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Evaluation of trap deployment patterns for behavioural control of apple maggot flies (Dipt., Tephritidae)

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Abstract: We evaluated three different deployment patterns of sticky red sphere traps, baited with a five-component blend of synthetic attractive fruit odour and placed on perimeter apple trees bordering adjacent habitat (front-row trees), for control of apple maggot flies, *Rhagoletis pomonella* (Walsh), in small plots of apple trees (about 30 × 30 m) in Massachusetts commercial apple orchards. Degree of fly penetration from front-row to interior apple trees was assessed for *R. pomonella* of wild origin and for marked adults released in habitats adjacent to front-row trees. Traps placed 10 and 5 m apart on front-row trees or grouped on a single central front-row tree performed as well as grower-applied insecticide sprays in preventing penetration of plots by wild and released flies and in preventing fruit injury. This was equally true for plots whose front-row trees consisted of cultivars comparatively susceptible to apple maggot as for plots whose front-row trees were comprised of comparatively tolerant cultivars. It was also true for each seasonal period during which sampling for treatment performance occurred.

Key words: *Rhagoletis pomonella*, apple pests, behavioural control, odour-baited traps

1 Introduction

Behavioural control of apple maggot flies, *Rhagoletis pomonella* (Walsh), in eastern North America relies on the use of odour-baited red sphere traps or similar traps placed on the perimeter-row trees (termed front-row trees) of apple orchards to intercept adults immigrating into orchards from unmanaged host trees (Prokopy et al., 1990, 1996, 2000; Bostanian et al., 1999; Bostanian and Racette, 2001). The vast majority of *R. pomonella* flies that threaten orchards come from unmanaged host trees in the vicinity of orchards. To date, most researchers and growers who have used a behavioural approach to apple maggot control have deployed baited spheres 5 or 10 m apart regardless of tree size, cultivar susceptibility and type of adjacent habitat. A distance of 5 m between traps has been recommended for Massachusetts orchards based on Massachusetts studies in a limited number of orchard blocks suggesting that traps 5 m apart were able to protect fruit from injury better than traps 10, 20, or 40 m apart (Prokopy et al., 1990; Christie et al., 1991). Recently, size of orchard trees has been found to influence degree of protection afforded by traps 5 m apart, with small and medium trees receiving better protection than large trees (Prokopy et al., 2001; Rull and Prokopy, 2001). To date, there has been no extensive study of cultivar composition of front-row trees as a possible factor influencing the comparative effectiveness of different deployment patterns of traps for controlling this insect.

In this study, we evaluated three different deployment patterns of odour-baited red spheres placed on front-row apple trees in 12 commercial orchards in Massachusetts. We also evaluated the influence of cultivar composition of front-row trees and time of year on deployment pattern performance. Further, we examined the impact of adjacent habitat structure on apple maggot fly abundance on traps. Degree of fly penetration from front-row to interior trees was assessed for *R. pomonella* of wild origin and for marked adults released in habitats adjacent to front-row trees.

2 Materials and methods

2.1 Block layout

The experiment was conducted in 2000 in 12 blocks of apple trees in 10 commercial orchards in Massachusetts. There were four blocks each of small (M.9 rootstock), medium-size (M.26 rootstock) and large (M.7 rootstock) trees. Each block consisted of seven rows of apple trees about 120 m long and about 30 m wide (from perimeter-row facing orchard border to interior) (fig. 1). In six blocks, front-row trees consisted of cultivars known to be comparatively susceptible to apple maggot (Gala, Jonagold, or Fuji), whereas front-row trees in the other six blocks consisted of cultivars comparatively tolerant of apple maggot (McIntosh, Empire, or Cortland) (J. Rull and R. J. Prokopy, unpubl. data). Interior rows consisted largely of mixtures among these six cultivars. Front

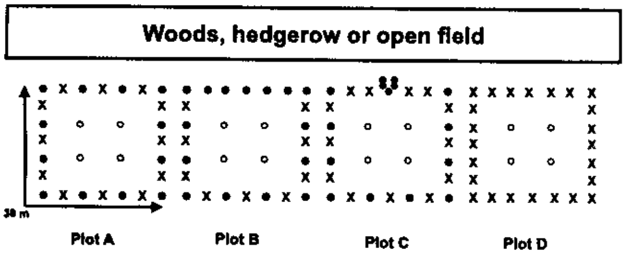

Fig. 1. Schematic illustration of layout of test plots. X, trees without traps; ●, trees with an odour-baited sticky red sphere trap; ○, trees with an unbaited sticky red sphere trap. Number of odour-baited traps per front row (adjacent to woods, hedgerow or open field): plot A, four traps 10 m apart; plot B, seven traps 5 m apart; plot C, seven traps, with five traps grouped on central tree of front row; plot D, plot sprayed with insecticide by grower. Within each orchard block, sequence of plots with front-row traps was randomized

rows were bordered by woods (four blocks), hedgerow (four blocks), or open field (four blocks). Vegetation comprising woods and hedgerows commenced 8–10 m from front-row trees. Unfortunately, limited availability of candidate experimental blocks did not permit a completely balanced design among the variables of tree size, front-row cultivar and structure of neighbouring habitat.

2.2 Experimental treatments

Each of the 12 blocks was divided into four contiguous equal-sized plots. Each plot was sprayed by growers with insecticide and fungicide in April, May and June to control a variety of insect and disease pests. Thereafter, each plot received a different treatment (fig. 1).

One of the plots (termed grower-control) was sprayed by the grower two or three times with phosmet or azinphos-methyl during July and August to control apple maggot. For grower convenience, this plot was always at the end of the block.

Each of the other three plots received no insecticide after June but instead received traps on front-row trees to intercept immigrating apple maggot adults and thereby provide behavioural control. Each trap consisted of an 8-cm red wooden sphere coated with Tangletrap (Great Lakes IPM, Vestaburg, Michigan, USA) and baited with a 4 g blend of five synthetic attractive fruit volatiles contained in a polyethylene vial (after Zhang et al., 1999). Traps were deployed in early July at mid-canopy height in a way that maximized visual appearance and attractiveness (after Drummond et al., 1984).

It would have been ideal to have included a fifth plot within each block untreated in any manner for control of apple maggot. To have done so, however, could have severely jeopardized marketability of the fruit, as the apple maggot can rapidly colonize and substantially damage unprotected fruit (Glass and Lienk, 1971).

Traps on front-row trees were deployed as follows: 10 m apart in plot A (four traps in total); 5 m apart in plot B (seven traps in total); and five traps grouped on the central front-row tree in plot C, with 15 m between that tree and the nearest trapped front-row trees to either side (seven traps in total). The front-row deployment pattern in plot A was aimed at re-evaluating the effectiveness of this pattern as reported in Prokopy et al. (1990) and Christie et al. (1991). The deployment pattern in plot B has been the standard in Massachusetts to date, whereas in plot C it was based on findings by J. Rull and R. J. Prokopy (unpubl. data) suggesting that grouping of baited traps on the same tree might enhance visual-based competitiveness of traps with developing fruit (which become larger and redder as the season progresses) at little or no sacrifice of olfactory-based competitiveness of traps with developing fruit on that and nearby trees. Plots A, B and C also received baited red spheres 10 m apart on interior back-row trees and on interior divider trees that separated one plot from another or the surrounding area. Finally, each of the four plots received a total of four unbaited red spheres deployed on trees near the centre of the third and fifth row of each plot. These unbaited spheres were intended to monitor extent of penetration of apple maggot flies into the interior of the plot.

2.3 Releases of marked flies

Apple maggot fly pupae were collected from infested fruit of unmanaged apple trees in 1999, stored at 3°C from autumn through spring, and thereafter kept at 25°C for about 30 days until adult eclosion. Flies were placed in 30 × 30 × 30-cm Plexiglass cages containing protein, sugar and water until 10–14 days old, when they attained sexual maturity.

Our intent was to release marked mature flies in the vegetation bordering the front row of each plot and measure extent of fly penetration into the interior of the plot. As all plots were in commercial orchards, only males were marked and released, precluding possible oviposition by females. Mature male *R. pomonella* respond to synthetic fruit volatiles and to red spheres in a way very similar to females (Rull and Prokopy, 2000). For marking, males were removed individually from cages, held gently under a fine mesh, and marked on the pronotum with a small dot of oil paint (Testors, The Testor Corporation, Rockford, USA). A different colour of paint was used for respective groups of flies released adjacent to each plot. One day prior to release, a group of 32 similar-marked males was placed in a 6 × 6 × 12-cm transparent plastic box having an opaque cover. For ventilation, the box had a 2 cm diameter hole on each side and a 4.5-cm diameter hole at the top. All holes were covered with removable netting. Each box was provided with protein, sucrose and water and was mounted on a wooden pole pushed into the ground until the box was 20 cm above the ground. The base of the pole was coated with Tangletrap to prevent ants from gaining access to the flies.

For release, a box of marked flies was positioned opposite to the centre of each of the four plots and about 10 m from front-row trees. This distance ensured that release sites were protected by overhanging vegetation (in the case of woods and hedgerows). Netting covering the hole in the top of the box was removed, and flies were allowed to depart at will. Time of release varied from 10:00 to 13:00 hours, with more than 50% flies leaving boxes within 3 h and more than 95% within 24 h. Flies that remained in a box after 24 h (never more than three) were deducted from the 32 intended for release. Releases opposite all four plots in the same block occurred on the same day and within the period of 21 July to 10 September. There was one release per plot.

2.4 Assessment of treatment performance

To assess treatment performance, wild flies captured by front-row, back-row, divider and interior monitoring traps were counted and removed every 2 weeks from mid-July until mid-September (approximate time of harvest), for a total of five sampling dates. On each sampling date, traps were cleared of all insects and debris and, if necessary, re-coated with Tangletrap. On the same day, we examined 10 fruit on each of the 10 randomly selected interior trees per plot (20 fruit on each of the 10 trees at harvest) for oviposition punctures, which were dissected to confirm larval presence.

Accumulation of released flies on traps was assessed 5 days after release. Findings of Rull and Prokopy (2000) indicated that nearly all captures of marked mature males released adjacent to commercial orchards occur within 5 days after release.

2.5 Data analysis

Unless indicated otherwise, data were analysed by ANOVA followed by comparison of treatment mean values using the least significant difference test at the P = 0.05 level.

3 Results

For combined data across all 12 orchard blocks and all five sample periods (fig. 2), significantly fewer wild apple maggot flies were captured by front-row traps 10 m apart than by front-row traps 5 m apart or traps grouped on the central front-row tree, between which there was no significant difference. The same pattern of results occurred with marked-released flies. For both wild and marked-released flies, there were no significant differences among treatments (including grower-control plots) in captures on interior unbaited monitoring traps or, for the three treatments with traps, in captures on back-row traps. Indeed, mean numbers of wild flies or percentages of marked-released flies captured by interior monitoring or back-row traps were remarkably similar among treatments. Finally, mean percentages of sampled fruit injured by apple maggot were essentially identical (no significant differences) among the four treatments: 0.07, 0.07, 0.08 or 0.07% injured fruit in plots where spheres were 10 m apart, 5 m apart, or grouped on a central front-row tree or plots that were sprayed, respectively.

For data subdivided according to blocks having comparatively susceptible vs. comparatively tolerant cultivars as front-row trees (fig. 3), the pattern of results was again similar for wild and marked-released flies. For comparatively susceptible front-row cultivars, significantly fewer wild flies or marked-released flies were captured by front-row traps 10 m apart than

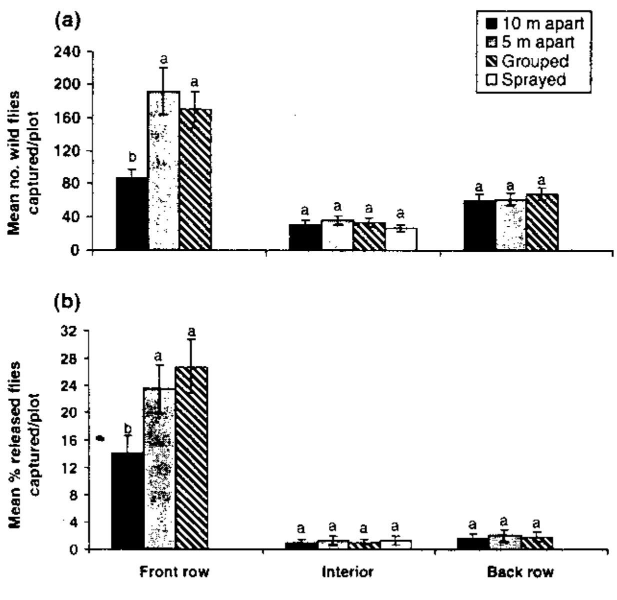

Fig. 2. Across all 12 apple orchard blocks and all sample periods, mean number (±SEM) of wild apple maggot flies (a) or mean percentage (±SEM) of marked-released apple maggot flies (b) captured by odour-baited spheres placed 10 or 5 m apart on front-row trees of a plot or grouped on the central front-row tree of a plot, by unbaited monitoring spheres placed at the interior of a plot (including grower-sprayed plot), or by odour-baited spheres placed 10 m apart on back-row trees of a plot. For each fly type and sphere position, mean values superscribed by the same letters are not significantly different according to ANOVA and least significant difference tests (0.05 level)

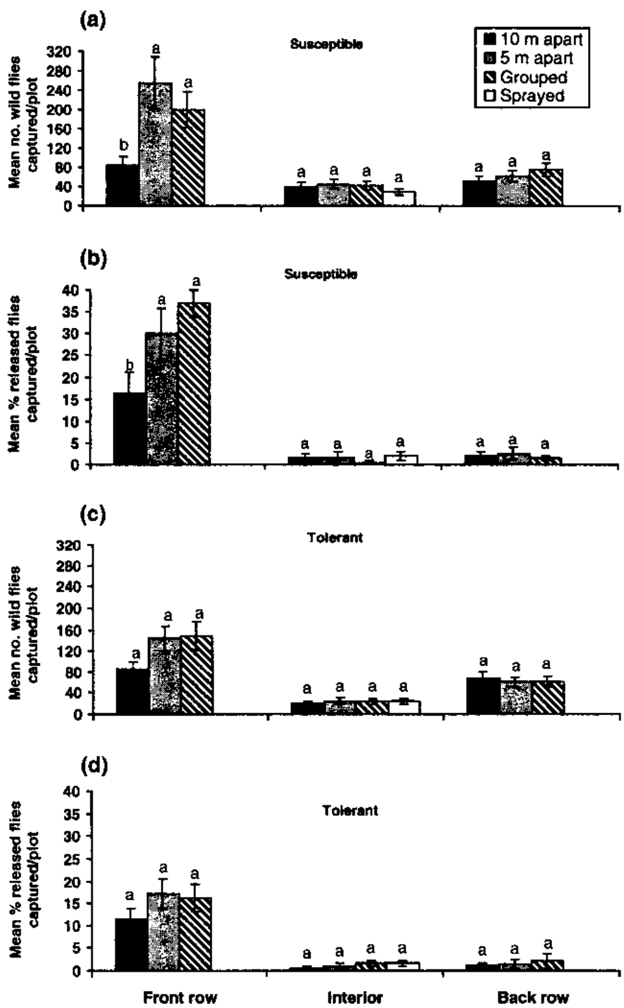

Fig. 3. Across all five sample periods, mean number (±SEM) of wild apple maggot flies (a, c) or mean percentage (±SEM) of marked-released apple maggot flies (b, d) captured by spheres when orchards were segregated according to front rows comprised of comparatively susceptible cultivars (six orchard blocks) or comparatively tolerant cultivars (six orchard blocks). See legend of fig. 2 for additional explanation

by front-row traps of the other two deployment treatments, between which there was no significant difference. However, for comparatively tolerant front-row cultivars, there were no significant differences among trap deployment treatments in front-row captures of either type of fly, although numerically very few flies were captured by front-row traps 10 m apart. For neither comparatively susceptible nor comparatively tolerant front-row cultivars was there any significant difference among trap deployment treatments in captures of wild or marked-released flies on interior monitoring traps or back-row traps.

According to *t* tests, across all treatments, front-row traps on comparatively susceptible front-row cultivars captured numerically (but not significantly) more wild flies than front-row traps on comparatively tolerant front-row cultivars ($\bar{x} \pm$ SEM): 545.0 ± 182.5 vs. 378.8 ± 109.2 (P = 0.45). The same was true for marked-released flies, but the difference was significant (29.6 ± 5.8 vs. 16.1 ± 3.7, P = 0.01). Across all treatments, there were no significant differences in captures between comparatively susceptible and comparatively tolerant front-row cultivars for wild flies on interior monitoring traps (126.5 ± 45.7 vs. 68.7 ± 16.5, P = 0.26), for marked-released flies on interior monitoring traps (1.3 ± 0.3 vs. 1.1 ± 0.3, P = 0.88), for wild flies on back-row traps (188.2 ± 40.7 vs. 190.0 ± 48.1, P = 0.98), or for marked-released flies on back-row traps (2.2 ± 0.4 vs. 1.7 ± 0.4, P = 0.51). Such lack of significant differences in fly captures on interior monitoring or back-row traps may in part have been the result of the varied pattern of tree cultivar composition that typified interior rows containing monitoring or back-row traps.

For data on wild flies subdivided according to sample period, the pattern of results was strikingly similar from one sample period to the next (fig. 4). Front-row traps 5 m apart always captured numerically but not significantly more flies than front-row traps grouped on a central tree and always captured significantly more flies than front-row traps 10 m apart. There was no consistent pattern among trap deployment treatments in wild fly captures on interior monitoring or back-row traps from one sample period to the next.

When data on wild fly captures by unbaited interior monitoring traps were analysed separately for comparatively susceptible and comparatively tolerant front-row cultivars, we found no evidence for significant interaction between treatment type and sample period (P = 0.99 and 0.97 for susceptible and tolerant cultivars, respectively). This indicates that relationships among treatments in the degree to which wild flies were prevented from entering interiors of plots (as measured by captures on unbaited interior monitoring traps) did not vary significantly among sample periods, either for comparatively susceptible or comparatively tolerant front-row cultivars.

For combined data across all treatments and trap locations, nearly twice as many wild flies were captured in orchard blocks adjacent to woods or hedgerows than in orchard blocks adjacent to open fields, although differences were not significant (fig. 5). Conversely, significantly more marked-released flies were captured in orchard blocks adjacent to open field than in orchard blocks adjacent to woods, with blocks adjacent to hedgerows intermediate (fig. 5).

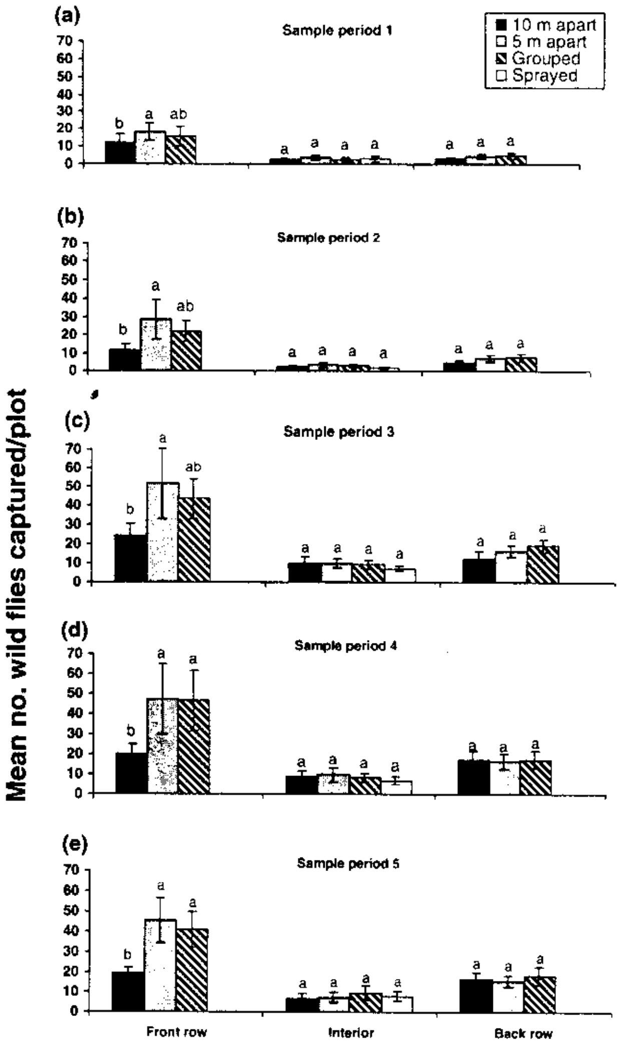

Fig. 4. Across all 12 apple orchard blocks, mean number (±SEM) of wild apple maggot flies captured by spheres when captures were segregated according to the five 2-week sample periods, which commenced in mid-July (period 1) and ended in mid-September (period 5). See legend of fig. 2 for additional explanation

4 Discussion

Our results indicate that all three trap deployment treatments on front-row trees were equally effective in preventing wild or marked-released flies from penetrating into the interior of test plots and preventing fruit injury. This was true regardless of whether comparatively susceptible or comparatively tolerant cultivars comprised front-row trees and regardless of the seasonal period during which sampling for treatment performance occurred. As measured by captures of flies on interior unbaited monitoring traps and percentage fruit injury, each trap deployment treatment was as effective as grower-applied insecticide sprays in preventing fly penetration into a plot and preventing fruit injury.

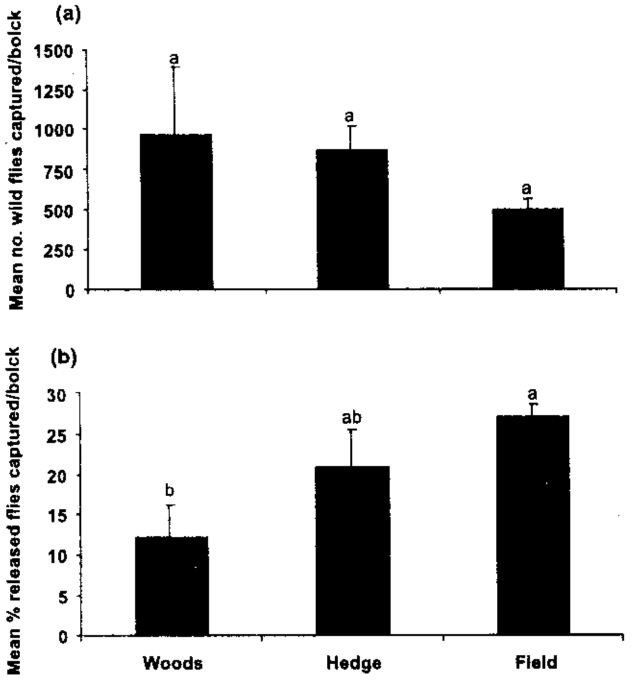

Fig. 5. Across all traps in all plots for all sample periods, mean number (±SEM) of wild apple maggot flies (a) or mean percentage (±SEM) of marked-released apple maggot flies (b) captured when orchard blocks were adjacent to woods (four blocks), hedgerows (four blocks), or open fields (four blocks). Mean values superscribed by the same letter are not significantly different according to ANOVA *and least significant difference tests (0.05 level)*

Front-row traps 10 m apart were just as effective as other trap deployment patterns in preventing fly penetration into a plot despite their overall capture of significantly fewer wild and marked-released flies than front-row traps of other deployment patterns. Perhaps it should not be surprising that front-row traps 10 m apart captured fewer flies than front-row traps of the other two deployment patterns because there were only four front-row traps per plot when 10 m apart compared with seven front-row traps per plot for the other two treatments. Further, fewer odour-baited traps per front row plot should translate into a lesser amount of synthetic attractive odour emanating from front-row trees and hence a decrease in probability of drawing wild or marked-released flies from nearby border areas onto front-row trees. For reasons not clear, differences between treatments in front-row captures were more pronounced in blocks where comparatively susceptible cultivars comprised front-row trees than in blocks where comparatively tolerant cultivars comprised front-row trees. Regardless of front-row cultivar, traps 5 m apart on front-row trees captured about the same numbers or percentages of wild or marked-released flies as traps grouped on a central front-row tree.

Across all front-row trap deployment treatments, back-row traps captured more than one-third as many wild flies as did front-row traps whereas back-row traps captured less than a twelfth as many marked-released flies as did front-row traps. This could be taken to suggest that substantial numbers of wild flies moved towards the interior of plots from the back sides of plots, which in 10 of the 12 blocks were bordered by rows of grower-sprayed apple trees. However, interior unbaited monitoring traps captured about half as many flies of each type as did back-row traps, suggesting that for both types of flies, the predominant flow of flies was from front row towards back row.

More wild flies entered orchard blocks from adjacent woods or hedgerows than from adjacent open field. This was not an unexpected finding in that wild flies originate predominantly from feral host trees in woods or hedgerows (Bostanian et al., 1999) and behave as if they could move much greater distances through patches of trees or shrubs than through patches of open terrain (Green et al., 1994). In contrast, marked-released flies entered orchard blocks in greater percentages when released in open fields than in hedgerows or woods. This too was expected in that there were no other trees or shrubs competing with apple trees in open-field situations. We did not attempt to count the number of wild host trees of *R. pomonella* adjacent to each block because Maxwell (1968) and our own previous experience has shown that *R. pomonella* flies are readily able to move 700 m or more from wild hosts into orchards.

Our finding here that odour-baited red sphere traps 10 m apart on front-row apple trees were as effective as same-type traps placed 5 m apart in preventing fly penetration into interiors of orchard plots contrasts with earlier findings of Prokopy et al. (1990) and Christie et al. (1991) in Massachusetts that odour-baited red sphere traps placed 10 m apart on front-row trees were inferior to traps placed 5 m apart in preventing fly injury to fruit of interior trees. The difference in findings may be the result of the smaller size of plots, the smaller populations of apple maggot flies used here, the use here of a five-component blend of attractive odour rather than only one of its components (butyl hexanoate) as used earlier, and differences in cultivar composition of trees comprising tests plots. Bostanian et al. (1999) were successful in controlling apple maggot flies in Quebec using red sphere traps baited with butyl hexanoate when traps were placed 10 m apart on front rows of comparatively tolerant cultivars (McIntosh and Empire), but the level of fruit protection was inferior when similar traps were placed about 10 m apart on front rows of a susceptible cultivar (Jersey Mac). Other types of odour-baited traps placed 10 m or more apart on front-row and/or interior fruit trees have succeeded in controlling the tephritids *Bactrocera oleae* (Gmelin) (Haniotakis et al., 1991) and *Ceratitis capitata* (Wiedemann) (Cohen and Yuval, 2000). Future studies on apple maggot flies should examine more thoroughly interactive effects of type and strength of odour-bait attractant, cultivar composition, plot size and distance between odour-baited traps, preferably under conditions of higher *R. pomonella* populations than what prevailed here.

Acknowledgements

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