# PHENOLOGY AND DISPERSION OF *DELIA RADICUM* (L.) (DIPTERA: ANTHOMYIIDAE) IN CANOLA FIELDS AT MORINVILLE, ALBERTA

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## ABSTRACT

*The phenology and dispersion of the cabbage maggot,* Delia radicum *(L.) (=* brassicae*), as a pest of Tobin canola (*Brassica campestris *L. cv.) was studied in commercial fields at Morinville, Alberta, from 1982 to 1984.* D. radicum *is predominantly univoltine at Morinville. Adults emerge from overwintered puparia from mid-May to mid-July, and are most abundant in and around canola fields from the end of May through the first three weeks of June. The females commence to oviposit on canola when the crop bolts (about mid-June), preferring plants with greater stem diameter. Larvae inflict root damage mainly during July, by the end of which most have pupated. Most puparia overwinter, and flies of the relatively insignificant second generation do not oviposit on canola. Roots damaged by maggot feeding are invaded by* Fusarium *rot fungi, and it is hypothesized that the crop mortality reported in some seasons occurs when weather conditions favour the spread of fusaria from invasion sites around maggot wounds. Flies aggregate along sheltered field margins during the early season, but this behavior declines and eventually ceases as the crop forms a canopy. Catches of both sexes inside fields indicate a clumped dispersion not related to distances from margins.* D. radicum *varies considerably with respect to emergence dates and the number of generations in different parts of its range. It is argued that marginal climate and shortage of alternate hosts late in the season must select against bivoltinism in the NW Agricultural Region of Alberta, in which Morinville is situated. The populations found in this region are the most northern in North America.*

## RÉSUMÉ

*De 1982 à 1984, l'auteur a étudié la distribution saisonnière et la dispersion de la mouche du chou,* Delia radicum *(L.) (=* brassicae*), ravageant le canola Tobin (*Brassica campestris *L. cv.) dans des champs cultivés près de Morinville en Alberta. D'une manière prédominante* D. radicum *n'a qu'une génération par année à Morinville. Elle passe l'hiver à l'état de puparium et les adultes émergent de la mi-mai à la mi-juillet, atteignant un sommet d'abondance dans les champs de canola de la fin de mai jusqu'à la troisième semaine de juin. Les femelles commencent à pondre lorsque les tiges commencent à s'allonger (environ à la mi-juin), préférant les plants à tige plus grosse. Les larves causent des dommages aux racines surtout en juillet, à la fin duquel la plupart se sont métamorphosées en puparia. La majorité des puparia vont demeurer à ce stade pendant l'hiver, alors que les mouches qui émergent le même été pour former une seconde génération peu importante ne pondent pas sur le canola. Les racines endommagées par les asticots sont envahies par la moisissure* Fusarium, *et l'auteur émet l'hypothèse que la mortalité du canola à certaines saisons a lieu lorsque les conditions climatiques favorisent la dissémination des fusaria à partir des sites d'infection autour des blessures d'asticots. Les mouches se rassemblent le long des bordures abritées des champs tôt en saison, mais ce comportement s'estompe pour éventuellement disparaître pendent que le canola forme un couvert feuillue. Les captures d'individus des deux sexes au milieu des champs indiquent une dispersion contagieuse sans rapport avec la distance les séparant des bordures. Les dates d'émergence et le nombre de générations de* D. radicum *varient considérablement suivant les différentes parties de l'aire de répartition. L'auteur est d'avis que les conditions climatiques marginales et la rareté d'autres plantes-hôtes tard en saison doit exercer une sélection contre la production d'une seconde génération dans la* *région agricole du nord-ouest de l'Alberta où est situé Morinville. Les populations de mouches du chou habitant cette région sont les plus septentrionales d'Amérique du Nord.*

## INTRODUCTION

Root maggots of the genus *Delia* have been recognized as serious pests of cole crops (Brassicaceae/Cruciferae) for more than a century. Their biology and control in market gardens has been intensively investigated both in North America and Europe. However, relatively little attention has been paid to their role as pests of rapeseed cultivars. The only previous journal articles dealing with root maggots as pests of rapeseed in Canada are those of Allen (1964) and Liu & Butts (1982).

This paper deals with the cabbage maggot, *Delia radicum* (L.) ( = *brassicae* Wiedemann, *brassicae* Bouché), as a pest of Tobin canola[1] (*Brassica campestris* L. cv.) at Morinville, Alberta. Morinville is situated about 20 km north of Edmonton City Limits in the NW Agricultural Region as defined by Alberta Agriculture (actually slightly south of the geographical center of the province). *D. radicum* is the primary cause of damage to canola roots at this location, while the turnip maggot, *D. floralis* (Fallén), is of negligible importance (its numbers amounting to only 0.2% of those of *D. radicum*).

The rise of canola rapeseed to the status of a major field crop in Alberta occurred during the 1970's following the introduction of improved cultivars with low erucic acid content (Veeman, 1985). During this period agencies of the Alberta Government received many reports of damage by root maggots, mainly during July and mainly from the more northern areas of cultivation. Surveys to determine the extent of the problem commenced in 1981 (Liu & Butts, 1982; Liu, 1984) and I undertook field studies from 1982 to 1985. These field studies had the objective of obtaining various kinds of basic biological information relevant to consideration of the need for and feasibility of control measures. The studies were conducted in commercial canola fields under normal agricultural practices.

My first year's work in 1982 identified *D. radicum* as the species primarily responsible for damage to canola at Morinville, but the data obtained could not be reconciled with the assumption made by Brooks (1951) that this species has three to five generations a year throughout Canada. Consequently, continuous monitoring of the phenology of all stages of this species was identified as a major component of studies during the following two seasons. The adult sampling program was designed so that dispersion could also be analysed, since conflicting conclusions were reached by recent authors regarding possible edge effects and movement of flies between host crops and field margins.

The data on the phenology of adults are the most extensive of those presented here, being based on study of about 12,000 specimens. Only the 1984 data for immature stages and damage accumulation is presented, this being the most useful for permanent record because of uniform crop development in that season and large sample size. Additional data for Morinville and other sites in the NW Agricultural Region are available in report form (Griffiths, 1985).

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[1]Canola is defined as rapeseed cultivars of *Brassica campestris* L. and *B. napus* L. with $<5\%$ erucic acid and $<3$ mg glucosinolates/g of oil-free meal. Tobin is presently the most widely grown *campestris* cultivar in Northern Alberta, being particularly well suited to areas with a short growing season.

## MATERIAL AND METHODS

### Study Area and Crops

From 1982 to 1984 studies were conducted near Morinville, Alberta (53° 48′N, 113° 39′W), on land farmed by Mr. Maurice Schayes. This land is former lake bottom (Recent Lake Edmonton), now well drained by a network of deep ditches. The soil is one of the richest in Alberta, classified as orthic black (Navarre silty clay loam, mean pH 6.8). Legal descriptions of the fields monitored are SW11-56-25 (1982), NW11-56-25 (1983) and SE22-56-25 (1984). In each field the full quarter-section (0.8 X 0.8 km) except for minor exclusions was sown to Tobin canola, grown in 3- or 4-year rotation with other field crops such as wheat, barley and alfalfa. Sowing dates were May 14-15 in 1982, May 18 in 1983 and May 1-2 in 1984. Seed was treated with "Vitavax RS" (carbathiin: thiram: lindane) for control of seedling diseases and flea beetles, but no insecticides applied subsequently during the growing season.

### Climatic Data

Rainfall in the study fields during the 1983 and 1984 growing seasons was recorded with a "Rainwise" digital rain gauge read three times a week. During the 1984 season a continuous record of soil temperature at 5 and 15 cm depth was obtained with a remote thermograph (Weathertronics Inc.). Calculations of atmospheric thermal units are based on the data for Namao Airport (about 20 km SE of Morinville) published by Environment Canada, with use of Arnold's (1960) table of corrections for days with minima below the assumed developmental zero of 6.1°C (following Eckenrode & Chapman, 1972).

### Sticky Trapping

Eight trapping stations were maintained from May 17 to July 28/29, 1982. Two were sited at the edge of the crop along wooded margins (dominated by *Populus* spp., with dense shrub layer); two on a raised grassy margin (dominated by *Bromus inermis* Leyss.); and four inside the field. Each station consisted of three sticky traps (one yellow, one white, one silvery grey) constructed by stapling painted milk cartons to stakes. The cartons were coated with "tangle trap" on both sides, so that vertical sticky surfaces of about 400 $cm^2$ per trap were presented. Initially the traps were set at about 45 cm above ground, but were raised in late June to keep them just above the crop canopy. Cartons were replaced as necessary (at least every two weeks). All trapped anthomyiid flies were retrieved in vials of diesel oil (a solvent for "tangle trap"), from which they were transferred to 98% ethanol in the laboratory.

### Bowl Trapping

Circular bowls ("Duraware 98") with a depth of 11 cm and internal diameter of 20.5 cm (presenting an aperture of about 330 $cm^2$) were used to trap adult flies during 1983 and 1984. The bowls were half filled with Galt's solution (1:1 mixture of glycerol and water saturated with picric acid) and set with their outturned rims about 5 cm above ground. Three short stakes around each bowl ensured that it could not be overturned. Trapped flies were retrieved in vials of 70% ethanol.

During 1983, 13 trapping stations were maintained from May 20 to August 12 and cleared three times each week. Each station consisted of two bowls (one yellow, one white) and a tall marker stake. Four stations were sited at intervals of 50 m along a raised grassy margin (dominated by *Bromus inermis* Leyss.); nine were sited inside the field at distances from the margin of 50 m (two stations), 100 m (two stations), 150 m (two stations) and 200 m (three stations).

During 1984, 24 trapping stations of the same composition were maintained from May 15 to August 13, and again cleared three times each week. Four stations were sited at the edge of the crop along a wooded margin (containing several *Populus* and *Salix* spp., with dense shrub layer); four at intervals of 50 m along an interface with short grass turf; and 16 inside the field along two transects at distances from the margin of 12.5, 25, 37.5, 50, 75, 100, 150 and 200 m.

**Emergence Trapping**

During 1984, twelve 1 X 1 m emergence traps were placed in the previous season's study field at Morinville. The field had been sown to alfafa but not disced after harvest of the canola. The traps were in place from May 1 to June 13 and (after a gap at the farmer's request) again from June 22 to July 16. Each trap was of pyramidal shape, with a vial of Galt's solution (for collection of emerged insects) suspended below its summit. The same twelve traps were placed on previous season's canola plots on the University Farm (South Edmonton) from May 2 to August 19, 1985.

**Analysis of Trap Catches**

All anthomyiid flies were identified to species and recorded. Females of *D. radicum* were then dissected and classified as non-gravid (in early stages of ovarian development), gravid (containing eggs with striate chorion) or spent (with empty egg follicles). The incidence of two fungal diseases which prevent further reproduction, caused by *Entomophthora muscae* (Cohn) Fresenius and *Strongwellsea castrans* Batko & Weiser, was also recorded. The diseases were distinguished by the manner of sporulation, through intersegmental membranes for *Entomophthora*, into ventral abdominal cavities for *Strongwellsea*.

**Root Sampling**

In 1984, 250 roots were sampled at weekly intervals from June 22 to August 6 (shortly before harvest). Samples consisted of five roots (with surrounding soil cores) collected at each of 50 points along a transect (distance of each point from the preceding randomly selected within a maximum of 50 m). Only plants contributing to the canopy were sampled. The following data were recorded: presence or absence of eggs and first-instar larvae, numbers of second and third instar larvae, damage status, basal stem diameter and growth stage. Root damage was classified into three categories: (1) first-instar damage only (with only fine channels on the upper part of the rootstock), (2) non-lethal late-instar damage (with deeper scars caused by feeding of larvae of the second and/or third instars), and (3) fatal late-instar damage (with rootstock severed or extensively rotting). Basal stem diameters were measured to the nearest millimeter with "Manostat" calipers (Mecanic Type 6911). Growth stages were classified according to Harper and Berkenkamp (1975) (Table 1).

From July 9 to August 6, samples of (approximately) 50 roots in damage category 2 and 50 control roots (without maggot damage) were retained for the purpose of fungal isolation and identification. This work was undertaken at the Fairview Laboratory of Alberta Agriculture. Roots were scrubbed (to remove surface organisms) prior to tissue sampling. For maggot-damaged roots, tissue samples were taken from around the wounds. Three culture media were used (Nash-Snyder, Water Agar and Acidified Potato Dextrose Agar).

Table 1. Growth stages of canola according to Harper & Berkenkamp (1975) (descriptions based on main stem)

| | | |
|---|---|---|
| 0 | | Preemergence |
| 1 | | Seedling |
| 2 | | Rosette |
| | 2.1 | First true leaf expanded |
| | 2.2 | Second true leaf expanded (add 0.1 for each additional leaf) |
| 3 | | Bud |
| | 3.1 | Inflorescence visible at centre of rosette |
| | 3.2 | Inflorescence raised above level of rosette |
| | 3.3 | Lower buds yellowing |
| 4 | | Flower |
| | 4.1 | First flower open |
| | 4.2 | Many flowers opened, lower pods elongating |
| | 4.3 | Lower pods starting to fill |
| | 4.4 | Flowering complete, seeds enlarging in lower pods |
| 5 | | Ripening |
| | 5.1 | Seeds in lower pods full size, translucent |
| | 5.2 | Seeds in lower pods green |
| | 5.3 | Seeds in lower pods green-brown mottled |
| | 5.4 | Seeds in lower pods brown |
| | 5.5 | Seeds in all pods brown, plant senescent |

**Puparium Sampling**

During 1983 and 1984 samples of puparia were obtained after swathing of the canola crop by searching soil within 0.5 X 0.5 m quadrats (randomly selected). All anthomyiid puparia were collected for identification and rearing.

## RESULTS

**Adult Phenology**

Adults of *D. radicum* emerge after overwintering as puparia in the soil. At Morinville they were first trapped around fields sown to canola in samples for May 21-25 (1982), May 23-25 (1983) and May 15-18 (1984), and became abundant by the end of May (Fig. 1-3). In each year high catches continued through about the first three weeks of June, except when activity was depressed by cold rainy weather. During the last week of June through July catches declined, and by early August only occasional flies were taken.

The bowl traps used in 1983 and 1984 (Fig. 2-3) caught males in greater numbers than females only at the beginning of the season; numbers of either sex became similar in early June, and from late June females were taken in greater numbers than males. The sticky traps used in 1982 caught generally higher numbers of males throughout the season, consistent with the relative inefficiency of such traps in capturing females reported by Finch & Skinner (1982).

The majority of females taken up to the end of June were non-gravid, and such females continued to be present throughout the season (Table 2). This suggested that recently emerged flies were immigrating over an extended period. Emergence trapping (Table 3) has confirmed

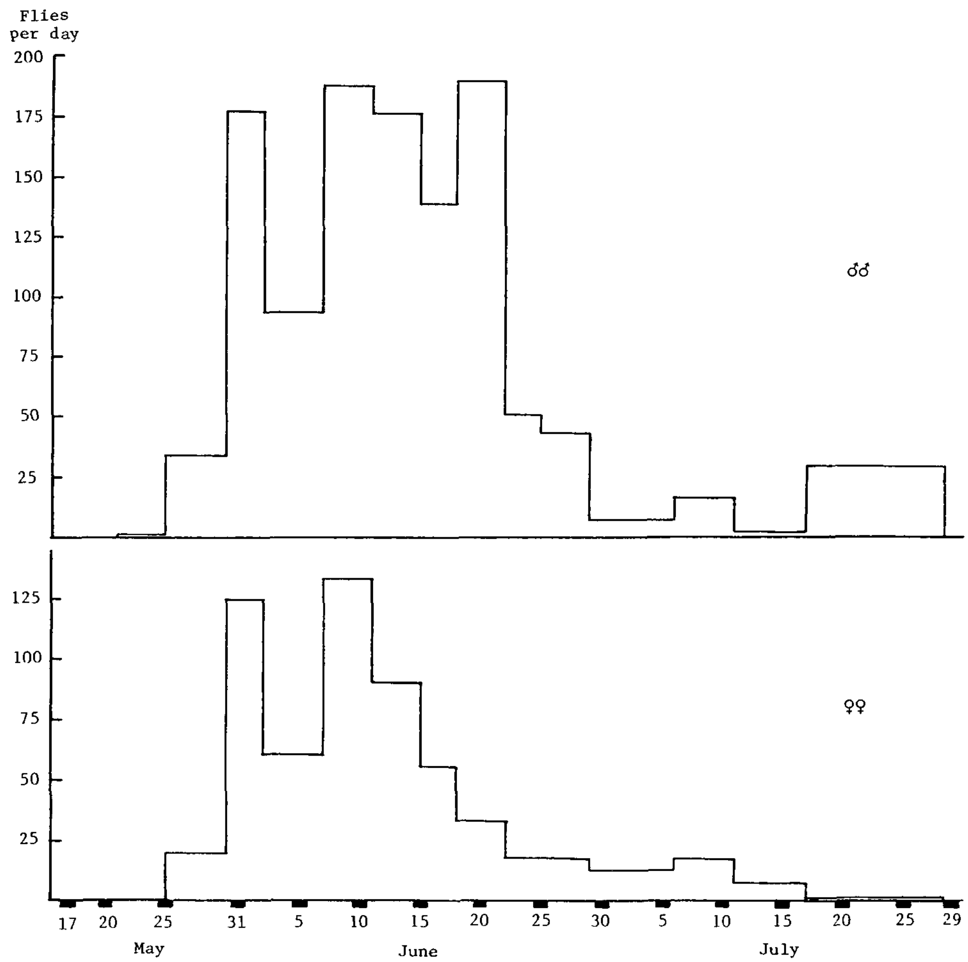


Fig. 1. Captures of adults of *D. radicum* (L.) on sticky traps in and around canola field during 1982.

that the adults emerge from overwintered puparia from late May to mid-July. In 1984 adults of *D. radicum* were taken in emergence trap catches at Morinville from May 23-25 to July 13-16; the corresponding dates for 1985 (Edmonton data) are May 24-27 to July 5-8.

Gravid females were present from the last week in May, well before the start of oviposition on the canola crop, and continued to be present throughout the season.

Females infected with either of the two fungal diseases, *Entomophthora muscae* (Cohn) Fresenius and *Strongwellsea castrans* Batko & Weiser, may be counted as non-reproductive. Those infected with *E. muscae* show general degeneration of their internal organs. *S. castrans* does not invade the reproductive organs, but infected females are reported to be unable to

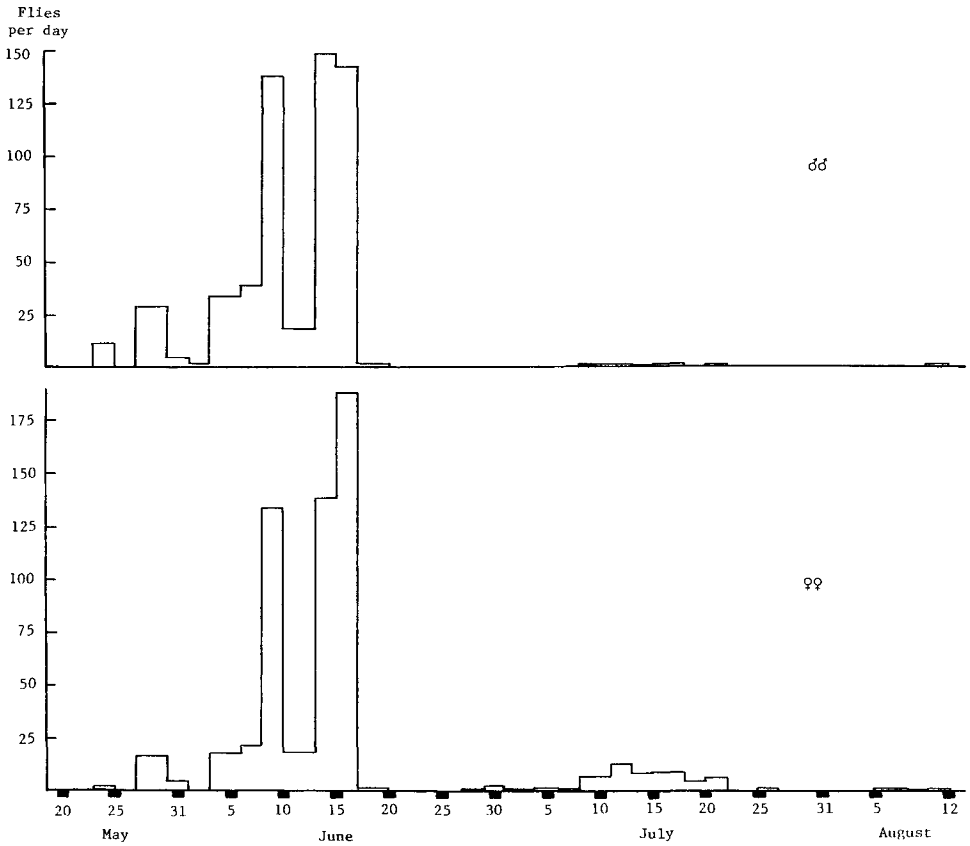


Fig. 2. Captures of adults of *D. radicum* (L.) in 26 bowl traps in and around canola field during 1983.

reproduce because of inadequate nutrition for their eggs (Nair and McEwen, 1973; Humber, 1976). I accept this conclusion, since I did not find mature eggs inside any females so infected. Neither disease became prevalent at Morinville until late June. During July 1983 a considerable epidemic of *S. castrans* was recorded.

Since it was demonstrated that adults of the first generation continue to emerge during July, the appearance of a second generation cannot be inferred from the trap data (Fig. 1-3). The low mid-July peak of females in 1983 consisted largely of old diseased individuals, surely belonging to the first generation. Collections of puparia in canola fields have confirmed that very few adults emerge during the same season. For instance, only two flies emerged during the same season from 110 puparia collected during August 1984. The data indicate that *D. radicum* is predominantly univoltine at Morinville.

**Oviposition**

Although gravid females first appeared around canola fields in late May, they did not oviposit on the crop while this remained in the seedling and rosette stages. During early June,

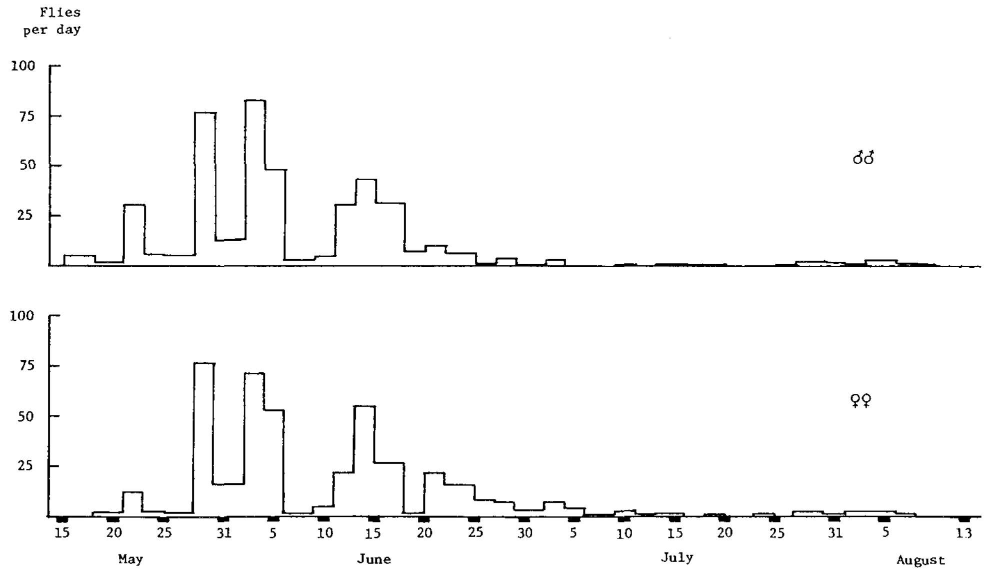


Fig. 3. Captures of adults of *D. radicum* (L.) in 48 bowl traps in and around canola field during 1984.

larvae of *D. radicum* have been found in the Edmonton area only on early-sown garden cole crops (such as radish and cabbage) and on weeds growing as winter annuals, especially volunteer rapeseed and stinkweed, *Thlaspi arvense* L..

The canola crop monitored in 1984 (Table 4) began to bolt on June 13. On June 15 eggs were recorded on 8.4% of plants, indicating that oviposition had commenced about the time of bolting. All plants with eggs on that date were at stage 3.2 (*i.e.*, the bud stage with inflorescence raised above the level of the rosette).

In canola the eggs are normally deposited on the base of the stem or on adjacent soil. Analysis of stem diameter data indicates that plants with greater stem diameter are preferred for oviposition (Table 5).

The peak of oviposition in 1984 was not determined, since rainfall prior to sampling made some values for the proportion of plants with eggs unreliable. However, most oviposition must have been completed by July 6, since gravid females were scarce after that date. On July 30 eggs were found on only 0.8% of plants. The absence of larvae in late August (when puparia were sampled) confirmed that there was no second period of oviposition on canola during August.

**Larval Phenology and Damage Accumulation**

In 1984 (Table 4) larvae were first recorded on June 22, becoming common (but mostly still in first instar) by the end of June. The highest proportions of plants with late- (second- and/or third-) instar larvae were recorded on July 9 and July 16. Thereafter numbers of larvae declined, and only 2% of plants still had late-instar larvae on August 6 (about a week before swathing). No larvae were found on August 21 and 27 (after swathing).

Table 2. Captures of adult females of *D. radicum* (L.); breakdown according to ovarian condition and disease status during different stages of crop development.

| 1982 (48 sticky traps) | [1]Period 1<br>My 21 - Je 15 | Period 2<br>Je 15 – 29 | Period 3<br>Je 29 - Jy 29 |
|---|---|---|---|
| Non-gravid | 1242 | 309 | 67 |
| Gravid | 425 | 81 | 74 |
| Spent | 0 | 1 | 27 |
| *Strongwellsea* - infected | 0 | 0 | 1 |
| *Entomophthora* - infected | 0 | 32 | 64 |
| 1983 (26 bowl traps) | My 23 - Je 13 | Je 13-29 | Je 29 - Au 12 |
| Non-gravid | 325 | 504 | 16 |
| Gravid | 160 | 154 | 15 |
| Spent | 0 | 0 | 1 |
| *Strongwellsea* - infected | 0 | 0 | 104 |
| *Entomophthora* - infected | 0 | 0 | 3 |
| 1984 (48 bowl traps) | My 15 - Je 13 | Je 13-29 | Je 29 - Au 10 |
| Non-gravid | 460 | 235 | 44 |
| Gravid | 92 | 70 | 17 |
| Spent | 0 | 5 | 6 |
| *Strongwellsea* - infected | 0 | 6 | 11 |
| *Entomophthora* - infected | 1 | 1 | 0 |

[1]The periods into which the data are divided approximately represent the early season from crop germination to bolting (period 1), the mid season of rapid crop growth (period 2), and the late season of full crop canopy (period 3).

The persistence of a high proportion of plants showing first-instar damage only (Table 4) is believed to be due to the destruction of larvae by carabid and staphylinid beetles. A complete list of predatory beetles trapped in the field is available in report form (Griffiths, 1985). Several of the most abundant species are known or suspected to include root maggots in their diet (see Wishart *et al.*, 1956; Coaker and Williams, 1963; Coaker, 1965; Finlayson and Campbell, 1976).

The more severe damage caused by feeding of late-instar larvae normally consists of more or less vertical furrows on the main rootstock (Fig. 4). Most such damage was inflicted during July (Table 4). By August 6 the proportion of plants showing late-instar damage rose to 43.2%, which must have approached the cumulative total for the season since very few larvae were still feeding at that date.

Larvae which have fed on canola roots normally form puparia in neighbouring soil, rarely in their feeding furrows. The peak of puparium formation at Morinville in 1984 occurred between

Table 3. Captures of adults of *D. radicum* (L.) in 12 emergence traps (each 1 x 1 m) set in fallow fields under canola the previous season (1984 data for Morinville, 1985 data for University Farm, South Edmonton).

| 1984 dates | Males | Females | 1985 dates | Males | Females |
|---|---|---|---|---|---|
| My 1–23 | 0 | 0 | My 2–24 | 0 | 0 |
| My 23–25 | 1 | 0 | | | |
| My 25–28 | 0 | 1 | My 24–27 | 1 | 2 |
| My 28–30 | 0 | 0 | My 27–30 | 0 | 1 |
| My 30–Je 2 | 0 | 2 | My 30–Je 2 | 0 | 0 |
| Je 2–4 | 2 | 1 | Je 2–5 | 3 | 0 |
| Je 4–6 | 1 | 1 | Je 5–8 | 2 | 1 |
| Je 6–9 | 1 | 1 | | | |
| Je 9–11 | 2 | 2 | Je 8–11 | 1 | 0 |
| Je 11–13 | 1 | 0 | Je 11–14 | 4 | 0 |
| | | | Je 14–17 | 0 | 3 |
| Je 13–22 | na | | Je 17–20 | 5 | 3 |
| Je 22–25 | 0 | 1 | Je 20–23 | 1 | 1 |
| Je 25–27 | 0 | 0 | Je 23–26 | 0 | 0 |
| Je 27–29 | 0 | 2 | Je 26–29 | 1 | 2 |
| Je 29–Jy 2 | 2 | 2 | Je 29–Jy 2 | 0 | 2 |
| Jy 2–4 | 1 | 0 | | | |
| Jy 4–6 | 0 | 0 | Jy 2–5 | 0 | 0 |
| Jy 6–9 | 0 | 3 | Jy 5–8 | 0 | 1 |
| Jy 9–11 | 0 | 0 | Jy 8–Au 19 | 0 | 0 |
| Jy 11–13 | 0 | 0 | | | |
| Jy 13–16 | 1 | 1 | | | |
| Jy 16– | na | | | | |

July 16 and July 23, as indicated by the divergence of the values for roots with late-instar damage and roots with late-instar larvae between these dates (Fig. 5). In 1983 the peak at Morinville was about one week later in a later sown crop (Griffiths, 1985).

Confirmation that the 1984 data on immature stages and damage accumulation was entirely attributable to *D. radicum* was provided by a sample of 115 puparia collected from the soil on August 21 and 27. Of these puparia 110 were identified as belonging to *D. radicum*, the remaining five as those of the saprophagous *Pegohylemyia betarum* (Lintner).

**Crop Mortality**

During 1984 only 1.2% mortality of plants attacked by larvae of *D. radicum* was recorded (Table 4). However, Liu and Butts (1982) estimated 13.5% mortality on the same farm in 1981, and a similar level of mortality is suggested by 1983 data (Griffiths, 1985).

Table 4. Progress of root maggot infestation in canola field during 1984.

| Dates | n | unaffected % | eggs only % | total with eggs % | first-instar damage only % | non-lethal late-instar damage % | fatal late-instar damage % | total with late-instar larvae % | predominant growth stage (see Table 1) |
|---|---|---|---|---|---|---|---|---|---|
| Je 2 | 100 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 2.2 |
| Je 9 | 100 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 2.3 |
| Je 15 | 500 | 91.6 | 8.4 | 8.4 | 0 | 0 | 0 | 0 | 3.2 |
| Je 22 | 250 | 93.2 | >2.8 | >2.8 | 2.8 | 1.2 | 0 | 1.2 | 3.3 |
| Je 29 | 250 | 80.4 | 6.0 | 8.8 | 11.6 | 2.0 | 0 | 0.8 | 4.1/4.2 |
| Jy 9 | 250 | 56.4 | >0.4 | >1.2 | 25.2 | 17.2 | 0.8 | 16.4 | 4.2/4.3 |
| Jy 16 | 250 | 33.6 | >2.0 | >4.0 | 45.2 | 19.2 | 0 | 13.6 | 4.4 |
| Jy 23 | 250 | 46.4 | >0 | >0 | 22.4 | 31.2 | 0 | 4.0 | 5.1 |
| Jy 30 | 250 | 26.8 | 0.4 | 0.8 | 34.0 | 38.4 | 0.4 | 3.2 | 5.2 |
| Au 6 | 250 | 17.8 | 0 | 0 | 39.6 | 42.0 | 1.2 | 2.0 | 5.3 |

Data are expressed as the percentage of plants in each category.
"Late-instar" in the above column headings means second and/or third instar. Certain recorded values for the percentage of plants with eggs (those preceded by >) are believed to be underestimates, since rainfall prior to sampling may have washed eggs into the soil where they were not seen.

**Association of Maggot Damage and Fungal Root Rot**

Fungal isolation from the series of root samples collected in 1984 gave inconclusive results for *Rhizoctonia* and *Pythium*, but demonstrated that maggot-damaged roots were invaded by *Fusarium* spp. with far greater frequency than were roots without maggot damage (Fig. 6). By August 6 the incidence of fusarial infection in maggot-damaged roots rose to 66%, while the corresponding value for control roots (without maggot damage) was only 14%. Four species of *Fusarium* have been identified in cultures grown from these isolates: *Fusarium avenaceum* (Corda ex Fr.) Sacc. *Fusarium sambucinum* Fuckel, *Fusarium tricinctum* (Corda) Sacc. and *Fusarium acuminatum* Ellis & Everh. (determined by Dr. G. A. Neich of the Biosystematics Research Institute, Agriculture Canada).

**Dispersion**

Flies were consistently trapped in much higher numbers along sheltered (wooded or tall grass) field margins than inside the fields during the early season, while the crop was still in the seedling or rosette stages (Table 6). During the mid season of rapid crop growth and oviposition (period 2 of Table 6), the proportion of flies taken along sheltered margins was initially high but declined as the crop began to flower and to develop a canopy. During the late season of full

Table 5. Mean basal stem diameters of Tobin canola plants attacked and not attacked by *D. radicum* (L.) during 1984.

| Dates | Mean diam. of plants attacked (mm ± 1 S.D.) | (n) | Mean diam. of plants not attacked (mm ± 1 S.D.) | (n) | *t* |
|---|---|---|---|---|---|
| Je 22 | 7.35 ± 2.11 | (17) | 6.76 ± 1.66 | (233) | 1.386 |
| Je 29 | 7.69 ± 1.92 | (49) | 6.58 ± 1.88 | (201) | 3.690* |
| Jy 9 | 7.86 ± 1.92 | (109) | 7.06 ± 1.85 | (141) | 3.335* |
| Jy 16 | 8.16 ± 1.55 | (166) | 7.53 ± 1.67 | (84) | 2.957* |
| Jy 23 | 8.46 ± 1.55 | (134) | 7.43 ± 1.45 | (116) | 5.399* |
| Jy 30 | 8.32 ± 1.43 | (183) | 7.73 ± 1.30 | (67) | 2.959* |
| Au 6 | 8.43 ± 1.55 | (207) | 6.98 ± 1.05 | (43) | 5.861* |

*Differences between means significant at $P < 0.01$.
The data for plants attacked include every plant for which eggs, larvae or root damage attributable to *D. radicum* were recorded. Only plants contributing to the canopy were sampled.

crop canopy (period 3 of Table 6), catches along sheltered margins ceased to be consistently higher than inside the fields and were actually lower in two of the three seasons.

The adult data for 1983 and 1984 are suitable for analysis for possible edge effects (i.e. decline of catches with increasing distance from field margins) (Table 7). No such effect was demonstrated in either year. The calculated correlations between catches and distances are either non-existant or far too low to reject the null hypothesis (that there is no edge effect) at $P = 0.05$.

The 1983 and 1984 data have also been tested for random dispersion inside the fields by comparing the mean and variance of catches on particular dates. If dispersion were random, the mean ratio of the values (and slope of the regression line) should approach unity. The calculation for 1983 is shown in Fig. 7. This demonstrates a strongly clumped dispersion when the flies were abundant, without significant difference between the sexes. Results for 1984 are similar but less conclusive due to a lack of high values.

## DISCUSSION

### Phenology

The finding that *D. radicum* is predominantly univoltine at Morinville refutes Brooks' (1951: 116) assumption that this species (as *Hylemya brassicae*) has three to five generations a year throughout Canada. Evidently, Brooks made an invalid generalization on the basis of data for southern Ontario. Subsequent literature has shown that this species varies considerably with respect to emergence dates and the number of generations in different parts of its wide holarctic range.

Finch and Collier (1983) have classified populations in England and Wales into early-, intermediate- and late-emerging types, with different mean day-degree requirements for emergence after overwintering. They demonstrated that this variation with respect to

Table 6. Captures of adults of *D. radicum* (L.); comparison between captures on field margins and inside fields during different stages of crop development.

| 1982 (each value for 6 sticky traps) | Period 1 My 21 - Je 15 Males | Females | Period 2 Je 15–29 Males | Females | Period 3 Je 29 - Jy 29 Males | Females |
|---|---|---|---|---|---|---|
| Wooded margin | 1450 | 1322 | 545 | 294 | 22 | 46 |
| Grassy margin | 1046 | 182 | 800 | 85 | 69 | 48 |
| Inside field | 65 | 81.5 | 75.5 | 22 | 205 | 75 |
| 1983 (each value for 8 bowl traps) | My 23 - Je 13 Males | Females | Je 13–29 Males | Females | Je 29 - Au 12 Males | Females |
| Grassy margin | 305 | 281 | 296 | 266 | 6 | 13 |
| Inside field | 114.9 | 90.7 | 129.3 | 174.2 | 9.7 | 56 |
| 1984 (each value for 8 bowl traps) | My 15 - Je 13 Males | Females | Je 13–29 Males | Females | Je 29 - Au 10 Males | Females |
| Wooded margin | 458 | 397 | 118 | 113 | 11 | 23 |
| Turf interface | 82 | 18 | 18 | 19 | 1 | 3 |
| Inside field | 25.25 | 34.5 | 27.75 | 46.25 | 7.25 | 13 |

emergence is heritable, and hence genetically based. The populations monitored at Morinville show an extended emergence period (indicative of genetic heterogeneity) comparable with Finch and Collier's late-emerging type.

The previously reported populations whose phenology is most similar to that recorded at Morinville are those in southern Finland. Varis (1967) there reports the presence of adults and immature stages of the first generation during similar time periods, but adults of the second generation (peaking in August) were relatively more numerous.

Most previous Canadian studies of *D. radicum* refer to multivoltine populations found in southern British Columbia, Ontario and Quebec. Nair and McEwen (1975) reported three complete generations and usually a partial fourth in southwestern Ontario; in most years emergence from overwintered puparia peaked in mid-May, and numbers of flies taken in traps peaked narrowly about May 20-25. In the light of Finch and Collier's (1983) conclusions, I infer that these multivoltine populations must be genetically more homogenous with respect to emergence after overwintering than are the populations at Morinville.

Read (1985) has reported that populations on rutabagas in Prince Edward Island are partly univoltine (some puparia of the first generation overwintering). But adults of all populations sampled by Read commenced to emerge after overwintering much later than at Morinville, with peaks in July or even August. Since the soil temperatures recorded for Prince Edward Island and the Edmonton area differ little during May and June, I infer that the genetic

Fig. 4. Washed roots of Tobin canola (*Brassica campestris* L. cv.) damaged by larval feeding of *D. radicum* (L.), July 23, 1984. Note the discoloration around the feeding scars indicative of fungal invasion of the tissue.

properties of populations of *D. radicum* in these two areas must be very different with respect to emergence.

Whether the predominant univoltinism recorded at Morinville applies to populations throughout the prairie provinces requires clarification. Swailes (1958) reported two generations a year infesting crops grown under irrigation in SW Alberta, but his data do not demonstrate whether the second generation is complete or only partial. Allen's (1964) assumption that there are two generations a year in Manitoba was not supported with valid data. His statement that well developed maggots were found on rapeseed roots in mid-October requires comment: Roots of the season's rapeseed crop decompose after harvest in August and become unsuitable as food for phytophagous larvae like those of *D. radicum*. If larvae were found in October, either they were feeding on late-germinated plants or they were saproghagous larvae not belonging to *D. radicum*. Allen's data for relative numbers of larvae and puparia of the first generation suggest

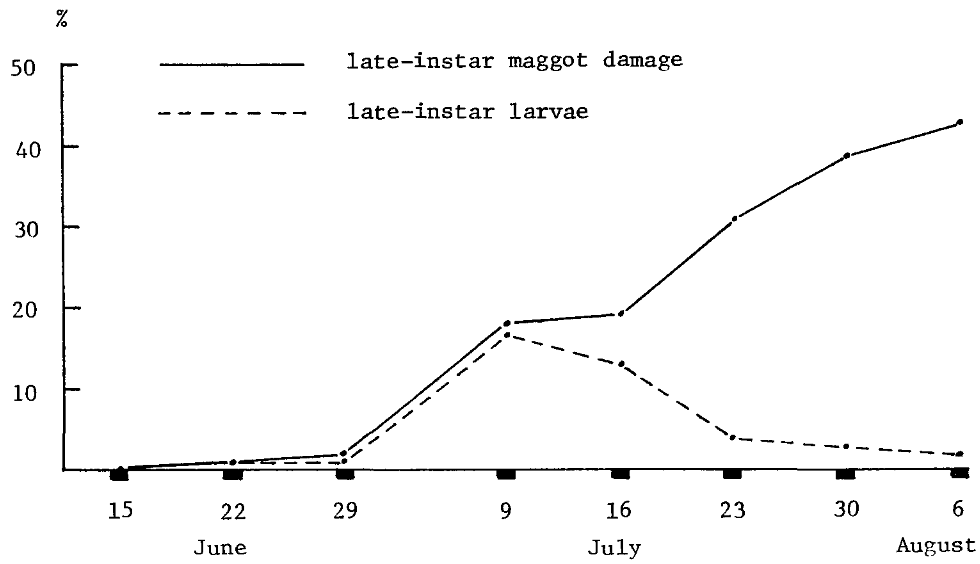


Fig. 5. Accumulation of late-instar maggot damage to canola roots in comparison with presence of late-instar larvae during 1984. Data are expressed as percentages of roots examined (sample size 250). The divergence of the lines plotted between July 16 and 23 indicates that the peak of puparium formation occurred during this period.

a peak of puparium formation in agreement with my 1983 data for Morinville (about one week later than in 1984). So it is possible that the phenology of populations in Manitoba is essentially the same, but further information is needed.

**Environmental Considerations**

Eckenrode and Chapman (1972) have estimated that in Wisconsin 653 atmospheric day-degrees (C°) are required for each non-overwintering generation of *D. radicum*, assuming a developmental zero of 6.1°. How valid this estimate is for Alberta is uncertain. There may be genetic differences between populations with respect to day-degree requirements, and local relationships between atmospheric temperatures and the soil temperatures to which larvae and puparia are exposed may differ. Nevertheless, it may be instructive to apply Eckenrode and Chapman's estimate, as the best available.

If May 20 is assumed as the first emergence date for overwintered females at Morinville, then 653 day-degrees from that date would have accumulated by July 27 in 1982, by July 29 in 1983 and by August 1 in 1984. If these dates are accepted as the earliest possible emergence dates for adults of the partial second generation, then the numbers of flies possibly belonging to this generation taken at Morinville were relatively insignificant. The remaining day-degrees from August 1 were 490 in 1982, 540 in 1983 and 523 in 1984. Eckenrode and Chapman's data suggest that 450-500 day-degrees are required after the emergence of second-generation females for their progeny to reach the stage of puparial diapause. Accordingly, the remaining day-degrees after August 1 are marginal for the survival of progeny of second-generation flies

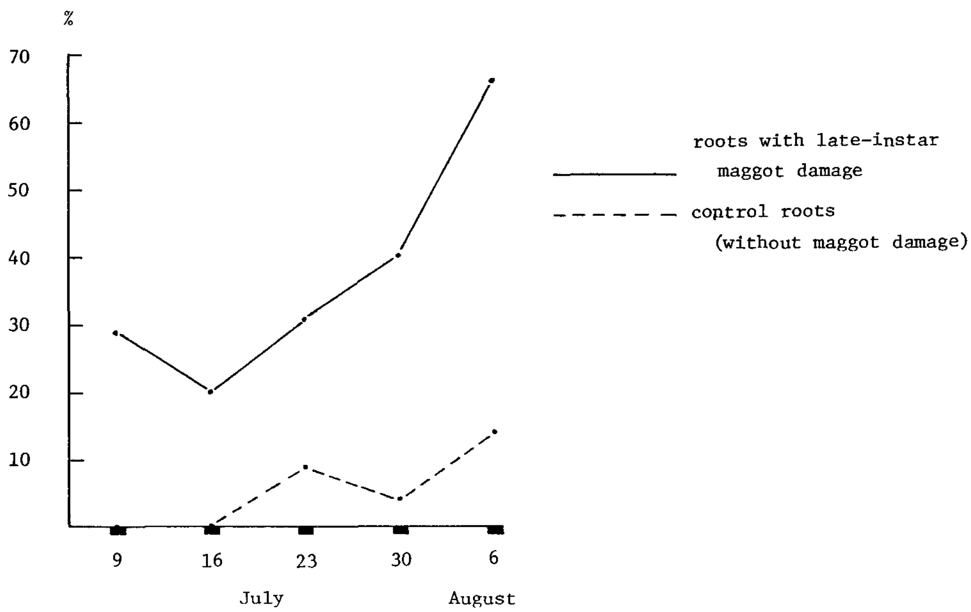


Fig. 6. Influence of late-instar maggot damage on frequency of fusarial infection of canola roots during 1984. Data are expressed as the percentages of roots examined, based on intended samples of 50 (actually 49–65) in each category. Differences on all dates are highly significant in $\chi^2$ test of 2X2 table, $P < 0.001$.

and losses due to freezing before diapause must occur.

Since canola becomes senescent in August and no longer attractive for oviposition, the partial second generation of adults must seek alternate hosts. The most suitable hosts in late summer and fall are root crops, such as turnip and rutabaga, but they are not extensively grown in Alberta. An exception is the market-garden area in NE Edmonton, where larvae of the second generation can be found on rutabaga up to freezeup in late October (M. Steiner, personal communication). Possibly the second generation is relatively more numerous at this location because of the cultivation of root crops. Outside market-garden areas, a shortage of alternate hosts late in the season, as well as marginal climate, must tend to select against bivoltinism. The numbers of adult flies emerging from canola fields is enormous (estimated in the range of millions per quarter section in 1984 and 1985), and the supply of alternate hosts for oviposition would be grossly insufficient if more than a small fraction of these flies emerged during the same season. The early commencement of emergence in the spring (before the new canola crop is suitable for oviposition) is probably to be explained by the availability of stinkweed, *Thlaspi arvense* L., a very abundant weed in Alberta. This is most suitable as a host early in the season. In late summer stinkweed becomes senescent, and the general availability of cruciferous weeds is reduced by harvesting operations and cultivation of fallow fields for weed control.

Microclimatic conditions in canola fields are most favourable for larvae of *D. radicum* during July, when the full crop canopy stabilizes soil temperatures. The continuous record of soil temperatures maintained at Morinville in 1984 showed that the mean temperature at 5 cm

Table 7. Captures of adults of *D. radicum* (L.) in bowl traps on transects inside canola fields; analysis for possible edge effects (calculation of correlation between actual ranks and ranks expected on the assumption of an edge effect, using Spearman's rank correlation coefficient $r_s$).

| | Trapping Station | Distance (m) from margin | Numbers of flies Males | Females |
|---|---|---|---|---|
| 1983 | 1 | 50 | 30 | 55 |
| | 2 | 50 | 85 | 104 |
| | 3 | 100 | 75 | 77 |
| | 4 | 100 | 71 | 66 |
| | 5 | 150 | 62 | 102 |
| | 6 | 150 | 101 | 93 |
| | 7 | 200 | 97 | 104 |
| | 8 | 200 | 58 | 58 |
| | 9 | 200 | 62 | 63 |
| 1984 | 1 | 12.5 | 14 | 34 |
| | 2 | 12.5 | 25 | 22 |
| | 3 | 25 | 26 | 30 |
| | 4 | 25 | 8 | 26 |
| | 5 | 37.5 | 10 | 23 |
| | 6 | 37.5 | 25 | 25 |
| | 7 | 50 | 9 | 15 |
| | 8 | 50 | 10 | 23 |
| | 9 | 75 | 5 | 8 |
| | 10 | 75 | 20 | 29 |
| | 11 | 100 | 4 | 8 |
| | 12 | 100 | 26 | 19 |
| | 13 | 150 | 9 | 15 |
| | 14 | 150 | 14 | 32 |
| | 15 | 200 | 9 | 7 |
| | 16 | 200 | 27 | 59 |

$r_s$ = 0.00 (males 1983), 0.03 (females 1983), 0.11 (males 1984) and 0.28 (females 1984).

depth during July was 12.3° (C ) with mean daily fluctuation of 6° (i.e. 3° above and below the mean); at 15 cm depth the mean was 13.6° and the mean daily fluctuation 4°. According to Read (1965) larvae of *D. radicum* suffer mortality if continuously exposed to temperatures above 22°. This soil temperature was not reached during July, so larvae were not exposed to heat stress.

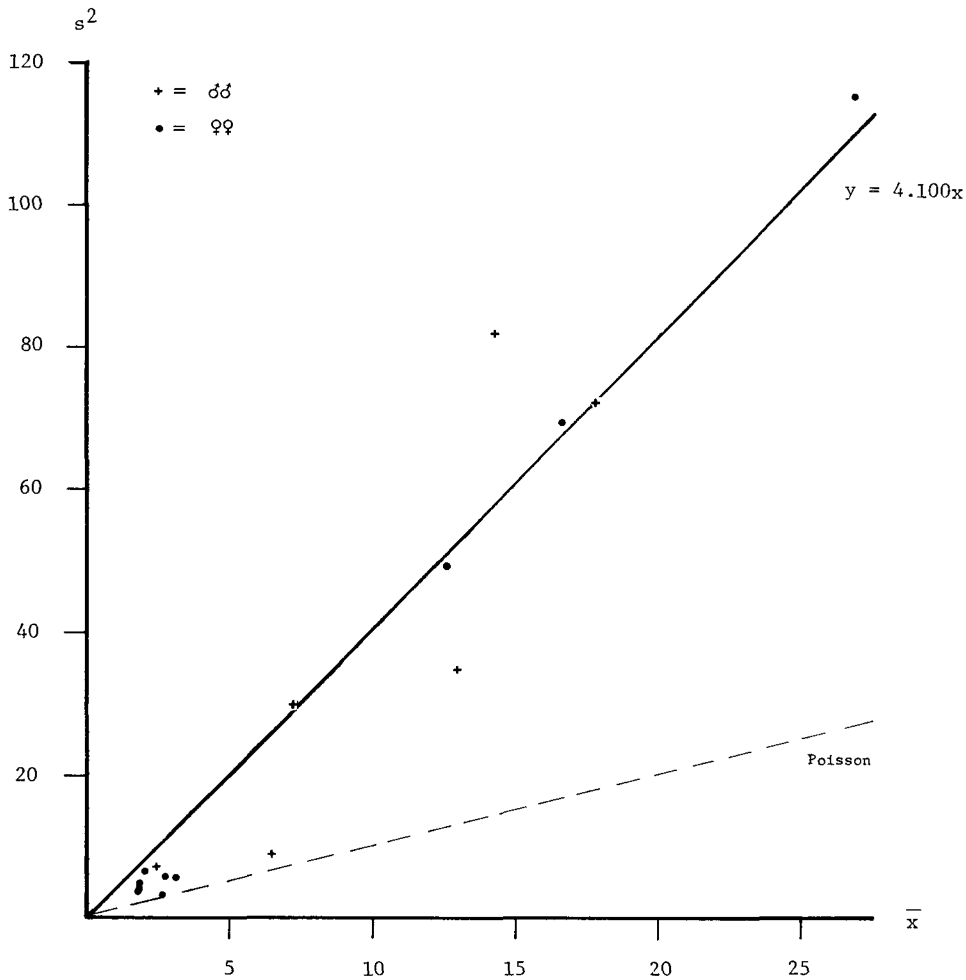


Fig. 7. Captures of adults of *D. radicum* (L.) inside canola field during 1983 analysed for deviance from Poisson distribution. $\bar{x}$ and $s^2$ = mean and variance of catches per trapping station (for 2- or 3–day periods). Points have been plotted for all dates with mean catch for either sex greater than 1. The difference in slope between the regression line plotted and that given by the Poisson distribution (x = y) is highly significant (slope of regression line 4.100 ± 0.223; slope for Poisson distribution 1.000). A single regression line has been drawn, since those for males and females calculated separately are not significantly different.

**Crop Mortality**

the validity of attributing mortality in canola crops to root maggot attack requires comment. R. S. McDonald (personal communication) has found that plants grown in sterile soil in the laboratory are not killed at levels of infestation far higher than the maximum of five late-instar larvae per root observed in the field. This suggests either that attribution of mortality to maggot feeding is erroneous, or that additional factors not duplicated in McDonald's work are involved. Since many roots of plants severed following maggot attack show symptoms of fungal root rot, the question arises whether invasion of roots by pathogenic fungi is facilitated by maggot damage or merely coincidental. The sampling program designed to answer this question has given an unambiguous answer: the correlation of *Fusarium* infection with maggot damage is highly significant (Fig. 6), but no significant correlation was demonstrated for any other group of fungi. This suggests the hypothesis that crop mortality in maggot-infested fields occurs when weather conditions favour the spread of fusaria from invasion sites around maggot wounds. Whether this hypothesis is correct may not be determined for some time, since pathogenicity trials of the several species of *Fusarium* isolated are required.

**Dispersion**

Differing observations have been published regarding the movement of adults of *D. radicum* between host crops and field margins. Hawkes (1972) reported that the flies showed a cyclical daily pattern of activity in a cabbage field in England, visiting the crop in the early afternoon then returning to hedgerows for feeding on flowers; numbers of flies captured in traps declined with increasing distances from hedgerows. However, Finch and Skinner (1973) failed to confirm aggregations in hedgerows at another site, but reported that males tended to aggregate along crop interfaces particularly during the first generation. Reasons for the different behavior at different sites are not fully understood.

The present data for canola fields can be explained in terms of seasonal changes in the availability of food and shelter, as follows: While canola is still in the seedling or rosette stages (period 1 in Table 6), it provides little shelter from wind or sun, since the rosette leaves normally do not exceed a few cm in length. Nor are there any food sources inside the fields. Aggregations of flies along sheltered field margins during this period surely occur generally in Alberta, having also been documented at two other continuously monitored sites (Griffiths 1985). The need for flies to seek food and shelter along field margins declines during the mid season of rapid crop growth and commencement of flowering (period 2 in Table 6). During the late season of full crop canopy (period 3) the crop provides both food and excellent shelter, and flies have no need to commute from field margins.

Differences between the present results and those obtained in row crops like cabbage may be attributed to the very different physical structure of the crops. During the early season canola provides much inferior shelter to that provided by most row crops because of the smaller size of the plants; but during the late season it forms a complete canopy providing much superior shelter to that provided by any row crop.

It is noteworthy that no edge effect was detected at Morinville in rows of traps extending up to 200 m from field margins. This suggests that the average distance travelled by flies commuting from field margins must exceed 200 m. The edge effect at much shorter distances reported by Hawkes (1972) may have been due to some peculiarity of the field studied, since neither Finch and Skinner (1973) nor the present studies confirm it.

The finding that catches of *D. radicum* inside canola fields show a clumped dispersion appears attributable to the fact that field crops are not entirely uniform in their development and density (hence, some areas of fields are more attractive than others). The data cannot be interpreted as influenced by male swarming, since there is no significant difference between the sexes with respect to their dispersion inside the fields.

**Practical Significance**

The economic significance of infestations of *D. radicum* in canola fields in Alberta remains to be quantified. If it is decided to supplement nataural controls with insecticides, seed-drill applications would need to be effective up to 7-11 weeks after sowing (dependent on sowing date). The development of new granular formulations with delayed release of the active ingredient would probably be required. Other forms of insecticidal intervention seem unpromising. The extended period of emergence of adults would make adulticiding less effective than in the case of populations with narrow generation peak. Larviciding seems scarcely feasible in canola fields because of lack of ground access and poor spray penetration of the crop canopy during July. Both adulticiding and larviciding would destroy predatory and parasitic insects, which are presently abundant in canola fields during late June and July.

During the early and mid season, samples of adult flies for survey purposes will be most readily obtained by siting traps along sheltered field margins. Placement of traps inside fields (and trampling the crops) will not normally be necessary. Use of bowl traps containing Galt's solution is recommended because: (1), this solution is resistant to desiccation and repellent to children and other vertebrates; (2), the retrieval procedure requires only a few minutes per trap; and (3), flies are retrieved in good condition suitable for dissesction or permanent preservation.

The differences in phenology shown by populations of *D. radicum* in different parts of its range make this species an excellent subject for studies of intraspecific evolution, both in a wide context and with respect to implications for pest management. Hitherto, most studies (both in North America and Europe) have been conducted with multivoltine populations of a single geographical origin, and whether their conclusions are generally applicable is not always clear. More comparative studies using populations of different geographical origin are needed. The NW Agricultural Region of Alberta is a ready source of material representing the most northern populations in North America.

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## REFERENCES

Allen, W.R. 1964. The occurrence of cabbage maggot on rape in Manitoba and evaluation of insecticides for control. Proceedings of the Entomological Society of Manitoba 20: 54–58.

Arnold, C.Y. 1960. Maximum-minimum temperatures as a basis for computing heat units. Proceedings for the American Society for Horticultural Science 76: 682–692.

Brooks, A.R. 1951. Identification of the root maggots (Diptera: Anthomyiidae) attacking cruciferous garden crops in Canada, with notes on biology and control. Canadian Entomologist 83: 109–120.

Coaker, T.H. 1965. Further experiments on the effect of beetle predators on the numbers of the cabbage root fly, *Erioischia brassicae* (Bouché), attacking brassica crops. Annals of Applied Biology 56: 7–20.

Coaker, T.H. and D.A. Williams. 1963. The importance of some Carabidae and Staphylinidae as predators of the cabbage root fly, *Erioischia brassicae* (Bouché). Entomologia Experimentalis et Applicata 6: 156–164.

Eckenrode, C.J. and R.K. Chapman. 1972. Seasonal adult cabbage maggot populations in the field in relation to thermal-unit accumulations. Annals of the Entomological Society of America 65: 151–156.

Finch, S. and R.H. Collier. 1983. Emergence of flies from overwintering populations of cabbage root fly pupae. Ecological Entomology 8: 29–36.

Finch, and G. Skinner. 1973. Distribution of cabbage root flies in brassica crops. Annals of Applied Biology 75: 1–14.

Finch, S. and G. Skinner. 1982. Trapping cabbage root flies in traps baited with plant extracts and with natural and synthetic isothiocyanates. Entomologia Experimentalis et Applicata 31: 133–139.

Finlayson, D.G. and C.J. Campbell. 1976. Carabid and staphylinid beetles from agricultural land in the Lower Fraser Valley, British Columbia. Journal of the Entomological Society of British Columbia 73: 10–20.

Griffiths, G.C.D. 1985. Field studies of *Delia radicum* (L.) as a pest of canola in Northern Alberta. Technical Report, Farming for the Future 82–0123 and 83–0150. ii + 98 pp. Alberta Agriculture (Government of Alberta), Edmonton.

Harper, F.R. and B. Berkenkamp. 1975. Revised growth-stage key for *Brassica campestris* and *B. napus*. Canadian Journal of Plant Science 55: 657–658.

Hawkes, C. 1972. The diurnal periodicity and cycle of behaviour of the adult cabbage root fly (*Erioischia brassicae*). Annals of Applied Biology 70: 109–118.

Humber, R.A. 1976. The systematics of the genus *Strongwellsea* (Zygomycetes: Entomophthorales). Mycologia 68: 1042–1060.

Liu, H.J. 1984. Surveys of root maggot damage to canola in Alberta and Northern British Columbia, 1981–1983. Alberta Environmental Centre, Vegreville. 31 pp.

Liu, H.J. and R.A. Butts. 1982. *Delia* spp. (Diptera: Anthomyiidae) infesting canola in Alberta. Canadian Entomologist 114: 651–653.

Nair, K.S.S. and F.L. McEwen. 1973. *Strongwellsea castrans* (Phycomycetes: Entomophthoraceae), a fungal parasite of the adult cabbage maggot, *Hylemya brassicae* (Diptera: Anthomyiidae). Journal of Invertebrate Pathology 22: 442–449.

Nair, K.S.S. and F.L. McEwen. 1975. Ecology of the cabbage maggot, *Hylemya brassicae* (Diptera: Anthomyiidae), in rutabaga in Southwestern Ontario, with some observations on other root maggots. Canadian Entomologist 107: 343–354.

Read, D.C. 1958. Factors influencing infestation and injury of rutabagas by root maggots (Diptera: Anthomyiidae) in Prince Edward Island. I. Field studies. Canadian Journal of Plant Science 38: 188–198.

Read, D.C. 1965. Notes on factors influencing diapause in the cabbage maggot, *Hylemya brassicae* (Bouche). Canadian Entomologist 97: 177–181.

Swailes, G.E. 1958. Periods of flight and oviposition of the cabbage maggot, *Hylemya brassicae* (Bouché) (Diptera: Anthomyiidae) in southern Alberta. Canadian Entomologist 90: 434–435.

Varis, A.–L. 1967. Studies on the biology of the cabbage root fly (*Hylemya brassicae* Bouché) and the turnip root fly (*Hylemya floralis* Fall.). Annales Agriculturae Fenniae 6: 1–13.

Veeman, M.M. 1985. Canola in the Canadian economy. Agriculture and Forestry Bulletin 8: 7–10.

Wishart, G., J.F. Doane and G.E. Maybee. 1956. Notes on beetles as predators of eggs of *Hylemya brassicae* (Bouché) (Diptera: Anthomyiidae). Canadian Entomologist 85: 634–639.