia radicum* (L.), was studied under field conditions for cabbage, *Brassica oleracea* L. var. *capitata* L. (Brassicaceae), and rutabaga, *Brassica napus* L. var. *napobrassica* (L.) Reichenb. (Brassicaceae), in 1994 and 1995. The numbers of eggs laid on traps were compared with the numbers deposited in the soil next to the plant. Also, the incidence of oviposition (*i.e.*, the percentage of samples with eggs) on soil and traps was compared. A total of 5160 eggs was collected from 5208 samples, but just 16% of all samples had eggs. For cabbage, early in the 1994 season, the incidence of oviposition in soil samples was double that on traps, and the number of eggs per sample was greater also. Oviposition incidence and the number of eggs per sample during the rest of the summer were similar. In the 1995 cabbage trial, the incidence of oviposition early in the season was again higher in soil samples than on traps, and there were fewer eggs per trap than per soil sample. For rutabaga, the number of eggs was similar using both methods early in the second generation, but from mid-August there were more eggs per trap than per soil sample. The incidence of oviposition in the rutabaga trial was similar on traps and in soil through most of the experiment. In this study, felt traps did not adequately detect the timing of cabbage maggot oviposition in the critical early season.

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Résumé—De 1994 à 1995, nous avons étudié en champ l'efficacité d'un piège à oeufs pour détecter le début de la ponte de la mouche du chou, *Delia radicum* (L.), sur le chou, *Brassica oleracea* L. var. *capitata* L. (Brassicaceae) et sur le rutabaga, *Brassica napus* L. var. *napobrassica* (L.) Reichenb. (Brassicaceae). Le nombre d'oeufs déposés sur la piège et dans le sol autour de la plante-hôte, ont été comparés. « L'incidence de la ponte », définie comme le pourcentage des échantillons avec des oeufs, sur le piège et dans le sol, ont aussi été comparés. Un total de 5160 oeufs ont été recueillis sur l'ensemble des 5208 échantillons. Seize pourcent des échantillons contenaient des oeufs. Pour le chou, l'incidence de la ponte et le nombre moyen d'oeufs en début de saison 1994 étaient beaucoup plus élevés dans le sol que sur la piège, alors que pour le reste de l'été ils étaient similaires. Dans l'essai du chou de 1995, l'incidence de la ponte en début de saison était beaucoup plus élevée dans le sol que dans les pièges, et le nombre d'oeufs retrouvés sur chaque piège, était moins élevé que dans le sol. Pour le rutabaga, les nombres d'oeufs recueillis en début de saison par nos deux méthodes étaient similaires. Cependant, à la mi-août, on a observé un plus grand nombre d'oeufs sur les pièges que dans les échantillons

[1] Contribution No. 127 of the Atlantic Cool Climate Crop Research Centre.
[2] Corresponding author (e-mail: dixonpl@em.agr.ca).
[3] Present address: PO Box 515, Portugal Cove, Newfoundland, Canada A0A 3K0.
[4] Present address: Atlantic Food and Horticulture Research Centre, Agriculture and Agri-Food Canada, Kentville, Nova Scotia, Canada B4N 1J5.
[5] Present address: Department of Agricultural, Food and Nutritional Science, University of Alberta, Edmonton, Alberta, Canada T6G 2P5.

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de sol. Dans cette étude, le piège à oeufs n'a pas permis de détecter le début de la ponte de la mouche du chou à la période critique du début de la saison.

Introduction

The cabbage maggot, *Delia radicum* L. (Diptera: Anthomyiidae), affects cruciferous crops across Canada (Ritchot *et al.* 1994), frequently limiting the production of cabbage, *Brassica oleracea* L. var. *capitata* L. (Brassicaceae), and rutabaga, *Brassica napus* L. var. *napobrassica* (L.) Reichenb. (Brassicaceae), in Newfoundland (Morris 1959*a*). Larvae feed on roots of host plants, stunting development and killing young crucifers when maggot populations are high. In Newfoundland, there is one full and a partial second generation of cabbage maggot each year (Morris 1959*a*, 1959*b*). Crucifers that survive the first generation of maggots are usually strong enough to withstand damage from the second generation. In the case of rutabagas, however, maggots attack the marketable part of the plant, and both generations can reduce the edible yield.

Despite advances in alternative control methods for the cabbage maggot (Humphreys and Mowat 1994; Vernon and Mackenzie 1998; Vänninen *et al.* 1999), chemical insecticides usually are required to control maggot infestation in cabbage and rutabaga (van de Steene 1997). Optimal timing of the application depends on fly activity and pinpointing the time when oviposition begins. Monitoring of *D. radicum* by commercial scouts or through provincial extension is an option available in those provinces with intense agriculture. In Newfoundland, however, vegetable farms are generally small and widely dispersed throughout the province. This makes field scouting impractical, so growers must find alternate ways of monitoring the cabbage maggot. There are traps available to catch adults, but it is difficult to identify adult *D. radicum*, even with specialized training, and distinguish it from a diversity of similar species found on traps. Current insecticide application regimes target early instar larvae and a monitoring method that can detect oviposition is necessary for the correct timing of applications.

Felt egg traps (Freuler and Fischer 1982) have been used successfully in Europe (Ravn and Esbjerg 1994; van de Steene 1997) to detect oviposition by the cabbage maggot. Furthermore, they have been compared favourably with the established, but time-consuming, method of recovering eggs from the soil next to host plants (Freuler 1988; Meadow *et al.* 1996; Bligaard *et al.* 1999); however, some reports indicate that felt traps are not reliable early in the season (Bligaard *et al.* 1999), or under abnormally wet or dry conditions (Meadow *et al.* 1996).

The objective of the present study, part of a larger experimental study on forecasting, emergence patterns, and integrated management of cabbage maggot in Newfoundland, was to compare the effectiveness of felt egg traps with soil egg counts in detecting the timing of oviposition by *D. radicum* on cabbage and rutabaga.

Materials and methods

Three field trials were conducted during 1994–1995 at the Atlantic Cool Climate Crop Research Centre of Agriculture and Agri-Food Canada in St. John's, Newfoundland (47°31′N, 52°47′W). Trials consisted of 16 plots of cabbage 'Stonehead' and 16 plots of rutabaga 'Laurentian' arranged in four replicates in a randomized complete-block design. Cabbages were grown from seed and field-transplanted on 16–17 June 1994 and 19 June 1995. Each cabbage plot was 3.0 × 3.7 m with 50 plants spaced at 30 cm in 10 rows. In 1995 in an attempt to relate numbers of cabbage maggots and damage, we manipulated population levels using fabric row covers (Reemay®). Of the 16 plots that were transplanted on 19 June, 12 plots were covered and eggs were

counted only in the remaining 4 plots. Row covers were removed from 4 of the 12 plots on 12 July (8 plots uncovered) and a further 4 plots were uncovered on 1 August (12 plots uncovered), resulting in differing numbers of samples through the season. Damage was similar in all plots and this part of the study was not considered further.

Rutabagas were field-seeded on 20 June 1994 in plots measuring 1.0 × 3.7 m. They were subsequently thinned to 35 plants per plot spaced at 15 cm in 7 rows. Prior to planting, cabbage plots were fertilized with 10–20–20 NPK at 4667 kg/ha, and rutabaga plots with 8–16–8 NPK + boron at 4952 kg/ha. Weeds were controlled with one preplant application of Treflan EC (trifluralin 545 g/L) applied at 1.5 L/ha. Additional weed control and watering were done by hand as required and no other pesticides were used. Rutabagas were seeded in 1995, but due to adverse weather, germination was poor and consequently the plants were not monitored.

All eggs recorded were assumed to be *D. radicum*. *Delia platura* (Meigen), the seedcorn maggot, and *Delia florilega* (Zetterstedt), the bean seed maggot, also oviposit on crucifers in Newfoundland, but they are secondary feeders, their eggs are usually found later in the season than those of *D. radicum* (Morris 1959*b*) and are readily distinguishable from those of *D. radicum* (Brooks 1951). No eggs of either of these species were observed in our study. Eggs of the turnip maggot, *Delia floralis* (Fallén), are difficult to distinguish from those of *D. radicum* (Shaw 1972), but *D. floralis* has not been recorded from the island part of Newfoundland (Griffiths 1991; PL Dixon, unpublished data).

The sampling unit was a single plant. At the beginning of each season, four plants within each plot were randomly selected for soil sampling, and four for felt-trap monitoring. Plants were checked 2–3 times per week throughout the growing season. To avoid edge effects, eggs were not sampled from plants in the two outer rows of each plot. Felt traps (Freuler and Fischer 1982) were 6 cm in diameter and made of spirals of coarse grey felt held together by a Velcro® closure. Each trap was fitted tightly around the plant stem at soil level. During monitoring each trap was carefully removed, spirals spread apart, and the number of eggs counted. Following egg removal and destruction, each trap was repositioned around the plant stem. The inner spirals were removed as necessary during the growing season to accommodate plant growth and to maintain a tight fit around the stem. With cabbage, traps stayed at soil level as the plants grew, but with rutabaga, they were gradually raised above the soil surface because of the growth habit of this vegetable. Traps on older rutabaga were assessed as described, and the fleshy part of the vegetable near the trap examined as well.

For soil monitoring, approximately the top 2 cm of soil within 2 cm of the plant stem was gently teased *in situ* with a spatula, and the eggs removed and counted. As the plants, especially rutabaga, grew through the season, the total volume of soil sampled increased. The same plants were sampled each time for both soil samples and traps, and any eggs on plant stems or in the crevice between stems and soil were counted. For older rutabaga, 2–3 cm of the edible portion perpendicular to the soil surface was also checked for eggs.

Air temperature and precipitation records were obtained from the Atmospheric Environment Service of Environment Canada, which maintains a weather station at the Research Centre in St. John's. Degree days (°d) were calculated by averaging the minimum and maximum air temperatures over a 24-h period, and subtracting 4.4°C, the base developmental threshold for cabbage maggot in Newfoundland (Coady and Dixon 1997).

For analysis, numbers of eggs collected from felt traps were compared directly with numbers of eggs in soil samples over the growing season in three experimental trials. From these data, the average numbers of eggs per trap and soil sample were calculated. The cumulative total was calculated for each observational day and plotted

against the day of the year; a cubic spline curve was fitted to each experimental series to portray the trend over time. We assumed these curves to be a general measure of the cumulative abundance of eggs for each day of the growing season. The growing season for each trial was partitioned into three parts of approximately the same length. The incidence of oviposition (*i.e.*, the probability that eggs were present) in the traps and soil samples was estimated for the six combinations (*i.e.*, three periods by two sampling methods). The observed incidence was defined as the number of samples with at least one egg divided by the number of samples taken. The number of samples with eggs, in relation to the number of traps or soil samples, were analysed as binary data in a generalized linear model (McCullagh and Nelder 1983). For each experimental series, the sampling method, period, and their interaction were factorial effects in the model. The significance of the interaction was assessed against the theoretical variance for the binomial distribution and the probability level for significance was taken as $P \leq 0.05$.

Results and discussion

A total of 5160 eggs was collected from 5208 samples in three trials (Table 1), but overall, only 16% of samples had eggs. Eighty-six percent of all cabbage samples and 80% of rutabaga samples had no eggs. Eggs laid in felt traps were readily visible. Those recovered from soil samples generally were found in the crevice between the soil and the base of the plant; few eggs were found on top of the soil although some were found on the stem at the plant base. Eggs on the soil surface may have been underestimated as they would have been easily accessible to ground beetles and other predators. For example, in the laboratory, *Bembidion lampros* (Coleoptera: Carabidae) and *Amara familiaris* (Coleoptera: Carabidae) ate an average of 6 and 58 cabbage maggot eggs per day, respectively (Finch and Elliott 1994). Both species are present in our study area, with *B. lampros* often in large numbers (Coady 1999).

The pattern of oviposition over the growing season indicated a larger first generation followed by a smaller second generation. For cabbage in 1994, observed peak oviposition by first generation flies was on day 173 (22 June), the first sampling day. Eggs were counted only for cabbage on this date because the rutabaga plants were too small to support traps. Because an unknown portion of early egg-laying was missed, peak oviposition may have occurred earlier than day 173. Based on our studies, adult cabbage maggots begin to emerge at about 180–200 air degree-days (air °d) above a base threshold of 4.4°C (Coady and Dixon 1997). Collier and Finch (1988), using a developmental threshold of 6°C, found that oviposition starts after the accumulation of an additional 60–80°d, which is equivalent to 45–60°d at a base threshold of 4.4°C. On day 173 in 1994, about 262 air °d had accumulated, which meant that the first generation of flies would have emerged, and oviposition begun, earlier in June.

Peak oviposition for the second generation in 1994 occurred on, or about, day 220 (8 August), after an accumulation of approximately 800 air °d at a base threshold of 4.4°C. Finch and Collier (1986) reported that an average of 580°d above a base temperature of 6.0°C are required to complete one generation of cabbage maggot. An additional 100°d, or 700°d in total above 6.0°C, are needed for the next generation to reach its egg-laying peak. At a base of 4.4°C, this is about 520°d, much less than observed in our study. However, Finch and Collier (1986) used soil not air temperatures, and as the populations are from different localities, caution must be exercised when comparing degree-day models.

For cabbage in 1995, the first generation egg counts peaked on day 185 (4 July) at about 300°d, following five previous sampling times. Only 183°d had accumulated by the earliest sampling date on day 172 (21 June) so that most of the oviposition period

TABLE 1. Summary statistics for *Delia radicum* eggs observed in cabbage and rutabaga.

	Cabbage 1994		Cabbage 1995		Rutabaga 1994		
Experimental details	Soil	Trap	Soil	Trap	Soil	Trap	Total
Number of sampling units	1087	1088	752	750	765	766	5208
Samples with eggs	243	122	103	61	139	176	844
Oviposition incidence (%)*	22	11	14	8	18	23	16
Total number of eggs recorded	1913	651	437	448	477	1234	5160
Mean number eggs per sample	1.8	0.6	0.6	0.6	0.6	1.6	1

* Percentage of samples with at least one egg.

TABLE 2. Incidence of oviposition* by *Delia radicum* on felt traps or in soil during different time periods for cabbage in 1994 and 1995 and rutabaga in 1994.

	Period†	Trap (%)	Soil (%)
Cabbage 1994	173–193	18±1.7	45±2.2
	194–214	5±1.3	3±1.0
	215–228	5±1.4	2±0.9
Cabbage 1995	172–185	6±2.5	32±4.8
	186–207	13±2.3	18±2.7
	208–235	6±1.1	7±1.2
Rutabaga 1994	207–217	22±2.6	26±2.8
	218–231	38±3.0	23±2.6
	232–251	13±1.9	5±1.4

NOTE: Values in the last two columns are given as the mean ± SE.

* Percentage of samples with at least one egg.

† Day of year.

would have been included. Between 1994 and 1995 there was a 50–60°d difference in peak oviposition by the first generation. Other studies have shown similar ranges in the degree-days required for emergence of adults from overwintered pupae (Eckenrode and Chapman 1972). There was no obvious second generation in 1995. More eggs were recovered from cabbage plants after mid-July in 1995 than in 1994, possibly because in 1995 there were no neighbouring rutabaga crops to divert flies. In 1994, young rutabaga plants in the adjacent field may have attracted second generation flies away from the cabbage (Ellis *et al.* 1979).

For both cabbage trials, oviposition occurred less often on traps than in soil samples early in the season (Figs. 1*a*, 1*b*). In 1994, eggs were abundant in the first soil count, and the oviposition incidence was much higher in soil (91%) than in traps (14%). There was a total of 911 eggs in soil samples, an average of 14 (SE = 2) eggs per sample and a range of 0–60. On traps there was a total of 44 eggs, an average of 0.7 (SE = 0.3) eggs per trap and a range of 0–12. Eggs were unlikely to have been in the soil before the traps were set because the crop was not present. The lower slope in the fitted curve for the traps indicates fewer daily captures for the remainder of the first generation (Fig. 1*a*). In 1995, the felt traps did not have eggs until after day 178, although soil samples detected eggs on day 172 (Fig. 1*b*). The near parallel curves in 1995 indicate that after an initial delay, a similar number of eggs were found in the felt traps and in the soil samples.

The incidence of oviposition depended on the sampling method and period (Table 2). During the first period (day 173–193) for cabbage in 1994, oviposition occurred in twice as many soil samples as in traps (45 *versus* 18%), but in the later two periods

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twice as many traps as soil samples had eggs present (5 *versus* 3 or 2%). For cabbage in 1995, oviposition in the initial period (day 172–185) occurred on only 6% of the felt traps compared with 32% in soil samples. In the later two periods, the incidence of oviposition for both methods was within sampling variation.

For rutabaga in 1994, only the second generation was monitored because seedlings were too small to support traps when first generation flies were present. At the beginning of the second generation, traps and soil samples had similar numbers of eggs, but later there were more eggs on the traps (Fig. 1*c*). During the initial period (day 207–217), the incidence of oviposition was within sampling variation for both methods (22 *versus* 26%; Table 2), but in later periods twice as many felt traps had eggs as soil samples (38 *versus* 23% and 13 *versus* 5%; Table 2). Overall, there were slightly fewer traps with no eggs at all and twice as many eggs per trap compared with soil samples (Table 1). We observed that when rutabaga with felt traps grew above soil level, all eggs recorded were found on the traps and none on the rutabaga bulb or in the soil. This is probably because after a gravid female lands on the leaves of an acceptable plant, she walks down the stem towards the base and oviposits in the soil (Traynier 1967), or in this case, in the trap.

In the rutabaga 1994 and cabbage 1995, we used regression to explore the response of the number of eggs laid as the proportion of plants visited increased. These relationships could be described with simple linear models ($0.72 < r^2 > 0.96$), with the number of eggs in traps increasing more rapidly than in soil samples as the percent visits increased ($P < 0.01$). This reflects a higher propensity for more eggs to be found on the traps than in the soil when visited. A similar comparison of the cabbage 1994 data was not possible due to a late sampling start. This higher detection level in the traps may be due to decreased egg predation, increased visibility, or other causes.

We also examined whether individual egg traps or soil sample sites with zero eggs on one occasion had eggs deposited at one or more other sampling times, *i.e.*, whether any were chronically visited or avoided. On average over all three trials, 15.1% (SD = 2.6) more traps than soil sites had no eggs at any sampling time, indicating that oviposition site selection was not random and that certain egg traps in particular were avoided through the season. This trend was evident only for traps with zero or few visits; as the number of visits increased, data from soil sites and traps were similar.

Most of the research comparing soil and felt-trap monitoring originates from Europe, where insect pressure is often greater than that encountered in this experiment. Our oviposition rates were either "very low" or "low," according to a scale developed by Bligaard *et al.* (1999). They report that when few eggs were deposited, felt traps considerably underestimated egg numbers, particularly at the beginning of oviposition. Although Meadow *et al.* (1996) report strong correlations between soil samples and felt-trap catches, they too note that felt-trap counts were lower at the beginning of the season when oviposition was low. Ouden and Theunissen (1988) also report that felt traps are not effective when there are few eggs. In their study, 13 times more eggs were recovered from soil samples than from felt traps when the oviposition rate was low, but there was little difference when the rate was high.

Reasons for the apparent inefficiency of the traps, especially at the beginning of the season, may be related to plant age, felt-trap condition, and (or) age and physiological status of the flies. Gravid cabbage maggot females, of the right age and physiological condition, first orient to a host plant by odour and visual cues. Upon landing, contact chemoreception plays an important role in host selection and oviposition behaviour (Roessingh *et al.* 1997). Although the event sequence leading to host-plant acceptance or rejection is well known, factors involved in the decision to lay eggs at the point of ovipositor extension and probing are not. Egg deposition is influenced by soil moisture and organic matter content (Kostal *et al.* 2000), and by the presence of

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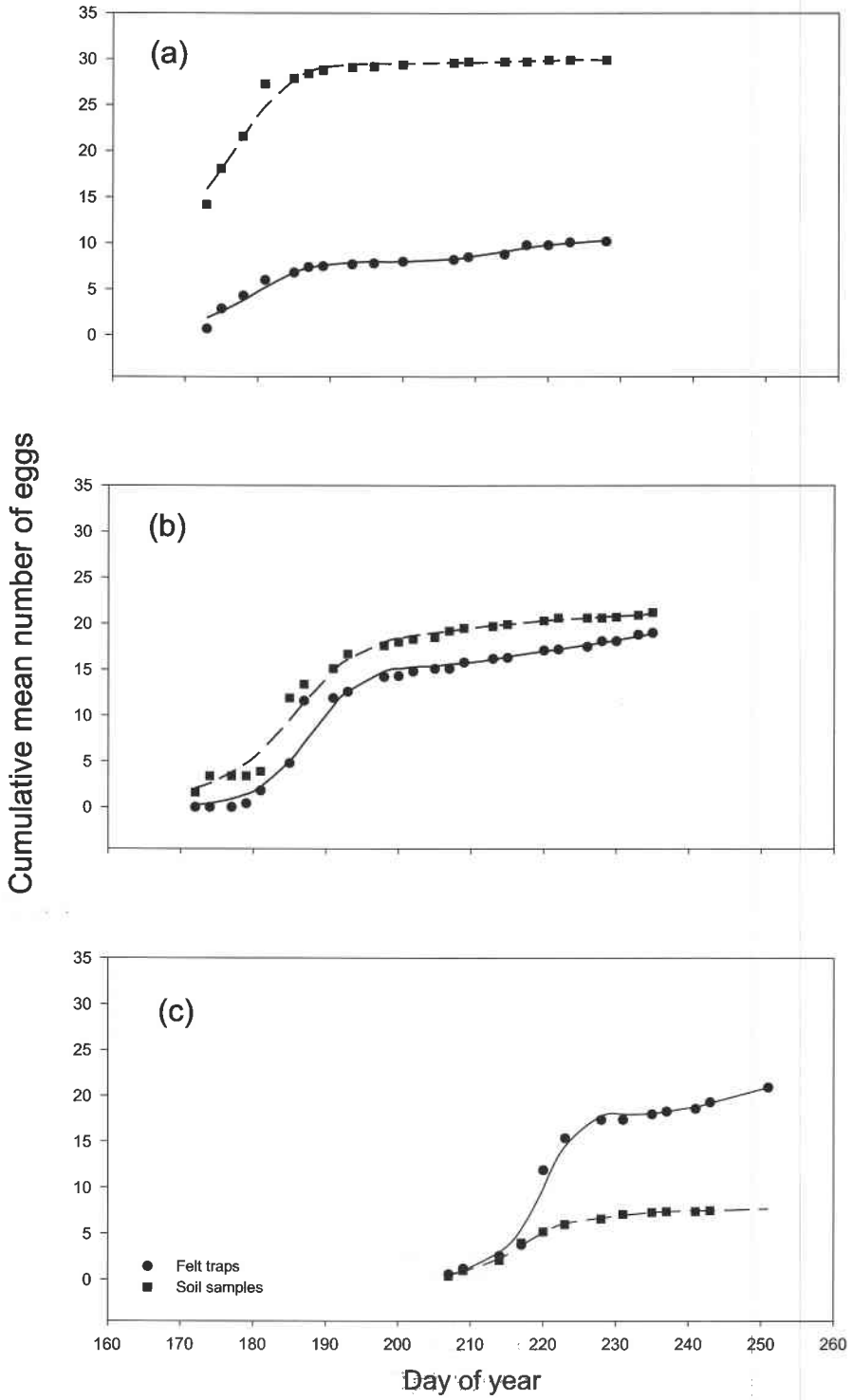

FIGURE 1. Cumulative mean number of *Delia radicum* eggs on cabbage in 1994 (*a*), on cabbage in 1995 (*b*), and on rutabaga in 1994 (*c*). Day 170 = 19 June 1994 and 1995.

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irregularities in the soil particles (Traynier 1967); however, the cues present when the tip of the ovipositor encounters a felt trap are not known. Bligaard *et al.* (1999) postulate that flies depend more on specific stimuli at the beginning of the oviposition period and become less discriminating later. It is possible that when the female is particularly sensitive, felt traps halt the egg deposition process, and thus fewer eggs are recovered from traps than from soil. It should be noted that oviposition was similar on soil and in traps at the beginning of the second generation in rutabaga. Any potential sensitivity was confined to the first generation.

In terms of felt-trap condition, Meadow *et al.* (1996) found that traps did not perform well when extremely wet, dry, or clean. Bligaard *et al.* (1999) reported that traps classified as wet and clean, dry and clean, and dry and soiled, caught relatively fewer eggs than traps with other combinations of moisture and cleanliness. In our study, weather did not appear to affect trap catches, but because precipitation level rather than trap moisture was monitored, we cannot be certain.

In our study, eggs were detected in soil samples, but not on felt traps, early in the season in cabbage plots. For rutabaga, the incidence of oviposition was similar in traps and soil samples, although the number of eggs per plant was higher using the traps. Traps may therefore be useful for monitoring oviposition by second-generation flies, particularly in rutabaga. For first generation cabbage maggot, however, traps are not sufficiently reliable if control measures need to be taken soon after oviposition has started. For crops where thresholds are used, reliable estimates of egg laying are needed, and our results indicate that these traps would not be sufficiently precise. If traps are used to indicate when eggs are present, then some precision can be sacrificed. Presence/absence tests may be an inexpensive way of indicating infestation levels (Meadow *et al.* 1996).

Because felt traps are inexpensive and simple to use (Bromand 1988), they may be acceptable to farmers with little time to assess pest numbers and few options for monitoring the cabbage maggot. Collecting soil from the base of plants and removing eggs by flotation provides a more accurate count, but this method is time consuming and impractical for many growers. As well, a high content of organic matter in the soil, such as in many of the vegetable-growing areas of Newfoundland, would make it difficult to find all of the eggs (Meadow *et al.* 1996). Counting eggs in soil *in situ* is possible, but eggs are small and not easily detected in the field (Bligaard *et al.* 1999).

Temperature-based forecasting models are able to predict adult cabbage maggot emergence on a regional basis (Finch and Collier 1986). Because timing of oviposition over short distances varies due to factors such as temperature microclimates, crop phenology, and the relative proportions of early- and late-emerging biotypes (Walgenbach *et al.* 1993), farm- or field-specific monitoring is necessary to improve the local precision of regional forecasts. Using felt traps alone early in the season would be risky even with the improvement in accuracy that would occur by placing traps in the crop after adult emergence has been forecasted on a regional level. Felt egg traps would not constitute a reliable method for detecting the onset of oviposition by the cabbage maggot, especially for the first generation and when oviposition rates are low.

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