ECONOMIC ASSESSMENT OF CABBAGE MAGGOT DAMAGE IN CANOLA IN ALBERTA

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INTRODUCTION

Canola crops are regularly infested by larvae of the cabbage maggot, Delia radicum (L.) (Diptera, Anthomyiidae), in areas of Alberta with relatively high summer rainfall, especially north and west of a line from Red Deer to Edmonton to St. Paul. This distribution of infestations is correlated with the Central Alberta Storm Track, which produces a July peak in precipitation. Root maggot infestations also occur, but less frequently, in the Peace River Region, where the most abundant species is the turnip maggot, D. floralis (Fallén). For further background information on the biology and distribution of these and related species of Delia in North America, see my taxonomic treatment (Griffiths 1991).

Investigations on root maggots in canola in Alberta during the early eighties provided basic biological information, including the timing and distribution of infestations (Liu and Butts 1982, Liu 1984, Griffiths 1986a, Griffiths 1986b). However, we did not at that time obtain adequate quantifications of the effect of maggot infestations on seed yield and quality under field conditions.

The objectives of the present project during the 1989 season were to develop a system for measuring the economic impact of root maggots in canola by use of large insect exclusion cages; and to obtain estimates of the effect of cabbage maggot damage on canola yield and quality. During 1990 these objectives were expanded to include tests of the efficacy of experimental chemical formulations for seed-drill application. All objectives have been achieved.

MATERIALS AND METHODS

The 1989 trial on the University Farm (Michener Park) consisted of 144 1 x 1 m plots, arranged in two identical blocs within which the design was as close to random as possible given the constraint imposed by the sowing machinery and use of large cages. The following were the four treatments:

- A Open plots, naturally maggot-infested (n = 24)
- B Plots in cages with north wall missing, naturally maggot-infested (n = 24)
- C Caged plots, with minor artificially induced maggot damage (n = 24)
- D Caged plots, without maggots (n = 72)

The cages were 3.5 x 3.5 x 1.83 m high, each containing 4 plots (one of treatment C and 3 of treatment D in the case of complete cages). The net consisted of tan-coloured polyester screening with mesh size of 2 mm. This allowed small insects (including some flea beetles) to pass through, but excluded root flies of all species.

Note that treatment A is not directly comparable with treatments C and D. Comparison between treatments A and B gives differences attributable to reduced energy input inside cages (45% reduction of incoming radiation). Comparison between treatments B, C and D gives differences attributable to the effects of maggot infestation in plots subject to the identical radiation regime.

The plots were sown mechanically to Tobin canola (Brassica campestris

L. cv.) treated only with Vitavax RS (carbathiin, thiram, lindane) on May 9 and exclusion cages installed on May 10-14. All plots were hand-weeded and thinned to 40 plants per m^2 on June 14-16. During June 26 to July 3 maggots were transferred to one plot inside each complete cage (treatment C) at the rate of 1 maggot per plant. Root samples were collected from a reserve plot at 2-weekly intervals during July for the purpose of bacteria isolation. Maggot-infested plots were harvested by hand on August 8 (treatment A) and August 10 (treatment B), those inside cages (treatments C and D) on August 15-16. Following drying in cotton bags, plants were threshed with an Almaco Plot Thresher on August 23 and seed yield per plot recorded. Roots were washed and rated on August 22-26. Seed weight and oil content (using an NMR Analyzer, Magnet Type 10) were recorded on August 28-29. Protein analysis was conducted by the Soils and Animal Nutrition Laboratory during September to November.

The 1990 trials were conducted at two separate sites (Michener Park and Ellerslie) on the University Farm. Soil at both sites is classified as chernozemic (Malmo Silty Clay Loam), but the level of available plant nutrients is unusually high at Michener Park. In this respect the Ellerslie site is more typical of farmland in Alberta.

At Michener Park the trial consisted of 256 1 x 1 m plots (arranged in two identical blocs within which the design was as close to random as possible). The following were the 8 treatments:

- A Open plots, naturally maggot-infested without chemical maggot control (n = 32)
- B Open plots, seed treated with Amaze (oftanol) at 12 ml active per kilo (liquid coating) (n = 32)
- C Open plots, seed treated with Amaze (oftanol) at 48 ml active per kilo (liquid coating) (n = 32)
- D Open plots, seed with added Counter (terbufos) at 5 lbs per acre (coated granules) (n = 32)
- E Open plots, seed with added Furadan (carbofuran) at 5 lbs per acre (coated granules) (n = 32)
- F Open plots, seed treated with Lorsban (chlorpyrifos) at 12 g active per kilo (coated powder) (n = 32)
- G Plots in cages with north wall missing, naturally maggot-infested (n = 32)
- H Caged plots, without maggots (n = 32)

At Ellerslie the trial consisted of 192 plots (treatments A-F only), since no cages were installed at this site.

All plots were sown to Alto canola (Brassica napus L. cv.) on May 4 at an intended rate of 100 plants per m^2. All seed was treated with benomyl--thiram-lindane or the equivalent Benolin-R as a precaution against seedling pests and diseases. The term "untreated" in this paper is to be understood to mean without additional chemical treatment. The five additional chemical treatments (B-F) were all experimental formulations designed to delay release of the active ingredient to coincide with maggot hatching in the second half of June. The rates of application for B, D, E and F were rates approved for other uses in canola; the rate for C was an enhanced rate close to the maximum practicable.

Cage frames were erected at Michener Park soon after sowing and the nets pulled over them and dug in on May 29. Plots at Michener Park were weeded by hand during June 11-15, those at Ellerslie sprayed with the herbicide Muster at 30 g per hectare on June 6. Ratings of root damage were conducted on June 22, July 18 and at harvest. Root samples were collected from a reserve plot for fungal isolation on July 24. Open plots were harvested during August 13-16 and caged plots on August 17. After drying plants were threshed and seed yield recorded on September 18-19. Seed weight and oil content were recorded on September 20-25. Protein analysis was conducted during September to November.

Data were analyzed with a standard statistical program on the University of Alberta computer and differences in treatment means subjected to t-test and two-way F-test. Where not otherwise stated, the estimates of probability obtained by both tests are in the same range. Any effect not duplicated in the two identical blocs into which each trial was divided was considered to represent "noise" (fortuitous or unexplained variation). All values given represent means ± 1 standard error. In presenting the 1990 data two cages have been omitted for some parameters on account of aphid infestation.

RESULTS

Level of Maggot Infestation

When roots were examined after harvest, virtually 100% of plants in naturally infested plots proved to have been damaged by maggots both in 1989 and 1990. Climatic conditions were highly favourable for root maggots in both years, with July precipitation above the longterm mean (Edmonton International Airport: 105.8 mm [1989] and 149.3 mm [1990], 1951-80 mean 91.6 mm. Source: Environment Canada, Atmospheric Environment Service).

In plots to which one larva per plant had been transferred (treatment C in 1989), 47.2 ± 2.9% of the plants were found to have a single maggot scar on their rootstock when inspected after harvest. This was clearly below the economic damage threshold, since in no parameters was the difference between treatments C and D significant. For purposes of further analysis treatment C has therefore been pooled with treatment D.

During 1990 root ratings were also conducted during the growing season. The results (Table 1) document a slower progress of infestation during June in plots treated for maggot control, but the proportion of plants showing significant damage progressed to high levels in all plots by mid-July.

Table 1. Proportion of Alto plants showing significant maggot damage (1990) (n = 120 for all values)

Treatment	Michener Park		Ellerslie	
	June 22	July 18	June 22	July 18
A (untreated)	90%	99.2%	70%	100%
B (Amaze, low)	65%	94.2%	50.8%	90%
C (Amaze, high)	65%	88.3%	48.3%	83.3%
D (Counter)	65%	91.7%	46.7%	95.8%
E (Furadan)	56.7%	95.8%	38.3%	87.5%
F (Lorsban)	60%	97.5%	41.7%	94.2%

Note: Roots were rated in four categories: (1) undamaged, (2) with first--instar maggot damage only, (3) with late-instar damage, but still viable, (4) with late-instar damage, non-viable (with systemic foot rot, rotted off or severed). In order to simplify presentation, the values for categories 3 and 4 have been pooled (as "significant maggot damage") in the above table. The proportion of plants in category 4 was generally very low (maximum 10% in untreated plots at Michener Park on June 22).

Correlation between Maggot Infestation and Foot Rot

During 1989 virtually all Tobin plants in naturally maggot-infested plots (treatments A and B) died and set seed prematurely as a result of secondary foot rot. By harvest time the stems had turned brown and the rootstock had either rotted off or become totally discolored. But all plants in plots without maggot damage (treatment D) retained green stems and clean white roots at harvest. The correlation between foot rot and prior maggot damage was thus absolute. Only plants with minor artificially induced maggot damage (treatment C) showed an intermediate incidence of foot rot. This was not quantified, but it appeared that only a few plants in each plot had totally discolored roots. Bacteria isolation showed that no pathogenic bacteria were associated with maggot wounds; the foot rot symptoms were entirely attributable to Fusarium infection.

Isolation of fungi from maggot wounds in 1990 again demonstrated the presence of various Fusarium species, but the variety Alto resisted the spread of this infection much better than did Tobin the previous season. Most plants in naturally maggot-infested plots retained green stems and some healthy root tissue at harvest, with discolored tissue (indicative of Fusarium infection) confined to the vicinity of maggot wounds. As in the previous season, there was no incidence of foot rot in plants not damaged by root maggots.

Vegetative Vigour

In the 1989 Tobin trial differences in canopy height between naturally maggot-infested plots (treatments A and B) and plots protected from maggots (treatments C and D) first became apparent at the beginning of July. On July 7 canopy heights in protected plots were estimated at almost 20% higher. A few days later the difference became even more pronounced, because plants in maggot-infested plots began to lodge while those in protected plots mostly remained erect until harvest.

Since all plots had been thinned to the same density (40 plants per m^2), the mean number of racemes per plant at harvest indicates relative vegetative vigour. In naturally maggot-infested plots this number was 8.07 ± 0.25 (n = 48), in protected plots 14.44 ± 0.49 (n = 96) (difference significant at $p < 0.001$).

In the 1990 Alto trials differences in vegetative vigour were much less pronounced. Caged plots without maggots (treatment H) showed less lodging after windstorms in early July than did comparable maggot-infested plots (treatment G). The mean number of racemes per plant is a less satisfactory indicator of vegetative vigour in the case of Alto, since this variety has been selected for erect growth with few racemes. The mean number of racemes per plant in naturally maggot-infested plots (treatments A and G) at Michener Park was 4.87 ± 0.13 (n = 64), in protected plots (treatment H) 5.38 ± 0.14 (n = 32) (difference significant at $p < 0.02$). Of the chemical treatments only the high rate of Amaze (C) significantly increased the mean number of racemes. At Michener Park this value for treatment C was 5.85 ± 0.23 (n = 32) compared with 4.87 ± 0.16 (n = 32) for the untreated control (treatment A) ($p < 0.005$ in t-test, < 0.001 in F-test); at Ellerslie the values were 4.35 ± 0.14 (n = 32) for treatment C compared with 3.77 ± 0.16 (n = 32) for treatment A ($p < 0.01$).

Seed Yield

In the 1989 Tobin trial highly significant differences were recorded between treatments A and B (indicative of the effect of reduced energy input inside cages) and between treatments B and C+D (indicative of the effect of excluding root maggots) (Table 2).

Table 2. Mean seed yield (grams) of Tobin per 1 x 1 m plot (Michener Park, 1989)

Treatment	Yield	n	Difference from B
A (open, maggot-infested)	132.9 ± 8.0	24	+70.8% ($p < 0.001$)
B (caged, maggot-infested)	77.8 ± 7.2	24	0
C+D (caged, minor or no maggot damage)	118.0 ± 4.1	96	+51.7% ($p < 0.001$)

If the assumption is made that the proportional effect of root maggot infestation is the same at different energy input levels, the potential yield of Tobin at this site in open plots in the absence of losses due to root maggots is estimated at 201.6 g/m^2. This estimate is credible, since yields over 200 g/m^2 (=2000 kg/ha) have frequently been obtained at this site in published trials of campestris varieties, when maggots were controlled by overdosing with insecticides.

The 1990 trials show that Alto is much less affected by maggot attack and secondary root rot than is Tobin. Table 3 shows the data for Michener Park comparable with Table 2 above.

Table 3. Mean seed yield (grams) of Alto per 1 x 1 m plot at Michener Park, 1990 (excluding plots chemically treated for maggot control)

Treatment	Yield	n	Difference from G
A (open, maggot-infested)	306.8 ± 8.5	32	+75.4% ($p < 0.001$)
G (caged, maggot-infested)	174.9 ± 8.0	32	0
H (caged, minor or no maggot damage)	191.4 ± 6.7	24	+ 9.4% ($p < 0.2$)

Whether or not the 9.4% increase in yield of caged plots attributed to exclusion of root maggots is significant is not conclusively demonstrated. The results for plots chemically treated for maggot control are also not entirely conclusive for this site (Table 4). Only the high rate of Amaze gave a probably significant yield increase. Since this treatment also produced the highest yield at Ellerslie, it appears justified to accept this increase as significant. The difference between treatments B and C (+12.2%, representing a rate response) is almost certainly significant ($p < 0.01$).

Table 4. Mean seed yield (grams) of Alto per 1 x 1 m plot at Michener Park, 1990 (all open plots)

Treatment	Yield	n	Difference from A
A (untreated)	306.8 ± 8.5	32	0
B (Amaze, low rate)	288.3 ± 7.8	32	- 6.0% ($p < 0.2$)
C (Amaze, high rate)	323.6 ± 8.8	32	+ 5.5% ($p < 0.2$)
D (Counter)	318.3 ± 8.5	32	+ 3.7% (ns)
E (Furadan)	287.6 ± 8.3	32	- 6.3% ($p < 0.2$)
F (Lorsban)	296.3 ± 6.4	32	- 3.4% (ns)

The comparable data for the less fertile, lower yielding Ellerslie site (Table 5) are much more conclusive and readily interpretable. There is a clear rate response in the case of Amaze, the high rate giving a yield increase of 20.2%. This can only be attributed to maggot control, since the incidence of other pests and diseases was negligible. If the four chemical treatments at approved rates of application (B,D,E and F) are compared, the yields are not significantly different (all within 10-15% higher than those of untreated plots).

Table 5. Mean seed yield (grams) of Alto per 1 x 1 m plot at Ellerslie, 1990

Treatment	Yield	n	Difference from A
A (untreated)	188.6 ± 7.7	32	0
B (Amaze, low rate)	208.0 ± 7.0	32	+10.3% ($p < 0.1$)
C (Amaze, high rate)	226.6 ± 6.1	32	+20.2% ($p < 0.001$)
D (Counter)	214.3 ± 5.5	32	+13.7% ($p < 0.01$)
E (Furadan)	215.7 ± 5.5	32	+14.4% ($p < 0.01$)
F (Lorsban)	209.0 ± 8.3	32	+10.8% ($p < 0.1$)

Seed Weight

In the 1989 Tobin trial highly significant differences were recorded between treatments A and B (indicative of the effect of reduced energy input inside cages) and between treatments B and C+D (indicative of the effect of excluding root maggots) (Table 6). The obvious explanation of the latter difference is that the observed premature dying off of plants in maggot-infested plots resulted in a higher proportion of small seeds at harvest. No increase in seed weight as a result of exclusion or control of root maggots was demonstrated by the 1990 data for Alto, presumably because few plants in maggot-infested plots died off prematurely.

Table 6. Mean 1000-seed weight (grams) of Tobin (Michener Park, 1989)

Treatment	Weight	n	Difference from B
A (open, maggot-infested)	2.21 ± 0.04	24	+10.9% ($p < 0.001$)
B (caged, maggot-infested)	2.00 ± 0.04	24	0
C+D (caged, minor or no maggot damage)	2.75 ± 0.03	96	+37.6% ($p < 0.001$)

Oil Content

Seed from plots inside cages showed a reduced oil content in both seasons, indicative that reduced energy input reduces oil content (Table 7). No significant differences attributable to exclusion of root maggots were demonstrated. Nor were any significant increases in oil content attributable to chemical maggot control demonstrated at either site in the 1990 trials.

Table 7. Mean oil content (%) (Michener Park)

Variety	Year	Treatment	Oil Content	n	Difference from A
Tobin	1989	A (open)	42.5 ± 0.3	24	0
		B+C+D (caged)	38.1 ± 0.2	120	-10.3% ($p < 0.001$)
Alto	1990	A (open)	44.2 ± 0.2	32	0
		G+H (caged)	41.0 ± 0.2	56	- 7.4% ($p < 0.001$)

Protein Content of Meal

In the 1989 Tobin trial highly significant differences were recorded between naturally maggot-infested and protected plots (Table 8), but no such effect was demonstrated for Alto in 1990. The chemical treatments applied in 1990 had no significant effect on protein content at Michener Park, but treatments E and F (Furadan and Lorsban) significantly increased protein content at Ellerslie (Table 9). The cause is unknown, but seems unlikely to have anything to do with maggot control since there was no rate response with respect to Amaze.

Table 8. Mean protein content of Tobin (% oil-free meal containing 5% moisture) (Michener Park, 1989)

Treatment	Protein Content	n	Difference from A+B
A+B (maggot-infested)	44.73 ± 0.33	36	0
C+D (minor or no maggot damage)	47.61 ± 0.30	36	+ 6.43% ($p < 0.001$)

Table 9. Mean protein content of Alto (% oil-free meal containing 5% moisture) (Ellerslie, 1990)

Treatment	Protein Content	n	Difference from A
A (untreated)	43.71 ± 1.19	9	0
B (Amaze, low rate)	45.15 ± 0.89	9	+ 3.28% (ns)
C (Amaze, high rate)	43.75 ± 1.61	9	+ 0.09% (ns)
D (Counter)	44.62 ± 1.43	9	+ 2.06% (ns)
E (Furadan)	47.38 ± 0.78	9	+ 8.39% ($p < 0.05$ in t-test, < 0.02 in F-test)
F (Lorsban)	48.47 ± 1.24	9	+10.88% ($p < 0.02$ in t-test, < 0.01 in F-test)

CONCLUSIONS

Root maggot feeding on canola is followed by invasion of the wounds by soil-borne Fusarium spp., producing "foot rot" symptoms if the infection spreads throughout the rootstock. The correlation between maggot damage and fusarial invasion was absolute during the present study, there being no root rot at harvest in roots without maggot damage.

Both in 1989 and 1990 the level of natural maggot infestation in unprotected plots on the University Farm (Edmonton) was virtually 100%. The two years were climatically similar and highly favourable for cabbage maggot, with above average July precipitation.

The Polish variety Tobin proved highly susceptible to foot rot after maggot attack. This caused reduced vegetative vigour, lodging and premature death and seed setting of plants in unprotected plots. Potential production benefits with respect to Tobin in wet seasons in infested parts of Alberta if maggots can be controlled are estimated as an increase in seed yield of about 50%, an increase in seed weight of about 40%, and an increase in the protein content of meal of about 6½%. Oil content would not be affected. Note that the above estimate of potential yield increase may be still understated, since the cages used in these trials excluded large insect pollinators which are believed to be necessary for maximizing the yield of Tobin.

The Argentinian variety Alto proved much more resistant to foot rot than was Tobin, showing only slight reduction in vegetative vigour and a low incidence of premature death following maggot attack. The effect of maggot infestation on yield of Alto appears related to soil fertility. Only minor yield increases were obtained by excluding or controlling root maggots at Michener Park (a site of unusually high soil fertility), but at the less fertile Ellerslie site four experimental chemical treatments at rates of application approved for other uses increased yields by 10-15%; an enhanced rate of application for Amaze produced a rate response, increasing yield by 20%. The probable explanation for the site difference is that plants are better able to recover and compensate for damage in more fertile soil. Significant differences in seed weight, oil content or protein content of meal were not attributable to maggot control in Alto.

The Ellerslie data confirm the validity of the chemical control concept: to develop seed-drill formulations with delayed release of the active ingredient to coincide with maggot hatching in the second half of June. In order to prevent economic losses it appears sufficient to reduce the level of infestation in late June.

ACKNOWLEDGEMENTS

The cages used in this project were constructed and maintained by Ryan & Hilchie Ltd. Land and various services were provided by the University Farm (Department of Plant Science, University of Alberta, Edmonton) through the agency of Mr. Delbert Degenhardt. During 1990 Mr. E.A.P. (Andy) Brown and Mr. Galt Baalim of Grow Tec Ltd. dressed seeds with experimental chemical formulations of their own design and provided other assistance during the growing season. Protein analysis at the Soils and Animal Nutrition Laboratory of Alberta Agriculture was arranged by Mr. Michael Dolinski and Mr. Ed Redshaw. Isolation of fungi and bacteria was conducted by Dr. Prem Kharbanda (Alberta Environmental Centre, Vegreville) and Mr. David A. Kaminski (Horticultural Research Center, Brooks). A photographic record of the project was made by my wife, Deirdre E. Griffiths.

REFERENCES

GRIFFITHS, G.C.D. 1986a. Phenology and dispersion of *Delia radicum* (L.) (Diptera: Anthomyiidae) in canola fields at Morinville, Alberta. Quaest. Entomol. 22: 29-50.

GRIFFITHS, G.C.D. 1986b. Relative abundance of *Delia floralis* (Fallén) and *D. radicum* (L.) (Diptera: Anthomyiidae) in canola fields in Alberta. Quaest. Entomol. 22: 253-260.

GRIFFITHS, G.C.D. 1991. Anthomyiidae. Flies of the Nearctic Region 8(2), No. 7: 953-1040.

LIU, H.J. and BUTTS, R.A. 1982. *Delia* spp. (Diptera: Anthomyiidae) infesting canola in Alberta. Can. Entomol. 114: 651-653.

LIU, H.J. 1984. Surveys of root maggot damage to canola in Alberta and Northern British Columbia, 1981-1983. AEC Vegreville. 31 pp.