# Aphid (Homoptera: Aphididae) accumulation and distribution near fences designed for cabbage fly (Diptera: Anthomyiidae) exclusion

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## ABSTRACT

Aphids accumulate near exclusion fences designed to intercept *Delia radicum* (L.) movement into fields. Aphid accumulations increase with increasing fence height, but are not affected by fence overhang length. Overall aphid levels are higher in small (4.3 m square) enclosed plots than in unenclosed plots. Enclosing large (38 m square) plots does not alter overall aphid catches, but does alter aphid distribution within enclosures. In large enclosures aphid accumulations are higher at enclosure perimeters than interiors, with the highest accumulations near enclosure corners. This concentric distribution is not observed in unfenced areas, and is not altered by the addition of a trap crop outside an enclosure.

**Key words:** *Myzus persicae*, *Delia radicum*, physical control

## INTRODUCTION

The brassica pest *Delia radicum* (L.) (Diptera:Anthomyiidae) tends to fly close to the ground (Vernon and MacKenzie 1998), where it can be intercepted by mesh exclusion fences erected around brassica plantings to reduce crop damage (Vernon and MacKenzie 1998; Päts and Vernon 1999; Bomford *et al.* 2000). In contrast, aphids (Homoptera: Aphididae) commonly migrate at altitudes between 10 and 2,000 m (Isard *et al.* 1990). Exclusion fences are unlikely to intercept aphid movement due to aphids' tendancy to move close to the ground only when making short, local flights or preparing to alight. Aphids are known to alight in areas where wind speeds are low, perhaps due to passive deposition (Lewis and Dibley 1970), or active behaviour (Kennedy and Thomas 1973). Since an exclusion fence may act as a partial windbreak, aphid accumulations may occur inside the fence, which could be a concern to growers wishing to adopt this pest management tool. This paper reports observations of aphid distribution inside fenced enclosures during several experiments initially conducted to test *D. radicum* exclusion by mesh fences.

## MATERIALS AND METHODS

**Fence height study.** Exclusion fences consisted of wooden frameworks covered with 1-mm-mesh nylon window screening (Stollco Industries Ltd., Port Coquitlam, BC), enclosing 5 m square plots. At the top of each fence, the vertical screen was bent over a horizontal wooden sill (5 cm wide) along the top of the fence posts, to form a 22 cm outward overhang, angled downward at 30-35° along triangular pieces of plywood secured to the fence posts. There was no screen overhang projecting into the inside of the enclosures. Fence heights (from ground level to the bottom of the outward overhang) of 30, 60, and 90 cm were tested. The open check plots had the same structure as the 30-cm fence, but without the vertically oriented nylon screen. The trial was arranged as a four by four Latin square, with adjacent blocks 4 m apart.

Fences were installed by 26 April 1991 in a 50 by 55 m field located at Abbotsford, BC. The field had been planted in raspberries for the 3 years previous, and had been kept virtually weed free during the previous growing season. To prevent weed growth, soil on the inside of the enclosures was covered with landscape fabric (Lumite 994, Division of Synthetic Ind., Norcross, Georgia), and soil in a 1 m strip centred along the fence perimeter was covered with black plastic. On 29 April, 1991, twenty 2-week-old rutabagas, *Brassica campestris* var. *napobrassica* (L.) 'Laurentian,' were transplanted into the plots along each of five parallel rows cut into the landscape fabric. Exposed soil around rutabagas was weeded weekly.

On 4 July 1991, counts of aphids, aphids parasitized by aphidiid wasps (Hymenoptera: Aphidiidae), and syrphid fly larvae (Diptera: Syrphidae) were recorded for 15-23 rutabaga leaves from each of the five crop rows of each plot. The mean number of insects per leaf was calculated for each insect in each treatment. Data were analyzed by ANOVA, and treatment means were separated using Tukey's test.

**Standard fence design.** A modified version of the fence used in the previous study was used in all remaining studies. Aluminum framed window screens of 1 mm black nylon mesh (210 cm long by 120 cm high) (Stollco Industries, Port Coquitlam, BC) were supported between wooden fence posts (7.5 cm by 9 cm wide by 120 cm high) to form vertical panels. At the top of each panel a wooden fence top (2 cm high by 8 cm wide by 210 cm long) rested on the top edge of the aluminum frame. From this wooden top, separate strips of 1-mm-mesh nylon screen were attached to form collection overhangs of specified lengths angled downward at 45° on both sides of the fence, and held in place by plywood triangles attached to the tops of the fence posts. All exposed fence components were black.

**Sticky trap design.** Sticky traps were used to monitor winged aphid populations in all remaining studies. Traps were made from sheets of white cardboard (4-ply Railroad Board; Domtar Fine Papers, Toronto, ON) painted on both sides with yellow, semigloss enamel paint (Yellow 776, Cloverdale Paint and Chemicals, Surrey, BC), cut into 10 by 14 cm rectangles and dipped in a commercial insect adhesive (Stiky Stuff, Olson Products, Medina, OH). Traps were attached to wooden stakes, with the bottom edge (14 cm long) 15 cm above the ground, and were oriented to face north-south.

**Overhang length studies.** The experimental site was a regularly mowed field of mixed grass near Abbotsford, BC. The trials were arranged in a randomized complete block design with four replicates, 30 m apart. Each replicate contained three 7 x 7 m square treatment plots, 10 m apart, covered with black woven landscape fabric to prevent the growth of weeds. The three treatment plots in each block were as follows: (1) an unfenced control plot, (2) a plot enclosed by a fence with a 25-cm-long collection overhang, and (3) a plot enclosed by a fence without an overhang (trial 1: 13 July – 10 August, 1994), a fence with a 12.5 cm collection overhang (trial 2: 12-30 August, 1994) or a fence with a 50 cm collection overhang (trial 3: 23 August – 14 September, 1995). The positions of plots in each block were randomized at the start of each trial. Fences enclosed a 4.3 x 4.3 m square in the centre of each plot.

At the beginning of each trial, black plastic flats of 50 6- to 15-d-old radish, *Raphanus sativus* (L.) 'Cavalrondo,' seedlings were evenly spaced throughout a 3.5 x 3.5 m square in the centre of each plot. Radishes were watered daily for the duration of each trial.

Winged aphid catches on sticky traps placed 1.5 m north-east and south-west of the center of each plot were recorded every 2-6 d throughout each trial, following trap replacement. Data were transformed (square root ($x$ + 0.5)) to correct for heterogeneity of variance. For each trial, mean aphids per trap were calculated for each 2-6 d trapping session for each treatment, and the effect of treatment and block on mean aphids per trap for each 2-6 d trapping session was tested by ANOVA and means separated using Tukey's test (Zar 1984). Data from all 2-6 d trapping sessions in each trial were then pooled, the effect of treatment and block on mean aphids per trap tested by ANOVA, and means separated using Tukey's test.

**Concentric enclosure study.** A 41 x 41 m square in a regularly mowed field of mixed grass near Abbotsford, BC was covered with black landscape fabric to prevent weed invasion, and to provide a uniform environment throughout the experimental area. Four concentric enclosures were constructed in the centre of the experimental area using standard exclusion fences. The innermost enclosure was a 4.5 x 4.5 m square; the next a 13.5 x 13.5 m square; the next a 22.5 x 22.5 m square; and the outermost a 31.5 x 31.5 m square.

On 23 June 1994, 324 flats of 50 7-d-old radish seedlings were arranged in a 1 m grid (18 rows and columns) throughout the experimental area. Eighty-one sticky traps were arranged throughout the experimental area in a 9 row and 9 column grid, with 4.5 m between consecutive traps. All traps were replaced at 3-7 (mean 5) d intervals, until 17 August 1994 – a total of 10 trapping sessions. Winged aphid catches on each trap were recorded for each trapping session.

Traps were grouped into one of five levels, according to their location (Table 1). Mean aphid catches for each level were calculated and ranked for each trapping session. Trapping sessions were treated as replicates in time. Friedman's test (Zar 1984) was used to test the null hypothesis that mean aphid catches were equivalent for each level; rankings were separated using a variation of Tukey's test for multiple comparisons of nonparametric data (Zar 1984). Cumulative aphid distribution throughout the experimental area was mapped using 3-dimensional graphing software (MSGraph 8.0, Microsoft 1997).

**Table 1**

Trap locations by level in concentric enclosure study.

| Level | Distance from outer fence (m) | Traps | Trap location in relation to fenced enclosure(s) |
|---|---|---|---|
| 1 | +2.50 | 32 | Outside 31.5 m enclosure |
| 2 | -2.50 | 24 | Between 22.5 and 31.5 m enclosures |
| 3 | -6.75 | 16 | Between 13.5 and 22.5 m enclosures |
| 4 | -11.25 | 8 | Between 4.5 and 13.5 m enclosures |
| 5 | -15.75 | 1 | Inside 4.5 m enclosure |

**Large enclosure studies.** Three 38 x 38 m squares in a regularly mowed field of mixed grass near Abbotsford, BC were covered with black landscape fabric. Treatment areas were arranged in a line oriented roughly perpendicular to the main southwest wind direction, with adjacent plots ~20 m apart. Sticky traps and flats of 10-d-old radishes were evenly spaced throughout each experimental area, according to the design of the previous experiment.

Experimental areas were randomly assigned to one of three treatments: (1) no fence (Control); (2) a 38 by 38 m square standard fence, enclosing all of the radish plants (Fence); and (3) a 30 by 30 m square standard fence, with radish plants also encircling the fence to act as a trap crop (Fence + Trap crop). Due to the large size of the treatment plots, replication was conducted over time in 1995. The treatments were initially established on 29 May 1995, and were subsequently re-randomized on three additional occasions (11 July, 15 August, 12 September) to allow four replicated blocks. Traps were changed every 3-7 d (mean, 4 d) for a period of 21-28 d (mean, 24 d). Cumulative aphid distributions for each treatment were mapped using 3-dimensional graphing software (MSGraph 8.0, Microsoft 1997). ANOVA was used to test for effects of treatment and block (time) on overall aphid catches. The average aphid catch for each enclosure treatment and block (time) on sticky traps immediately inside the enclosure was compared to that on the remaining traps using the Wilkoxon paired-sample test (Zar 1984).

## RESULTS

**All studies.** Aphids caught in all studies were predominantly *Myzus persicae* (Sulzer), but the proportion was not quantified. Total aphid catches varied considerably from one trapping session to another, following no apparent trends. Differences between treatments tended to be most pronounced for trapping sessions with relatively high aphid catches.

**Fence height study.** A total of 3,637 aphids were found on the 1,244 leaves sampled. More aphids were found in plots enclosed by 90-cm-high fences than in plots without fences or plots with 30-cm-high fences ($P$=0.008) (Fig. 1A). Aphid accumulations increased with increasing fence height over the range of fence heights tested, but were not significantly higher inside plots surrounded by 30- and 60-cm-high fences than in unfenced control plots (Fig. 1A). No block effect was detected.

A total of 127 aphids were parasitized by aphidiid wasps and 35 syrphid fly larvae were found on the leaves sampled. Both of these aphid biocontrols were more numerous inside plots enclosed by 90-cm-high fences than in other experimental plots ($P$=0.007, aphidius; $P$=0.002, syrphid) (Fig. 1A,B). No block effect was detected.

**Overhang length studies.** A total of 18,526 winged aphids were caught on sticky traps over the course of the three overhang length trials. Significant ($P$<0.05) treatment, block, and trapping date effects were detected in all trials. A significant interaction between treatment and trapping date was attributed to a positive correlation between total aphid catch and strength of the treatment effect. More winged aphids were caught on sticky traps inside the fenced enclosures than in unfenced check plots in each of the trials (Table 2). The presence of overhangs, and overhang length had no effect on aphid catches (Table 2).

**Concentric enclosure study.** A total of 37,894 winged aphids were caught on sticky traps over the course of this study, averaging 468 aphids per trap and 46.8 aphids per trap for each trapping session. Aphid catches varied tremendously between trapping sessions, ranging from 0.6 aphids per trap on 5 July, to 237.0 aphids per trap on 11 August.

Trap location had a significant ($P$<0.001) effect on aphid catches, with traps within the outer two enclosures (levels 2 and 3) catching the most aphids (Table 3; Fig. 2). Traps in level 2 caught more aphids than those in levels 1, 4, or 5; traps in level 3 caught more than those in level 4 (Table 3). Aphid catches peaked near the inner corners of the largest enclosure (Fig. 2). Catches were below average around the outer perimeters and towards the center of the study area (Fig. 2).

**Large enclosure study.** A total of 25,419 aphids were caught throughout this study, averaging 26 aphids per trap for each block (time). The mean aphid catches (± SE), were 2006 ± 1098, 2085 ± 802, and 2264 ± 1148 in the Check, Fence, and Fence + Trap Crop treatments, respectively. No significant difference in mean aphid catches were detected between treatments. The block effect was highly significant ($P<0.0001$), indicating variation in aphid catches over time.

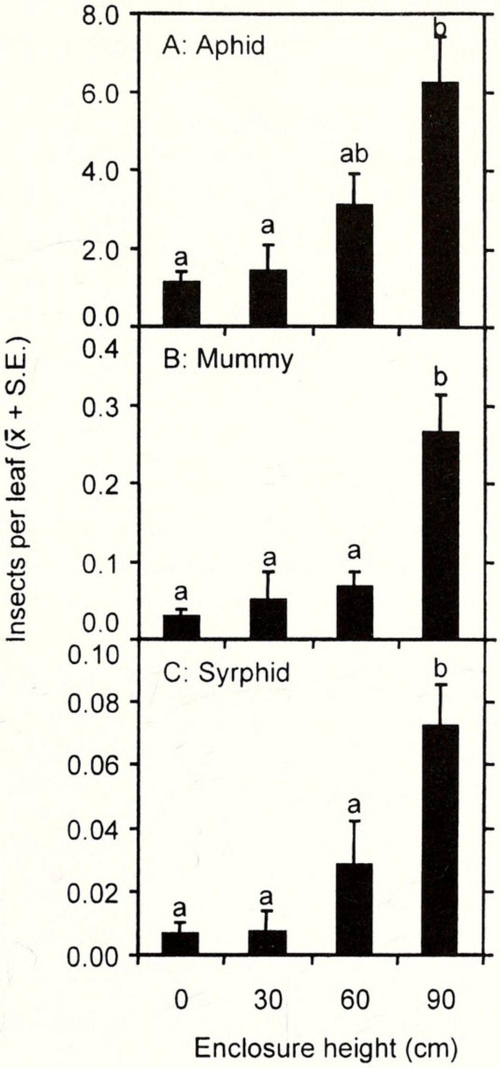


**Figure 1.** Counts of living aphids (A), aphids parasitized by aphidiid wasps (B), and syrphid larvae (C) on leaves of rutabagas growing inside exclusion fences ranging from 0-90 cm in height ($n$=4). Bars with the same letter are not significantly different, Tukey's test, $P<0.05$.

**Table 2**

Average aphid catch on sticky traps in unfenced plots of radish and plots of radish enclosed by 120-cm-high exclusion fences with varying overhang lengths.

| | Mean aphid catch by trial, $n$=4[a] | | |
|---|---|---|---|
| Treatment | Trial 1 (13/7/94 -10/8/94) | Trial 2 (12/8/94 -30/8/94) | Trial 3 (23/8/95 -14/9/95) |
| No fence | 97.9 *a* | 292.7 *a* | 154.0 *a* |
| Fence without overhang | 364.7 *b* | - | - |
| Fence with 12.5 cm overhang | - | 930.2 *b* | - |
| Fence with 25 cm overhang | 494.2 *b* | 923.9 *b* | 715.9 *b* |
| Fence with 50 cm overhang | - | - | 658.1 *b* |

[a]Means within a column followed by the same letter are not significantly different, Tukey's test, $P<0.05$.

Aphid catches were above average near the outer edges of fenced enclosures particularly near the enclosure corners (Fig. 3B,C). This pattern was not observed in the unfenced control plots (Fig. 3A). Aphid catches on traps immediately inside the enclosure fences were higher (P<0.001) than for the remaining traps inside both the Fence and Fence + Trap Crop treatments. This concentric distribution was not observed in the control plots.

**Table 3**

Winged aphid catches, by level, in five levels of a concentric enclosure study. Rank sum is the sum of aphid catch ranking for each of 10 trapping sessions, according to Friedman's analysis of variance by ranks.

| Level | Total traps | Aphids per trap per session, $n$=10 ($\bar{x}$ ± S.E.) | Rank sum, $n$=10[a] |
|---|---|---|---|
| 1 (outer traps) | 32 | 36.8 ± 18.2 | 21.5 *ab* |
| 2 | 24 | 60.5 ± 30.5 | 45.0 *c* |
| 3 | 16 | 50.0 ± 24.7 | 40.0 *bc* |
| 4 | 8 | 40.3 ± 21.4 | 20.5 *a* |
| 5 (center trap) | 1 | 43.3 ± 25.3 | 23.0 *ab* |

[a]Rank sums followed by the same letter are not significantly different, Tukey's test, $P$<0.05.

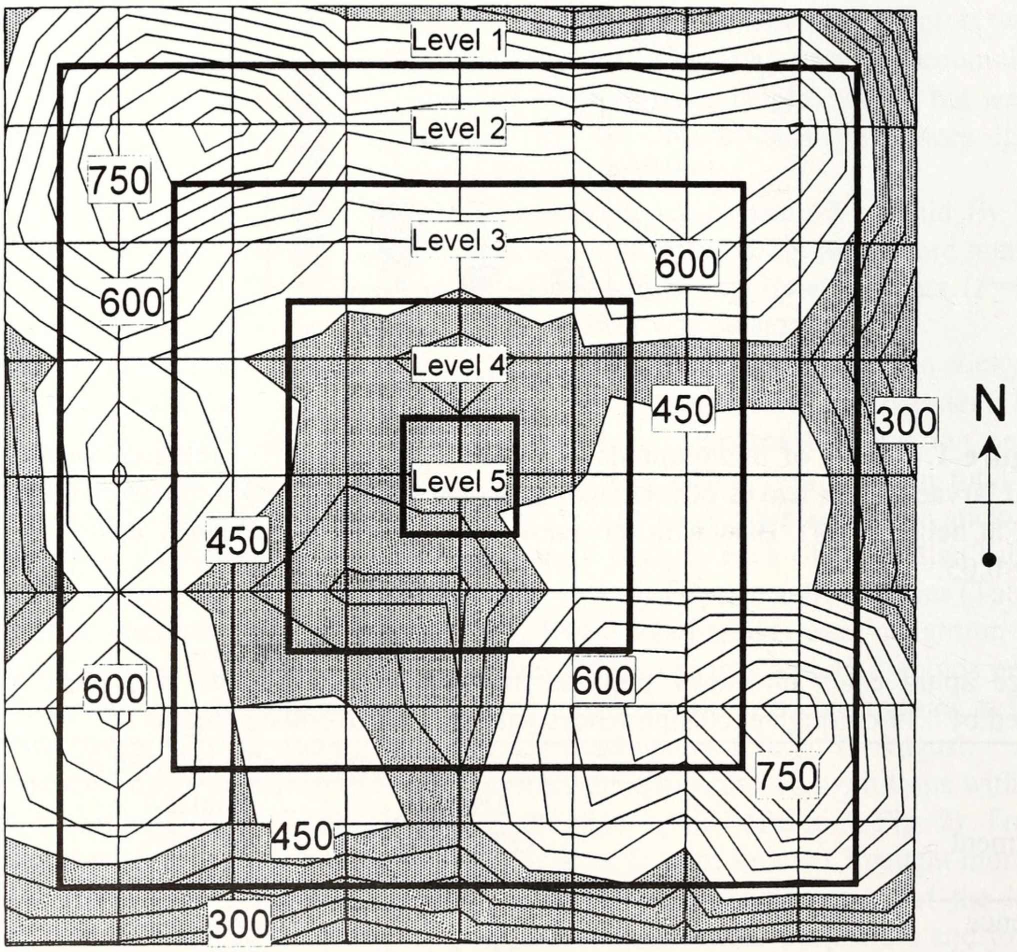


**Figure 2.** Contour map showing aphid distribution in an experimental area with concentric exclusion fences (heavy lines). Sticky traps were placed at grid nodes. Contour lines show total aphid catch per trap after 10 trapping sessions ($\bar{x}$ = 468), at intervals of 50, and are labeled at intervals of 150. Areas with total catches below 450 aphids per trap (approximate average) are shaded gray. One square = 4.5 by 4.5 m.

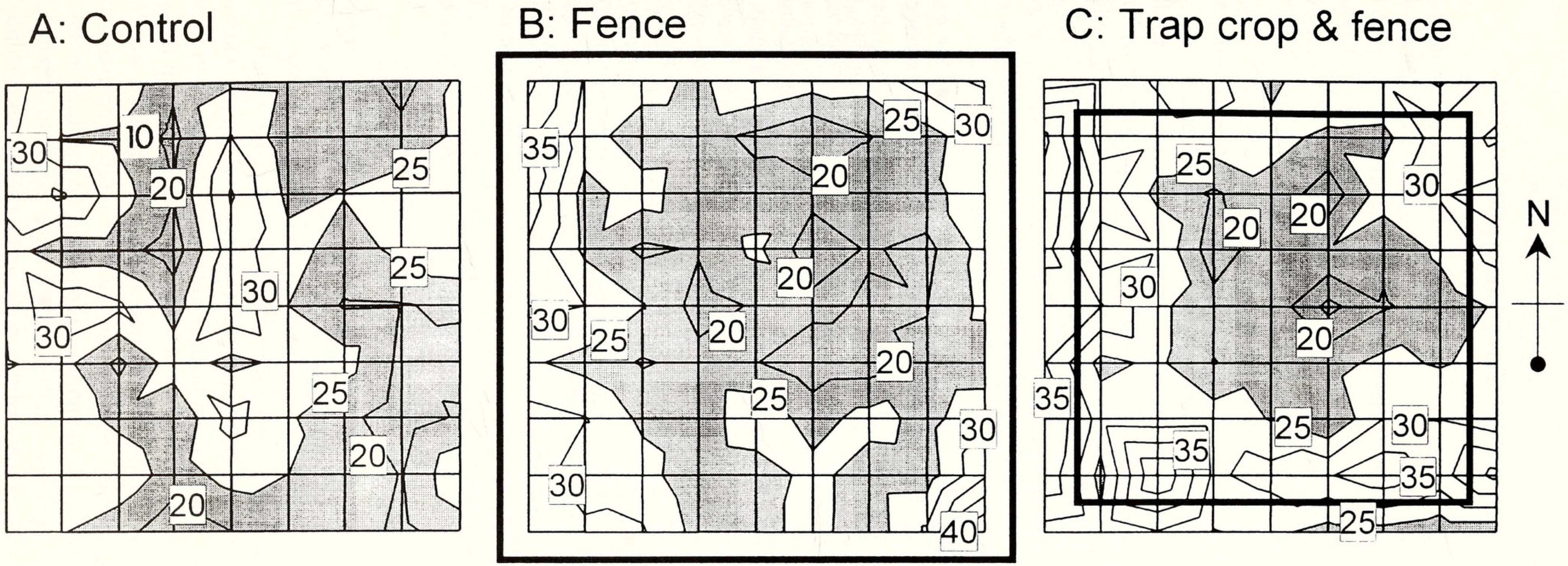


**Figure 3.** Contour map showing aphid distribution in unfenced control plots (A), plots entirely surrounded by exclusion fences (B), and plots surrounded by a trap crop and exclusion fence (C). Heavy lines denote exclusion fences. Sticky traps were placed at grid nodes. Contour lines show average aphid catch per trap ($n$ = 4; $\overline{x}_A = 25$, $\overline{x}_B = 26$, $\overline{x}_C = 28$), at intervals of 5. Areas with average catches below 25 aphids per trap (approximate average) are shaded gray. One square = 4.5 by 4.5 m.

## DISCUSSION

We conclude that exclusion fences trigger aphid accumulations near enclosure perimeters. Inside small enclosures, where all enclosed areas are relatively near the enclosure perimeter, exclusion fences increase aphid numbers overall. In large enclosures higher aphid catches near enclosure edges are counterbalanced by comparatively low aphid catches far from enclosure edges, resulting in an altered aphid distribution within enclosures, but no overall change in aphid catches.

Aphid accumulations inside exclusion fences are affected by fence height, but not overhang length. In small enclosures 30 - 90-cm-high, aphid accumulations increase with fence height. Lewis and Dibley (1970) hypothesized that small insects, such as aphids, are passively carried by wind currents, and deposited in the lee of windbreaks by swirling eddies, which are larger for taller windbreaks, assuming constant windbreak permeability. Kennedy and Thomas (1973) agreed that aphids accumulate in areas where windspeeds are low, but argued that this was an effect of aphid behaviour rather than passive deposition. Whether due to active behaviour or passive deposition, both authors agree that aphid accumulations will be highest where windspeed is reduced, as we observed near exclusion fences.

At our study locations the prevailing daytime wind blew from the southwest. Prevailing night winds blew from the northeast. The regular reversals in the local prevailing wind direction made it difficult to establish any relationships between the location of aphid accumulations within enclosures and wind direction, particularly since we made no observations of the time of day when winged aphids were caught.

Our observation that overhang length has no effect on aphid accumulations conflicts with the finding that overhangs reduce cabbage fly movement into fenced enclosures (Bomford *et al.* 2000). This may be because exclusion fences intercept the low-flying cabbage flies, but not aphids, which maintain a higher altitude before alighting. Overhangs will only reduce insect movement into enclosures if insects fly into the exclusion fence, then encounter the overhang as they attempt to move up and over the fence.

More syrphid fly larvae, which feed on aphids, and aphids parasitized by aphidiid wasps were found inside 60-cm-high fences than in control plots. These insects may have been attracted to the higher concentrations of their aphid hosts within the small enclosures, or they may accumulate in the same low windspeed areas where aphids tend to alight. The fact that the exclusion fences did not reduce immigration of these predators and parasites suggests that this physical control tactic could compliment efforts to use these beneficial insects for the biological control of aphids.

The highest aphid accumulations in large enclosures occurred near enclosure corners. Corner traps likely catch aphids moving from two directions, whereas traps near the middle of an edge likely catch only aphids coming from one direction. Traps placed inside small enclosures catch aphids coming from all directions, resulting in the marked increase in aphid catches observed in small enclosures relative to control plots.

Positioning an exclusion fence between a perimeter trap crop and the main crop had no effect on overall aphid accumulations, as compared to control plots without a fence, or plots entirely enclosed by a fence. Plot size was held constant in these experiments, such that allowing room for a trap crop required a reduced enclosure size. The area of reduced aphid accumulations in the interior of the Fence + Trap Crop plots was correspondingly smaller than the area of reduced aphid accumulations in the fully enclosed plots.

In our concentric enclosure study all traps were the same distance from a mesh fence, yet traps towards the outer edge of the study areas caught more aphids than traps towards the center of the study area. This was the same distribution pattern observed in our large enclosure study, suggesting that local aphid distributions are better predicted by the distance from the outer edge of an enclosed area than distance from a fence.

Extrapolating from our observations in experimental plots, we would expect aphids to accumulate near the outer edges of fields enclosed by exclusion fences. By comparison, fields without exclusion fences should have similar overall aphid levels, but aphids will be more randomly distributed throughout the field area. The more predictable aphid distribution within fields surrounded by exclusion fences could allow producers to target field edges for insecticide applications intended for aphid control, reducing control costs, insecticide use, and soil compaction, while preserving an area of refuge for biological control organisms in field interiors.

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