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Management of root maggots, *Delia* spp. on oilseeed rape in Manitoba

Final Report

Submitted by
N.J. Holliday
Department of Entomology
Faculty of Agricultural and Food Sciences
University of Manitoba
Winnipeg, Manitoba R3T 2N2

UNIVERSITY OF MANITOBA

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Abstract

- From 1999 to 2001 studies were performed on the influence of agronomic practices on the numbers of cabbage root maggots and on the root damage inflicted by them in canola in Manitoba. Some studies continued in 2002.
- Three avenues of research were used:
    - A large field plot experiment exploring effects of tillage regime and seeding rate
    - Studies of distribution of insects and damage at the margins of fields and plots
    - Analysis of surveys of 959 commercial canola fields done in 1997 - 2000.
- Major findings were:
    - Fields with short rotation intervals invariably had higher levels of root damage
    - Root damage was less after zero tillage than after conventional tillage
    - Root damage was lower when higher seeding densities were used or plant density was higher
    - Wind-breaks reduced the number of larvae and root damage within 20 m of field margins
    - Particularly in the absence of wind-breaks, larval numbers and root damage were elevated within 20 m of crop margins.
- There was evidence of yield loss when root damage ratings exceeded 3.5 - 4 (where 4 = 51 - 75% of tap-root surface damaged). These rating levels were exceeded in individual plants in plots and near field margins throughout the study, and in 2000, the most severely damaged commercial field had an average damage rating of 3.5. There has been a long-term trend in Manitoba for root maggot incidence and damage severity to increase.
- Major recommendations to reduce maggot damage are:
    - Short rotation intervals between canola crops should be avoided
    - Zero tillage practices should be used to maintain crop residues on the soil surface **before** seeding canola, but **after** a maggot-infested canola crop conventional tillage should be practiced
    - Higher seeding rates should be used to promote higher plant densities
    - Wind-breaks should be established around canola fields
- Our data on the distribution of maggots near crop margins suggest that the following practices be adopted:
    - Sampling to assess the general levels of root maggots in canola fields should be done no less than 20 m from the field margin
    - If insecticidal methods of root maggot control become available, consideration should be give to applying them only at the field margins
    - Small plots, such as those used by plant breeders, are particularly vulnerable to high levels of root maggot attack, and can be protected by embedding them within a larger stand of canola or another root maggot host, or by surrounding them with fly-proof barriers > 1 m in height.

Background and Objectives

This report provides a summary of the activities, results and conclusions of a three year (1999-2001) project funded in part by the Canola Agronomic Research Program (CARP) of the Canola Council of Canada. Additional funding for the project was received from the Agricultural Research and Development Initiative (ARDI) of the Province of Manitoba.

In the original application to these agencies, it was proposed that there would be two graduate student projects, with one student supported by a scholarship. Under that scenario, the project would have had two main objectives:

1. To reduce injury caused by cabbage maggot population in Manitoba through tillage and other cultural practices.
2. To increase host-plant resistance of oilseed rape to cabbage root maggots.

In fact, the scholarship-holding student failed to materialize, which reduced overall funding to the project and, after some preliminary studies, no further work was done on objective 2. This change in plan was communicated to CARP in 1999. All work focussed on objective 1 and it is the results relating to this objective that are reported here.

Methods

Field plot studies

In the summer of 1999, 2000 and 2001, a large-scale field plot trial at the Carman Research Station of the Department of Plant Science, University of Manitoba, was used to test the effect of seeding rate and tillage practice on the number of cabbage root maggots and the on amount of damage caused. The trials had a nested design of two treatment types, with each type having two levels. The treatments consist of a zero tillage regime and a conventional tillage regime, crossed with levels of low (4 kg/ha) and high (8 kg/ha) seeding rates within each treatment. Treatments were replicated on four plots with two subplots each, totalling eight subplots; subplots were 30 m x 60 m.

The conventional tillage treatment in 2000 and 2001 consisted of harrowing in the fall, and again in the spring, preceding seeding. In 1999, conventional tilled subplots were tilled only in the spring before seeding. Zero till plots received no tillage. All subplots were seeded at either the high or low seeding density with Limagrain LG3295 Round-up ready canola using a zero-till drill. Seed was treated with Foundation dual-purpose seed treatment and Roundup is applied for weed control in late June. In 2000, and again in 2001, fungicide was applied for sclerotinia control.

In each year, numbers of larvae and pupae, and predator activity, were assessed at weekly intervals for each subplot. Eggs were also sampled in 1999 and 2000. Eggs, larvae and pupae were sampled by random selection of plants in each subplot. Samples were not taken from the peripheral 5 m of each plot. Eggs were collected from the soil surface around the selected plant, and then a soil core, centred on the plant was extracted. Soil cores were removed to the laboratory where eggs, larvae and pupae were recovered by hand sorting. In 2000 and 2001, the plant root was rated on a five point root damage rating scale (Dosdall et al. 1994) in which 1 represents < 10% of root surface damage, and 5 represents 75-100% of root surface damaged. In 1999, root rating was done only once, at the time of canola harvest. In all three years, predators were sampled using pitfall traps. Yields were estimated from each subplot by taking a 60 m swath through the middle of the subplot with a plot combine, and weighing the total seed yield from the swath. In 1999 and 2000, activity patterns of adult cabbage root were investigated using attractant traps containing water and detergent and baited with allyl isothiocyanate.

Data for eggs larvae, pupae, root damage ratings and yield were analysed by analysis of variance for individual years and for the overall three years of the study. Because of the difference in tillage treatment in 1999 and the following two years, an additional analysis was performed to assess the effects of tillage over 2000 and 2001. Data for eggs, larvae and pupae were logarithmically transformed prior to analysis. Data on patterns of activity of adult cabbage root maggots and on predator catches have not yet been fully analysed, and are not presented in this report.

Edge effects

In 1999, data from small plots (1 m wide) showed far higher levels of root maggot damage than was observed in our samples taken from the interior of the large plots, and it was inferred that this might mean that the edge of plots were more heavily infested with root maggots. To test this, after harvest in fall 1999, we sampled the 30 x 60 m field plots. A total of 20 transects (sample lines perpendicular to the edge of the crop) were sampled at intervals from the edge of the plot to 10 m from the edge. At each interval a root was pulled up and rated for damage.

In 2000, 2001 and 2002, edge sampling was done in commercial fields, using a standard approach. Each selected canola field was at least 64 ha and more-or-less square. Fields were sampled at about the time of peak larval abundance. Samples were taken at 0, 0.33, 0.67, 1, 2, 3, 4, 5, 10, and 20 m from the field edge along transects at the centre of each accessible side of each field. Additional samples were taken near the centre of the field. Each sample consisted of a single canola root and the adhering soil. The samples were individually bagged and taken to the laboratory where the number of larvae and the root damage rating for the root was determined.

Distribution of root maggot damage among commercial fields

Through collaboration with Dr J. Gavloski, Manitoba Agriculture and Food, and Dr D. McLaren, Agriculture and AgriFood Canada Brandon Research Station it was possible to access a large body of data on cabbage root maggot root damage ratings in commercial fields. Data for 1997-2000 have so far been analysed, and data for 2001 will soon be available.

Results and Discussion

During the course of the study, abundance of cabbage maggots and the seasonal pattern of their distribution varied with the year (Fig. 1). Root maggots were moderately abundant in 1999 and the season allowed a portion of the population to complete a second generation. In our field plots, in 1999, the second generation of larvae successfully completed their development on the roots of canola after harvest. In 2000 and 2001 there was only a single generation of root maggots. Maggots were extremely abundant in 2000, but rather scarce in 2001. Consequently, data from 2001 frequently did not show the effects that were being tested for, and the analysis was generally most sensitive in 2000.

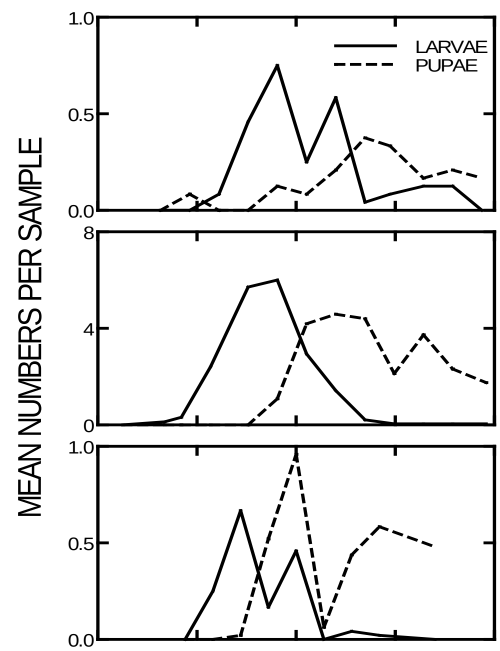

Figure 1 Seasonal abundance of larvae and pupae in field plots.

In the field plot trials, there were no significant effects of treatments on numbers of eggs, either when each year was considered separately, or when both years of egg sampling were analysed together. Efficiency of sampling eggs was very dependent upon weather and soil conditions, and this may have accounted for the absence of significant effects. As a result, effects of treatments on eggs are not discussed further.

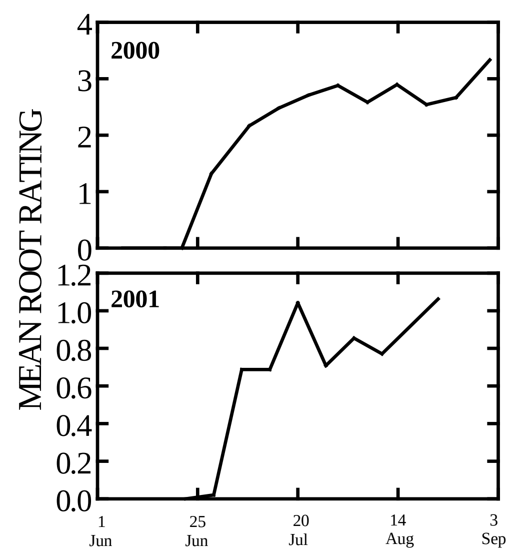

Figure 2. Seasonal pattern of change in root damage ratings in 2000 and 2001.

In 2000 and 2001, when root damage rating in field plots was performed at weekly intervals throughout the growing season, the damage rating increased from about 0 in late June to a plateau by the end of July (Fig. 2), a period that coincides with the time root maggot larvae are abundant in the field (Fig. 1). After July, little change occurred in the root damage rating and so it was concluded that root ratings performed at any time after the end of July could be compared with one another.

Effect of tillage

The effect of tillage was investigated only in field plots, although surveys to be done in commercial fields in 2002 will allow correlation of tillage regime with maggot attack, and so will be a method of verifying our results.

In 1999, there were more larvae in the zero tilled plots than in conventionally tilled plots (Fig. 3), although this effect was not statistically significant. In 2000 and 2001, more larvae were present in the conventionally plots than in the zero tilled plots and overall this effect was significant (F = 4.6; df = 1,15; P <0.05). Tillage did not significant affect the number of pupae in any of the three years; however in 2000, when pupae were most abundant the effect of tillage was almost significant (F = 6.6; df = 1,3; $P \approx 0.08$) and there were more pupae in the conventionally tilled plots (Fig. 4).

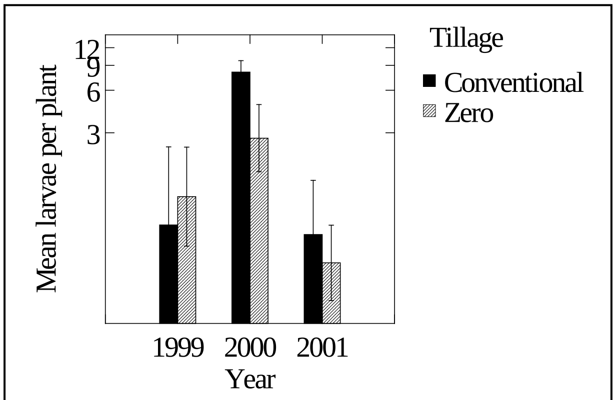

Figure 3. Effect of tillage on mean number of larvae per plant at the peak of larval abundance. Note vertical axis is on a log scale to improve

The effect of tillage on final root ratings was quite consistent from year to year (Fig. 5): in all years root damage was more severe in conventionally tilled plots than in zero-tilled plots. This effect was statistically significant in individual years in 1999 and 2000, and was significant overall (F = 9.8; df = 1,15; P <0.01). Despite this, there were no significant effects of tillage regime on overall yield (Fig. 6).

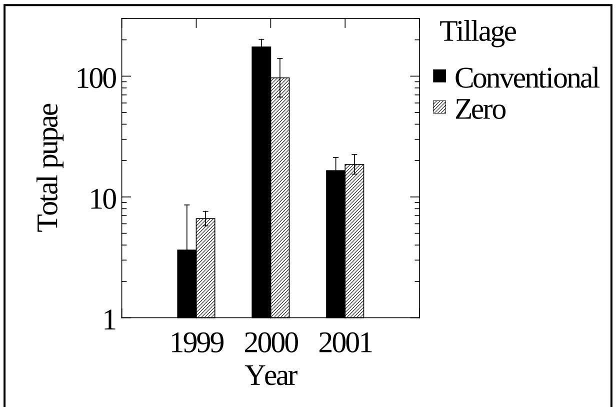

Figure 4. Effect of tillage on total number of pupae collected in field plots. (Note vertical axis is on a log scale to improve clarity).

The finding that root ratings were lower in zero tillage is opposite to that of a sometimes-significant trend reported by Dosdall et al. (1998) that root ratings are higher in zero tillage systems. In discussions with Dosdall, it appears that the conventional tillage plots he used were under a zero tillage regime until a few weeks before seeding of the canola crop, and so differ in treatment from those in this study. In our study, in 2000 and 2001, conventionally tilled plots received both fall and spring tillage treatments and closely approximate the production practices on non-zero-till farms in Manitoba. It should also be noted that, in 1999, our larval densities were higher in the zero-tilled plots and that in this year our conventional tillage regime was rather similar to that of Dosdall (1998). Overall, it appears

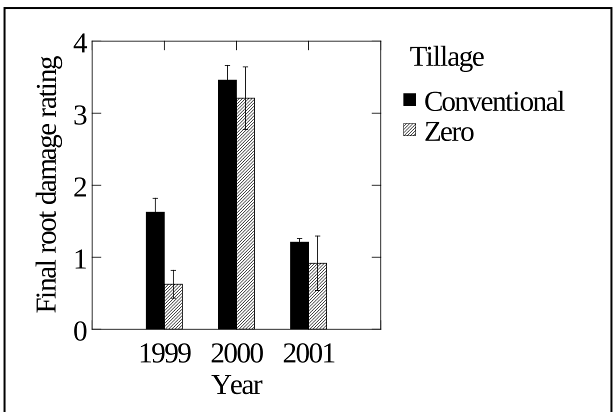

Figure 5. Effect of tillage on final root damage ratings.

that in southern Manitoba, root damage is consistently diminished when canola is seeded into a zero-tillage system. This is not surprising, since the crop residues provide over wintering habitat for predators that are very influential in dictating maggot mortality in subsequent crops. Evidence that the influence of tillage regime on root ratings operates through predation is shown in Fig. 7, which shows the relative abundance of eggs and larvae in 2000. Egg abundance was virtually the same under both tillage regimes, whereas there were more larvae in conventionally tilled plots than in zero-tilled plots. This suggests that female cabbage maggots did not exhibit preference for one type of tillage over another and that the number of eggs laid in each type of plot was similar. The effect of tillage regime operated sometime between deposition of eggs and the assessment of larvae in roots, and it is at this time, when larvae are very small and still on the surface of roots that predation is known to be very significant (Coaker & Williams 1963, Finlayson et al. 1980). When the data on predators caught in pitfall traps become available, it may be possible to corroborate the presumed effect of tillage on predator activity.

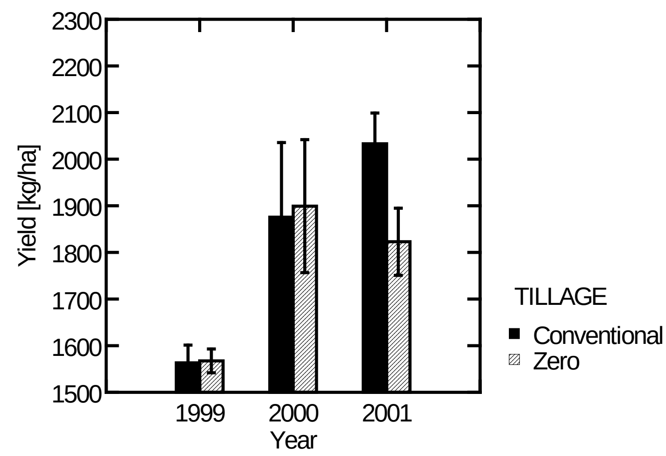

Figure 6. Relationship between tillage regime and yield in field plot experiment..

It should be noted that (Dosdall et al. 1996)) showed unequivocally that tillage of fields infested with maggot pupae at the end of a canola crop inflicts considerable mortality on cabbage maggot pupae. Therefore, the preferred pattern of tillage for management of root maggots in canola in southern Manitoba appears to be to use zero-tillage in the fall and spring preceding the canola crop to enhance maggot predation during the growing season, but to use conventional tillage following the canola, to reduce the number of maggot pupae that survive winter.

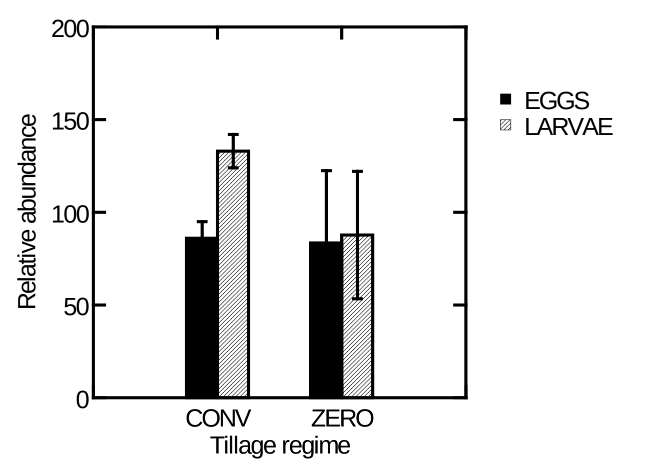

Figure 7. Relative abundance of eggs and larvae in conventional and zero-tilled plots in 2000.

The effect of crop rotation

Crop rotation effects were studied by using the extensive database of information collected under the direction of Drs Gavloski and McLaren. Over the four years for which analyses have been done, root-rating information was available for a total of 959 fields. Root ratings varied according to year, and so were analysed within each year. As can be seen (Table 1), in every year, the highest average rating was observed in the fields with the shortest rotation interval, and in three of the four years, this pattern was statistically significant.

Table 1. Summary of fields surveyed for root ratings and effect of rotation interval on root rating.

	Year							
	1997		1998		1999		2000	
Number of fields sampled	187		247		204		321	
Average root rating	1.05		0.62		0.99		1.20	
Rotation effect	% of fields	Root rating	% of fields	Root rating	% of fields	Root rating	% of fields	Root rating
Back to back	0	-	0	-	7	1.30	4	1.58
2 years	26	1.19	29	0.75	33	1.10	28	1.35
3 years	35	1.07	38	0.61	21	0.92	29	1.23
4 years	20	1.03	22	0.51	25	0.91	23	1.07
5 years	19	0.96	10	0.58	13	0.79	15	0.96
Test that shortest rotation has highest rating	$P \approx 0.10$		$P < 0.05$		$P < 0.05$		$P < 0.05$	

Effect of plant density

Information on the effect of plant density comes both from the controlled experimental system of the field plots and from field surveys. In the field plots, plant density was manipulated by seeding at two different rates. Although formal measures of plant density were not made for each sample taken, the different seeding rates produced high and low plant densities. In the field surveys plant density was measured directly, although in 1997 densities were classified into three categories, rather than recorded quantitatively.

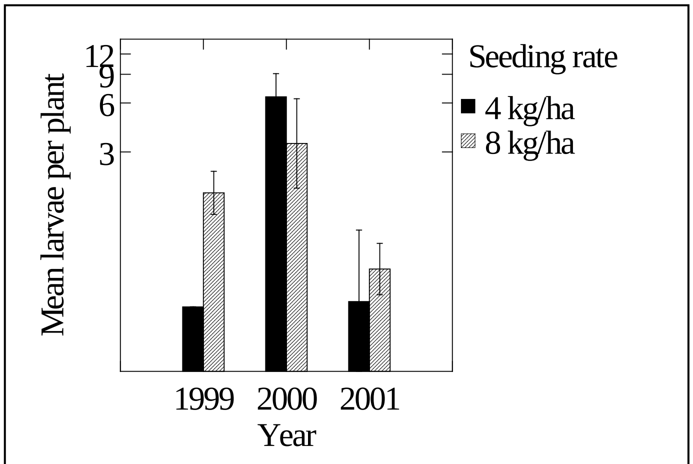

Figure 8. Effect of seeding rate on mean number of larvae per plant at peak of larval abundance. (Note vertical axis is on a log scale to improve clarity).

In the field plots experiment, seeding rate had a variable effect on the abundance of larvae (Fig. 8) at their seasonal peak. Considering total larval abundance over the season, there was no consistent significant effect of seeding density. However, in 2000, when maggot abundance was highest, there was a significant effect of seeding rate on total larval abundance ($F = 9.4$; df = 1,3; $P < 0.05$): larvae were more abundant on a per plant basis at the lower seeding rate. In 2000 and 2001, pupal abundance tended to be higher on a per plant basis in plots with the lower seeding rate (Fig. 9), but this effect was not quite significant. In all three years, root damage ratings at the end of the season were higher in plots in which seeding density was at the lower rate (Fig. 10). Overall, this was a significant effect ($F = 7.8$; df = 1,15; $P < 0.05$). Despite the effect of seeding rate on root rating, there was no significant effect of seeding rate on canola yield either in individual years or overall (Fig. 11).

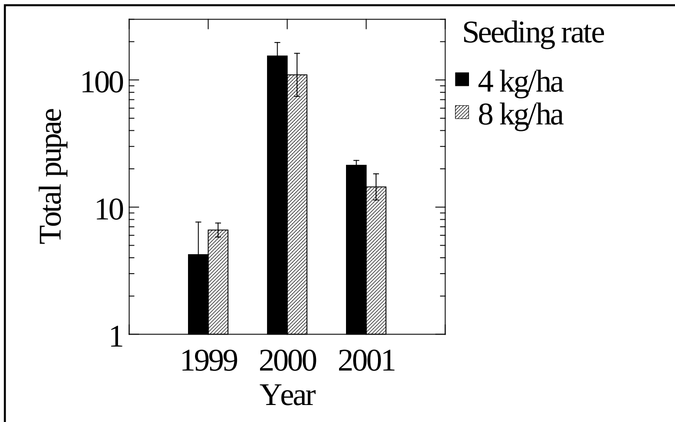

Figure 9. Relationship between seeding rate and total number of pupae per plot. (Note vertical axis is on a log scale to improve clarity).

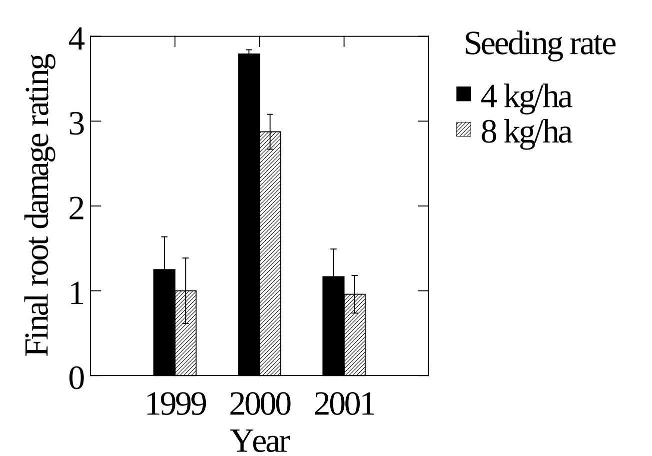

Figure 10. Relationship between final root damage rating and seeding rate in field plot experiment.

In field surveys, the qualitative classification of plant density used in 1997 was not related to root damage ratings. Similarly, in 1998, when quantitative plant densities were recorded, there was no significant relationship with root rating. In 1999 and 2000 plant density significantly influenced the root damage rating after accounting for the influence of rotation interval. In each of these two years the relationship of plant density to root rating was negative: that is, lower plant densities were associated with higher levels of damage, as was the finding from the field plot experiment. In the field surveys, the effect was most visible in 2000 (Fig 12), yet even here the relationship is not strong because of the many potentially confounding variables in a field survey embracing several regions, cultivars and seeding dates. Nevertheless, the finding that low plant densities are significantly associated with higher root damage in two years out of three for which good data are available, is a reasonably strong validation of the experimental result.

The tendency for higher plant densities to result in lower root damage ratings has also been reported by (Dosdall et al. 1998). This relationship may be because female cabbage maggot flies are believed to prefer to lay eggs close to thick stems; however it may also be a dilution effect: if the number of maggots is fixed then there will be fewer per plant when plant density is higher.

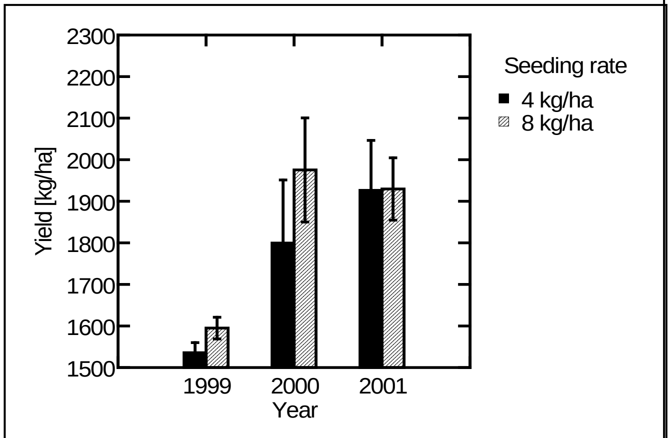

Figure 12. . Effect of seeding rate on yield in the field plot experiment.

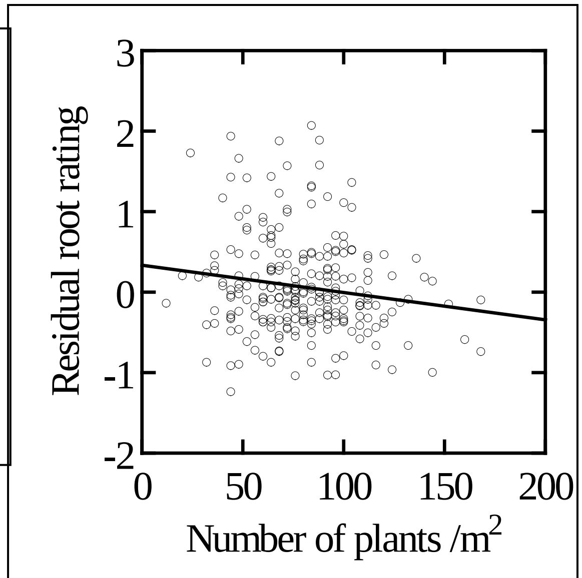

Figure 11. Relationship between plant density and root damage ratings after the

Distribution of cabbage root maggots and root damage at the edge of fields

In 1999, the edge samples around the experimental field plots revealed that the intensity of root damage was greatest near the edge of field plots (Fig. 13). This effect was highly significant (F = 22.0; df = 1,140; P <0.001).

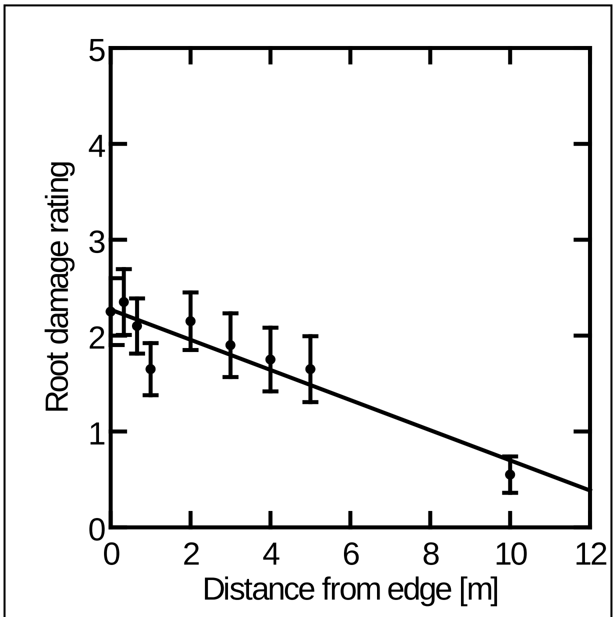

Figure 13. Relationship of root damage rating to distance from the edge of large experimental plots in 1999.

In 2000, we studied whether this edge effect phenomenon occurred in commercial fields by sampling 28 transects in seven canola fields near Pilot Mound and Stonewall. Wind-breaks were found to affect the number of root maggots (F = 15.7; df = 1,224; P <0.001): on average, at the edge of fields without wind-breaks there were about four times the number of larvae as at edges with wind-breaks (Fig. 14). When wind-breaks were absent there was a strong effect of distance from the field margin on their abundance (F = 5.7; df = 1,224; P <0.05), but there was no such relationship when wind-breaks were present (Fig. 14). The elevated numbers of larvae at the edge of fields did not penetrate beyond about 20 m into the field: there was no significant difference in the number of larvae at 20 m and at the centre of the field (*t* = 0.80, df = 27). The pattern of root damage ratings was similar to that for larvae (Fig. 15). Near the edge of fields without wind-breaks root damage was about 50% higher than when wind-breaks were present (F = 20.3; df = 1,224; P <0.001). In the absence of a wind-break, there was elevated damage at the edge of the field, and this declined with distance from the edge (F = 5.8; df = 1,224; P <0.05), but this effect did not occur in the presence of a wind-break. At 20 m from the edge of the field, root damage ratings were not significantly different from those at the center of the field (*t* = 0.96, df = 27).

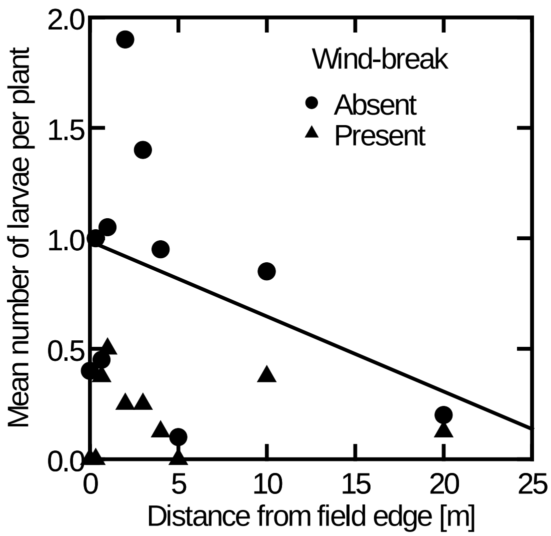

Figure 14. Abundance of larvae near the edge of commercial canola fields with and without wind-breaks in 2000. Regression line is shown fitted to data for absence of wind-break.

In 2001, we attempted to repeat the study in commercial fields to confirm the existence of the edge effect and the influence of windbreaks upon it. Although we sampled a total of seven commercial fields in Oak Bluff, Stonewall, Steinbach and Dugald areas, there were insufficient root maggots in any of the fields for an edge effect to be detectable.

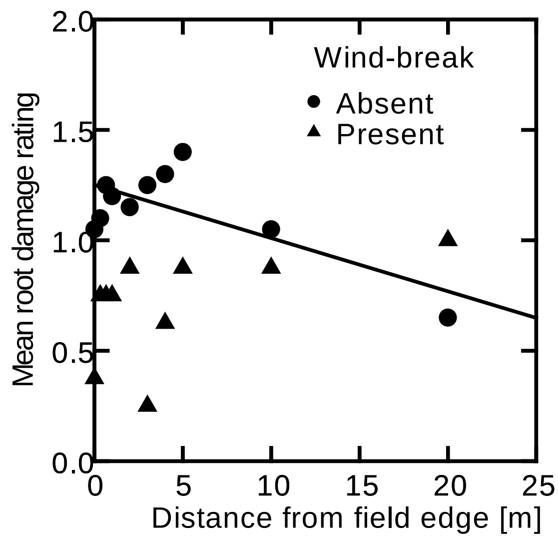

Figure 15. Root damage ratings near the edge of commercial canola fields with and without wind-breaks in 2000. Regression line is shown fitted to data for absence of wind-break.

In 2002, we sampled 19 transects from five fields in the Pilot Mound and Darlingford areas, and although numbers of cabbage root maggots were not as high as in 2000, our attempt to validate the previous data was more successful. Our data show similar trends to those found in 2000. Numbers of larvae close to the field margin in the absence of windbreaks were twice those in the presence of windbreaks, and there was a decline in larvae with the distance from the field margin. The same pattern was observed in root ratings although root ratings in the absence of windbreaks were only about 5% higher than in the presence of windbreaks.

The patterns of larval distribution are consistent with our knowledge of flight behaviour of root maggot adults (Vernon and MacKenzie 1998). Adults fly within 1 m of the ground and tend not to climb to fly over obstructions. Consequently, even low wind-breaks are adequate to prevent many flies from entering a field. The stronger effects of this behaviour on larval distribution than on root damage is no doubt due to the timing of our root damage assessments: we did the assessments at the same time as larvae were collected, and at this time larvae would inflict damage in the field for about two more weeks. It was impracticable to return to fields to determine final root damage ratings in the same locations as we had done larval assessments.

The implications of this pattern are that assessing of populations or root damage within 20 m of a field margin tends to overestimate infestation levels in the field as a whole. If suitable insecticidal control measures were available and economically justified, they may only be needed near the field margin. Further, the presence of a windbreak appears to be beneficial in reducing the maggot damage within 20 m of a field margin. While this strip may not seem particularly important, it should be considered that a 20m wide strip around a quarter section represents 9.7% of the total area (15.7 acres).

Synthesis and Conclusions

Current populations of root maggots in Manitoba probably seldom cause economic loss under large-scale field conditions. Economic loss occurs in Alberta, partly because root maggot injury is often associated with root rot, and this condition is more prevalent in the *Brassica rapa* cultivars grown in northern agricultural regions of Alberta. Notwithstanding this, the level of infestation of cabbage root maggots in Manitoba has tended to increase, and the level of infestation has also increased. In the middle of the most severely affected commercial fields root ratings averaged 2.9 in 1997, 2.7 in 1998, 2.8 in 1999 and 3.5 in 2000. At the edge of fields we sampled and in our field plots individual root ratings of 4 (51-75% of the taproot surface damaged) were not uncommon. The relationship between yield and root damage rating has not been definitively described, and was not a primary objective of this research. However, by plotting the final root

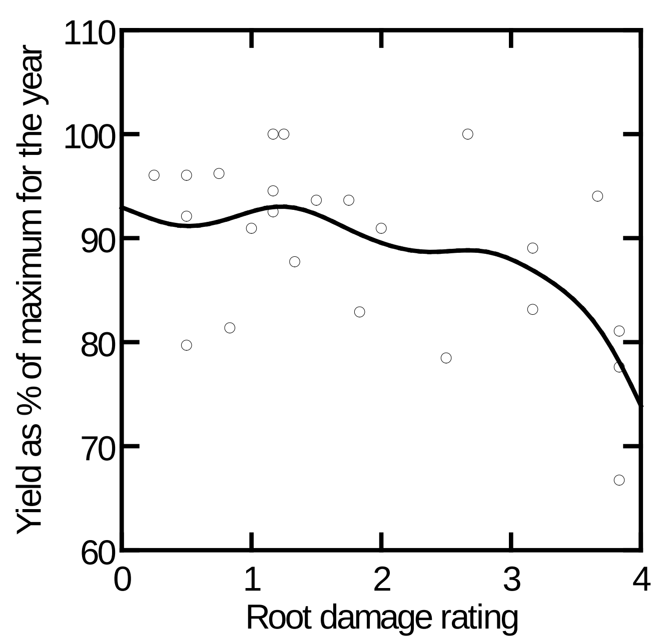

Figure 16. Relationship between final root ratings and yield. Root ratings are the average final root rating for each of the eight plots in the field plot study in each of the three years. Yield for plots in each year is expressed as a % of that in the highest-yielding plot in that year. The trend line is an empirical fit using distance-weighted least squares.

ratings for our field plot experiment against the yields for each plot expressed as the percent of the maximum yield in any plot for that year (Fig. 16), it appears that root ratings above 3.5 - 4, yield loss begins to occur. Thus, it may be that any additional increase in root maggot levels in Manitoba may cause yield loss.

Our studies show that a number of agronomic techniques will provide some reduction in maggot incidence or root ratings or both. These are:

- Avoidance of short rotation intervals between canola crops
- Using zero tillage to maintain crop residues on the soil surface **before** seeding canola
- Using higher seeding rates to promote higher plant densities
- Establishing wind-breaks around canola fields

In addition to these practices, the literature also suggests that after a maggot-infested canola crop conventional fall tillage will reduce the carryover of maggots to the following year. Our data on the distribution of maggots near crop margins suggest that the following practices be adopted:

- Sampling to assess the general levels of root maggots in a canola field should take place no less than 20 m from the field margin
- If insecticidal methods of root maggot control become available, consideration should be give to applying them only at the field margins
- Small plots, such as those used by breeders, are particularly vulnerable to high levels of root maggot attack and consideration should be given to embedding them within a larger stand of canola or another root maggot host, or surrounding them with fly-proof barriers > 1 m in height.

Impact

Cabbage root maggot problems show long-term trends of increase in severity in canola in prairie Canada, and are currently estimated to cause losses of $100 million in some years (Soroka et al. 2002). Although one "suppressant" pesticide is available for maggot management, it is of limited effectiveness because of the time of attack of the root maggots. In the long term, biological control may provide a permanent solution to the problem of cabbage maggots, and this laboratory is working actively on that option. However, manipulation of agronomic practices is the only current method available to producers for management of maggots, and may continue to be important even when biological control suppresses maggot populations. The package of recommendations outlined above should do much to maintain root maggot populations in canola fields below levels that cause economic loss, even as maggot populations continue to increase.

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