THE EFFECT OF TILLAGE AND SEEDING RATE ON INFESTATIONS OF CABBAGE ROOT MAGGOTS, *DELIA RADICUM* (L.) (DIPTERA: ANTHOMYIIDAE) IN CANOLA, *BRASSICA NAPUS* (L.), IN MANITOBA

A Thesis
Submitted to the Faculty

of

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by

Amy K. Hawkins-Bowman

In Partial Fulfillment of the
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of

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The Effect of Tillage and Seeding Rate on Infestations of Cabbage Root Maggots, *Delia radicum* (L.) (Diptera: Anthomyiidate) in Canola, *Brassica napus* (L.), in Manitoba

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A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of

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Dedication

I would like to dedicate this document
to my husband, Patrick and
to my two bright and wonderful children, Katie and Elias.

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Abstract

Amy Hawkins-Bowman. University of Manitoba, 2005. **THE EFFECT OF TILLAGE AND SEEDING RATE ON INFESTATIONS OF CABBAGE ROOT MAGGOTS, *DELIA RADICUM* (L.) (DIPTERA: ANTHOMYIIDAE) IN CANOLA, *BRASSICA NAPUS* (L.), IN MANITOBA**

Advisor: Dr. N.J. Holliday

Delia radicum (L.) is an important pest of canola on the Canadian prairies, feeding on the roots of canola and other Brassica crops. In both vegetable and canola crops *D. radicum* can cause significant yield losses. Natural controls, predators and parasitoids, have not been reducing the populations sufficiently to prevent yield losses in canola. No insecticides are registered for use on *D. radicum* in canola. Agronomic practices may be the best method of reducing yield loss associated with this pest.

Two management practices tillage treatment and seeding rate were applied to experimental fields of canola at the Carman Research Station in Manitoba. Tillage treatment was applied as zero tillage or conventional tillage. Seeding rate treatment was applied as high or low seeding rates. Results show that zero tillage systems have lower root damage ratings then conventionally tilled systems in Manitoba. Also that lower seeding rates have lower root damage ratings then higher seeding rates in Manitoba.

Currently in Manitoba, *D. radicum* is not affecting yield. This study supported the recommendations that zero tillage or minimal tillage should be implemented when growing canola in Manitoba and canola should be seeded at higher rates to reduce damage associated with this pest.

Table of Contents

List of Tables

List of Figures

Chapter I: Introduction

Canola became the recognized name for low erucic acid rapeseed in 1980 (Daun 1986). This name has been registered across the world and the crop is now important in many countries (Daun 1986). Specifically, canola is a vital part of the Canadian agricultural economy and since 1983, more than 90% of the rapeseed grown in Canada meets the canola requirements. *Brassica napus* (L.) is the predominant species of canola grown in the Eastern Prairies. Canola oil is used for human consumption, and canola meal is used as a feed supplement for livestock, including cattle, pigs, and chickens (Daun 1986).

The first report of cabbage root maggot, *Delia radicum* (L.) on oilseed rape in Manitoba was in 1958 (Allen 1964). Since this time, the area seeded to canola has increased and reports of cabbage root maggot in canola have also increased. Research on cabbage root maggots on canola in Manitoba has not been exhaustive; however since the early 1990s research has been occurring in Alberta (Dosdall *et al.* 1998). While yield losses are not commonly associated with this pest in Manitoba (Turnock *et al.* 1992), they are of great economic significance in Alberta (Dosdall *et al.* 1994). Surveys of this pest in canola have shown that 96% of fields surveyed in Manitoba and Saskatchewan were infested by cabbage root maggots (Soroka *et al.* 2004).

The cabbage root maggot is a common pest of many vegetable brassica crops, such as, broccoli and rutabaga. In Manitoba, there is only one pesticide registered for use on this pest and only in vegetable crops (Manitoba Agriculture, Food and Rural Initiatives 2005). With no registered insecticides to control *D.*

radicum in canola it is necessary to find other methods to help reduce yield loss resulting from root maggot infestations.

Over the past twenty-five years, agronomic methods have changed. Zero tillage has been recommended to producers as a way to reduce soil erosion, lower fuel consumption and improve soil moisture retention (Borstlap and Entz 1994). Research has been conducted in Alberta for the past decade to determine how management practices affect populations of cabbage root maggot in canola (Dosdall *et al.* 1998 and 2003). Minimal research has been conducted in Manitoba to explore the effects of agronomic practices on cabbage root maggot.

Changing plant density can affect many different levels of agro-ecosystems, potentially altering carabid abundance and movement, cabbage root maggot oviposition, and crop yield, to name a few (Dosdall *et al.* 1996b). In Alberta, research has been conducted on the effects of seeding rate and row spacing on cabbage root maggot damage (Dosdall *et al.* 1998). Results from these and other studies show the potential importance of plant density on populations of cabbage root maggots (Dosdall *et al.* 1998; Finch *et al.* 1976).

The need for research conducted under Manitoba conditions on cabbage root maggots in canola led to the development of this study. The overall objectives for this research were three fold:

1. Develop a better understanding of the effects of tillage and seeding rate on immature *Delia radicum* infestations and the subsequent

changes (if any) of root damage ratings, yield and seed quality for canola in Manitoba;

2. Develop a better understanding of the effects of tillage and seeding rate on mature *D. radicum* nimbers in canola in Manitoba;
3. Develop a better understanding of the effects of tillage and seeding rates on the numbers of predators of *D. radicum* in canola in Manitoba.

Chapter II: Literature Review

INTRODUCTION

Delia radicum (L.) is a member of the order Diptera (true flies) and the family Anthomyiidae and is commonly known as cabbage root maggot or cabbage maggot (Griffiths 1991a). Diptera are one of the largest orders of insects and can be distinguished from other insects by the presence of only one pair of functional flight wings, the front wings (Borror *et al.* 1989). For a detailed description of this order and the family Anthomyiidae please refer to Borror *et al.* (1989).

Throughout the Holarctic region, *Delia* spp. are pests of cruciferous crops (Dufault and Sears 1982) or phytophagous on other plant species (Griffiths 1991a). A large number of publications have been written regarding root maggot attacks on a variety of host plants (Brooks 1951); many of these papers concern *Delia radicum* (Linnaeus) (Diptera: Anthomyiidae). This pest feeds on a number of crop plants including: rutabaga, cauliflower, cabbage, and oil seed rape (Bracken 1988; Liu and Butts 1982; Miles 1952; Nair and McEwen 1975).

Delia radicum has four life stages: egg, larva, pupa, and adult . Damage to brassica crops is caused by the three larval instars feeding, primarily but not exclusively, on the roots. To understand the significance of this pest in western Canada, it is essential to understand the status of the pest across the northern hemisphere. In this review I strive to develop a better understanding of the ecology, the wide variety of potential control tactics, and the status of the pest's effects on horticultural crops and canola (oil seed rape) in western Canada.

ROOT MAGGOTS

Delia spp. in Canada

Three major economic pest *Delia* spp. (Griffiths 1991a) will be discussed: *Delia radicum* (Linnaeus), *Delia floralis* (Fallén), and *Delia planipalpis* (Stein). *Delia radicum* originated in Europe and was introduced to North America (Griffiths 1991a). In the early 1950s, *D. radicum* had been reported in 8 out of the 10 provinces (Brooks 1951). As of the early 1990s populations of *D. radicum* were present in all 10 provinces in Canada (Griffiths 1991a). The apparent changes in distribution could be attributable to a change in host and the expansion of area in which host crops are grown. The natural enemies and voltinism for *D. radicum* will be discussed in more detail later in this review.

Delia planipalpis has been recorded in Alberta, British Columbia, Manitoba, Northwest Territories, Ontario, Saskatchewan and Yukon (Griffiths 1991a). The principal host of this root maggot is radish (*Raphanus sativus* L.); however, it has been found on many other brassica crops (Kelleher 1958), including cabbage, canola, cauliflower, rutabaga, mustard, Brussels sprouts, and turnip (Griffiths 1991a). This root maggot is considered native to western North America because it occurs in areas remote from cultivation as well as in agricultural regions (Griffiths 1991a). It is parasitized and preyed on by the same species of Coleoptera as *D. radicum* (Kelleher 1958). *Delia planipalpis* may have three generations per year in the southern portion of its range; however it is univoltine in the more northern portion of the range (Kelleher 1958).

Delia floralis has been recorded in Alberta, British Columbia, Labrador (Newfoundland), Manitoba, Northwest Territories, Ontario, Quebec, Saskatchewan, and Yukon (Griffiths 1991a). Host plants of this species are mostly the same as those of *D. radicum* and *D. planipalpis*. Some weed plants have been listed as hosts for *D. floralis*: *Thlaspi arvense* (L.), stinkweed; *Sisymbrium altiissimum* (L.); and *Brassica kaber* (DC)(Griffiths 1991a). Staphylinidae species found to parasitize *D. radicum* and *D. planipalpis* are also reported to be parasitoids for *D. floralis* (Griffiths 1991a). This root maggot is univoltine through out its North American range. The remainder of this review will focus on *D. radicum*.

DELIA RADICUM

Nomenclature

Linnaeus first described *Delia radicum* (Linnaeus) in 1758 as *Musca radicum* (Griffiths 1991a). Since that time, due to ignorance of Linnaeus' description, *D. radicum* has had seventeen different synonyms. Pont (1981) was the first to resolve this nomenclatural confusion (Griffiths 1991a). In most of the literature reviewed, three different names were used: *Hylemya (Hylemyia) brassicae* (Bouché), *Erioischia brassicae* (Bouché), and *Delia radicum*

(Linnaeus). For the purpose of this review *Delia radicum* will be used regardless of the nomenclature the author of individual papers used.

Biology

Adult *Delia radicum* feed on nectar from flowers to obtain energy and nutrients (Finch 1971). In western Canada on canola, *D. radicum* is generally univoltine or bivoltine (Turnock *et al.* 1992). On vegetables, this pest has been known to complete two or three generations in Manitoba, depending on how early the crop is sown and on weather conditions (Allen 1964, Bracken 1988). In Wellesbourne, England two generations are usually observed. Once diapause has been terminated a further 14 days at 20°C is needed for flies to emerge (Finch and Collier 1983). In parts of Canada such as in Ontario, Manitoba and Alberta, adult emergence begins in May and continues into June (Kelleher 1958; Nair and McEwen 1975); some degree of variation occurs in this timing depending on geographic location (Miles 1952; Nair and McEwen 1975; Turnock *et al.* 1992), and phenotypic polymorphism (Muona and Lumme 1981). Under laboratory conditions, emergence continues for 10-11 days (Whistlecraft *et al.* 1985).

In the field, mating occurs near the site of emergence and gravid females seek appropriate host plants and lay eggs at the base of brassica plants (Finch 1971; Finch and Skinner 1973). Male flies are either blown or actively disperse into areas with a greater amount of nectar producing plants (Finch and Skinner 1975). Females are not blown by the wind, but actively disperse in search of appropriate oviposition sites (Finch and Skinner 1975). Dispersal is upwind or at a small angle to the wind (Finch and Skinner 1982a). Laboratory studies confirm that gravid females use upwind orientation and show that flight is stimulated by host plant odour plumes; this behaviour allows females to locate host plants (Hawkes *et al.* 1978). Under field conditions host plant odour also acts as an attractant and aggregator (Hawkes 1974). Female flies exhibit specific flight patterns once plants have been located, and contact and re-contact with the host plant is necessary to stimulate oviposition (Kostal and Finch 1994); to induce oviposition, plants must contain active glucosinolates (Nair and McEwen 1976). Isothiocyanates, which are break-down products of glucosinolates, are important in attracting females to the host plant (Nair *et al.* 1976). In Wisconsin, females will lay eggs for up to 21 days under field conditions (Eckenrode and Chapman 1971). In June, in Manitoba, six to seven days after adults emerge, oviposition in canola (oilseed rape, *Brassica napus* L.) begins and may continue for up to 3 weeks (Turnock *et al.* 1992). The time of oviposition depends on the crop, soil temperature, and accumulation of degree-days (Eckenrode and Chapman 1971; Whistlecraft *et al.* 1985). Females lay an average of 41 eggs over 16 days (Kelleher 1958) at the base of cruciferous plants. Females are more uniformly distributed throughout crops and disperse more actively than males (Finch and Skinner 1973).

Using what is known about oviposition requirements for *D. radicum*, research has been conducted on oviposition deterrents; these are chemicals that hinder the gravid female's egg laying choices (Jones and Finch 1987). These chemicals may be an important source of protection for vulnerable plants. One such chemical was extracted from the frass of the garden pebble moth caterpillar, *Evergestis forficalis* (L.) and was found to deter oviposition when applied to any cruciferous plant species (Jones and Finch 1987). When monoterpenes, alone or blended with other chemicals were applied to rutabaga, oviposition was deterred. Some of the chemical blends used for this research were terpinolene, γ-phellandrene, and myrcene (Ntiamoah and Borden 1996). Long chain fatty acids act as oviposition deterrents; these may also provide some protection for vegetable fields (Cole *et al.* 1989). The presence of aphids also deters oviposition. Approximately 250 cabbage aphids, *Brevicoryne brassicae* (L.) or peach-potato aphids, *Myzus persicae* (Sulz.) on a brassica plant are sufficient to deter oviposition by *D. radicum*. While this may be an effect of alarm pheromones, it is more likely the result of physical disruption of host-plant selection for the flies. Gravid females probe the leaves of host plants before moving down the plant stem to lay eggs in the soil; when this probing was disrupted by physical contact with an aphid the fly would stop probing for a short period, preventing sufficient positive stimuli to induce oviposition (Finch and Jones 1989).

Time of egg hatching is a function of accumulated thermal units both in the soil and in the air (Eckenrode and Chapman 1972). Darker soils warm up faster in the spring, and accumulate thermal units faster than lighter coloured soils or those soils, such as on zero tillage fields, with crop stubble. These warmer soils, therefore, let eggs hatch earlier than lighter coloured soils or soils with crop stubble. In Manitoba on canola, hatch generally begins in the last week of June or the first week in July (Allen 1964) and larvae proceed to develop through three instars.

Rate of larval development depends on temperature and quality of food source (Whistlecraft *et al.* 1985; Griffiths 1991a). Under standard rearing conditions (19 ± 1°C; 60 ± 5% RH; LD 16:8 h) larval development lasts 18-22 days (Whistlecraft *et al.* 1985). In fields of canola in Manitoba, female flies were collected in June and first-generation adults were found in August of that same year, and the duration of immature stages (egg-larva-pupa) totals approximately 2 months (Turnock *et al.* 1992).

The length of the pupal period is affected by diapause cues (Nair and McEwen 1975), thermal accumulation, and moisture (Whistlecraft *et al.* 1985; Eckenrode and Chapman 1971). In laboratory studies, newly hatched larvae were exposed to three different temperatures (10.5°C, 12°C and 14°C) and photoperiods of 10:14, 11:13, 12:12, 13:11, 14:10, and 15:9 h L:D to determine the effect of temperature and photoperiod on induction and duration of diapause (Johnsen and Gutierrez 1997). Pupae developing from these larvae were then held at 17°C and 16:8 h L:D until adult emergence. The number of individual pupae entering diapause was higher at shorter photoperiods across all temperatures and at low temperatures across all photoperiods. Diapause developmental time, the time required from diapause induction until adult emergence, increases with increasing temperature and decreases with increasing photoperiod. Johnsen and Gutierrez (1997) concluded that the effect of temperature on diapause induction is greater than the effect of photoperiod.

Diapause development requires lower winter temperatures. When the low temperatures begin in relation to photoperiod determines when adults will emerge in the spring (Collier and Finch 1983). Proximity of overwintering puparia to the soil surface does not affect mortality, during winters in the United Kingdom; however, if puparia are greater then 4 cm deep the emerging flies fail to reach the surface (Finch and Skinner 1980). Thermal unit requirements have been used to predict cabbage root maggot emergence and peak larval periods to develop better control programs (Eckenrode and Chapman 1971 & 1972).

In North America, *D. radicum* is found in gardens and cultivated lands (Griffiths 1991a). While feeding on the taproot of brassica plants, larvae construct tunnels; these tunnels may cause uncomplicated physical damage, or plants may suffer from subsequent invasions by pathogenic organisms (Turnock *et. al.* 1992; Whistlecraft *et al.* 1985; Liu and Butts 1982). Death of the plant is not always the result of attacks by this pest. *Delia radicum* may cause direct loss to producer yields of broccoli, cauliflower, rutabaga, turnip, radish, or indirect loss to yields of canola. Direct losses occur when the maggot tunnels throughout the harvestable portion of a root crop, such as rutabaga, turnip, and radish (Bracken 1988; Brooks 1951; Doane and Chapman 1962; Eckenrode and Chapman 1971; Libby *et al.* 1974; Nair and McEwen 1975). Indirect losses result when the maggot feeds on roots of crops where the harvestable portion is above ground, such as cauliflower, broccoli, cabbage, and canola, causing a reduction in total yield (Bligaard *et al.* 1999; Finch *et al.* 1976; Goble *et al.* 1972; Brooks 1951; Miles 1950). The cabbage root maggot may cause damage to the heads of cauliflower and broccoli, which is direct damage to harvestable portion of the plant.

The crops where indirect yield damage is a concern are most vulnerable in the first 5-7 weeks after germination (Matthews-Gehringer and Hough-Goldstein 1988). This is when it is essential for plants to establish a good root system to ensure the growth of the crop and adequate yields. If these crops are not protected from *D. radicum* in the first 5-7 weeks of growth, the injury caused by this pest may be enough to kill the plant (Matthews-Gehringer and Hough-Goldstein 1988). Where the damage to the crop is directly to the harvestable root portion, tunnelling may reduce yields at any point during the crop's growth (Doane and Chapman 1962).

Natural Enemies

Parasitoids

The first extensive records of parasitoids of *Delia radicum* were published in 1957 (Wishart 1957; Wishart *et al.* 1957). The two primary species parasitizing *D. radicum* in Europe and Canada are *Aleochara bilineata* (Gyllenhal) (Coleoptera: Staphylinidae) and *Trybliographa rapae* (Westw.) (Hymenoptera: Cynipidae). *Aleochara bilineata* is the most important parasitoid of *D. radicum* in Canada (Soroka *et al.* 2002). In Europe, *Aleochara bipustulata* (L.) is another significant parasitoid of the cabbage root maggot (Fournet *et al.* 2000); however, recent literature has established that this staphylinid is not present in North America (Hemachandra *et al.* 2005). In France, females of *A. bipustulata* have significantly longer reproductive potential and life spans than *A.*

bilineata (Fournet *et al.* 2000). While *A. bipustulata* has useful biological control characteristics making it a candidate as a biological control agent, *A. bilineata* has higher rates of increase, higher host specificity and host acceptance, and its developmental time is better synchronized with *D. radicum* (Fournet *et al.* 2000). This means that *A. bilineata* is the better choice for further studies of biological control of *D. radicum* (Fournet *et al.* 2000). *Aleochara bipustulata* should be evaluated for introduction in to North America as a biological control agent (Soroka *et al.* 2002).

Adults of *A. bilineata* feed on host eggs and first instar larvae. Immature *A. bilineata* drill a small hole in the external puparium of *D. radicum*, enter the puparial case and develop through three larval instars as ectoparasitoids of the pupa. To gain entrance into the host puparium, larvae gnaw holes in the dorsal surface of puparia, but may also gnaw holes in the lateral or ventral surfaces (Royer *et al.* 1998). The locations chosen for these holes is not random, but are in areas of the puparium with fewest ridges (Royer *et al.* 1998). At the completion of larval development, third instars pupate within the host puparia and emerge as adults, several weeks after the first generation of *D. radicum* has emerged (Soroka *et al.* 2002). The rate of parasitism by *A. bilineata* increases with an increase in temperature, but at low temperatures the parasitoid is unable to respond to changes in host density (Turnock *et al.*1995). Parasitism rates in *D. radicum* puparia vary depending on locations from 5-23% (Hemachandra 2004). In the 1990's, parasitism rates from this same parasitoid in the London, ON. area was 0-38% (Turnock *et al.* 1995). Mass rearing and release of *A.*

bilineata adults to coincide with emergence of *D. radicum* larvae could provide better control than relying on natural populations of this parasitoid (Soroka *et al.* 2002). In the United Kingdom, in order to achieve control of *D. radicum* in cauliflower crops two staphylinid beetles per plant would need to be released (Finch and Collier 2000).

Trybliographa rapae is a larval parasitoid; eggs are laid in first, second or third instar larvae (Fournet *et al.* 2000). Generally, rates of parasitism by *T. rapae* are 11% in *D. radicum* larvae. Parasitism rates of pupae vary and are related to locality (Hemachandra 2004).

Multiparasitism, the condition when an insect is parasitised by two or more parasites of different species (Torre-Bueno 1978) does occur with *A. bilineata* and *T. rapae* (Reader and Jones 1990). *Aleochara bilineata* does not always differentiate between puparia that have been previously parasitized by *T. rapae* and those that have not. Once the larva has drilled through the puparial casing it can then determine whether it has been previously parasitized. If an *A. bilineata* larva does parasitize a puparia containing *T. rapae*, the staphylinid larva does not develop at a sufficient rate to destroy the *T. rapae* larva and does not complete development itself (Reader and Jones 1990). This can result in neither parasitoid developing to the reproductive stage and ultimately may lower the total level of parasitism of *D. radicum* (Reader and Jones 1990). In Manitoba, parasitism rates of *T. rapae* were affected by multiparasitism with *A. bilineata* (Hemachandra 2004).

Predators

Coleoptera are the most important predators of *D. radicum* eggs and larvae (Finch 1996). Carabidae is the most important predator family while staphylinids are somewhat less important predators (Wishart *et al.* 1956). There is a linear relationship between the numbers of eggs eaten and the length of individual carabid beetles, for every 1 mm increase in beetle length above 2.7 mm an additional 18 eggs were eaten per beetle per day (Finch 1996). In the United Kingdom four species of small carabid beetles, indigenous to Europe, can destroy approximately 90% of the first generation of cabbage root maggot eggs: *Bembidion lampros* (Hbst.), *Trechus obtusus* (Er.), *B. quadrimaculatum oppositum* (Say), *T. quadristriatus* (Schrank) (Finlayson 1976). Of these four species two are commonly found in the Prairie Provinces: *B. lampros* and *B. quadrimaculatum* (Melnychuck *et al.* 2003). In Saskatchewan, there were four other species of Carabidae that dominated pitfall trap collections: *B. obscurellum* (Motschulsky), *Agonum placidum* (Say), *Amara littoralis* (Mannerheim), and *B. nitidum* (Kirby) (Melnychuck *et al.* 2003). In Ontario, *B. quadrimaculatum oppositum* (Say) were the most abundant and most important predators of *D. radicum* eggs in cabbage (Wishart *et al.* 1956). While *B. nitidum* (Kirby) were not common in the Belleville, ON. area, they are fairly common in the Prairie Provinces and are considered an important egg predator in these areas (Wishart *et al.* 1956). *Pterostichus melanarius* (Ill.) are known to feed on cabbage root maggot eggs in the United Kingdom (Finlayson 1976); however, a recent study in Washington, U.S.A. found that these large carabid beetles might actually prefer