Identifying Agronomic Practices that Conserve and Enhance Natural Enemies of Insect Pests of Canola

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Lloyd M. Dosdall

Department of Agricultural, Food and Nutritional Science
4-16B Agriculture-Forestry Centre
University of Alberta
Edmonton, AB T6G 2P5

1. Abstract

Yield losses from infestations of root maggots (*Delia* spp.) (Diptera: Anthomyiidae) can be severe in canola crops in central Alberta, Canada. Studies were undertaken to manipulate agronomic practices that have potential to affect crop yield, root maggot infestations, and the survival and abundance of *Aleochara bilineata* (Coleoptera: Staphylinidae), which is an important natural enemy of root maggots. Tillage regime (conventional versus zero tillage), row spacing, and seeding rate were manipulated to assess effects on root maggot and *A. bilineata* populations. In general greater root maggot incidence and damage, and greater population density of *A. bilineata*, occurred in plots subjected to a conventional tillage regime than to zero tillage. Relatively greater parasitism of root maggot puparia by *A. bilineata* occurred in plots in zero than in conventional tillage. No consistent effects were observed on *A. bilineata* activity in relation to seeding rate and row spacing. We found no evidence to conclude that tillage regime had a significant effect on canola seed yield. Yields in relation to seeding rate and row spacing were variable. In the context of integrated crop management in canola cropping systems, canola growers should utilize zero tillage in conjunction with adopting the currently recommended seeding rates of between 5.6 to 9.0 kg per ha and row spacing of 30 cm because this can bring advantages in terms of improved management of root maggots and other important canola pests like flea beetles and weeds.

This final report for the project is subdivided in two parts. The first deals with the agronomy of manipulating canola row spacing, tillage type, and seeding rate; the second

component deals with effects of these manipulations on root maggots and its principal natural enemy, the staphylinid beetle *Aleochara bilineata*.

Part I. Effects of tillage regime, seeding rate, and row spacing on seedling emergence, yield, seed weight, and seed quality of canola (*Brassica napus*) in central Alberta

Part I. Introduction

Canola (*Brassica napus* L. and *Brassica rapa* L.) is one of the major oilseed crops grown worldwide, and the crop has undergone significant expansion of its production area during the past two decades (Howlett et al. 2001). In the Canadian prairies, canola is an economically important crop produced on more than five million ha of Canada's 76 million ha of farm land (Statistics Canada 2009). Low-disturbance direct seeding into standing stubble is a very effective practice for increasing the water supply and for reducing evaporation (Cutforth et al. 2006). There is growing interest among farmers worldwide to adopt conservation tillage to overcome various constraints to crop production. One of the most important benefits of conservation tillage, which maintains surface residues and standing stubble, is the ability to trap snow, improve water infiltration, reduce run-off, and minimize evaporative losses (Smika and Unger 1986). A recent survey revealed that 25 and 53% of cropped land in the Canadian prairies is seeded with reduced and zero-tillage production practices, respectively (Statistics Canada 2010). However, it appears that a considerable number of farmers in Canada still prefer to produce canola under conventional tillage. Conventional tillage systems involve cultivating and harrowing the topsoil, but soil erosion by both water and wind are accelerated, often resulting in extensive soil degradation (Young et al. 1994). As a rule, reduced tillage systems improve water storage and availability of water for crop growth (Lafond and Derksen 1996).

Different seeding rates can be used to adjust plant densities in fields for a number of reasons (Neal 1981). Increased plant density can be associated with changes in the rate of development of canola plants and such developmental alterations can eventually cause changes in the magnitude of each yield component. A common expectation is that increasing seeding rates with a specific row spacing will result in increased plant density at harvest. However, the density of mature plants at harvest depends upon a series of factors and processes, including the initial seeding rate, germination rate, natural seedling mortality, and plant losses from environmental stresses, including insects and diseases (Robert and Walker 1994).

The optimal row spacing for crops is often established through empirical observations, and once established, row spacing recommendations change little over the years (Neal 1981). In practice, row spacing and plant density must be considered concurrently (Neal 1981). In the history of canola research trials in the past 20 years, various research studies have been conducted to realize improved grain yield and quality in canola by manipulating row spacings in conjunction with other agronomic practices, but such studies have been documented in the absence of pest infestations and without consideration for the role of natural enemies of these pests.

Canadian canola production history indicates that Canadian farmers adopted hybrid canola varieties rapidly because of enhanced plant vigor and improved yields relative to conventional canola (Blackshaw et al. 2008). Adoption of hybrid canola increased from

15 to 70% during 2003 to 2008. Herbicide-tolerant technology has also received widespread adoption. The 2006 harvest comprised 95% non-conventional herbicide-tolerant canola varieties that included 50% resistant to glyphosate (Roundup Ready), 30% resistant to glufosinate ammonium (Liberty Link), 15% resistant to imidazoline (Clearfield), and 5% conventional canola (Broad 2005).

The introductions of herbicide-tolerant canola systems and hybrid canola varieties have changed the nature of canola production (Harker et al. 2003). However, the high cost of production involved for hybrid canola often tempts producers to cut back on various farm operating costs including costs associated with seeding rate and tillage. The objective of this study was to investigate the impact of conventional versus zero tillage systems, used in conjunction with four seeding rates and three different row spacings on seedling emergence, seed yield, seed weight, and percent seed protein and oil contents of the herbicide-tolerant hybrid canola variety InVigor 5020.

Part I. Materials and Methods

Study Sites and Experimental Design. The study was conducted at two sites in central Alberta: Lacombe (113°44´W; 52°28´N) and Vegreville (112°03´W; 53°30´N). Soil type at both sites was black Chernozemic loam. At Lacombe soil composition was 34% sand, 39% silt, and 27% clay with a pH of 7.3 and 9.3% organic matter. At Vegreville the soil composition was 35% sand, 34% silt, and 31% clay with a pH of 6.3 and 7.2% organic matter.

Plots were seeded to a cereal crop (barley, *Hordeum vulgare* L.) in the years preceding the study. Plots subjected to zero tillage were seeded directly into the cereal stubble with minimal disturbance of the surface crop residue. No additional tillage was done for seedbed preparation as compared to conventional tillage where the soil was worked with at least two cultivations to a depth of approximately 8 cm prior to seeding. Weeds were removed when canola was in the three- to four-leaf stage with glufosinate ammonium herbicide at the recommended rate of 500 g ai/ha along with clethodim at 15 g ai/ha and Amigo® (surfactant) at 0.5% v/v.

Plots of *B. napus* cv. InVigor 5020 were seeded at Lacombe on 10 May 2007 and 5 May 2008, and at Vegreville on 15 May in 2007 and 2008. The sites were fertilized according to the soil test recommendation for canola production. Plots at Lacombe were seeded with a Conserva Pak® no-till drill whereas plots at Vegreville were seeded with a double-disc no-till drill.

The field experiment was a randomized complete block, strip-plot design with four replicate plots per treatment. Tillage treatment (conventional- and zero-till) was assigned to 'vertical strips' and the 12 treatment combinations (4 by 3 full factorial: seeding rate had four levels and row spacing had three levels) were assigned randomly to 'horizontal strips' perpendicular to the tillage treatment strips. Row spacings used in the study were 22, 30, and 45 cm, and seeding rates were 2.5, 5.0, 7.5, and 10.0 kg per ha. Each sub-plot measured 4 by 15 m. Seed number was adjusted for each seeding rate and row spacings to achieve target canola densities of 60, 120, 180, and 240 plants per square meter. These seeding rates corresponded approximately to 0.5, 1.0, 1.5, and 2.0 times the recommended seeding rates for canola production (Thomas 2003).

Data Collection. Data collected for this study included plant emergence counts, canola seed yield, 1,000 kernel weight, canola seed oil seed protein contents. Plant emergence counts were taken when the rows of seedlings were easily visible. At Lacombe, plant emergence counts were performed on 3 June 2007 and 5 June 2008 whereas in Vegreville the counts were completed on 5 June 2007 and 9 June 2008. Two counts of seedlings were performed from each treatment sub plot. For each count the total number of plants from either side of a one-meter strip of a randomly selected row was used. To avoid edge effects, the two rows along the plot edges were not used for emergence counts.

At Lacombe canola plants were swathed on 21 August 2007 and 27 August 2008. Swathing was performed when 30 to 40% of seed on the main stem had undergone color change. The swathed canola was threshed approximately two weeks later when the seed moisture content dropped to approximately 10%. At Vegreville canola plants were directly combined on 28 August 2007 and 27 August 2008 after applying Reglone® as a chemical desiccant.

During the fall of each production year the harvested canola from both sites was processed to determine the dockage due to weed seed contamination and 1,000 kernel weight. After threshing, the grains were further analyzed to determine the oil and protein contents. Protein content was determined using Near-Infrared Reflectance Spectroscopy. Oil content was determined from 20 g of whole seeds from the clean sample with Nuclear Magnetic Resonance utilizing a Newport Analyser MklllA. Samples were dried in coin envelopes for 48 h at 35ºC, followed by cooling for 24 h at room temperature. Results of oil and protein analyses were reported as percentages of seed weight.

Data Analysis. Treatment effects were determined by analysis of variance (ANOVA) using the Proc Mixed procedure (SAS Institute Inc. 2003). Methods of Gomez and Gomez (1984) were used as a basis for comparing fixed treatment effects (seeding rate, row spacing, and tillage regime) having block (replication) as a random effect.

Part I. Results

Environmental Conditions. Precipitation at Lacombe during the growing season of 2007 from April to June exceeded long-term mean values (1971-2008), but in July precipitation was considerably lower than the long-term mean value (Table 1). Thereafter precipitation was similar to long-term mean values. In 2008, precipitation at Lacombe was lower than the long-term mean values throughout the growing period except for June when approximately 25 mm more precipitation was received than the mean. Mean air temperature at Lacombe during the 2007 growing season was consistent with the long-term average values although in April the mean temperature was lower than the long-term mean, and in July the temperature exceeded than the long-term average by nearly 4ºC. In 2008, temperatures were relatively consistent with long-term average values, except for slightly cooler than the normal conditions in April (Table 1).

At Vegreville, approximately two-fold more precipitation occurred than the long-term mean value (1971-2008) in the month of April in both years (Table 1). In 2007 precipitation was lower than long-term mean values from May through September for every month except August. In 2008 precipitation was similar to the long-term mean in May, less than the long-term normal in June, July, and September and greater than the normal value in August. Most of the time, in 2007, mean air temperatures exceeded the long-term mean values (1971-2008) except in the month of April. However, in 2008 the mean air temperature was similar to the long-term mean values every month except April (Table 1).

Seedling Emergence – Plant Density. Tillage regime, seeding rate, and row spacing had statistically significant effects on seedling emergence at Lacombe in 2007 (tillage regime: $P = 0.0130$; seeding rate: $P < 0.0001$; and row spacing $P = 0.0016$) and Vegreville in 2008 (tillage regime: $P = 0.0310$; seeding rate: $P < 0.0001$; and row spacing: $P = 0.0024$) (Table 2). Seeding rate had statistically significant effects on seedling emergence in two other site-years, Lacombe in 2008 ($P < 0.0001$) and Vegreville in 2007 ($P = 0.0081$). At Lacombe in 2007, mean canola plant density was greater in zero-tilled plots than in plots subjected to conventional tillage. At Vegreville in 2008, mean canola plant density was greater in plots subjected to conventional tillage compared with zero-tilled plots. In all four site-years, mean canola plant density increased steadily with an increase in seeding rate and this increase occurred both in conventional- and zero-till plots.

Seed Yield. At Lacombe in 2007, canola yield was similar and not significantly different for plots subjected to conventional tillage compared with zero tillage ($P = 0.1981$) (Table 2). However, the effect of seeding rate on mean yield was statistically significant ($P = 0.0043$). Mean yield per hectare was not significantly affected by row spacing ($P = 0.2410$). No significant interactions were observed for tillage by seeding rate, tillage by row spacing, seeding rate by row spacing, or tillage by seeding rate by row spacing (Table 2).

At Lacombe in 2008, canola yield was not affected statistically by tillage regime ($P = 0.2931$) (Table 2). Similarly, yield was not affected by seeding rate ($P = 0.2472$). Mean canola yield was not significantly affected by row spacing ($P = 0.3233$) (Table 2). At Lacombe in 2008, the two-way interaction of tillage regime and seeding rate and the three-way interaction of tillage regime, seeding rate, and row spacing were statistically significant (*P* = 0.0374 for the two way interaction and *P* = 0.0317 for the three way interaction) (Table 2).

At Vegreville in 2007, yields of conventional- and zero-till plots were similar (*P* = 0.9968) (Table 2). The mean yield per hectare more or less remained constant over the range of seeding rates evaluated in this study. Mean canola seed yield was similar for all row spacings and both tillage systems (*P* = 0.6428).

At Vegreville in 2008, mean canola grain yield in conventionally tilled plots exceeded that of zero-till plots but this difference was not significant statistically (Table 2). Mean yields failed to show a trend with seeding rate (*P* = 0.8841). Row spacing had a statistically significant effect on yield (*P* = 0.0308).

Seed Thousand Kernel Weight, Protein, and Oil Contents. Analysis of variance revealed that the main effect, tillage regime, had a statistically significant effect on 1,000 kernel weight in three of four site-years: Lacombe 2008: *P* = 0.0190; Vegreville 2007: *P* = 0.0384; and Vegreville 2008: *P* = 0.0478 (Table 2). At Lacombe in 2008, the plots subjected to conventional tillage produced higher mean seed weight as compared to zero-tilled plots. At Vegreville in 2007, zero-tilled plots produced higher mean 1,000 kernel weights as compared to conventionally-tilled plots. However, in 2008, at Vegreville, the plots tilled conventionally produced greater mean 1,000 kernel weights as compared to zero-tilled plots. At Vegreville in 2007, the three-way interaction of tillage regime by seeding rate by row spacing was statistically significant (*P* = 0.0256) (Table 2). Seed weights were similar among different seeding rates and row spacings (Figures 2.8, 2.9).

For all sites and years, seed protein content was unaffected by tillage treatment and seeding rate (Table 2). At Lacombe in 2007, only row spacing produced statistically significant results for canola seed protein content (*P* = 0.0048). The highest mean protein content (23.3%) was obtained from plots with a row spacing of 30 cm and the lowest mean protein content (22.5%) was obtained from canola grown at a row spacing of 22 cm. In 2008, at Lacombe, the two-way and the three-way interactions produced statistically significant results for canola seed protein content (seeding rate by row spacing: *P* = 0.0008; tillage by seeding rate by row spacing: *P* = 0.0420). However, at Vegreville both in 2007 and 2008 none of the individual treatments or treatment combinations produced statistically significant results on protein content (*P* > 0.05). In 2008, at Lacombe in zero-tilled plots, the seeding rate of 7.5 kg per ha at a row spacing 30 cm produced highest protein content (22.6%) whereas the seeding rate of 5.0 kg per ha at a row spacing of 22 cm produced the lowest protein content (19.7%). In plots subjected to conventional tillage, the seeding rate of 10.0 kg per ha by row spacing of 30 cm produced the highest seed protein content (21.7%) and the seeding rate of 7.5 kg per ha at a row spacing of 22 cm produced the lowest seed protein content (19.6%).

Only two main effects, seeding rate and row spacing, had statistically significant effects on seed oil content in 2007 at Lacombe (*P* = 0.0027 for seeding rate and *P* = 0.0043 for row spacing) (Table 2). But in 2008, at Lacombe, the two-way interaction (seeding rate by row spacing) and the three-way interaction (tillage regime by seeding rate by row spacing) produced statistically significant results for seed oil content (*P* = 0.0018 for the two-way interaction and *P* = 0.0046 for the three-way interaction). At

Vegreville, both in 2007 and 2008, none of the main treatment effects or treatment combinations produced statistically significant results for seed oil content (Table 2).

In terms of row spacings, least square mean differences between all three pairs of row spacings were statistically significant (P = 0.0015 for row spacings of 22 and 30 cm, P = 0.0203 for row spacings of 22 and 45 cm, and P = 0.0467 for row spacings of 30 and 45 cm). At the same time, in both tillage treatments least square mean difference between 22 and 30 cm resulted in statistically significant results (P = 0.0169 for zero-tilled plots; P = 0.0037 for conventionally-tilled plots).

Part I. Discussion.

Environmental conditions during all four site-years were generally conducive to good seedling germination and emergence. However, at Vegreville in 2007, canola plants in one section of the experimental site were not as vigorous in their development as in the remainder of the site. Upon completion of thorough examinations of the seedlings at this site, and after considering its cropping history, it was concluded that there was some herbicide carry-over from previous years that affected plant development and yield. Data from the affected plots were therefore not included in the analysis.

Seed germination and seedling emergence result from a series of biological events initiated by water imbibitions followed by enzymatic metabolism of storage nutrients (Gusta et al. 2003). Seedling emergence is apparently more sensitive than germination to adverse environmental conditions and differences in seed quality (Clarke and Moore 1986). In this study, uniform emergence of canola seedlings was observed in all site-years except the herbicide-damaged area in Vegreville in 2007. Nevertheless canola seedling counts varied among site-years.

Following seed germination and seedling emergence, successful crop establishment depends on many factors which include soil moisture, soil temperature, seeding depth, pest issues and other abiotic and biotic factors. Canadian studies (Thomas 2003) have shown that under favourable conditions 60 to 80% of seed planted produces viable plants, and this declines to 40 to 60% of germinated seeds under average conditions. Anticipated plant densities for different seeding rates used for this study were 60, 120, 180 and 240 plants per square meter for seeding rates of 2.5, 5.0, 7.5 and 10.0 kg per ha respectively. However, not all the treatment combinations achieved the expected plant densities. Nevertheless, in general, in all site-years at the time of counting, mean canola plant density for each treatment combination exceeded the desired plant density of *B. napus* for optimum yield, which is 70 to 120 plants per square meter (Alberta Agriculture 2009). Moreover, the achieved plant densities at the time of counting surpassed the 50% emergence estimate, which is considered as a representative average of canola emergence under field conditions (Harker et al. 2003). Usually, in an experimental set-up like this, low soil temperature and lack of available moisture in the spring can delay and reduce seedling emergence (Gusta et al. 2003). Many canola crops have delayed and reduced emergence if precipitation does not occur within 10 to 14 days of sowing (Zheng et al. 1998).

In general, zero-tilled plots had relatively greater plant density as compared to conventionally-tilled plots in all site-years except in Vegreville in 2008. This result was presumably attributed to improved utilization of water from spring snow melt facilitated by the surface-retained barley stubble. Stubble retention is widely promoted as a key component of conservation cropping systems designed to reduce erosion and soil degradation, increase water availability to crops and maintain soil organic matter (Bruce et al. 2006). However, at Vegreville in 2008, greater plant density was obtained in conventionally-tilled plots and this is likely due to increased soil temperatures during seed germination and seedling emergence in conventionally-tilled plots as compared to zero-tilled plots.

As expected in all site-years, increasing seeding rates from 2.5 to 10.0 kg per ha increased plant densities significantly and this result is in conformity with previous studies conducted by Brandt et al. (2007) and Christensen and Drabble (1984). This trend was reported in both tillage regimes in the current study. Recommendations for canola in North Dakota and western Canada are to seed between 5.6 and 9.0 kg per ha, depending on seed bed conditions at the time of seeding, with the aim of establishing a plant population of 40 to 200 plants per square meter (Berglund and McKay 2002; Thomas 2003).

Row spacing resulted in statistically significant results for plant density at Lacombe in 2007 and at Vegreville in 2008. Most previous studies of interactions among plant densities and row spacings were conducted in situations where seed numbers were not adjusted for each row spacing and seeding rate as in this study. Sims (1976) reported a significant increase in plant populations (plant density) corresponding to reduced row spacing, and Christensen and Drabble (1984) stated that plant densities varied significantly between row spacings but there was no clear pattern. In this study, at Lacombe in 2007 in both tillage regimes, plant density increased with increasing row spacing from 22 to 30 cm and then plant density decreased with increasing row spacing from 30 to 45 cm. However, at Vegreville in 2008 plant density increased with increasing row spacing from 22 cm to 45 cm in both tillage regimes. Reasons for these variable results are not known.

Canola grain yield is the product of four major components including number of plants per unit area, number of pods per plant, number of seeds per pod and the seed weight (Thomas 2003; Clarke et al. 1978). Agronomic practices and the environment greatly influence each canola yield component (Thomas 2003). In this study, there is no evidence to conclude that tillage regime had a significant effect on yield. Results suggest that regardless of tillage regime, crops responded similarly in terms of photosynthesis and all the other crop physiological processes related to grain production. These results are in conformity with the findings of Brandt et al. (1992). At the same time, canola grain yield obtained from all four site-years under different treatment combinations exceeded the average canola yields from 1990-2000 for western Canada (Thomas 2003). In fact, exceptional grain yields were obtained at Lacombe in 2008, where the mean seed yields from each treatment combination ranged from 4,300 to 4,800 kg per ha. Results of this study can perhaps be explained because growing season moisture was plentiful during all site-years, so tillage regime differences did not influence the final seed yield of canola in Lacombe and Vegreville.

Seeding rate had no significant effect on canola grain yield in all but one site-year. This finding is in agreement with the studies conducted by Kondra (1975) and Degenhardt and Kondra (1981) who found that seeding rates had no consistent effect on yield. Similarly Christensen and Drabble. (1984) determined that there were no significant yield differences due to seeding rates. However, several studies found important yield effects in relation to seeding rate. Clarke et al. (1978) determined that the effects of seeding rates on seed yield were more pronounced than those reported by Kondra (1975), and indicated that higher rates than those recommended may be beneficial. A seeding rate of 4 kg per ha reduced seed yield compared with rates of 8.0, 12.0 or 16.0 kg per ha (Brandt et al. 1992). Surprisingly Morrison et al. (1990) achieved maximum yields with low seeding rates of 1.5 and 3.0 kg per ha. Clarke and Simpson (1978) achieved maximum yield with a seeding rate of 20.0 kg per ha under dryland conditions and 5.0 to 10.0 kg per ha under irrigated conditions. It is evident, therefore, that previous canola seeding rate studies have given variable results.

Like seeding rate, row spacing had no significant effect on grain yield in all but one site-year. Narrow row spacing generally produced higher yields than wider row spacing in oilseed crops (Kondra 1975). This pattern was generally observed in my studies even though the effect of row spacing on canola seed yield was not statistically significant in most site-years. From different tillage regimes, canola seed yield for Lacombe in 2008 produced variable results for similar seeding rate and row spacing combinations. These results indicate that each agronomic treatment combination at Lacombe in 2008 provided a unique production system for the crop. Moreover, these different responses agree with the findings of Kondra (1975). Kondra (1975) determined that changes in row spacing affect the crop's response to seeding rates. Since yield results are not consistent and differ from previous studies with *B. napus*, further research on agronomic combinations is warranted.

The 1,000 kernel weight is a measure of seed size. Because of this variation in seed size, the number of seeds and, consequently, the number of individuals in a given mass of seed is also highly variable (Alberta Agriculture 2009). Thousand kernel weight is the most important component of yield (Clarke et al. 1978). In my study tillage regime had a significant effect on 1,000 kernel weight in most of the site-years except in Lacombe in 2007. Moreover, different tillage regimes produced variable results for 1,000 kernel weight depending on site-year. However, tillage regime had no significant effect on seed yield in any site-year. Moreover, different tillage regimes produced variable results for seed yield. Therefore 1,000 K weight and seed yield do not have a specific correlated relationship for different agronomic practices tested in this study.

Single treatments and treatment combinations produced variable results for canola seed protein content. However, at Vegreville both 2007 and 2008, results indicated that there were no significant effects on seed protein content for different treatments/or treatment combinations. The two main treatments, tillage regime and seeding rate, had no effects on seed protein concentration in any site-year. Seeding rate studies of Harker et al. (2003) were in conformity with this study and determined that seeding rate had no effect on primary seed constituent concentrations such as protein and oil. However, Kondra (1977) determined that seeding rate had a significant effect on protein content in one test. McKenzie et al. (2006), in a study on mustard, discovered that seeding rate did not affect protein content.

At Vegreville, both in 2007 and 2008, results indicated that there were no significant effects on seed oil content for different treatments/or treatment combinations. Results for tillage regime on seed oil content in our studies are in conformity with the study conducted by Grant et al. (2004), who also found that tillage management did not influence seed oil concentration in any site-year. Kondra (1975) stated that row spacing and seeding rate had no significant effects on oil content. However, tests conducted by Kondra (1977) revealed that seeding rate had a significant effect on oil content.

The two tillage regimes did not appear to influence effects on final grain yields. Therefore adopting zero or reduced tillage to produce canola should result in both short- and long-term benefits to the farming community. Nevertheless, the overwhelming evidence from many studies over a large number of ecoregions has found that reduced tillage is associated with many benefits for farmers that include reduced requirements of human labour, fuel and equipment (Lafond and Derksen 1996; Stinner and House 1990; Jensen and Timmermans 1991). The long-term benefits of adopting zero-till systems are many, including reduction of greenhouse gases, increasing soil organic matter content, and perhaps altering/enhancing the composition of beneficial soil fauna and flora in commercial farming systems. Evidence from previous studies also indicates that crop yields can be maintained or improved in zero-tillage for most crops grown in western Canada (Lafond and Derksen 1996).

In this study, adjusting seeding rate was not related to grain yield, and row spacing alone did not influence final grain yield. However, when row spacing interacted with seeding rate and tillage regime, favorable results were obtained depending on the location and the year of production. It appears that seed weight and final canola seed yield did not have a clear relationship. Evidently, other factors also play vital roles in determining the final seed yield and seed weight by influencing the growth and development of canola yield components. However, the 30 cm row spacing produced favorable results in most cases. Therefore, adopting 30 cm rather than 22 cm would be favorable in the long run especially when seeding on standing stubble. Our study indicates that canola production in western Canada can benefit from adopting zero tillage in conjunction with 5.0 kg per ha to 9.0 kg per ha seeding rate and approximately 30 cm row spacings.

Part II. Effects of tillage regime, seeding rate, and row spacing on infestations of *Delia* spp. (Diptera: Anthomyiidae) and population density and parasitism of the predator-parasitoid *Aleochara bilineata* Gyllenhal (Coleoptera: Staphylinidae).

Part II. Introduction. Root maggots (*Delia* spp.) (Diptera: Anthomyiidae) are serious pests of canola in western Canada. Yield losses from root maggots have been determined at 20% in crops of *Brassica napus* L. and 50% in *Brassica rapa* L. (Griffiths 1991a), amounting to approximately $100 million annually in Alberta alone (Soroka et al. 2004). In Alberta, *Delia radicum* (L.), *Delia floralis* (Fallén), and *Delia platura* (Meigen) are the major root maggot species infesting canola (Griffiths 1986a, 1986b, 1991b; Broatch et al. 2006). *Delia radicum* and *D. floralis* are oligophagous on Brassicaceae and larvae attack fresh roots, but *D. platura* is polyphagous and typically feeds on root tissues already damaged by other root maggot larvae (Brooks 1951; Griffiths 1991b). Larval feeding can lead to reductions in root weight and root sugar content, stunted growth, premature lodging, decreased raceme numbers, and decreased seed yields (McDonald and Sears 1992; Griffiths 1991a; Soroka et al. 2004). Because chemical control with insecticide is not an option for managing root maggot infestations in canola (Soroka et al. 2004), manipulation of agronomic practices like altering plant density, row spacing, tillage regime, and crop fertility have been identified as important components in the integrated management of these pests (Dosdall et al. 1996a, 1996b, 1998, 2002, 2004).

An important area of research that has been inadequately studied involves identifying ways to manipulate canola agronomic practices to provide more suitable habitat for natural enemies of root maggots in canola production systems. In Canada, the natural enemies of root maggots comprise the staphylinid beetles *Aleochara bilineata* Gyllenhal and *Aleochara verna* Say (Coleoptera: Staphylinidae), the hymenopteran *Trybliographa rapae* (Fitigae), and various species of carabid beetles (Coleoptera: Carabidae) (Colhoun 1953; Read 1962; Turncock et al. 1995; Dixon et al. 2004; Hemachandra et al. 2007). Of these, the predator-parasitoid rove beetle, *A. bilineata*, was identified as the most common and effective natural enemy of *Delia* spp. in western Canada (Broatch et al. 2008; Hemachandra et al. 2007). This insect is of considerable interest in canola production because adults are predators, consuming large quantities of root maggot eggs and larvae (Read 1962). The beetle is also a parasitoid. Soon after hatching, the first-instar larva of *A. bilineata* locates a root maggot puparium, bores through the puparial wall, and attaches itself ectoparasitically to the developing fly within (Broatch et al. 2008). The *A. bilineata* larva remains inactive during winter, but in spring it resumes development and consumes tissues of its host, eventually killing it (Royer et al. 1998).

Recent studies of Broatch et al. (2008) determined that emergence and seasonal activity periods of *A. bilineata* in canola were well synchronized with occurrence of pre-imaginal life stages of its principal hosts, *D. radicum* and *D. platura*, with beetle emergence beginning shortly after the onset of root maggot oviposition.

Manipulation of plant density, tillage regime, and row spacing were found to influence damage by *Delia* spp. to canola (Dosdall et al. 1998, 1996a), but no previous studies have been undertaken to investigate effects of such agronomic practices on the activity density or parasitism levels of *A. bilineata.* In this study, it was hypothesized that habitat management, through implementation of various agronomic practices, could alter microclimatic conditions and so influence predation and parasitism by *A. bilineata* on pre-imaginal life stages of root maggots. The study objective was to determine the effects of tillage regime, row spacing, and plant density on infestations of root maggots, and activity density and parasitism levels of *A. bilineata* on root maggots.

PART II. Materials and Methods

Field Operations and Data Collections. The study sites at Lacombe and Vegreville are well known from previous studies to have consistently abundant root maggot populations. The study site characteristics, experimental design, and plot dimensions are described in Part I.

Data collected for this study from the treatment sub-plots included assessments of root maggot oviposition, root maggot damage ratings, rove beetle activity density, and rove beetle parasitism levels on root maggot puparia.

Root maggot oviposition was assessed once each week for a three-week period spanning the period of peak oviposition at each site. During sampling, 25 randomly selected canola plants were examined *in situ* and the numbers of *Delia* spp. eggs laid at the base of these plants and in the soil in a 1-cm radius and to a 1-cm depth around the plants were counted and recorded using the method of Dosdall et al. (1994). Examinations for eggs began when plants were at the three- to four-leaf stage of development.

At the end of the season, plots were combined to determine seed yields per plot. After harvest, roots of 100 plants per treatment (25 from each replicate sub-plot) were randomly selected, excavated, washed, and scored for degree of root maggot damage.

Damage ratings were determined using the method of Dosdall et al. (1994), where 0 represented no damage, 1 represented superficial damage of up to 10% of the root surface, 2 represented damage of between 11 and 25% of the root surface with minor tunneling, 3 represented 26-50% surface damage with tunneling, 4 represented 51-75% damage to the root surface and extensive tunneling, and 5 represented complete severance of the root and 76-100% surface damage.

Each year, field populations of *A. bilineata* were investigated using pitfall trap captures. Pitfall traps were established in each replicate sub-plot in spring and samples were collected weekly during the entire cropping season. At Lacombe pitfall traps were established on 21 June 2007 and 3 June 2008, whereas at Vegreville the traps were established on 25 June 2007 and 18 June 2008.

Traps were maintained for a total of eight and 11 weekly collections from Lacombe in 2007 and 2008, respectively. At Vegreville, traps were maintained for a total of eight collections in both 2007 and 2008.

Each sub-plot contained two pitfall traps. The traps were positioned randomly within each plot with the requirement that the traps be at least 1.5 m in from the plot edges. Pitfall traps consisted of two GenPak® plastic cups placed one inside the other. Cups had a diameter of 11 cm, and a depth of 15 cm. For each trap, a hole slightly more than 15 cm deep and 11 cm in diameter was excavated in the soil. The bottom cup was placed into that hole, just below ground level. The second cup was placed within the first and the rim height was adjusted by adding top soil so it remained in line with the ground level. Each pitfall trap contained approximately 50 mL of fluid (50% solution of propylene glycol) for preserving insects. During trap collections, the inner sleeve component of each trap was removed from the sub-plot and the collected insect samples were carefully transferred to a labeled jar partially filled with 70% ethanol. In the laboratory, specimens were later sorted, identified, and data recorded.

Identifications of *A. bilineata* specimens were performed using Klimaszewski (1984), with verification of selected specimens confirmed by Dr. J.D. Hummel. Voucher specimens from the study have been deposited in the Strickland Museum of Entomology, University of Alberta, Edmonton, AB.

Sex was determined for each specimen through dissection, and comparison with line drawings of Klimaszewski (1984). Total population count was processed against individual treatment combinations using the PROC MIXED procedure of SAS statistical software (SAS Institute Inc. 2003), and sex was reported as percentages of the overall collection of males and females for that year, based on the dates when they were removed from the pitfall traps. When sex determination was not possible because abdominal structures were damaged (e.g., the genital structures), the specimens were not included in the totals.

In spring of each year following harvest of the plots, collections were made of root maggot puparia from each sub-plot. In this process, soil was carefully excavated around taproots of canola stubble to a depth of approximately 5 to 8 cm using a trowel. Soil was cleaned from the taproots and puparia found were removed and preserved in 70% ethanol. A total of 25 puparia was collected from each treatment sub-plot and returned to the laboratory where they were dissected and examined for the presence or absence of *A. bilineata* larvae. At Vegreville in 2007, plots were mistakenly tilled after harvest and as a consequence, no puparia collections were made for this site-year.

Data Analysis. Treatment effects were determined by analysis of variance (ANOVA) using the Proc Mixed procedure (SAS Institute Inc. 2003). Methods of Gomez and Gomez (1984) were used as a basis for comparing fixed treatment effects (seeding rate, row spacing, and tillage regime) having block (replication) as a random effect.

Because of occasional losses of pitfall trap samples from excessive rainfall or flooding, *A. bilineata* trap captures were standardized for trapping effort (beetles per trap per day) prior to analysis. On each sampling date the two trap captures for each sub plot were combined and divided by the sum of the total number of trapping days. In addition, the catch rates for all sampling dates were combined for each plot to obtain a total catch rate for the year.

PART II. RESULTS

Root Maggot Oviposition. In 2007, oviposition at Lacombe increased gradually over the three-week sampling period, with peak egg-laying observed on 15 and 21 June (Figure 1). At Vegreville, however, egg numbers on all assessment dates were lower than those at Lacombe, with significantly more mean *Delia* spp. eggs per plant deposited on 18 June than later in the season. In 2008, oviposition at Lacombe was generally lower than in 2007 with similar numbers of eggs per plant recorded on all sampling dates. At Vegreville, oviposition decreased gradually over the sampling period with peak egg-laying observed on 25 June 2008 (Figure 1).

At Lacombe, in both 2007 and 2008, plants developing in plots tilled conventionally were subjected to significantly greater root maggot oviposition than for plants grown under a zero tillage regime (*P* < 0.05) (Table 3). However at Vegreville in 2008, zero-tilled plots had greater root maggot oviposition than conventionally tilled plots. Root maggot oviposition was significantly affected by seeding rate for three of four site-years (*P* < 0.05). In both tillage regimes, greatest numbers of mean eggs per plant were observed for canola grown at the lowest plant density (approximately 60 plants per m^2 or 2.5 kg seeds per ha), and fewest were observed on plants grown at the highest density (240 plants per m^2 or 10 kg seeds per ha). At Vegreville, no statistically significant effect was observed for oviposition at the different seeding rates in 2007. Row spacing had no significant effect on root maggot oviposition in three of four site-years (*P* > 0.05). However, at Lacombe in 2008, row spacing had a statistically significant effect on oviposition (*P* < 0.05) (Table 3), where mean eggs per plant decreased when row spacing increased from 22 to 45 cm in zero-tilled plots. Similarly, in conventionally-tilled plots root maggot oviposition declined as row spacing increased from 22 and 30 cm to 45 cm.

Root Maggot Damage to Canola Roots. In 2007, at Lacombe, mean root maggot damage ratings for plants were significantly greater when canola was grown under conventional tillage than with zero tillage (*P* < 0.05) (Table 3; Figure 2). However for all other site-years, mean root maggot damage ratings to canola were not affected significantly by tillage treatment (*P* > 0.05).

At Lacombe in both 2007 and 2008, a trend was observed whereby mean root maggot damage ratings to canola declined with an increase in seeding rate, especially under conventional tillage. However, this effect was not significant statistically (*P* >

0.05). At Vegreville in 2007 and 2008, mean root maggot damage per plant was similar as seeding rate increased from 2.5 kg per ha to 10 kg per ha (Table 3). In all four site-years, under both tillage regimes, root maggot damage to canola taproots was not affected significantly by row spacing ($P > 0.05$) (Table 3).

Pitfall Trap Captures of Aleochara bilineata. In total, 1,620 adults of *A. bilineata* were captured in pitfall traps in 2007 at Lacombe. The total male and female adults of *A. bilineata* were 925 and 695 respectively. Trap captures were highest in second sampling week (2 July) followed by the fourth sampling week (16 June) (Figure 3). In general male adult captures were high throughout the sampling period. At Vegreville in 2007, a total of 1,937 adults of *A. bilineata* were captured in pitfall traps, comprising 927 males and 1,010 females. Trap captures were high during the first week of sampling (2 July) and thereafter weekly captures declined (Figure 4). The final sampling week (20 August) experienced another peak in captures but the numbers were lower than during the first week of sampling. In general, female *A. bilineata* captures exceeded males during most sampling periods. In 2008 at Lacombe captures of adults of *A. bilineata* were higher than the 2007 collections at the same site. A total of 3,144 adults were captured in pitfall traps, and this number comprised 1,831 males and 1,313 females. Again at Lacombe in general, male adult captures were more abundant throughout the sampling period than females. Trap captures were high during the second sampling week (16 June) and then captures gradually declined to the fifth sampling week (7 July) (Figure 5). Thereafter a steady increase in trap captures was recorded until the final week of sampling (18 August). In 2008, Vegreville experienced the highest pitfall trap captures among all four site-years. In total, 5,439 adults of *A. bilineata* were captured comprising 2,667 males and 2,772 females. The first peak of adult trap captures was observed during the second sampling week (30 June) and then captures declined until the fourth sampling week (14 July) (Figure 6). Then, a steady increase in trap captures was recorded until the seventh sampling week (4 August). Trap captures declined towards the final sampling week (11 August). For the first four weeks, male *A. bilineata* dominated trap collections but thereafter females were captured in greater numbers until the end of the season.

Activity Density of Aleochara bilineata in Relation to Agronomic Practices. In all four site-years, mean *A. bilineata* activity density (adults per trap per day) was greater in conventionally tilled plots as compared to plots subjected to zero tillage. However, this treatment effect was statistically significant only at Lacombe in 2008 ($P = 0.0326$) (Table 3) (Figure 7).

In all site-years, no significant effects of seeding rate were observed for mean *A. bilineata* activity density ($P > 0.05$) (Table 3). Trends observed in the effects of seeding rate on *A. bilineata* activity density were variable; for example, at Lacombe in 2008, activity density declined with an increase in plant density, but at Vegreville in 2008, activity density of *A. bilineata* was greater at the highest plant densities.

Mean *A. bilineata* activity density has shown a variable trend in all four site-years at various row spacings, but the effect of row spacing was not significant statistically ($P > 0.05$) (Table 3). The most frequently observed trend in the different site-years involved decreasing activity density of *A. bilineata* with an increase in row spacing, especially for canola grown in plots tilled conventionally. Overall seeding rate, row spacing and their interactions with tillage regimens were not statistically significant (*P* > 0.05) (Table 3).

Aleochara bilineata Parasitism of Delia spp. Mean percent of parasitized *Delia* spp. puparia for this entire study varied between 38 and 74%. At Vegreville in 2008, significantly greater mean percent of parasitized puparia occurred in zero-tilled plots than in conventionally-tilled plots (*P* = 0.0228) (Table 3) (Figure 8). However, this effect was not observed at Lacombe in 2007 and 2008 (*P* > 0.05) (Table 3). Mean percentages of parasitized puparia at Lacombe in 2007 in plots subjected to zero and conventional tillage were 38% and 42% respectively. Highest mean percentages of parasitized puparia for this study were found at Lacombe in 2008, where 72 and 70% of puparia were parasitized in plots subjected to zero and conventional tillage, respectively. At Vegreville in 2008, mean percentages of parasitized puparia were 57 and 43% in plots subjected to zero and conventional tillage respectively. Although interactions of any kind in this study were not statistically significant in any of the site-years, few agronomic treatment combinations resulted in a greater percentage of parasitized puparia. For example, at Lacombe in 2008, zero-tilled plots seeded at 7.5 kg per ha resulted in 74% parasitized puparia. Likewise at Vegreville in 2008, zero-tilled plots seeded at 10 kg per ha resulted in 70% parasitized puparia.

The effect of seeding rate (plant density) of canola on mean percent of parasitized puparia was not significant statistically in any of the site-years (*P* > 0.05) (Table 3) (Figure 9). Similarly, row spacing of canola plants had no significant effect on mean percent of parasitized puparia in all three site-years (*P* > 0.05) (Table 3).

PART II. DISCUSSION

In all four site-years of this study, root maggot oviposition followed a similar trend whereby peak egg-laying was observed between 18-25 June, when most plants were in the four to five true-leaf or rosette stages of development. This oviposition pattern was similar to that recorded previously in canola with egg populations increasing to a peak in mid to late June (Dosdall et al. 1994, 1996a).

Increasing seeding rate was associated with reduced root maggot damage ratings for *B. napus* in three of four site-years. Increasing seeding rate increases plant density, and higher plant density promotes reduced basal stem diameter that is not favorable to ovipositing females of *Delia* spp. (Dosdall et al. 1996a). Reductions in oviposition are usually reflected in decreased taproot damage by larvae (Dosdall et al. 1996a, 1998). Observations in the current study agree with those of previous investigations of *Delia* spp. in canola (Dosdall et al. (1996a, 1998), and represent a relationship not uncommon in insect-host plant relations (A'Brook 1968; Farrell 1976).

Canola plant row spacing did not influence *Delia* spp. oviposition in three of four site-years. However, at Vegreville in 2008 fewest eggs were generally laid on plants grown at the widest spacing in plots subjected to either tillage treatment. Results from the Vegreville site in 2008 are in agreement with previous results of Dosdall et al. (1998), but it is unclear why this effect was not observed consistently.

In all four site-years, mean root maggot damage ratings to *B. napus* plants were greater for plants grown in conventionally-tilled plots than for plants grown in zero tillage. At Lacombe in 2007 and 2008, this result concurs with observations on root maggot oviposition because significantly more eggs were also laid on plants grown in conventional tillage. But in contrast, at Vegreville in 2008, greater root maggot oviposition per plant was observed in zero-till plots than in plots tilled conventionally; however, the root maggot damage ratings of plants were greater for plants grown in conventionally-tilled plots. This disagreement between root maggot oviposition and root maggot damage ratings of plants could perhaps be explained by the results of research by Hughes (1959a) who investigated natural mortality factors affecting of *Delia* spp. populations during their immature stages. Hughes (1959a) found that the three pre-imaginal stages of *Delia* spp. (eggs, larvae, and pupae) have different levels of mortality in natural systems, with the highest occurring during the egg stage, followed by the pupal stage, with the larval stage having lowest mortality. Hughes (1959b) implicated a number of important egg predators including carabid and staphylinid beetles as responsible for this mortality because they could consume large numbers of *Delia* spp. eggs. Broatch (2008) and Hummel (2009) studied carabid egg predators in Lacombe, and collected a considerable number of species, including *Bembidion* spp. However, to date, no similar studies of the coleopteran fauna have been undertaken at Vegreville. My results suggest that the diversity and/or abundance of beetle species at Vegreville differs from that found in Lacombe, and these differences may perhaps be responsible for the differences between sites in root maggot egg populations.

The life history of *A. bilineata* has been well studied, and it has been determined that first-instar larvae seek out host puparia, penetrate the puparial wall, and overwinter within the puparium; larvae complete their development and emerge from puparia following diapause in the spring (Royer and Boivin 1999). The recommended production practice for canola in western Canada is to rotate crops, so canola is usually not seeded on land on which the same crop was grown in the preceding year (Thomas 2003). In this study, plots were seeded to a cereal crop in the years before the canola plots were established; hence adults of *A. bilineata* would have migrated into the plots from elsewhere.

The number of weekly adult beetle captures from the two pitfall traps established within a single treatment sub-plot varied considerably, and this may be explained by the phenology of this species. In *A. bilineata*, mating starts just after emergence and females begin to oviposit on the second day after adult eclosion (Colhoun 1953). Maximum egg-laying occurs four to seventeen days later, and thereafter oviposition rate declines (Langlet et al. 1998). In view of this phenology, it is probable that the behavior pattern of individual *A. bilineata* in a given population would be variable and rather unpredictable; individual adults in a given treatment plot would be nonsystematic in terms of foraging, mating, oviposition, and larval parasitism. In this context, there are predicted to be greater chances that pitfall trap captures at times do not correlate with the total number of adult beetles attracted to a particular canola plot. Dixon et al. (2004) noted that pitfall trap monitoring of predators usually measures relative abundance and activity rather than absolute population density.

Greater activity density of *A. bilineata* occurred in conventionally-tilled plots in all four site years. Moreover plots subjected to conventional tillage had plants with greater root maggot damage ratings, indicating that *A. bilineata* was concentrated in patches of greatest resource availability. Insect predators and parasitoids use vision, audition, and/or olfaction to locate a suitable habitat (Royer and Boivin 1999). Tomlin et al. (1992) suggested that *A. bilineata* may use infochemicals to locate the best sites for mating, foraging and oviposition, by aggregating where *Delia* spp. are abundant. In the process of host location, *A. bilineata* adults can disperse as far as 5 km from a release point to aggregate in sites with high *Delia* spp. larval density (Tomlin et al. 1992). Olfactory stimuli arising from host plants infested by *Delia* spp. were found to be highly attractive to *A. bilineata* adults (Royer and Boivin 1999). Royer and Boivin (1999) found that water-soluble infochemicals arising from larval integument and larval frass associated with damaged rutabaga were attractive to *A. bilineata* adults. Nonetheless, the most reliable cue to attract *A. bilineata* adults is the effluvia of damaged rutabagas containing frass, but not root maggot larvae (Royer and Boivin 1999). Therefore it appears that observations from Lacombe are in agreement with the concept of this predator-parasitoid responding to infochemical cues arising from higher *Delia* spp. populations in some treatment plots.

Dixon et al. (2004) captured greater numbers of *A. bilineata* in plantings of rutabaga grown surrounded by bare soil than in plots with rutabaga undersown to clover (*Trifolium repens* L.). In this study, activity density of *A. bilineata* was significantly greater in conventionally tilled plots at Lacombe in 2008, and in all other site-years the beetle showed a trend in this direction. Foraging strategies of predators and parasitoids involve trade-offs between the quality and quantity of resources/prey obtained and time spent and risk associated with foraging (Gullan and Cranston 2005). It is quite possible that crop residue on the soil surface in the zero-till plots hampered locomotory movements by *A. bilineata*, and the residues could have placed limitations on their ability to capture prey. If so, this would help explain greater pitfall trap captures in conventionally tilled plots.

Activity density data of *A. bilineata* tended to be somewhat variable in relation to different seeding rates and row spacings, but this is perhaps not unexpected. Even in a suitable habitat, resources are rarely evenly distributed, and occur in more or less discrete microhabitat clumps, termed patches, and insects show a gradient of responses to these patches (Gullan and Cranston 2005). Patch selection is vital to successful foraging (Gullan and Cranston 2005). Moreover different *A. bilineata* biotypes may vary in their abilities to locate prey. As well, the damage inflicted to canola taproots may vary due to different species compositions of root maggots in different sites and years, and among treatment plots. Hence, these reasons may help explain why we failed to establish a clear relationship between the behavioral parameters of host *Delia* spp. and *A. bilineata* in field conditions.

Overall parasitism of *Delia* spp. by *A. bilineata* ranged from 38 to 74% in this cropping system. In the early 1950s research by Wishart (1957) in Newfoundland recorded parasitism of 34% by *A. bilineata* on *D. radicum* in cole crops. Turnock et al. (1995) observed a wide range of parasitism of *Delia* spp. by *A. bilineata* collected from commercial plots of rutabaga in southern Manitoba, Canada; parasitism ranged from 10 to 94% at Winnipeg. Hemachandra et al. (2007) recorded 18 to 52% parasitism of *Delia* spp. by *A. bilineata* in the Canadian prairies. The high percent parasitism of *Delia* spp. by *A. bilineata* in the range of 38 to 74% in the current study would be sufficient to suppress the *Delia* spp. egg and larval populations from these sites.

As noted, the high rates of activity density of *A. bilineata* in conventionally-tilled plots at Lacombe in 2008 were presumably due to a high root maggot density that attracted more beetle adults to those plots. In turn, more *A. bilineata* adults would have produced more first-instar larvae that could eventually parasitize more *Delia* spp. puparia in those plots. However, in 2008 at Vegreville, mean percent parasitism of *Delia* spp. puparia by *A. bilineata* was greater in zero-till plots that had plants with lower root maggot damage ratings than conventional-till plots. These observations seem contradictory to the concepts of infochemical attraction effects on adults, and density dependency with regard to movements of *A. bilineata* (Royer and Boivin 1999; Jones et al. 1993). It would have been expected that parasitism should also have been higher in conventionally tilled plots. This contradiction can perhaps be better understood through review of the biology of *A. bilineata*. Females oviposit near host plants infested by *Delia* spp. larvae (Fournet et al. 2001). Upon hatching, the first-instar larva of *A. bilineata* must locate a root maggot puparium, penetrate its wall, enter, and finally seal its entry hole all within an average life expectancy of only five to six days (Fournet et al. 2001; Royer et al. 1998). Moreover, *A. bilineata* first instars decrease their locomotory activity 36 h after eclosion, and they can spend 12 to 36 h in the process of chewing an opening through the puparial wall. When considering these life history characteristics, it is possible that the microenvironment of zero-till plots may have provided better conditions for parasitism than plots tilled conventionally. The cool, moist conditions provided by crop residues may have enhanced longevity of *A. bilineata* first-instars by delaying desiccation of the larvae and the residue may have provided some cover from carabid beetle predators during the vulnerable period prior to penetration of the root maggot puparial wall.

PROJECT SUMMARY

The studies described in this report have determined that the predator-parasitoid *A. bilineata* is important for reducing populations of root maggot pests in canola agroecosystems in central Alberta. Parasitism rates of 38 to 74% were found for *Delia* spp. puparia, and in addition, the large numbers of adults found in some site-years (e.g., > 5,400 adults at one study site in pitfall traps) indicate that vast numbers of root maggot eggs were removed by these insects.

The comparatively high percentage of parasitism of *Delia* spp. by *A. bilineata* observed in zero-till plots has important implications for agricultural production in central Alberta. Important advantages of utilizing zero-till systems for canola production are the reduced requirements of human labour, fuel and equipment (Lafond and Derksen 1996; Stinner and House 1990; Jensen and Timmermans 1991). The long-term benefits of adopting zero-till systems are many, including reduction of greenhouse gases, increasing soil organic matter content, and perhaps altering/enhancing the composition of beneficial soil fauna and flora in commercial farming systems. In addition to these benefits, canola producers in areas infested annually with high population densities of root maggots should be encouraged to adopt, or continue to utilize, zero or reduced tillage systems because results of this study showed lower root maggot infestations and higher parasitism in zero-till plots relative to plots tilled conventionally.

When considering seeding rates, results of this study were in agreement with previous research that determined reduced root maggot infestations at higher seeding rates (e.g., Dosdall et al. 1996, 1998). In addition to enhancing cultural control of root maggots, higher seeding rates in canola can reduce infestations of other pests. For instance, Dosdall et al. (1999) found that increasing seeding rates in canola reduced seedling damage by flea beetles (*Phyllotreta* spp.), and O'Donovan (1994) proposed increasing canola seeding rate to 7 kg per ha to minimize infestations of tartary buckwheat, *Fagopyrum tataricum* (L.) Gaertn. Current seeding rate recommendations for canola in North Dakota and Canada are between 5.6 to 9.0 kg per ha, depending on seed bed conditions at the time of seeding, with the aim of establishing a plant population of 40 to 200 plants per square meter (Berglund and McKay 2002; Thomas 2003). Therefore adopting a seeding rate between 5.6 to 9.0 kg per ha should bring advantages in terms improved management of root maggots and other important canola pests like flea beetles and tartary buckwheat.

We did not observe consistent results for root maggot infestations or for *A. bilineata* activity for different row spacings from this study. Nevertheless, evidence from previous studies by Dosdall et al. (1998) suggests that adopting wider row spacing resulted in reduced infestations of root maggots. In addition, Dosdall et al. (1998) found that widening row spacing in canola plantings tended to reduce seedling damage by flea beetles. In view of the above factors it is evident that adopting zero or reduced tillage in conjunction with a recommended seeding rate of at least 5.6 kg per ha and row spacing of 30 cm will facilitate integrated management of *Delia* spp. infestations in canola while helping maintain reasonably good seed yields.

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Table 1. Mean monthly temperature and precipitation data during the growing season at Lacombe and Vegreville, AB in 2007 and 2008 compared with long-term average values.

Lacombe

	Mean monthly precipitation (mm)			Mean monthly temperature (°C)		
			1971-2008			1971-2008
Month	2007	2008	Mean	2007	2008	Mean
April	51.5	-	21.0	2.4	1.3	4.3
May	117.9	46.4	55.6	9.8	10.3	10.1
June	174.0	100.6	75.7	14.9	13.5	13.9
July	48.8	50.6	89.4	19.1	15.3	15.4
August	69.2	56.2	70.8	13.2	15.5	14.7
September	46.0	10.4	47.3	9.4	10.3	9.8

Vegreville

	Mean monthly precipitation (mm)			Mean monthly temperature (°C)		
			1971-2008			1971-2008
Month	2007	2008	Mean	2007	2008	Mean
April	39.6	34.4	19.5	3.2	0.5	4.5
May	28.6	37.2	37.4	17.1	10.7	10.5
June	52.6	43.6	64.1	20.9	14.9	14.5
July	55.6	47.4	79.9	27.3	16.5	16.3
August	66.8	69.0	55.5	20.3	16.1	15.8
September	28.2	37.0	40.0	16.8	10.3	10.2

Source: National climate data and information archive. Environment Canada 2009.

Table 2. Analysis of variance results (***P*** values) for canola production data in 2007 and 2008 from Lacombe and Vegreville, Alberta. Statistically significant (*P* < 0.05) values are given in bolt font.

Effect	Percent seedling emergence	Seed Yield	Seed weight (1000kwt)	Seed protein concentration	Seed oil concentration
2007- Lacombe					
Tillage(T)	**0.0130**	0.1981	0.2513	0.2091	0.3835
Seeding rate(S)	**<0.0001**	**0.0043**	0.0799	0.1676	**0.0027**
Row spacing(R)	**0.0016**	0.2410	0.7032	**0.0048**	**0.0043**
T×S	0.0560	0.6564	0.6103	0.1442	0.2696
T×R	0.6062	0.4021	0.4030	0.6605	0.7162
S ×R	0.1592	0.7611	0.4147	0.8093	0.2698
T ×R × S	0.6297	0.0755	0.1884	0.8868	0.8576
2008- Lacombe					
Tillage(T)	0.7294	0.2931	**0.0190**	0.0596	0.0640
Seeding rate(S)	<**0.0001**	0.2472	0.2044	0.4828	0.3728
Row spacing(R)	0.6510	0.3233	0.9723	0.2340	0.3908
T×S	0.2431	0.6473	0.7938	0.2249	0.1949
T×S	0.1598	**0.0374**	0.6753	0.7646	0.9915
S ×R	0.1718	0.2033	0.2915	**0.0008**	**0.0018**
T ×R × S	0.0566	**0.0317**	0.4222	**0.0420**	**0.0046**
2007- Vegreville					
Tillage(T)	0.7945	0.9968	**0.0384**	0.1925	0.1276
Seeding rate(S)	**0.0081**	0.2931	0.9120	0.7562	0.6587
Row spacing(R)	0.0605	0.8062	0.2636	0.8928	0.6381
T×S	0.7197	0.1452	0.3210	0.1460	0.3461
T×R	0.3783	0.4750	0.3140	0.3749	0.1172
S ×R	0.7464	0.7212	0.1487	0.8859	0.8322
T ×R × S	0.5214	0.1274	**0.0256**	0.5278	0.4088
2008- Vegreville					
Tillage(T)	**0.0310**	0.0960	**0.0478**	0.7485	0.6054
Seeding rate(S)	**0.0001**	0.8841	0.3651	0.3629	0.2753
Row spacing(R)	**0.0024**	**0.0308**	0.4970	0.3835	0.5283
T×S	0.5104	0.3502	0.1052	0.1096	0.1261
T×S	0.4341	0.3196	0.5454	0.2883	0.3348
S ×R	0.5703	0.0671	0.9850	0.4410	0.3956
T ×R × S	0.3679	0.8908	0.1648	0.9528	0.7978

Table 3. Analysis of variance results (*P* values) for insect activity data in plots of *Brassica napus* grown in zero and conventional tillage at various row spacings and seeding rates at Lacombe and Vegreville, Alberta in 2007 and 2008. Statistically significant ($P < 0.05$) values are given in bold font.

Effect	***Delia* spp. oviposition**	**Canola root damage**	**Activity density of *A. bilineata***	**Parasitism of *A. bilineata* on *Delia* spp.**
2007- Lacombe				
Tillage(T)	**0.0406**	**0.0033**	0.1222	0.2722
Seeding rate(S)	**0.0001**	0.6117	0.4564	0.9610
Row spacing(R)	0.3305	0.5400	0.0628	0.7316
T×S	0.1362	0.0978	0.7291	0.1571
T×R	0.1120	0.6582	0.0871	0.7253
S ×R	0.1567	0.5051	0.3238	0.3454
T ×R × S	0.2789	0.3435	0.2531	0.1326
2008- Lacombe				
Tillage(T)	**0.0433**	0.2493	**0.0326**	0.3939
Seeding rate(S)	**0.0006**	0.061	0.1379	0.3319
Row spacing(R)	**0.0468**	0.1722	0.5386	0.3763
T×S	0.6412	0.0615	0.6584	0.6935
T×R	0.6529	0.2890	0.9850	0.4410
S ×R	0.2129	0.2178	0.9065	0.6037
T ×R × S	0.3263	0.0612	0.8214	0.2068
2007-Vegreville				
Tillage(T)	0.0660	0.6800	0.2223	N/A
Seeding rate(S)	0.5799	0.5990	0.5882	N/A
Row spacing(R)	0.5436	0.1750	0.5416	N/A
T×S	0.8929	0.4802	0.3611	N/A
T×R	0.1617	0.4805	0.4747	N/A
S ×R	0.5050	0.5463	0.2410	N/A
T ×R × S	0.5719	0.4943	0.7286	N/A
2008-Vegreville				
Tillage(T)	**0.0181**	0.0807	0.3939	**0.0228**
Seeding rate(S)	**0.0018**	0.0807	0.3319	0.2750
Row spacing(R)	0.1548	0.1584	0.3763	0.1198
T×S	0.3278	0.5611	0.6935	0.5587
T×S	0.4432	0.6452	0.441	0.5942
S ×R	0.2426	0.3772	0.6037	0.6114
T ×R × S	0.1342	0.9118	0.2068	0.1768

[1]N/A- In 2007, at Vegreville, the production site was mistakenly cultivated after harvesting the crop. Hence, puparia of *Delia* spp. were not collected in the following spring.

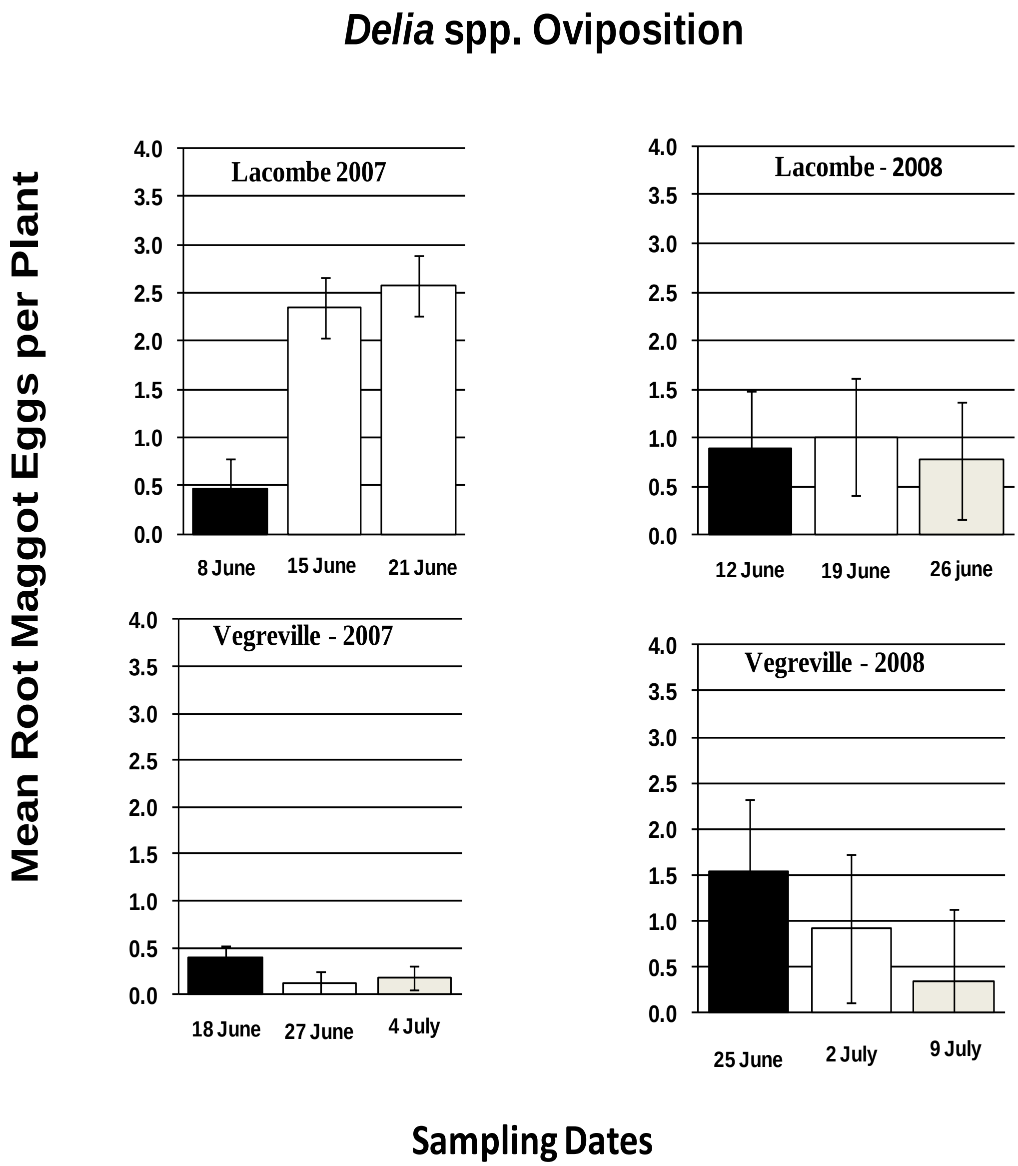

Figure 1. Mean root maggot eggs per plant of *Brassica napus* at Lacombe and Vegreville, AB in 2007 and 2008 seeded at different plant densities and row spacings under conventional and zero tillage regimes.

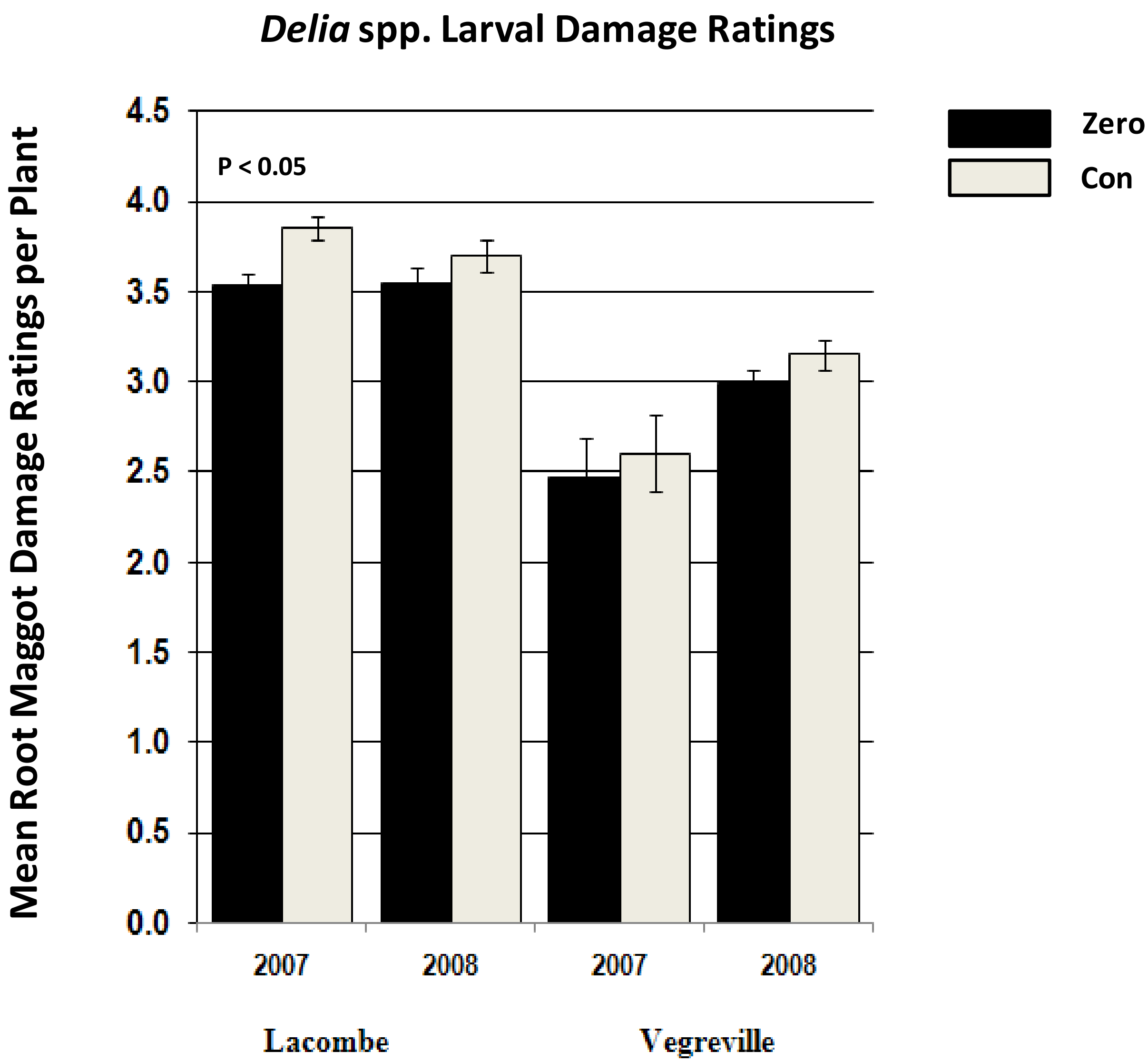

Figure 2. Mean root maggot damage ratings per plant of *Brassica napus* at Lacombe and Vegreville, AB in 2007 and 2008 seeded under conventional (Con) and zero (Zero) tillage regimes.

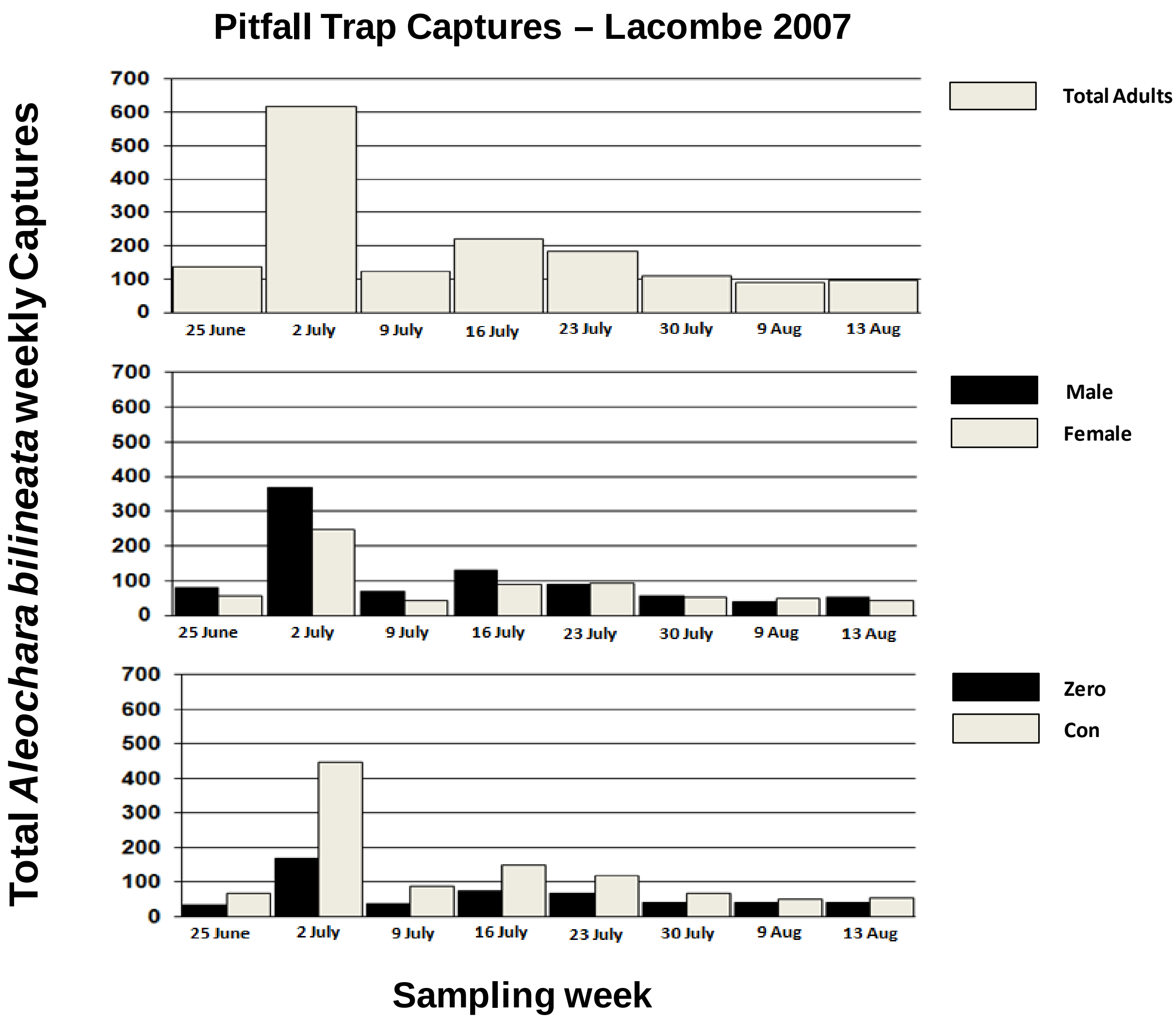

Figure 3. Weekly pitfall trap captures of *Aleochara bilineata* adults from plots subjected to conventional (Con) and zero (Zero) tillage treatments at Lacombe from 25 June to 13 August 2007.

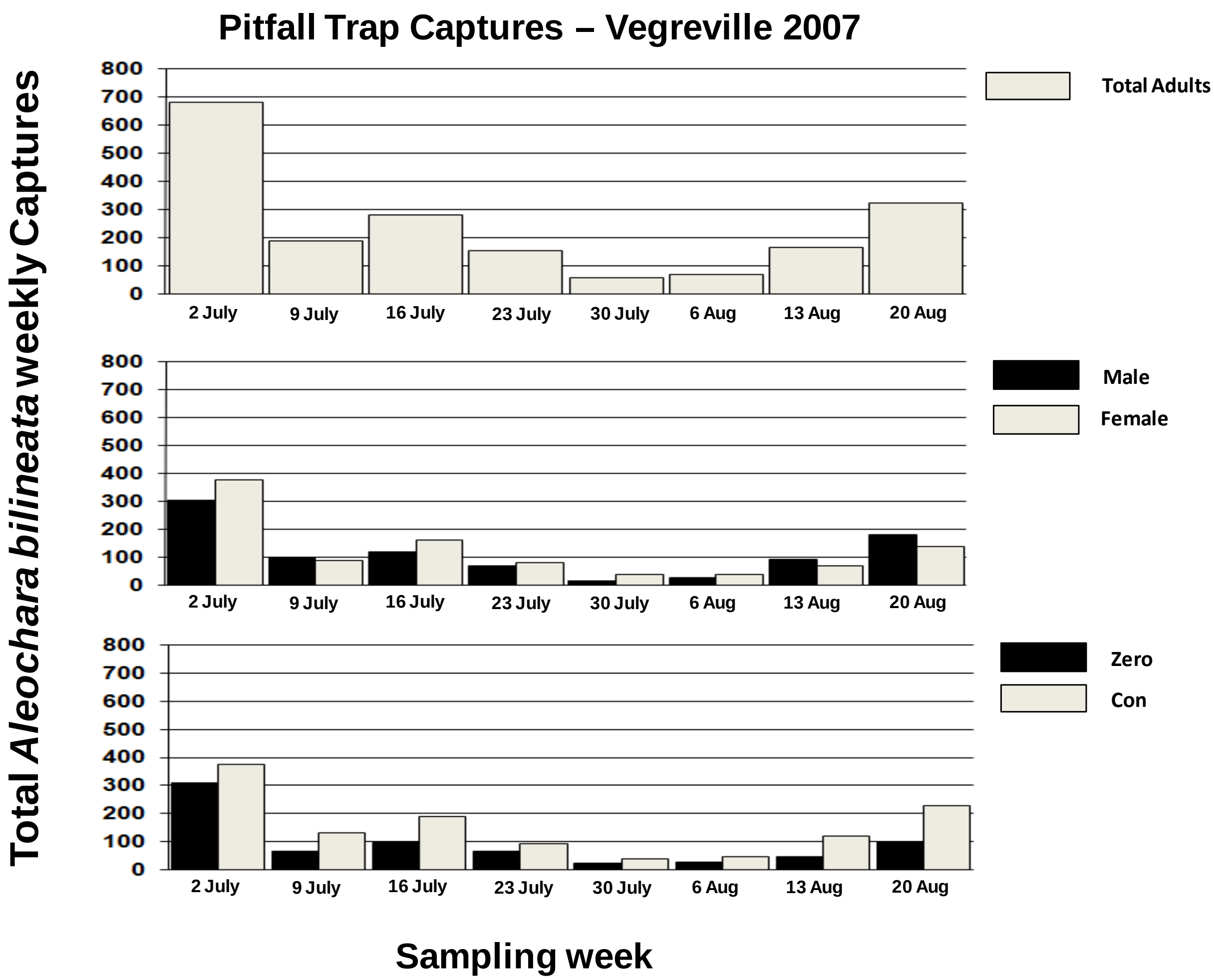

Figure 4. Weekly pitfall trap captures of *Aleochara bilineata* adults from plots subjected to conventional (Con) and zero (Zero) tillage treatments at Vegreville from 2 July to 20 August 2007.

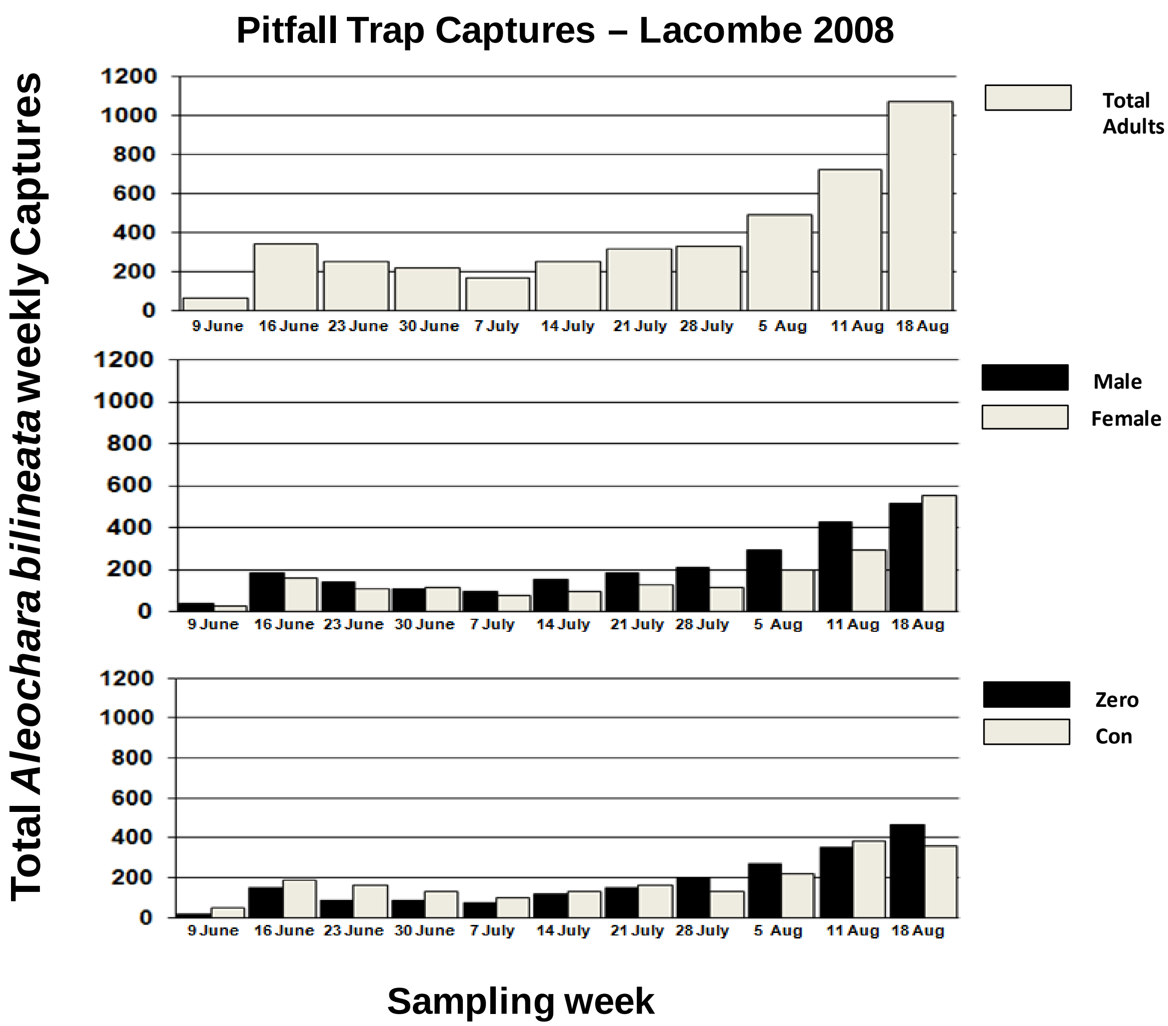

Figure 5. Weekly trap captures of *Aleochara bilineata* adults from plots subjected to conventional (Con) and zero (Zero) tillage treatments at Lacombe from 9 June to 11 August 2008.

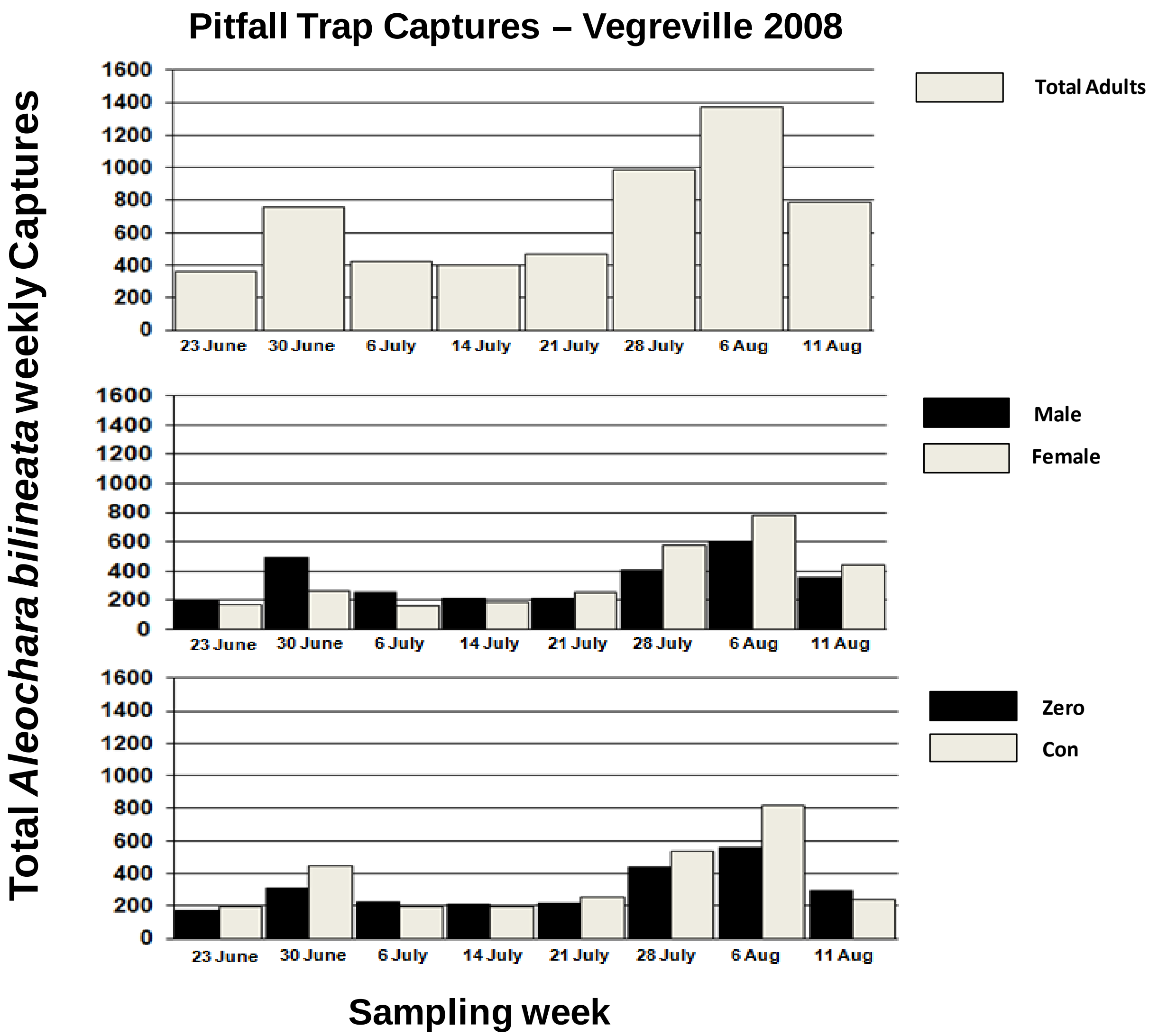

Figure 6. Weekly pitfall trap captures of *Aleochara bilineata* adults from plots subjected to conventional (Con) and zero (Zero) tillage treatments at Vegreville from 23 June to 11 August 2008.

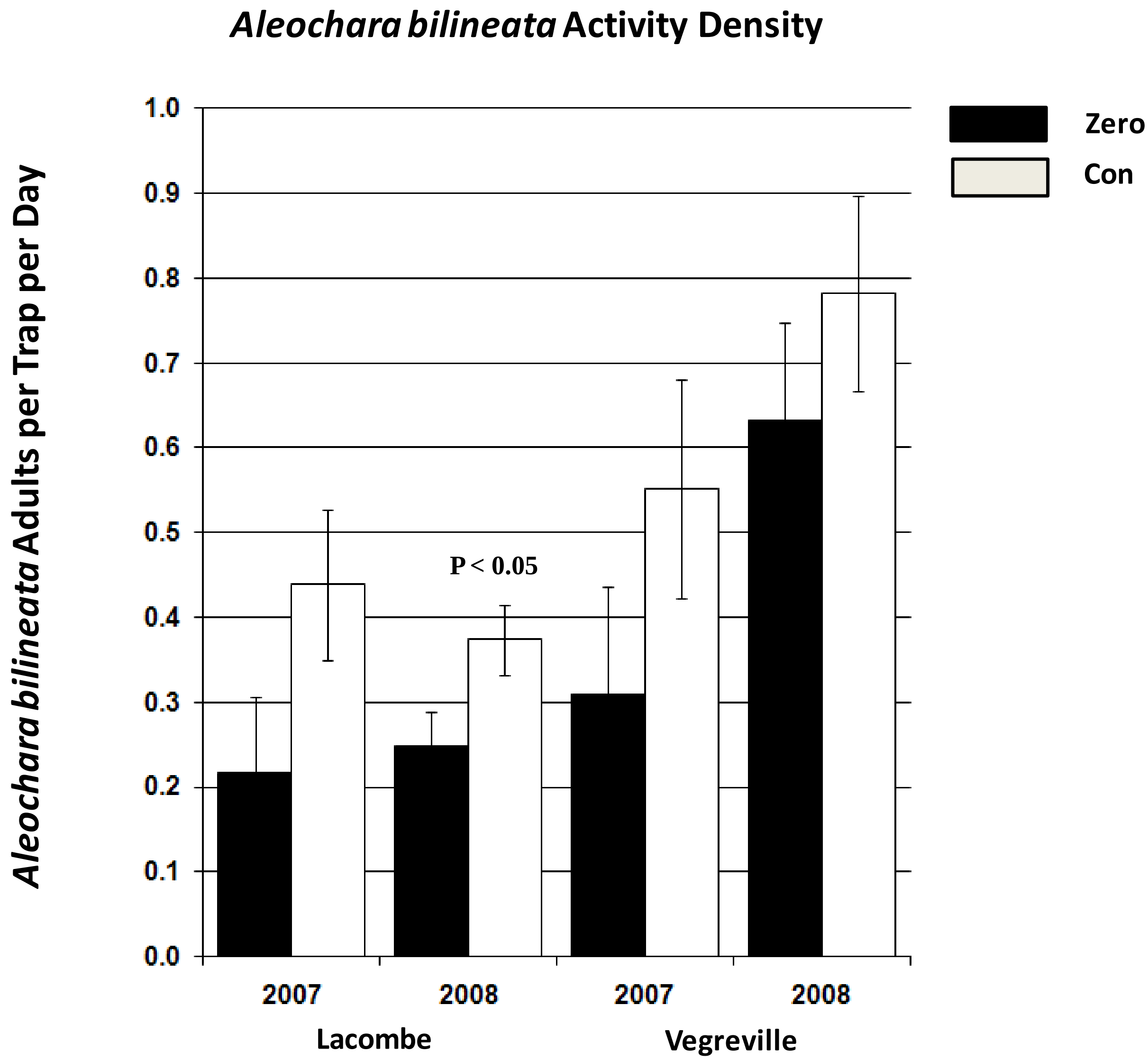

Figure 7. Mean *Aleochara bilineata* activity density in *Brassica napus* plots seeded at Lacombe and Vegreville, AB in 2007 and 2008 under conventional (Con) and zero (Zero) tillage regimes.

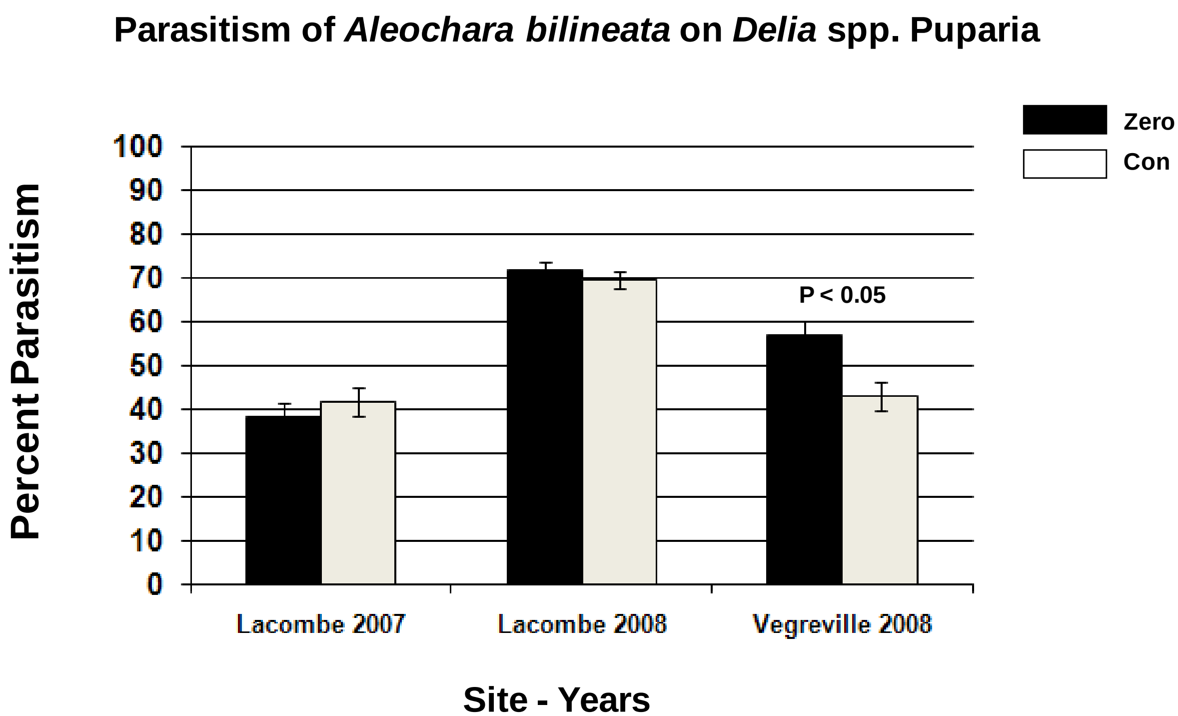

Figure 8. Mean percent parasitism of *Aleochara bilineata* on *Delia* spp. puparia in *Brassica napus* plots seeded under conventional (Con) and zero (Zero) tillage at Lacombe and Vegreville, AB in 2007 and 2008.

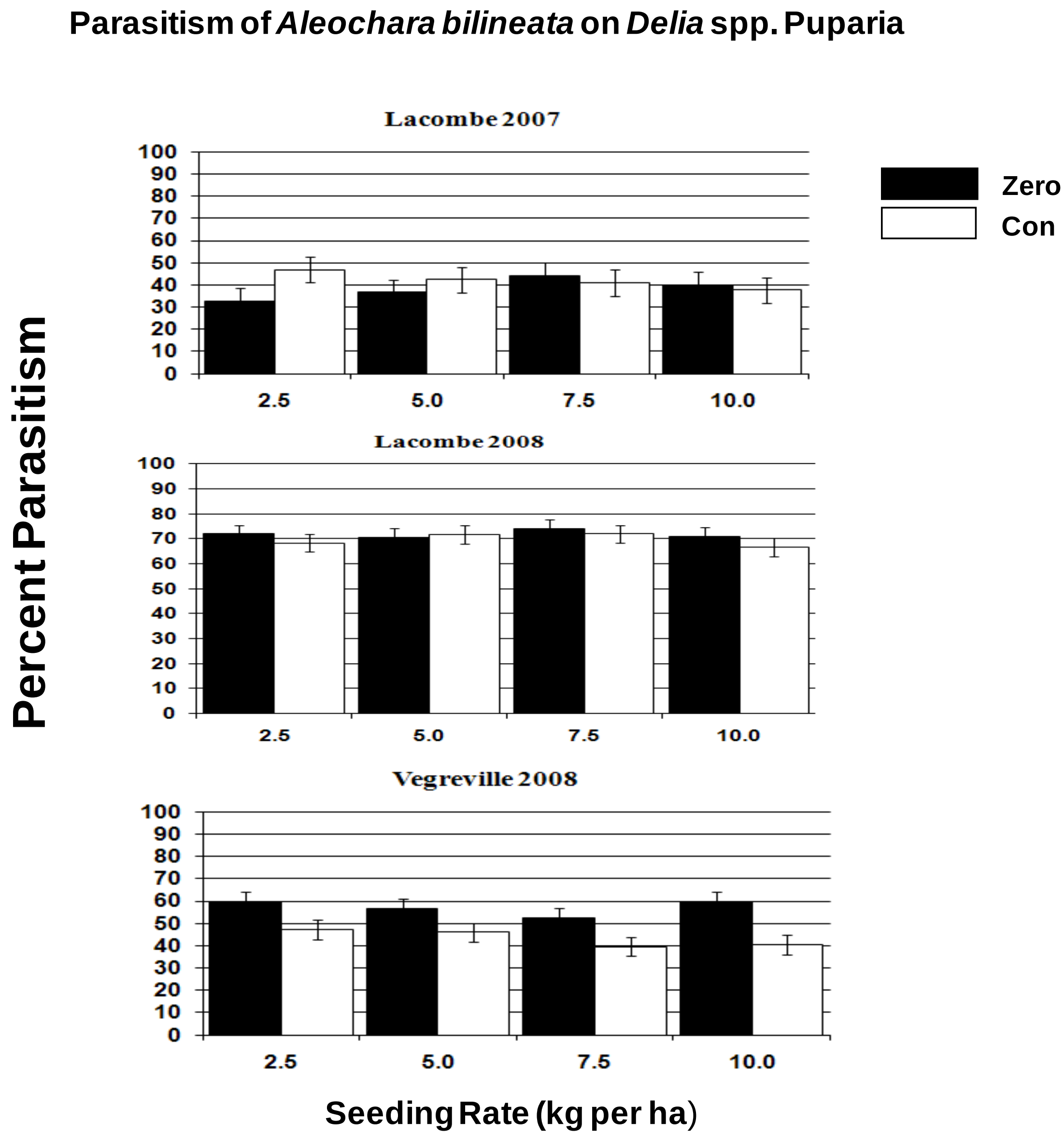

Figure 9. Mean percent parasitism of *Aleochara bilineata* on *Delia* spp. puparia in *Brassica napus* plots seeded at different rates (2.5, 5.0, 7.5 and 10 kg per ha) under conventional (Con) and zero (Zero) tillage regimes at Lacombe and Vegreville, AB in 2007 and 2008.