Evaluation of Various Deployment Strategies of Imidacloprid-Treated Spheres in Highbush Blueberries for Control of *Rhagoletis mendax* (Diptera: Tephritidae)

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ABSTRACT Biodegradable, ammonium-baited spheres treated with the neonicotinoid insecticide Provado (imidacloprid) at 2% (AI) were evaluated for controlling blueberry maggot flies, *Rhagoletis mendax* Curran. Three strategies for sphere deployment in highbush blueberries, *Vaccinium corymbosum* L., were compared with untreated control plots in 1999 and once again compared against control plots and organophosphate insecticide sprays in 2000. The patterns of sphere deployment were as follows: (1) perimeter deployment in which spheres were hung individually and spaced equally around the perimeter of experimental plots; (2) cluster deployment in which four groups of three spheres were hung in equally spaced perimeter locations of experimental plots; and (3) uniform deployment in which spheres were placed 10 m apart (in a grid-like pattern) within experimental plots. In 1999, there were no significant differences in fruit injury levels based on observed *R. mendax* oviposition scars and reared larvae among plots containing imidacloprid-treated spheres in perimeter, cluster, and internal-grid patterns. However, all plots containing spheres had significantly lower fruit infestation levels (<2%), compared with unsprayed control plots with no spheres deployed, which had infestation levels (>20%). In 2000, there were no significant differences in fruit injury based on observed *R. mendax* oviposition scars between plots containing imidacloprid-treated spheres in the three deployment strategies tested and plots that received Guthion (Azinphos-methyl) spray applications. However, significantly fewer *R. mendax* larvae were reared from berries collected from plots that received two applications of Guthion compared with plots in which imidacloprid-treated spheres were deployed. Irrespective of sphere deployment strategies, all sphere-treated and sprayed plots had significantly lower injury levels (<1.5%), based on numbers of reared larvae compared with berries collected from the control plots (>4.0%). Based on captures of flies on unbaited Pherocon AM boards placed in the center of treatment plots, we observed a suppression of *R. mendax* in plots containing imidacloprid-treated spheres compared with control plots. The potential of using imidacloprid-treated spheres as a behavioral control integrated pest management tactic for blueberry maggot flies is discussed.

KEY WORDS *Rhagoletis mendax,* imidacloprid-treated spheres, deployment strategies, behavioral control

GIVEN THEIR STATUS as insect pests of economic significance, species within the genus *Rhagoletis* have been the subject of a vast number of studies focusing on the development of integrated management strategies (Boller and Prokopy 1976, AliNiazee 1978, Prokopy et al. 1990, Liburd et al. 1999). Many of these studies have concentrated on the development and optimization of monitoring techniques (Kring 1970, Prokopy and Hauschild 1979, Drummond et al. 1984, Liburd et al. 2000) for early-season detection of adult flies. Effective monitoring techniques for fruit parasitic tephritids are of great importance given the strict tolerance levels imposed on maggot infested fruit (Liburd et al. 2000). Additionally, sensitive monitoring of adult flies in commercial settings can potentially reduce unnecessary, prophylactic pesticide applications.

In addition to the optimization of monitoring techniques for key *Rhagoletis* species, a considerable amount of research has dealt with the development of behavioral control methods designed to complement existing management techniques, such as pesticide spray applications (Prokopy and Mason 1996). Many of the behavioral control tactics involve the exploitation of fly response to visual and olfactory stimuli using fruit- or foliage-mimicking sticky traps baited with food- or host-fruit-mimicking synthetic attractants (Russ et al. 1973, Neilson et al. 1981, Stanley et al. 1987, Duan and Prokopy 1992). In addition to their effectiveness as monitoring devices, Prokopy et al. (1990) showed that appropriately baited and visually attractive traps had the potential of reducing fruit injury when deployed within orchards to intercept immigrating adult apple maggot flies, *Rhagoletis pomonella* (Walsh). Furthermore, Reynolds et al. (1998) found that both perimeter and within-orchard deployment

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patterns of odor-baited red sticky spheres reduced oviposition by apple maggot flies compared with control blocks without such traps.

The use of odor-baited sticky traps (Neilson et al. 1981, Liburd et al. 1998b) and biodegradable attract-and-kill devices (Liburd et al. 1999, Ayyappath et al. 2000) have been evaluated against *Rhagoletis mendax* Curran and have potential for implementation as behavioral control tactics. Liburd et al. (1999) reported that biodegradable, fruit-mimicking spheres treated with imidacloprid (Bayer, Kansas City, MO) effectively killed both blueberry maggot and apple maggot flies in field studies. In a later study, Ayyappath et al. (2000) demonstrated that biodegradable spheres treated with the neonicotinoid insecticide Actara (thiomethoxam) (Novartis, Greensboro, NC) were also effective in killing blueberry maggot flies in blueberry plantings. The results of this same study revealed that increasing the dosage of thiomethoxam used with biodegradable spheres prolonged their effectiveness when deployed in the field. Most recently, Prokopy et al. (2001) showed that both wooden and biodegradable insecticide-treated spheres were only slightly less effective than the use of organophosphate sprays or sticky red spheres in preventing fruit injury by *R. pomonella.*

The potential benefits of using insecticide-treated spheres instead of organophosphate applications or odor-baited sticky traps for control of *R. mendax* has been cited in recent studies (Liburd et al.1999, Ayyappath at al. 2000). However, there are no detailed studies demonstrating how insecticide-treated sphere deployment tactics within highbush blueberries, *Vaccinium corymbosum* L., affect the status of resident or immigrant populations of blueberry maggot flies. Also, no direct comparisons of conventional organophosphate sprays versus deployment of insecticide-treated spheres have been made with respect to controlling *R. mendax.* Consequently, there has been no documentation of preventing fruit injury caused by blueberry maggot fly oviposition with the use of insecticide-treated spheres.

The objective of this study was to evaluate three potential insecticide-treated sphere deployment patterns in highbush blueberry plantings to determine how they may impact fruit injury and infestation levels of *R. mendax.* Furthermore, the study aimed to compare insecticide-treated spheres, as a behavioral control tactic for blueberry maggot flies, with conventional spray applications of an organophosphate.

Materials and Methods

Field experiments to determine the effectiveness of biodegradable spheres treated with the neonicotinoid insecticide Provado (Imidacloprid) (Bayer, Kansas City, MO), for the control of blueberry maggot flies were conducted at an experimental blueberry farm in Douglas, MI, in 1999 and 2000. Biodegradable spheres (9 cm diameter), made with the specifications outlined in Liburd et al. (1999), were obtained from the United States Department of Agriculture (USDA) laboratory in Peoria, IL. Spheres were brush-painted with two coats of a mixture containing DevFlex latex green paint (ICI Paints, Cleveland, OH) (70%), sucrose feeding stimulant (20%), water (8%), and imidacloprid at 2% (AI) (Liburd et al. 1999). Spheres were allowed to dry for 72 h before field deployment. Biodegradable spheres were hung within the canopy of blueberry bushes within the cultivar Jersey at a height ≈15 cm below the tops of the uppermost bush according to the recommendations of Liburd et al. (2000). Biodegradable spheres used in blueberry maggot experiments were baited with polycon dispensers (Great Lakes IPM, Vestaburg, MI). The dispensers were attached to the strings used for hanging spheres and contained 5 g of ammonium acetate (Liburd et al. 1998b). The experimental designs were completely randomized blocks with four replications.

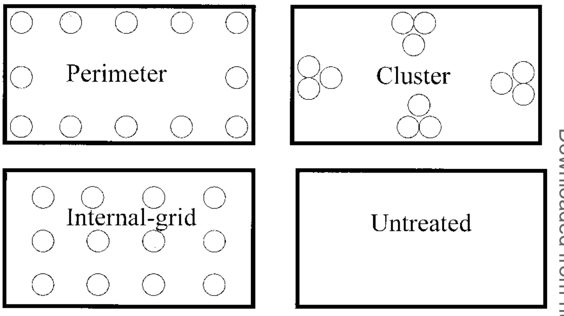

Fig. 1. Imidacloprid-treated sphere deployment strategies in highbush blueberry plots (10 by 40 m). ○, 9-cm-diameter, green imidacloprid-treated sphere.

1999. The experiment was designed to determine the most effective strategy for deploying (arrangement and interval distance) imidacloprid-treated spheres to control *R. mendax* and consequently prevent maggot injury and infestation. The experimental plots were 10 by 40-m rectangles, containing three rows of 12 highbush blueberries. Treatments were randomly assigned to the experimental plots contained within larger blueberry plantings. All treatment/replicate plots were spaced at least 20 m apart and treatments were assigned randomly with respect to field borders. During both years of the experiment, no insecticides were used in areas where imidacloprid-treated spheres were deployed. Twelve biodegradable, imidacloprid-treated spheres were used in each treatment/replicate (Fig. 1). The four treatments evaluated were as follows: (1) perimeter deployment in which spheres were hung individually and spaced equally around the perimeter of experimental plots (Fig. 1); (2) cluster deployment in which four groups of three spheres were hung in equally spaced perimeter locations of experimental plots (Fig. 1); (3) uniform deployment in which spheres were placed 10 m apart (in a grid-like pattern) within experimental plots (Fig. 1); and (4) untreated experimental plots containing no spheres (Fig. 1). All spheres were deployed on 30 June after the detection of the first adult blueberry maggot on Pherocon AM yellow sticky boards (Great Lakes IPM).

Fruit Evaluation. At the end of the growing season (5 August), 300 ripe blueberries (majority of berries turned blue around stem) were picked at random from each experimental plot and kept separate according to treatment. From each batch of 300 berries, 50 were randomly selected and examined under a magnifying lens for blueberry maggot fly oviposition scars. The numbers of berries with oviposition scars were used to calculate percentage of fruit injury. All 300 berries from each replicate were then placed over 0.5 cm mesh hardware cloth to allow larvae to exit the fruit and drop into containers filled with vermiculite (Liburd et al. 1998b). The vermiculite was sifted and blueberry maggot fly puparia were collected and counted to quantify fruit infestation.

2000. During our second field season, we evaluated the same three imidacloprid-treated sphere deployment strategies as described for 1999 and compared deployment tactics with standard treatment of Guthion 50 W (Azinphos-methyl) (Bayer) sprays. Azinphos-methyl sprays were made on 15 June, and 6 and 25 July with a tractor air-blast sprayer (Air-O-Fan, Reedley, CA). Plot sizes and experimental designs in 2000 were identical to those described for 1999; plots receiving Azinphos-methyl sprays were spaced 50 m or further away from sphere-treated plots. The five treatments evaluated were as follows: (1) perimeter sphere deployment; (2) cluster sphere deployment; (3) uniform sphere deployment; (4) two applications of Guthion 50 W at a rate of 1.7 kg/ha; and (5) untreated experimental plots containing no spheres or Azinphos-methyl sprays. All spheres were deployed on 20 June.

Fruit Evaluation. At the end of the growing season (8 August), 1,200 ripe blueberries were picked at random from each experimental block and fruit was kept separate according to treatment. Similar to our procedure in 1999, we randomly selected 50 from each batch of 1,200 and examined them under a magnifying lens for *R. mendax* oviposition scars. The numbers of berries with oviposition scars were again used to calculate percentage of fruit injury. All 1,200 berries from each replicate were then placed over 0.5-cm mesh hardware cloth as described for 1999 and blueberry maggot fly puparia were later collected and counted to quantify fruit infestation.

Monitoring. During the second year of our study (2000), two unbaited Pherocon AM yellow sticky boards (Great Lakes IPM) were hung 20 m apart in the center of each treatment plot to monitor *R. mendax* activity within treatments. Traps were positioned in the V-shaped orientation (folded into a 45° angle with apex downward and sticky surface outwards) (Prokopy and Coli 1978). Flies were counted and removed from traps two times per week and traps were replaced in the field every 2 wk.

Statistical Analysis. Percentage data from fruit injury analysis were acrsine transformed and fly monitoring data were square-root transformed ($x + 0.5$) to stabilize variances and then subjected to an analysis of variance (ANOVA). Least significant difference (LSD) tests were used to show treatment mean differences ($P = 0.05$) (SAS Institute 1989). The untransformed means and standard errors are presented in tables.

Table 1. Percentage of fruit injury due to *R. mendax* oviposition (Michigan, 1999)

Control strategy	% of fruit injury
	% oviposition scars from 50 blueberries
Perimeter deployment of spheres	0.3 ± 0.3b
Internal deployment of spheres	0.3 ± 0.3b
Cluster deployment of spheres	0.0 ± 0.0b
Untreated plots (control)	3.7 ± 0.2a
	% puparia from 300 blueberries
Perimeter deployment of spheres	1.3 ± 0.6b
Internal deployment of spheres	1.0 ± 1.0b
Cluster deployment of spheres	1.8 ± 0.5b
Untreated plots (control)	21.0 ± 2.4a

Mean ± SE within each experiment followed by the same letter are not significantly different, ($P = 0.05$, LSD test).

Results

1999. Significantly more oviposition scars ($F = 29.1$; df = 3, 9; $P < 0.01$) and puparia ($F = 71.1$; df = 3, 9; $P < 0.01$) were recorded from blueberries that were collected from the untreated plots (not containing spheres) compared with berries from plots that contained imidacloprid-treated spheres, regardless of their deployment pattern (Table 1). The numbers of oviposition scars in untreated blocks were three times higher than sphere-treated blocks. Likewise, the numbers of puparia in untreated blocks were 11.6 times higher than in sphere-treated blocks. We recorded no significant differences in the numbers of *R. mendax* oviposition scars and puparia from blueberries collected from plots containing imidacloprid-treated spheres in the three deployment strategies tested (Table 1). Finally, the percentages of fruit injury based on oviposition scars and puparia recorded were < 1 and 2%, respectively, in all plots containing imidacloprid-treated spheres (Table 1).

2000. The results of our second year's study were similar to those observed in 1999. Significantly ($F = 21.3$; df = 4, 12; $P < 0.01$) more oviposition scars and puparia ($F = 10.1$; df = 4, 12; $P < 0.01$) were found on berries picked from untreated control plots compared with plots containing imidacloprid-treated spheres or plots sprayed with Guthion (Table 2). Untreated (control) plots had >2.5 times as many oviposition scars or puparia compared with any of our plots treated with imidacloprid-treated spheres or Guthion sprays. We did not record any significant differences in the numbers of *R. mendax* oviposition scars or puparia from berries collected from plots containing imidacloprid-treated spheres in the three deployment strategies tested (Table 2). An important finding was that there were no significant differences in fruit injury, based on oviposition scar data, between plots containing imidacloprid-treated spheres and those

Table 2. Percentage of fruit injury due to *R. mendax* oviposition (Michigan, 2000)

Control strategy	% of fruit injury
	% oviposition scars from 50 blueberries
Perimeter deployment of spheres	4.0 ± 1.8b
Internal deployment of spheres	4.0 ± 0.8b
Cluster deployment of spheres	4.6 ± 1.0b
Guthion spray (organophosphate)	2.0 ± 0.8b
Untreated plots (control)	11.6 ± 1.0a
	% puparia from 1200 blueberries
Perimeter deployment of spheres	1.3 ± 0.3b
Internal deployment of spheres	0.8 ± 0.1b
Cluster deployment of spheres	1.0 ± 0.2b
Guthion spray (organophosphate)	0.1 ± 0.1c
Untreated plots (control)	3.9 ± 0.7a

Means ± SE within each experiment followed by the same letter are not significantly different, ($P = 0.05$, LSD test).

sprayed with Guthion (Table 2). However, plots treated with Guthion had significantly ($F = 10.1$; df = 4, 12; $P < 0.01$) fewer puparia compared with plots containing imidacloprid-treated spheres (Table 2).

In our monitoring program, significantly ($F = 9.3$; df = 4, 12; $P < 0.01$) more *R. mendax* flies were captured on Pherocon AM boards placed within control plots compared with fly captures in plots containing imidacloprid-treated spheres in perimeter, uniform, and cluster orientations and plots sprayed with Guthion (Table 3). There were no significant differences in the numbers of blueberry maggot flies captured on unbaited Pherocon AM boards within plots containing imidacloprid-treated spheres, regardless of deployment pattern, and plots sprayed with Guthion (Table 3).

Discussion

Our results showed that deployment of imidacloprid-treated, biodegradable spheres decreased blueberry infestation levels to 1% in 1999 and 0.8% in 2000 (with internal-grid deployment patterns), whereas untreated (control) plots had maggot infestation levels >20% and >3.2% in 1999 and 2000, respectively. In both years, there were no differences in fruit injury levels obtained using the three different strategies for sphere deployment. Several factors may have contributed to the observed nonsignificant differences, including that the blueberry planting used in our experiments had a residential population of *R. mendax* flies (emerging from within the planting), as well as immigrating populations invading from the surrounding areas and natural bogs. Perimeter trapping tactics could be effective in intercepting immigrants (Prokopy et al. 1990) into the planting, but the degree of fruit protection from fly oviposition is dependent on trap spacing, the pressure of immigrating flies, and field status with respect to the presence or absence of residential blueberry maggot fly populations. By contrast, the internal-grid pattern of sphere deployment may hold more potential in suppressing adult blueberry maggot flies and preventing fruit infestation in plantings harboring residential fly populations. Again, the effectiveness of the internal-grid pattern is dependent on the degree of sphere spacing and fly population densities within the planting. Also, factors such as fruit load, degree of fruit maturity, and the physiological status of *R. mendax* (Liburd and Stelinski 1999) may influence the effectiveness of the internal-grid deployment pattern. Overall, our experiments have implied that specific sphere placement patterns (perimeter versus internal-grid) may be less important in blueberry plantings that are exposed to both residential and immigrating *R. mendax* populations.

The observed nonsignificant differences among the deployment strategies tested also may have been due to equal levels of visual and olfactory stimuli provided by the odor-baited, fruit-mimicking spheres in each treatment plot. Given the strong attraction of *R. mendax* to 9-cm-diameter green spheres baited with ammonium acetate (Liburd et al. 1998a, 2000), it is possible that flies foraging within each of our plots had approximately equal probabilities of encountering the bait-odor or visual stimulus provided by the imidacloprid-treated spheres, irrespective of sphere deployment patterns. Therefore, the nonsignificant differences among deployment strategies may have been due to our relatively small plot sizes and comparatively small differences between baited sphere spacing in the perimeter treatments versus the uniform or cluster treatments. Future studies comparing the effectiveness of imidacloprid-treated sphere deployment strategies should be conducted within plantings known to harbor residential populations of *R. mendax*, as well as in plantings that are only infested seasonally by immigrant blueberry maggot flies. By conducting a comparison of residentially infested plots versus those that receive immigrants only, it may be possible to gain further insight into the importance of sphere deployment patterns for effective fruit protection. Also, future studies must include larger scale treatment plots before this technology can be recommended to growers as a possible substitute to conventional pesticide applications.

During our second field season (2000), we found that field-deployed, imidacloprid-treated spheres were only slightly less effective than conventional applications of a sprayed organophosphate (Guthion 50 W at 1.7 kg/ha) insecticide in providing fruit protection against *R. mendax* oviposition. We observed no difference in fruit injury (oviposition scars) and only

Table 3. Mean number of *R. mendax* captured on unbaited Pherocon AM boards within treatment plots (Michigan, 2000)

Control strategy	No. of *R. mendax*
Perimeter deployment of spheres	20.0 ± 4.4b
Internal deployment of spheres	19.3 ± 2.8b
Cluster deployment of spheres	16.5 ± 2.1b
Guthion spray (organophosphate)	14.5 ± 2.8b
Untreated plots (control)	47.0 ± 5.3a

Mean ± SE (25 June–8 Aug.) within each experiment followed by the same letter are not significantly different, ($P = 0.05$, LSD test).

a 0.9% difference in fruit infestation between plots sprayed with Guthion and plots protected by imidacloprid-treated spheres. These results indicate that it is possible to achieve fruit protection against *R. mendax* oviposition equivalent to the level obtained with broad-spectrum, organophosphate sprays in highbush blueberries. However, the sphere density used in our experiments to compare the various deployment patterns was relatively high. At an estimated cost of a $1.00 U.S. per sphere, commercial use of this technology would necessitate a smaller number of deployed spheres for this technology to be commercially viable and comparable to insecticide treatments. Future research must also focus on optimizing sphere deployment densities and determining whether effective and economically viable densities can be achieved.

Our monitoring program confirmed that blueberry maggot fly activity in plots containing imidacloprid-treated spheres was suppressed to a level similar to that observed in plots that were treated with Guthion. Similar suppression of fly activity has been recorded with the apple maggot fly foraging in areas where imidacloprid-treated spheres were deployed (Liburd et al. 1999, Prokopy et al. 2001). In a separate study, Stelinski et al. (unpublished data) showed that imidacloprid-treated spheres at 2% (AI) did not lose their effectiveness in killing *R. mendax* throughout the duration of the 9-wk period when sexually mature flies are ovipositing. We therefore suggest that a single deployment of ammonium-baited, imidacloprid-treated spheres could potentially provide effective, season-long control of blueberry maggot flies in a commercial setting.

Despite their effectiveness, the current version of biodegradable spheres is susceptible to rodent feeding. We encountered this problem in 2000 and replaced ≈10% of our spheres 2 wk after initial deployment. Future prototypes of insecticide-treated spheres must be more resistant to rodent feeding if this technology is to be effectively implemented as a control tactic for blueberry maggot flies. In addition, loss of spheres due to rodent feeding may require periodic replacements during the growing season.

This study documents that deployment of biodegradable, imidacloprid-treated spheres as a form of behavioral control reduces *R. mendax* infestation levels below 1%. Although, such levels are still above the currently mandated zero tolerance, we suggest that even greater control can be achieved by making spheres more attractive with effective and selective baiting systems, further optimizing sphere deployment and density strategies, and perhaps making fruit less attractive by coating it with visual or olfactory deterrents. Due to their target specificity and reduced impact on the surrounding environment, imidacloprid-treated spheres have potential for integration into a second level IPM program (Prokopy et al. 1990) by involving methods of cultural (Liburd et al. 1998b) and biological controls. Our study provides direct evidence for the potential of using biodegradable spheres treated with imidacloprid for control of blueberry maggot fly.

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