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COMPARISON OF MONITORING STRATEGIES AND EVALUATION OF SPINOSAD FORMULATIONS FOR MANAGEMENT OF KEY *RHAGOLETIS* SPECIES

By

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ABSTRACT

COMPARISON OF MONITORING STRATEGIES AND EVALUATION OF SPINOSAD FORMULATIONS FOR MANAGEMENT OF KEY *RHAGOLETIS* SPECIES

By

Kirsten Suzanne Pelz

In the eastern and midwestern United States, the cherry fruit fly, *Rhagoletis cingulata* (Loew), the blueberry maggot, *R. mendax* Curran, and the apple maggot, *R. pomonella* (Walsh) are important late-season pest of cherries, blueberries, and apples, respectively. Two insecticide formulations containing the naturalyte insecticide spinosad, GF-120 Fruit Fly Bait and SpinTor 2SC, were compared for control of, *R. pomonella* and *R. mendax.* Larval infestation in blueberries and apples was significantly lower in plots treated with GF-120 or SpinTor than in untreated control plots. Observations of wild *R. mendax* flies revealed that similar numbers of flies landed on blueberry foliage treated with spinosad bait, bait, or water droplets. However, flies on spinosad bait and bait treated plants spent significantly more time within 5 cm of the treatment droplets compared with control (water) droplets. Several monitoring strategies for *R. mendax* and *R. cingulata* were compared in abandoned blueberry plantings and cherry orchards. Significantly more *R. cingulata* were captured on Pherocon AM traps hung at the uppermost portion of cherry tree canopies (4.6 m) than in traps hung at the standard height for monitoring traps (2.1 m) or at 1.2 m. In comparisons of traps and lures, significantly more *R. cingulata* and *R. mendax* were captured on traps baited with ammonium acetate lures than unbaited traps or traps baited with concentrated fruit lures.

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CHAPTER ONE: INTRODUCTION

Michigan cherry, blueberry, and apple production. Michigan is the leading producer of cherries and blueberries in the United States. Tart cherries, *Prunus cerasus* L., are grown on 30,800 acres that produced an average of 234 million pounds of fruit from 1997 to 2001, or 75% of the national total (Anon. 2004a). An average of 53 million sweet cherries, *P. avium* (L.), were harvested in Michigan from 1997 to 2001, accounting for 12% of the U.S. production. Highbush blueberries, *Vaccinium corymbosum* L., are grown on ca. 18,000 acres in Michigan, with the 64 million pounds harvested in 2002 accounting for 33.4% of the national blueberry production (Anon. 2004a). Michigan has also historically ranked among the top three states in the U.S. for apple, *Malus domestica* Borkhausen, production with an average of 976 million pounds produced annually from 1997 to 2001 on 47,500 acres (Anon. 2004b). Apples represent 62% of the 1.4 billion pounds of fruit annually produced in Michigan.

Ecology and management of fruit fly pests of apple, blueberry and cherry. The eastern cherry fruit fly, *Rhagoletis cingulata* (Loew), the blueberry maggot, *R. mendax* Curran, and the apple maggot fly, *R. pomonella* (Walsh) are economically important late-season pests of commercial cherry, blueberry, and apple crops, respectively. Migration of flies into commercial plantings can result in severe economic losses if their activity leads to detection of larvae within host fruits. Indeed, detection of a single larva in harvested fruit can lead to rejection of all fruit from an infested field or from an infested load of fruit. This zero tolerance for infestation has driven the widespread use of broad-spectrum insecticides against fruit flies to attempt their complete control.

Distribution, host specificity and life history. Olfactory and visual cues produced by host plants mediate selection of hosts by *Rhagoletis* species for foraging, mating, and oviposition by fruit flies (Prokopy 1968a Moericke et al. 1975, Aluja and Prokopy 1993). The specificity of these stimuli limits the distribution of *Rhagoletis* species to a few associated plant genera (Prokopy et al. 1987, Bush and Smith 1998). In addition, host choice for a given species can be influenced by odor cues. For example, Linn et al. (2003) found that resident *R. pomonella* in hawthorn copses were more attracted to synthetic hawthorn fruit volatiles than to synthetic apple volatiles, while populations of *R. pomonella* resident in apple orchards were more attracted to apple volatiles than hawthorn volatiles. This difference in odor preference between races of *R. pomonella* underscores the strong host fidelity exhibited by members of the *Rhagoletis* genus.

Approximately 60 species of *Rhagoletis* flies have been described, dispersed broadly throughout the Holarctic and Neotropical regions (Bush 1966). The distributions of *R. cingulata*, *R. mendax* and *R. pomonella* extend throughout the northeastern and Midwestern U.S. (Bush 1966). Each of these economically important species feed only on one or a few fruit crops. Lowbush blueberry, *V. angustifolium* Aiton, and highbush blueberry are hosts of *R. mendax*, while *R. cingulata* infests sweet and tart cherries. Apple is the preferred host of *R. pomonella*, but this species is also a pest of cherries in Utah (Jorgensen et al. 1986, Jones and Davis 1989).

Most temperate species of *Rhagoletis*, including *R. mendax, R. cingulata* and *R. pomonella*, are typically univoltine (Fletcher 1989). Adults become sexually mature approximately one week after emergence and mate on the fruit or foliage of host plants. Virgin females forage on host foliage and are generally receptive to mating. As the season progresses, females that have mated previously are found more frequently on the fruit of host plants and copulation is often forced by males (Prokopy and Bush, 1973, Smith and Prokopy 1981, 1982). Females are gravid for one week, after which they oviposit into developing host fruit (Smith and Prokopy 1981). After inserting an egg just beneath the fruit skin, the female marks the site with an epideictic pheromone by dragging her ovipositor around the perimeter of the fruit, thereby deterring other females from ovipositing into the same fruit (Prokopy et al. 1972, Boller and Prokopy 1976). While each *Rhagoletis* female can lay up to 400 eggs, usually only one egg is deposited at a time.

Larvae hatch and develop within the host fruit for 2-4 weeks, depending on the softness, sugar content, and acidity of the fruit (Boller 1966, Dean and Chapman 1973, Boller and Prokopy 1976). Upon reaching the third instar, larvae tunnel out of the fruit and drop to the soil where they form a puparium (Lathrop and Nickels 1932, Boller and Prokopy 1976). *Rhagoletis* spp. spend the winter in diapause ca. 3-5 cm below the soil surface and emerge the following summer, although some individuals may not emerge for as long as four years (Lathrop and Nickels 1932). Diapause has been studied more extensively in *R. pomonella* and *R. mendax* than in *R. cingulata*. The onset of diapause in *R. pomonella* is brought about by decreased photoperiod and low temperature during the larval stage (Filchak et al. 2001). Adult emergence coincides with the phenology of their hosts, typically around the fruit ripening stage (see Table 1.1 for a list of fly emergence dates for each species in 2002 and 2003). Increases in light, moisture, and surrounding soil temperature foster adult emergence (Neilson 1962, 1964, Prokopy 1968b, Feder et al. 1997, Teixeira and Polavarapu 2002). Degree-day models for predicting adult emergence are helpful but not as accurate as those described for Lepidoptera, presumably due to the interaction of moisture and temperature driving *Rhagoletis* emergence. Teixeira and Polavarapu (2002) found that postdiapause development rates of *R. mendax* influence adult emergence and that these rates are probably determined by exposure to high temperature during prepupal development.

Table 1.1. Emergence dates (Accumulated Growing Degree Days) for *Rhagoletis* spp. (Michigan 2002, 2003).

Species	Location	2002	2003
R. cingulata	Sutton's Bay	7/17 (1473)	7/14 (1374)
	Benton Harbor	6/28 (1300)	--
	Fennville (2003)	--	7/7 (1291)
R. mendax	West Olive	7/8 (1469)	7/12 (1470)
R. pomonella	Fennville	7/15 (1405)	7/14 (1445)

Growing degree days (DD_{45}) were calculated using Baskenville E. from a start date of March 01 and obtained from www.agweather.geo.msu.edu.

Management history of *Rhagoletis*. In the past century, control of *Rhagoletis* species has followed the general trends in crop protection, progressing from cultural control methods, to extensive pesticide sprays, to the current integrated methods that combine a monitoring program with behavioral controls and a pesticide regime. Management of these species in fruit crops once relied on the destruction of infested fruit underneath hosts to prevent the emergence of flies the following year (Boller and Prokopy 1976). During the 1950s and 1960s, arsenics and DDT applications were employed to control adult fly populations prior to oviposition (Dean 1947, Boller and Prokopy 1976). As these chemicals fell into disuse due to environmental concerns and lack of efficacy, new classes of broad-spectrum insecticides, such as the organophosphates, targeting adult stages were registered and became the standard options for *Rhagoletis* control (Boller and Prokopy 1976, Wise et al. 2004). Increasingly stringent consumer demands, phytosanitary restrictions and federal (USDA) regulations have resulted in a zero tolerance for the presence of *Rhagoletis* larvae in fruit. This standard of larva-free fruit has necessitated the use of contact insecticides aimed at adults prior to egg laying, to obtain the desired level of control. Organophosphate and carbamate insecticides are typically used for control of *Rhagoletis* flies, and those registered for use in Michigan fruit crops include dimethoate (Cygon®), carbaryl (Sevin®), azinphosmethyl (Guthion®), phosmet (Imidan®), thiacloprid (Calypso®), and methomyl (Lannate®). In addition to having deleterious effects on beneficial insects, these products are also characterized by their acute toxicity to mammals. The high toxicity of broad-spectrum insecticides has caused concerns regarding environmental quality, worker safety, food safety and human health. In 1996, the Food Quality Protection Act (FQPA) was passed, wherein the U.S. Environmental Protection Agency (EPA) was required to review the registrations of all pesticides over a 10-year period. Considering the most toxic pesticides first, the EPA has begun to restrict the use and availability of organophosphates for non-agricultural and agricultural uses. Because of the more stringent review process after FQPA, reduced risk insecticides such as neonicotinoids, insect growth regulators, and naturalytes have been registered for use in fruit crops. Recently registered reduced risk products for use against fruit flies in apple, cherry, or blueberry include the neonicotinoids imidacloprid (Provado®) and thiamethoxam (Actara®), and formulations of the naturalyte spinosad (SpinTor®, GF-120®, Entrust®).

In addition to insecticides, cultural practices, trapping, and behavioral manipulation are important tactics and strategies for *Rhagoletis* management when used as part of an integrated program. Behavioral control methods employed against *R. pomonella* show promise as alternatives to insecticides in Integrated Pest Management (IPM) programs. Flies immigrating from nearby unmanaged orchards pose the greatest threat to commercial orchards; therefore, interceptive trapping with spheres may offer an alternative to broadcast sprays for preventing fruit infestation by *R. pomonella*. Red spheres baited with a five-component fruit volatile lure (Fein et al. 1982) or butyl hexanoate and deployed in perimeter row trees provided similar levels of control to traditional insecticide sprays (Reynolds et al. 1998, Prokopy et al. 2003a). To date, mass trapping with baited spheres as an alternative to pesticides has not been described for use against *R. mendax* or *R. cingulata*.

Recent work has shown the potential of the parasitic wasp *Diachasma alloeum* for control of *R. mendax* (Liburd and Finn 2003a, Stelinski et al. 2004). Parasitism of *R.*

mendax larvae in unmanaged blueberry fields can reach as high as 30-50% (Liburd and Finn 2003a). However, parasitic wasps do not provide the high level of fly control required in managed fields so the use of parasitic wasps as a management tactic must be supplemented by additional control measures. Availability of reduced-risk insecticides for fruit fly control may offer new opportunities for integrated control of *Rhagoletis* species combining these more selective products with conservation of natural enemies.

History of trap development. Trapping of *Rhagoletis* species is an important component of IPM programs as a method for determining fly emergence and population densities. In addition to detecting adult females during their pre-oviposition period, accurate trapping allows growers to appropriately time pesticide sprays, thereby preventing unnecessary sprays and reducing the possibility of resistance development. An insecticide is typically applied within seven days of capturing a single fly on traps deployed in apple and cherry orchards and blueberry plantings, targeting adult flies during the 8-10 day pre-oviposition period (Stanley et al. 1987, Howitt 1993, Liburd et al. 2001).

Research has focused on determining the optimal combination of trap shape, color, lure, and position in the crop for capturing *Rhagoletis* species. Trap color is an important factor mediating attraction of flies, as it provides a short-range (ca. 3 m) visual cue similar to that of the host foliage or host fruit (Green et al. 1994). The Pherocon AM yellow panel trap is most commonly used for monitoring *Rhagoletis* pests of temperate fruit crops (Prokopy and Coli 1978, Liburd et al. 1998a), however red or green sticky spheres are also used for *R. pomonella* and *R. mendax*, respectively (Reissig 1976, Prokopy and Hauschild 1979, Liburd et al. 1998a). Colored spheres are more attractive to flies than yellow traps later in the season, when mature female flies oviposit into fruit (Liburd et al. 1998b). Rebell traps are more effective in capturing *R. cingulata* than Pherocon AM traps or colored spheres (Liburd et al. 2001). It is likely that trap color and dimension (three dimensional versus two dimensional) play a role in the effectiveness of the Rebell trap, however to date the source of this heightened effectiveness compared to other traps has not been explored.

Ammonia-based attractants mimic volatiles produced by natural food sources of adult *Rhagoletis*, namely avian fecal material, and these volatiles are often used in combination with monitoring traps. The addition of an ammonia lure significantly increases the attractiveness of traps to flies, and ammonium acetate has been shown to be a more effective lure for attracting *R. mendax* than ammonium carbonate (Liburd et al. 1998a). In addition, lures releasing fruit volatiles can increase captures of *R. pomonella* on red sphere traps. A blend of synthetic apple volatiles (Reissig 1982, Fein et al. 1982, Zhang et al. 1999) mimics the odor emitted by host fruits, selectively attracting flies over a range of 20 m or more (Prokopy et. al. 1973, Stelinski and Liburd 2002). As a result, this trap and lure combination may be used to monitor *R. pomonella*, and has potential for control of populations via mass trapping (Reynolds et al. 1998, Rull and Prokopy 2001). Similar fruit-based volatile lures have not been described for use in capturing *R. mendax* or *R. cingulata*, however in recent studies significantly more *R. mendax* were captured on traps placed next to cages holding fresh blueberries than traps placed next to cages containing marbles, suggesting that blueberries release an odor attractive to *R. mendax* (L. Stelinski unpublished data).

Trap position also appears to have a substantial impact on the number of flies captured in monitoring traps. Liburd et al. (2000) showed that Pherocon AM traps folded in a V orientation (Prokopy and Coli 1978, Geddes 1989, Gaul 1995) and placed in the top one-third of blueberry bushes were the most effective at capturing *R. mendax* compared to other positions. In small (1.2 m or less) bushes, traps hung in the top and bottom of the bush canopy captured similar numbers of flies (Teixeira and Polavarapu 2001). In contrast, significantly more *R. pomonella* were captured on sticky yellow cards impregnated with ammonium acetate when traps were placed at 2.1 m in the canopy of apple trees compared to traps hung at 1.2 or 3.0 m (Reissig 1975). Drummond et al. (1984) found that placement of traps within 0.25-0.5 m of host fruit also significantly enhanced the number of apple maggot flies captured. To date there have been no published studies determining the effect of trap position on captures of *R. cingulata.*

Development of attracticidal spheres. Pesticide-treated spheres have shown promise as an alternative to sprays for control of *R. pomonella* and *R. mendax* (Hu and Prokopy 1998, Liburd et al. 1999, Prokopy et al. 2001, Stelinski and Liburd 2001, Liburd et al. 2003b). Colored spheres impregnated with the neonicotinoid insecticide imidacloprid and deployed in apple orchards or blueberry plantings achieved similar reduction (79%) in larval infestation compared to azinphosmethyl (Guthion) sprays (97%) (Stelinski and Liburd 2001). Pesticide treated spheres with sugar/wax discs affixed to the top of spheres have also shown promise for *R. pomonella* control (Prokopy et al. 2001). These discs are designed to provide a continuous film of sugar on the sphere for ca. 6 weeks or 6 in. of rainfall and, therefore, a constant food source for foraging *Rhagoletis* flies. Although sphere technology is promising as an alternative to broadcast pesticide applications, there are drawbacks that may hamper the adoption of this approach for control of *Rhagoletis* fruit pests. Labor costs associated with deployment of high numbers of spheres per acre and the cost of the spheres are prohibitive and may provide an explanation for their failure to gain popular usage in commercial agriculture (Prokopy et al. 2000, Prokopy et al. 2003c).

Baited insecticide formulations. Combining insecticides with an attractive phagostimulatory bait is a potential alternative control tactic to broadcast sprays or pesticide-treated spheres. The use of baited insecticide formulations against tephritid species has been practiced for nearly a century (Severin et al. 1914, Back and Pemberton 1917, Steiner 1952, 1955, Nishida et al. 1957, Roessler 1989, Peck and McQuate 2000, Burns et al. 2001, Moreno et al. 2001, Vargas et al. 2001, Prokopy et al. 2003b). Reproduction and longevity in tephritids are tightly linked to the intake of nutrients, particularly carbohydrates and amino acids and/or proteins (Hagen 1953, Drew and Yuval 2000). Thus, female *Rhagoletis* flies, like most tephritids, require a protein meal following eclosion for successful egg development, while carbohydrates, in the form of sugar, act as phagostimulants to both male and female flies (Prokopy 1993, Prokopy et al. 1994, Prokopy and Papaj 2000). The baits used in attract-and-kill pesticide formulations employ food-based attractants designed to mimic natural food sources, typically a yeast-derived enzymatic protein hydrolysate and a sugar (Steiner 1952, Prokopy et al. 1992, King and Hennessey 1996, Peck and McQuate 2000). Ammonia emitted from proteinaceous baits serves as the primary component that attracts flies (Bateman and Morton 1981, Mazor et al. 1987). Compared to conventional insecticide sprays, baited toxicants can be applied to a smaller area of the crop surface, as flies will move to interact with the droplets, reducing the amount of insecticide released into the crop ecosystem, and provide control targeted only at insects that feed on the bait (Prokopy et al. 1992). The behavioral response of *Rhagoletis* to these baits is poorly understood, although recent work by Barry and Polavarapu (2004) has shown that 8% sucrose is effective in stimulating *R. mendax* feeding. In addition, feeding assays comparing NuLure insect bait® (Miller Chemical and Fertilizer Co., Hanover, PA), SolBait® (USDA-ARS, Weslaco, TX), and AY50% (Mauri Yeast Australia) indicate that *R. mendax* spend significantly more time feeding on Solbait than on the other treatments (Barry and Polavarapu 2004).

Due to relatively low toxicity to mammals, malathion was originally incorporated into bait sprays for use against the oriental fruit fly, *Bactrocera dorsalis* (Hendel) (Steiner 1952, Steiner et al. 1961, Roessler 1989). Malathion bait sprays for the Mediterranean fruit fly, *Ceratitis capitata* (Wiedmann) and the Caribbean fruit fly, *Anastrepha suspensa* (Loew) have been used in eradication programs since the 1950's (Steiner 1952, Vargas et al. 2002)). These sprays consist of 20-25% malathion, a contact and stomach poison, combined with Stanley'sProtein Insect Bait (PIB-7), now known as NuLure Insect Bait (Miller Chemical and Fertilizer Co., Hanover, PA) (Buttery et al. 1983, Roessler 1989, King and Hennessey 1996, Vargas et al. 2002). NuLure® is used routinely in bait sprays due to its attractiveness to flies, low cost, and relative availability (Roessler 1989). Malathion bait sprays have been criticized for their adverse effects on biocontrol agents, pollinators, and other beneficial insects, as well as the destruction they cause to the paint on cars near aerial application sites (Gary and Musson 1984). In addition, concerns for environmental and human health have prompted the need for alternative bait spray formulations. Photoactive dyes and spinosad have been the latest subjects in the search for a replacement toxicant.

Photoactive dyes have been suggested as potential malathion alternatives in bait formulations due to their lack of contact activity and low vertebrate toxicity (McQuate et al. 1999, Peck and McQuate 2000, Moreno et al. 2001). The toxic activity of these dyes functions only when adult flies ingest the material, and light exposure then oxidizes the dye, causing mortality (Peck and McQuate 2000). Phloxine B (2',4',5',7'-tetrabromo-4,5,6,7-tetrachloro-flourecein, disodium salt) is formulated with protein bait for fruit fly control under the name SureDye® (Phytodye International, Baltimore, MD). However, use of phloxine B as an aerial spray is limited due to potential damage the dye may render to property (Peck and McQuate 2000).

Another alternative to the organophosphate malathion in baited insecticides is the naturalyte insecticide spinosad. Spinosad is derived from metabolites (spinosyns A and D) produced by the actinomycete *Saccharopolyspora spinosa* (Mertz and Yao 1990). Spinosad is a neurotoxin that acts directly on ganglia of the insect central nervous system, targeting nicotinic acetylcholine and GABA receptors (Salgado et al. 1997). Ingestion of spinosad results in periods of prolonged nervous system excitation and muscle contractions, culminating in paralysis and death after 24 h (Salgado 1998). It has low vertebrate toxicity ($LD_{50} > 3500$ mg/kg) and minimal impact on bees (DowElanco 1994, Thompson and Hutchins 1999) and is classified by the EPA as a reduced risk pesticide (Saunders and Bret 1997). Bee mortality following bait sprays results from contact with the wet toxic spray residue rather than direct feeding on the bait (Gary and Mussen 1984); therefore, spinosad represents a relatively safe alternative when bees are present as it has minimal contact activity in comparison to malathion (Cisneros 2002, Mazor 2003). However, Cisneros et al. (2002) found that spinosad may have deleterious effects on beneficial insects, in contrast to the findings of Bret et al. (1997).

Spinosad is the active ingredient in several insecticides produced by Dow Agrosciences: SpinTor®, Success®, Tracer®, Conserve®, Entrust®, and GF-120 Fruit Fly Bait®. SpinTor (EPA Reg. No. 62719-294), a non-baited sprayable formulation, was registered for use in the U.S. in 1998 and GF-120 Fruit Fly Bait, a baited sprayable formulation, was registered for use in apples, blueberries and cherries in 2002. The bait component of GF-120, described in Peck and McQuate (2000), consists of 70% corn protein (Mazoferm E802, Corn Products, Argo, IL). Like phloxine B bait sprays, Peck and McQuate (2000) found that spinosad bait sprays provided significant reduction in fruit infestation by Mediterranean fruit fly compared to untreated controls, although it was not as effective as malathion bait sprays. This study and others (King and Hennessey 1996, Peck and McQuate 2000, Prokopy et al. 2000, Burns 2001, Vargas et al. 2001, Vargas et al. 2002, Prokopy et al. 2003b) have indicated that GF-120 is effective for control of several tropical tephritid species, but its efficacy against *Rhagoletis* pests of temperate fruit crops has not been demonstrated.

Research objectives. The changes currently underway in the fruit industries as a result of federal regulations on pesticides have prompted the need for increased evaluation of reduced-risk insecticides and integrated approaches to fruit fly control. This requires a better understanding of fly behavior and the control tactics and management strategies currently available. The overall aim of the research presented herein was to advance current management programs for *Rhagoletis* pests of blueberry, cherry and apple by improving monitoring techniques and by evaluating the potential of new insecticide formulations for their control. The first objective was to determine the effectiveness of unbaited and baited spinosad formulations for control of *R. pomonella*, *R. mendax*, and *R. cingulata* under field conditions. Included within this objective was a goal to describe *R. mendax* interactions with the baited insecticide formulation, GF-120. The second objective was to determine the most effective trap position for capturing *R. cingulata* and *R. pomonella* within the canopy of their respective host trees. The final objective was to evaluate the response of *R. mendax* and *R. cingulata* to several trap and lure combinations, including fresh fruit. The approach taken in the first objective provides a unique multi-species comparison of the complex of *Rhagoletis* flies infesting Midwestern fruit crops. Although the latter two objectives do not encompass all three *Rhagoletis* species, the data included therein supplement previously published work, from which comparisons across the species can be made.

CHAPTER TWO. PROTECTION OF FRUIT AGAINST INFESTATION BY APPLE MAGGOT AND BLUEBERRY MAGGOT FLIES (DIPTERA: TEPHRITIDAE) USING COMPOUNDS CONTAINING SPINOSAD.

INTRODUCTION

The apple maggot, *Rhagoletis pomonella* (Walsh), and the blueberry maggot, *Rhagoletis mendax* Curran, are among the most important late-season pests of apples, *Malus domestica* L., and highbush blueberries, *Vaccinium corymbosum* L., respectively, in the eastern and northwestern United States (Bush 1966, Howitt 1993). Infestation of the crop by these frugivores renders it unmarketable in regions with quarantine restrictions for *R. mendax* and *R. pomonella*. Fruit destined for regions certified as being free of these pests is inspected and detection of one infested fruit leads to rejection of the entire load. Currently, organophosphates such as phosmet, malathion and azinphosmethyl are the most widely used insecticides in apples and blueberries for control of *Rhagoletis* fruit flies (Wise et al. 2003). However, increased restrictions on the use of these broad-spectrum insecticides imposed by the U.S. Environmental Protection Agency in response to the 1996 Food Quality Protection Act (FQPA) will create a challenge for successful pest management in these crops. In particular, extensions of the re-entry and preharvest intervals for the most efficacious insecticides against fruit flies will restrict their utility for the critical period of control just prior to harvest.

Some new insecticide chemistries have recently been registered that show promise as alternative controls for fruit flies, and others are being developed that should be registered over the next few years (Wise and Gut 2002, Wise et al. 2002). Spinosad is a naturalyte insecticide consisting of two compounds derived from the actinomycete *Saccharopolyspora spinosa,* spinosyns A and D (Mertz and Yao 1990). Baited formulations of this naturally-derived insecticide have been effective in controlling populations of several tropical fruit fly species, including Caribbean fruit fly, *Anastrepha suspensa* (Loew) (King and Hennessey 1996, Burns et al. 2001), Mexican fruit fly, *Anastrepha ludens* (Loew) (Moreno and Mangan 2003) and Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann) (Peck and McQuate 2000, Vargas et al. 2001, Vargas et al. 2002). Bait sprays at concentrations as low as 1 ppm spinosad have provided significant fruit fly control (King and Hennessey 1996, Peck and McQuate 2000).

Spinosad used alone or in combination with bait has received much less attention as a possible control for temperate species of fruit flies. Smith (1999, 2000) reported control of *R. indifferens* in small-plot trials using spinosad (Success, Dow AgroSciences, Indianapolis, IN) alone or with horticultural mineral oil (Kuhlmann and Jacques 2000). Two formulations of spinosad have recently been registered for use in blueberry and apple against *R. mendax* and *R. pomonella*, respectively, despite relatively little efficacy data against *Rhagoletis* fruit pests (Liburd et al. 2003, Reissig 2003). Spinosad was registered for use in apples and blueberries in 2002 as a foliar spray formulation (Success or SpinTor, Dow AgroSciences, Indianapolis, IN). GF-120 Fruit Fly Bait (Dow AgroSciences) is a baited formulation of spinosad that was first available for commercial use in apples and blueberries during 2003.

The lethal action of spinosad against *Rhagoletis* fruit flies occurs primarily through ingestion; there is little or no contact activity (Mangan and Moreno 1995, Vargas et al. 2002). Feeding by adult *R. pomonella* is greatest during the first week following emergence and decreases thereafter (Webster et al. 1979), so preventing larval infestation using spinosad is likely to require novel approaches that entice the fly to consume a lethal dose of the toxicant. Optimizing the use of baited insecticides will require a better understanding of how *Rhagoletis* flies respond to various formulations under natural field conditions. Specifically, parameters such as duration of efficacy and attractiveness to flies will need to be investigated. Although efficacy of baited spinosad has been demonstrated in many systems (see above), in greenhouse assays, Prokopy et al. (2003) showed attractiveness of GF-120 decreased 50% by 5 hrs post-application, suggesting the need for frequent reapplication.

The specific objectives of the current study were to: 1) determine the effectiveness of GF-120 Fruit Fly Bait in controlling two temperate fruit fly species, *R. pomonella* and *R. mendax* and 2) quantify the behavioral response of *R. mendax* flies to GF-120 under field conditions.

MATERIALS AND METHODS

Experimental Sites. Research was conducted in the summers of 2002 and 2003 in apple orchards at Michigan State University's Trevor Nichols Research Complex (Fennville, MI) and in a non-commercial highbush blueberry planting (Holland, MI). Field sites were chosen because of known histories of moderate to high infestations of *R. pomonella* or *R. mendax* and the lack of insecticide applications for at least two years.

Spinosad Sprays in Apples. In 2002, experiments were conducted in a 1.0 ha apple (var. 'Red Delicious') orchard planted on a 3.0 m within-row by 5.5 m between-row tree spacing, with treatments applied to 12.4 x 22 m (0.03 ha) plots. Experiments in 2003 were conducted in 39.2 x 55.8 m (0.08 ha) plots in the same orchard and in an adjacent 1.3 ha orchard (var. 'Rome') planted on a 2.4 m x 5.5 m tree spacing. The 2002 experiment consisted of the following four treatments: 1) GF-120 Fruit Fly Bait (spinosad bait), 2) SpinTor 2 SC (unbaited spinosad), 3) bait (which includes all compounds in GF-120 except spinosad) and 4) untreated (control). Protein-bait without the insecticide incorporated could not be obtained from the manufacturer in sufficient quantity during 2003; therefore only three treatments were compared. Experiments in both years were arranged in a randomized complete block design with four replicates and at least a one-row buffer between plots.

Initial applications of all treatments were made one week after the first *R. pomonella* fly was captured on Pherocon AM traps (Great Lakes IPM, Vestaburg, MI), on 11 July in 2002 and 15 July in 2003. An 80 ppm aqueous mixture of spinosad bait or bait (1:1.5 v:v) was applied at 2.4 liters/ha using a MeterJet spray gun (Model No. 23624-30L, Spraying Systems Co., Wheaton, IL). The handgun produced droplets with ca. 4-6 mm diameter. SpinTor was applied at 21.4 g [AI]/378 liters (8 oz in 100 gal/ acre) using an airblast sprayer (Model No. CP3000, John Bean Sprayers, LaGrange, GA, in 2002; Model No. 1029, FMC Corp., Lakeland, FL, in 2003). Spinosad bait and bait were applied weekly until harvest for a total of six applications and unbaited spinosad was applied every two weeks for a total of three applications.

The relative abundance of flies in each plot was estimated by captures on unbaited red sphere traps (Great Lakes IPM) placed at the center of each plot. One trap per plot was hung approximately 2.0 m above the ground and all foliage within 0.5 m the trap was cleared away (Drummond et al. 1984). Once per week, captured flies were counted and removed from monitoring traps.

Fruit infestation evaluations were conducted at the end of each growing season to determine the effectiveness of control for each treatment (12 September in 2002 and 02 September in 2003). A total of 100 apples per plot were randomly picked from the innermost four trees in 2002. In 2003, 250 apples were randomly picked from the innermost 10 trees. Fruit samples from each plot were kept separate and placed on wire hardware mesh suspended above trays containing fine vermiculite, allowing mature larvae exiting fruit to drop into the vermiculite medium and pupariate. After four weeks, the vermiculite was sifted for fly puparia, which were counted to determine the level of infestation per plot.

Effects of treatments on mean fly catches in traps throughout the season and mean larval infestation in fruit were determined by analysis of variance (ANOVA) followed by means separation using Fisher's protected least significant difference (LSD) procedure (*P*

= 0.05) (PROC GLM, SAS Institute 1998). Prior to analysis, fly capture data were normalized by square-root transformation $[(x + 0.5)^{1/2}]$.

Spinosad Sprays in Blueberries. Experiments were conducted in a 1.8 ha highbush blueberry field (var. 'Jersey') planted at 2.7 m x 3.7 m spacing, with treatments applied to 16.2 x 37 m (0.06 ha) plots in 2002 and 16.2 x 37.4 m (0.08 ha) plots in 2003. Treatments in 2002 and 2003 were the same as those tested in apple with the exception of SpinTor, which was applied at the lower registered blueberry rate of 14.2 g [AI]/ 378 liters (6 oz in 100 gal/acre). As in apples, bait was not available for the 2003 experiment. Four and five replicates of each treatment were used in 2002 and 2003, respectively, with treatments arranged in a randomized block design and plots separated by at least one row of bushes. All treatments were applied following the first fly caught on monitoring traps (08 July in 2002 and 12 July in 2003). Spinosad bait and bait were applied each week until harvest for a total of six applications as previously described. Unbaited spinosad was applied every two weeks for a total of three applications.

Monitoring of *R. mendax* adults was conducted using Pherocon AM traps hung in a V-orientation ca. 15 cm below the uppermost portion of the bush, the optimal position for capturing sexually mature *R. mendax* (Liburd et al. 2000). Each week, monitoring traps (one per plot) were checked for *R. mendax* flies, which were counted and removed.

Assessment of larval infestation was conducted using methods similar to those described for apples. Samples of 1000 blueberries per plot were harvested on 24 August in 2002 and 28 August in 2003. Fruit were held for one month before puparia were counted. Numbers of adult blueberry maggot flies captured on traps and larval infestation within treatments were compared by the analysis described above for *R. pomonella*.

Field Observations of *R. mendax*. The first objective of the behavioral component of the study was to compare the number and duration of *R. mendax* visits to plants treated with (1) spinosad bait, (2) bait only, or (3) untreated (control). The second objective was to quantify the behavioral interactions of *R. mendax* with the GF-120 Fruit Fly Bait formulated with or without insecticide. All observations were conducted in a 1.8 ha unsprayed *V. corymbosum* (cv. 'Jersey') field in Douglas, MI. This planting was chosen because it historically harbors a high population of *R. mendax* (Stelinski and Liburd 2001). The experiment was conducted using a randomized complete block design with three replicates of three treatments: 1) spinosad bait, 2) bait, and 3) water as a control, with each replicate consisting of one treated plant. Treatments were applied at the beginning of each week for four weeks. Five 10-μl droplets (2-3 mm in diameter, according to label recommendation) of each treatment were applied to each plant on the top surface of leaves spaced at least 30 cm apart. Observations of wild flies were conducted daily for five days post-treatment between 0800 and 1300 hours. During the observations, air temperature was *ca.* 21- 27°C. Investigators stood *ca.* 0.5 m away from a treated bush and observed the plant for 20 minutes or until an observed fly left the plant. Data were collected by recording observations of *R. mendax* into handheld micro-cassette audio recorders (Model No. 3-5375A, GE, Westminster, CO). The behaviors recorded were: 1) number and duration of fly visits to blueberry plants, 2) number and duration (s) of feeding events on treatment droplets, and 3) proximity of a fly (cm) to the nearest treatment droplet. The effects of treatments on mean numbers of *R. mendax* observed visiting blueberry bushes were determined using ANOVA followed by means separation using Fisher's protected least significant difference (LSD) procedure (P =

0.05) (PROC GLM, SAS Institute 1998). Prior to analysis, data were normalized by square-root transformation $[(x + 0.5)^{1/2}]$. A two-sided sign test (BIOMDIST, Microsoft Excel 2000) was used to determine whether the number of flies observed on blueberry bushes varied over time following treatments, where Y = (flies observed on days 0-2) – (flies observed on days 3-4) (Sokal and Rohlf 1981). The probability ($P = 0.05$) of no difference in response to treatment over time (mean $Y = 0$) versus a change in response (mean $Y \neq 0$) was determined.

RESULTS

Spinosad Sprays in Apples. In 2002, mean captures of adult apple maggot flies on sphere traps in spinosad bait (1.9 ± 0.5), SpinTor (2.7 ± 0.6), and bait treated plots (2.9 ± 0.6) were not significantly different ($F = 1.44$; df = 3,9; $P > 0.05$) than captures on sphere traps in untreated plots (3.7 ± 0.8). Similarly, the number of flies captured in 2003 on sphere traps in spinosad bait (11.6 ± 2.5), SpinTor (11.5 ± 3.0), and untreated (19.3 ± 3.6) plots were not significantly different ($F = 0.44$; df = 2,6; $P > 0.05$).

In 2002, larval infestation of apples was significantly lower ($F = 3.4$; df = 3,9; $P = 0.049$) in the untreated, SpinTor and spinosad bait plots compared with plots treated with bait (Table 2.1). There were no significant differences in mean apple infestation levels among the untreated, SpinTor and spinosad bait plots. In 2003, the percentage of apple infestation by *R. pomonella* was significantly lower in spinosad bait and SpinTor plots compared with untreated plots (Table 1) ($F = 7.16$; df = 2,8; $P = 0.02$).

Spinosad Sprays in Blueberries. In 2002, captures of adult flies on Pherocon AM traps hung in spinosad bait (0.68 ± 0.26), bait (1.46 ± 0.38), SpinTor (1.43 ± 0.43), and untreated (1.68 ± 0.29) plots were not significantly different ($F = 2.74$, df = 3,9, $P >$

0.05). Similarly, in 2003 there were no significant differences in the numbers of flies captured on traps among any treatments ($F = 2.71$; df = 2,8; $P = 0.3$).

In 2002, infestation of blueberries in plots treated with bait was not significantly different from that in untreated plots (Table 2.1). In both 2002 and 2003, blueberry plots treated with spinosad bait or SpinTor had significantly lower fruit infestation compared with untreated plots (2002: $F = 4.43$; df = 3,9; $P = 0.02$; 2003: $F = 7.14$; df = 2,8; $P = 0.007$) (Table 2.1).

Field Observations of *R. mendax*. There were no significant differences in the mean numbers of adult *R. mendax* observed visiting spinosad bait, bait or untreated blueberry bushes (Table 2.2). For all treatments, the mean numbers of flies visiting bushes did not differ between days 0-2 and days 3-4 (two-sided sign test $P = 0.286$, n = 22). The mean duration (s) of fly presence within 5 cm of spinosad bait and bait treatment droplets was significantly greater than the mean duration spent within the same distance of control (water) droplets ($F = 3.9$; df = 2,22; P = 0.03) (Table 2). Flies spent ca. 10-fold more time, on average, within 5 cm of GF-120 droplets than near water droplets. Although flies were observed feeding on droplets, the sample size observed was too small for analysis.

Table 2.1. Effect of different spinosad formulations on mean (± SEM) apple and blueberry infestation by the apple maggot, *R. pomonella* and the blueberry maggot, *R. mendax*, respectively.

Treatment	% Infested apples		% Infested blueberries	
	2002	2003	2002	2003
Sample size	100	250	1000	1000
Spinosad bait	0.9 ± 0.3b	0.4 ± 0.1b	0.5 ± 0.3b	0.1 ± 0.03b
SpinTor	0.6 ± 0.2b	0.2 ± 0.1b	0.6 ± 0.2b	0.3 ± 0.1b
Bait	2.9 ± 0.0a	--	2.5 ± 0.6a	--
Untreated (control)	1.0 ± 0.4b	1.2 ± 0.1a	3.3 ± 0.5a	4.4 ± 0.9a

Means within each column followed by the same letter are not significantly different, ($P < 0.05$, Fisher's Protected LSD Test). Data were subjected to arcsine transformation prior to analysis. Untransformed values are shown.

Table 2.2. Number (mean ± SEM) of *R. mendax* flies observed per weekly sample on blueberry plants treated with spinosad bait, protein bait, or water droplets and the duration (mean ± SEM) spent within 5 cm of the droplets. Data collected 14 July – 08 Aug. 2003.

Treatment	Number of flies observed	Duration within 5 cm of droplet (s)
Spinosad bait	8.8 ± 1.8a	598.0 ± 175.8a
Protein bait	11.8 ± 0.9a	381.3 ± 141.1a
Water (control)	8.0 ± 1.2a	53.6 ± 38.0b

Means within each column followed by the same letter are not significantly different ($P < 0.05$, Fisher's Protected LSD Test).

DISCUSSION

In light of the reduction in fruit infestation observed in apples (2002) and blueberries (2002 and 2003), unbaited and baited formulations of spinosad show promise for control of two of the most commercially important temperate fruit fly species, *R. pomonella* and *R. mendax*. Substantial levels of control were achieved for both *Rhagoletis* species when their respective host plants were treated with spinosad bait or SpinTor at recommended rates. In apples, spinosad bait provided 67% reduction in fruit fly infestation in 2003, while in blueberries there were 85% (2002) and 98% (2003) reductions in fly infestations compared with controls. GF-120 did not outperform the unbaited formulation of spinosad, but did provide equivalent control using only 0.5–1.5% as much active ingredient.

Although spinosad bait caused a reduction in fruit infestation, it did not eliminate infestation by *Rhagoletis* flies. In order for an insecticide-bait to be commercially viable for fruit fly control, it must provide extremely high fruit protection to allow growers to meet the stringent quality standards of the market. At least one infested blueberry or apple was collected in plots treated with GF-120 or SpinTor in 2002 and 2003. Complete suppression of fly infestation did not occur in earlier experiments conducted with spinosad formulations on Mediterranean fruit fly (Peck and McQuate 2000, Vargas et al. 2002) or the melon fly (Prokopy et al. 2003), yet these products are used commercially for fly control. Similarly, SpinTor did not prevent larval infestation of apples in small (single tree) plots with large apple maggot populations (Reissig 2003). In the current study, infestation of fruit in the relatively small test plots may have been due to immigration of flies from nearby untreated areas; therefore, future tests of SpinTor or spinosad bait should be conducted at a larger scale. Coverage of larger areas with these products may provide the high level of control required to meet the zero tolerance for infested fruit.

Observations of *R. mendax* in blueberry plantings revealed that similar numbers of flies visited blueberry plants treated with spinosad bait, bait, or water. Flies were observed within close proximity (5 cm) of spinosad bait and bait droplets. Mediterranean fruit flies exhibit attraction to GF-120 droplets on coffee plant leaves only when they are within several centimeters of the droplet (Barry et al. 2003). In the present study, *R. mendax* remained close to the droplet (within 5 cm) for significantly longer durations than near control water droplets (Table 2.2). As defined by Kennedy (1978), an arrestant chemical is that which causes orthokinetic movement (the insect alters its rate of movement) or klinokinetic movement (the insect alters its rate of turning). Alternatively, an attractive chemical is that which causes non-random movement, orientational movement of the insect toward the stimulus. The observational findings reported in Table 2.2 support the hypothesis that arrestment behavior in response to cues from the bait component of GF-120, rather than attraction, is the underlying mechanism for the efficacy of this product.

Prokopy et al. (2003) demonstrated that significantly fewer melon flies contacted GF-120 applied to sorghum (*Sorghum* sp.) (non-host) plants surrounding host cucumbers (*Cucumis sativus* L.) 1-4 days following application compared with freshly applied GF-120. In addition, GF-120 aged for 4 days under dry conditions retained half of its initial toxicity to melon flies despite the finding that a complete loss in attractiveness occurs after only one day under dry greenhouse conditions. In that study, stochastic (accidental) interactions between flies and the phagostimulants in GF-120 were the suggested mechanism by which ingestion of spinosad occurred.

The bait component of GF-120 contains only 1% (wt:vol) of the attractant ammonium acetate (Moreno and Mangan 2003). Field studies have shown that ammonia in Polycon dispensers or incorporated into Pherocon AM traps dissipates after approximately 2 weeks in the field, resulting in an almost complete loss of attractiveness (Liburd et al. 1998, K. S. Pelz unpublished data). Rapid volatilization of ammonia from spinosad bait may explain the lack of attraction reported here. Several studies indicate that increasing the amount of ammonium acetate or ammonium bicarbonate has a repellant effect on tropical fruit flies (Heath et al. 1994, Robacker 1995). In contrast, a recent study indicates that captures of *R. pomonella* increase with increasing percentages of ammonia (Yee and Landolt 2004). Future studies should test the effects of increasing the percentage of ammonia in spinosad bait on temperate fruit flies. If higher rates of ammonium acetate enhance the duration of arrestment on spinosad bait, it would be expected to increase the interaction of flies with the toxicant and the likelihood of preventing larval infestation.

Some technical challenges must be addressed in order to make the use of spinosad bait practical on a commercial scale. The current formulation must be applied frequently and requires reapplication following moderate to heavy rainfall. Modifications of the formulation to increase rain-fastness would greatly enhance its suitability for control of fruit flies in both temperate and tropical climates. Furthermore, the efficacy of spinosad bait could be improved by incorporation of host fruit volatiles, similar to the use of apple volatiles to enhance *R. pomonella* captures on spheres (Zhang et al. 1999). In addition, increasing the amount of ammonium acetate in the GF-120 formulation from 1% could potentially enhance its capacity to attract flies for a greater duration after application, and over a greater distance.

Pesticide-treated sphere traps that mimic host fruit have been the recent focus of bait-and-kill technology against *Rhagoletis* fruit flies, and these have provided substantial control of apple and blueberry maggot flies (Liburd et al. 1999, Stelinski and Liburd 2001, Stelinski et al. 2001). However, commercial use of attracticidal sphere traps has been limited due to the high rate of sphere deployment and cost of this approach (Stelinski et al. 2001). Baited insecticide formulations fit into the current system of pest control based on the use of sprayable pesticides, whereas employing pesticide-treated spheres for large-scale control requires a shift in convention. Sprayable formulations of spinosad and protein bait offer several other advantages, including ease of application, lower dosage of active ingredient, and reduced impact of insecticide load on the environment and non-target insects (Vargas et al. 2001, Vargas et al. 2002, Mazor et al. 2003). Due to their less restrictive pre-harvest intervals, compared with conventional insecticides, bait-and-kill formulations of spinosad may provide fruit protection close to harvest when growers have fewer control options available.

CHAPTER THREE. VERTICAL POSITIONING OF TRAPS AND HOST FRUIT PRESENCE INFLUENCE CAPTURES OF EASTERN CHERRY FRUIT FLY (DIPTERA: TEPHRITIDAE).

INTRODUCTION

The eastern cherry fruit fly, *Rhagoletis cingulata* (Loew), is an important late-season pest of cherries in the eastern and Midwestern United States (Frick et al. 1954). Adults emerge from overwintering puparia in mid-June, mate on the host fruit, and lay eggs into cherries (Pettit and Tolles 1930, Prokopy 1976). A sibling species, the black cherry fruit fly, *R. fausta* (Osten Sacken), has a similar biology and geographical range, but is only occasionally a pest in commercial orchards. Additionally, *R. cingulata* adults are more frequently found on host fruit than foliage (Smith 1984).

Michigan produces *ca.* 75% of the total U.S. tart cherries, *Prunus cerasus* L., and 12% of the U. S. sweet cherries, *P. avium* (L.) (Anon. 2004a). Zero tolerance standards for fly larvae in fruit require sensitive fly monitoring systems early in the growing season as part of integrated pest management (IPM) programs to prevent fruit infestation. To monitor *R. cingulata*, Pherocon AM boards are placed *ca.* 2.1 m from the ground within the tree canopy. The yellow traps are typically baited with an ammonia and protein hydrolysate lure (Bateman and Morton 1981), providing both visual and olfactory cues to attract flies. The first insecticide is applied after a single fly is captured on a monitoring trap. Three-dimensional Rebell traps, also yellow, are highly selective for both *R. fausta* and *R. cingulata* and are more effective for capturing *R. fausta* than baited Pherocon AM boards or red sphere traps (Liburd et al. 2001). However, Rebell traps are expensive and have not been widely adopted by Michigan cherry growers for monitoring.

Steady progress has been made in developing effective trapping systems for some important *Rhagoletis* pests of temperate fruit crops. Ammonium acetate is a highly effective olfactory lure for attracting *Rhagoletis* flies to monitoring traps (Reissig 1976, Liburd et al. 2001). Trap placement has been optimized for monitoring the apple maggot fly, *R. pomonella* (Walsh), (Reissig 1975, Drummond 1984) and the blueberry maggot, *R. mendax* Curran (Liburd et al. 2000, Teixeira and Polavarapu 2001). The optimal position for traps to monitor *R. pomonella* is approximately 2.1 m from the ground within the tree canopy (Reissig 1975, Drummond 1984) and 0.25-0.5 m from fruit, while traps for *R. mendax* are most effective when placed within the top of highbush blueberry, *Vaccinium corymbosum* L., plants when the bushes are 1.5 to 2.0 m high (Liburd et al. 2000, Teixeira and Polavarapu 2001). To date, the optimum positioning of traps for monitoring *R. cingulata* has not been reported.

Host volatile lures have been developed for trapping *R. pomonella* that provide a more accurate indication of fly presence than ammonium-based lures (Prokopy 2001, Stelinski and Liburd 2002) and show promise for development of attract-and-kill approaches to control this pest. A seven-component blend of apple volatiles was determined via field, wind tunnel, and olfactometer bioassays to attract *R. pomonella* (Fein et al. 1982, Reissig et al. 1982, Averill et al. 1988). Further experiments indicated that a five-component blend (Zhang et al. 1999) combined with a red sphere is the optimal trap for attracting the maximum number of *R. pomonella* (Stelinski and Liburd 2002). The capacity of spheres to capture more flies provides a viable method for mass-trapping, thus offering an alternative control tactic to pesticides. Recently, the Food Quality Protection Act (FQPA) called for the review of registrations for some of the most important insecticides traditionally used for fruit fly control. Thus, tactics using attractive lures for behavioral modification, such as mass trapping and novel attract-and-kill tactics (Foster and Harris 1997, Stelinski and Liburd 2001, Prokopy et al. 2004) may feature more prominently as valuable alternatives or supplements to insecticides. Prior to the development of an attractive synthetic apple volatile lure, Prokopy et al. (1973) showed that *R. pomonella* flies were attracted to the odor of apples. To date, it has not been determined whether *R. cingulata* are attracted to volatiles specific to their host fruit, cherries.

Based on studies of related fruit fly species, I hypothesized that trap placement within the cherry tree canopy and cherry volatiles would affect captures of *R. cingulata* on monitoring traps. My first objective was to compare high (4.6 m), standard (2.1 m), and low (1.2 m) trap heights to determine the response of *R. cingulata*. My second objective was to compare captures of *R. cingulata* on Pherocon AM traps hung adjacent to unripe sweet, unripe tart, ripe sweet, ripe tart cherries, or no cherries.

MATERIALS AND METHODS

Experimental Sites. In 2002, trap heights were compared in a mature, unmanaged tart cherry orchard located in southwestern Michigan (Van Buren Co.). Trap position and host-fruit attraction experiments were carried out in 2003 in separate unmanaged tart cherry orchards in southwestern Michigan (Van Buren Co. and Allegan Co.). All orchards used in these experiments were unsprayed, mature trees *ca.* 4.6 m in height.

Trap Height. The effect of trap height on captures of *R. cingulata* was determined by placing unbaited Pherocon AM traps (Trécé Inc, Adair, OK) at three positions within in cherry trees (ca. 4.6 m high): (1) below the tree canopy (*ca.* 1.2 m above ground), (2) at the standard trap height (*ca.* 2.1 m), or (3) in the top portion of the tree canopy *ca.* (4.6 m). Traps hung at 4.6 m were attached to a PVC pipe (6 mm diam.) and attached to trees. A tree was selected randomly and a single trap was placed at one of the three positions. Treatments were arranged with a distance of at least 20 m between trees (one trap/tree) and 30 m between blocks. Foliage surrounding all traps was removed in a 0.5 m radius (Reissig 1975). Five replicates of each treatment were arranged in a randomized complete block design. Flies were counted and removed from traps weekly for six weeks. To minimize position effects, all treatments were rotated one position clockwise after each weekly inspection.

Response to Cherries.

Fruit lure construction. For each treatment, 1.0 kg of fruit (described below) was washed and placed in 0.5 cm cheesecloth bags. These bags were placed in cylindrical enclosures (30.5 cm length X 15.2 cm diam.) constructed of 1 mm mesh aluminum window screening. Enclosures were designed to prevent flies from contacting fruit, yet allow the emission of olfactory stimuli. Cheesecloth fruit bags were suspended from a wire hanger in the enclosures with a twist tie such that fruit was *ca.* 3 cm from the cage walls. Enclosures were hung at 2.1 m above ground with surrounding foliage removed in a 0.5 m radius around the enclosures. Two Pherocon AM traps were hung on opposite sides of the enclosures 3 cm from the edge of the enclosure. All cherries within a radius of *ca.* 2 m were removed to prevent competition with the caged fruit.

Treatments. The following treatments were tested: 1) unripe tart cherries, 2) unripe sweet cherries, 3) ripe tart cherries, 4) ripe sweet cherries, and 5) no fruit (control). Ripe fruit was obtained from a local fruit market while unripe fruit was obtained from research orchards at Michigan State University's Trevor Nichols Research Complex (Fennville, MI). Five replicates of each treatment were arranged in a randomized block design. *R. cingulata* flies captured on the two traps adjacent to the fruit lures were counted and removed every 3 d. Following each trap check, all fruit was replaced with fresh fruit and treatment positions were rotated clockwise within blocks.

Statistical Analysis. Total fly captures on each trap across the seasons in both the vertical trap placement and fruit attraction experiments were subjected to analysis of variance (ANOVA). All data were square root-transformed $(x + 0.5)^{1/2}$ prior to analysis. Fisher's Least Significant Difference test (LSD, SAS Institute 1999) was used to separate mean differences among treatments ($P = 0.05$).

RESULTS

2002 Vertical Trap Placement. Captures of *R. cingulata* were significantly affected by trap height (F = 79.2; df = 2,8; $P < 0.05$), with more *R. cingulata* flies caught at 4.6 m within canopies of cherry trees than on traps placed at 2.1 m (standard trap height) or 1.2 m at the Van Buren Co. site (Figure 3.1A). Overall, more than three times the number of flies was captured on traps placed at 4.6 m than on traps hung at lower positions.

2003 Vertical Trap Placement. As in 2002, captures of *R. cingulata* flies were significantly affected by trap height (F =27.0; df = 2,8; $P < 0.05$). Significantly more flies were caught on traps hung at 4.6 m than on traps placed at a 2.1 m or 1.2 m height (Figure. 3.1B). Traps in the highest canopy position caught more than three times as many flies as those hung in either of the two lower canopy positions.

2003 Fruit Lure Trials. Captures of *R. cingulata* were not significantly affected by the type of fruit treatments placed near to traps at the Allegan Co. site (F = 2.26; df = 4,12; $P = 0.1$) (Table 3.1). However, at the Van Buren Co. site, significantly higher numbers of *R. cingulata* were captured on traps next to cages containing ripe tart cherries compared with the other treatments (F = 5.25, df = 4,8, $P < 0.05$).

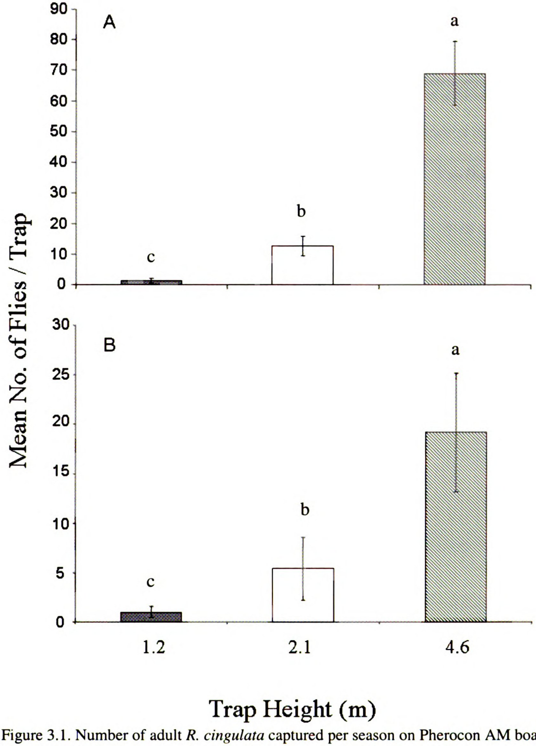

Figure 3.1. Number of adult *R. cingulata* captured per season on Pherocon AM boards placed at high (4.6 m), standard (2.1 m), and low (1.2 m) heights within cherry trees. The experiment was conducted in 2002 (A) and 2003 (B). Means with the same letter within years are not significantly different (Fisher's LSD Test, $P < 0.05$). Untransformed means are shown.

Table 3.1. Seasonal captures of adult *R. cingulata* on Pherocon AM boards hung adjacent to enclosures containing ripe or unripe sweet or sour cherries in Michigan cherry orchards.

Treatment (cherry type)	No. flies captured (mean ± SEM) at the indicated experimental site	
	Allegan Co.	Van Buren Co.
Ripe tart	9.5 ± 3.0 a	216.0 ± 32.5 a
Ripe sweet	4.0 ± 1.7 a	129.3 ± 31.1 b
Unripe tart	4.0 ± 1.1 a	97.0 ± 46.9 b
Unripe sweet	2.5 ± 0.9 a	78.0 ± 8.7 b
No fruit (control)	2.3 ± 0.8 a	94.7 ± 21.7 b

Untransformed means within each column followed by the same letter are not significantly different, ($P < 0.05$).

DISCUSSION

Captures of *R. cingulata* were substantially greater on traps placed at the highest position (4.6 m from the ground) compared with those hung at 2.1 m or 1.2 m. Flies may spend more time foraging in the uppermost portion of the host tree canopy, or traps placed higher in the tree may be more visible than those placed within the tree canopy. Similar results were obtained with *R. mendax* captures within blueberry bushes, where traps placed in the upper third of bushes captured the greatest number of flies (Liburd et al. 2001). In contrast, more *R. pomonella* are captured on Pherocon AM traps placed at 2.1 m within the canopy of apple trees than on traps at 1.2 or 3.0 m (Reissig 1975, Pelz et al. unpublished). We propose that monitoring traps for *R. cingulata* should be placed high in the tree canopy, to improve the sensitivity and accuracy of *R. cingulata* monitoring, allowing cherry growers to more effectively time insecticide applications. Additionally, the improved trap performance may provide growers with a higher level of confidence in monitoring, allowing decisions to treat a specific orchard to be delayed until a fly is captured.

At the Van Buren Co. site, the increased response of flies to Pherocon AM boards placed next to ripe tart cherries compared to unripe tart cherry, sweet cherry, and no fruit treatments suggests that the odors specific to ripe tart cherries are attractive to *R. cingulata*. Ripe tart cherries are present later in the season, a time when a greater proportion of the population of *R. cingulata* has reached sexual maturity. Female *Rhagoletis* flies spend more time on fruit compared to foliage searching for oviposition sites, while males spend more time on fruit waiting for females with which to copulate (Prokopy et al.1972, Prokopy and Bush 1973, AliNiazee, 1974, Boller and Prokopy

1976). In addition, the tough texture of unripe cherries may be a sub-optimal substrate for successful oviposition or larval development. Therefore, it is possible that *R. cingulata* have developed a preference for ripe tart cherry fruit due to the optimal combination of odor and developmental stage these fruit provide. Choice tests should be performed to determine the age, sex, and maturity of flies attracted to ripe tart cherries.

Although the results of the fruit lure trial at the Allegan Co. site did not indicate significant differences in fly responses to treatments, numerically higher numbers of flies were captured on traps placed next to ripe tart cherries. The lack of significant differences was possibly due to the low population of flies present at the site.

That fewer flies were caught on traps placed next to ripe sweet cherries than traps placed next to ripe tart cherries suggests a possible preference for the latter. Apple cultivar preferences are exhibited by *R. pomonella* (Dean and Chapman 1973, Rull and Prokopy 2001). Rull and Prokopy (2001 a) reported that traps in the 'Gala' cultivar amassed higher numbers of flies throughout the season and were more susceptible to oviposition than other cultivars. This cultivar represents a more attractive oviposition site for *R. pomonella*, possibly due to the odor and ripeness of fruit when females are searching for egg laying sites (Rull and Prokopy 2001a, b). A similar mechanism is possible for *R. cingulata.* Sweet cherry varieties ripen around two weeks after fly emergence. During this time, the majority of females are not sexually mature and therefore not searching for oviposition sites. Tart cherries continue to ripen after sweet cherry varieties have been harvested, leaving them available to flies during the peak oviposition period. Fruit firmness may also be a factor in selection of oviposition site, thus ripe fruit is likely a more appealing resource compared to unripe fruit. Future studies should be done to determine whether *R. cingulata* females preferentially oviposit into ripe tart cherries.

Our field results suggest that *R. cingulata* may be attracted to some volatile component(s) of tart cherry fruit. Further studies are needed to determine specific composition of fruit volatiles attractive to flies. A volatile lure for *R. cingulata* that incorporates attractive, host specific odors, similar to the five-component blend described for *R. pomonella* (Zhang et al. 1999), could enhance the current trapping capabilities of pest management programs. A recent study (Nojima et al. 2003a) has shown that a blend of host-specific volatiles from flowering dogwood fruit resulted in a greater flight response from dogwood-derived *R. pomonella* compared to blends originating from apple or hawthorn fruits. Similarly, *R. pomonella* originating in hawthorn fruit exhibited a greater response to a hawthorn volatile blend than to the apple volatile blend (Feder et al. 2003, Nojima et al. 2003b). Subjecting wild and commercial cherry fruits to these techniques will be necessary to determine the feasibility of developing a volatile lure for *R. cingulata*.

Ammonium acetate or ammonium carbonate lures are currently used in combination with traps for *R. cingulata*; however these lures are not selective for this species and capture many non-target insects (Stelinski and Liburd 2003). Traps lose effectiveness over time due to a decreased trapping surface and a reduction in visual attractiveness to flies, resulting in increased labor costs associated with trap replacement. Combining the knowledge of *R. cingulata* behavior obtained from these studies, we may be better able to approximate population levels within orchards through the use of species-specific trapping methods. These methods could eventually be incorporated into a system of mass-trapping, providing an alternative to conventional spraying as a system for fly control.

CHAPTER FOUR. INFLUENCE OF SYNTHETIC LURES AND TRAP TYPES ON CATCHES OF BLUEBERRY MAGGOT AND EASTERN CHERRY FRUIT FLY (DIPTERA: TEPHRITIDAE).

INTRODUCTION

Monitoring traps are used by blueberry and cherry growers to detect the presence and determine the seasonal activity pattern of the blueberry maggot, *Rhagoletis mendax* Curran, and the eastern cherry fruit fly, *R. cingulata* (Loew). The initial insecticide sprays targeting these pests are timed in response to the first fly captured on monitoring traps (Stanley 1987, Howitt 1993, Liburd et al. 2001). Optimizing trap design and lure type used for monitoring these pests may improve detection of fly emergence and activity, thereby optimizing and perhaps reducing insecticide applications (Kring 1970, Prokopy and Hauschild 1979, Neilson et al. 1981, Liburd et al. 1998, Liburd et al. 2000). Precise timing is especially critical for the more selective and less toxic insecticide chemistries being adopted as a result of the Food Quality Protection Act (1996) regulations. Unlike older insecticides, such as organophosphorous compounds, the efficacy of these new chemistries often requires their ingestion by the target pest; therefore, it is increasingly important that pesticides be applied immediately following fly emergence. Additionally, properly timed sprays should improve the likelihood that fly larvae will not be detected in harvested fruit, for which there is a zero tolerance.

Monitoring of *Rhagoletis* flies typically relies on the manipulation of behaviorally relevant visual and olfactory stimuli. These stimuli may mimic host foliage, host odor, or natural food sources (Prokopy and Coli 1978, Prokopy and Hauschild 1979, Neilson et al.

1981, Duan and Prokopy 1992, Liburd et al. 1998, 2001). Pherocon AM boards baited with release devices containing ammonium acetate are highly effective monitoring tools for both *R. mendax* and *R. cingulata* (Prokopy and Coli 1978, Liburd et al. 1998, 2001), as well as other *Rhagoletis* species (Prokopy and Hauschild 1979). Current commercially available lures for these species consist of plastic dispensers containing 2.0 g ammonium acetate, which are affixed to traps. Researchers using ammonium acetate for field studies have relied on plastic chargers, or polyethylene vials, affixed to traps for deployment of the volatile (Liburd et al. 1998, 2001). However, in Michigan the majority of cherry and blueberry growers typically deploy the 'prebaited' Pherocon AM boards, containing ammonium acetate and protein hydrolysate impregnated within the Tangle-Foot sticky coating covering the traps, rather than deploying the dual system of an unbaited Pherocon AM board with manually attached ammonia dispenser.

Recent studies have shown that apple volatiles used in combination with red sphere traps attract and capture high numbers of apple maggot flies (Prokopy et al. 1973, Stelinski and Liburd 2002). In contrast, attractive and effective host fruit volatiles for use with monitoring traps for *R. mendax* and *R. cingulata* have not been identified, although some blueberry volatiles have shown promise for *R. mendax* (Liburd 2004).

Green spheres and Rebell traps are more effective than Pherocon AM boards for *R. mendax* and *R. cingulata*, respectively, in that they capture the maximum number of flies (Liburd et al. 1998, 2001). Compared to Pherocon AM boards, however, these traps are more expensive. The higher cost can be somewhat offset by reusing them, but this requires an additional expenditure to replace the adhesive. Rebell traps and Pherocon AM boards are yellow, reflecting light across similar wavelengths as host foliage. These traps differ primarily in shape; therefore it is suggested that the three dimensional structure of the Rebell trap is more attractive to flies than the two-dimensional structure of Pherocon AM traps (Liburd et al. 2001). Alternatively, trap size may be responsible for the superior performance of Rebell traps. Rebell traps have a total surface area of 642 cm^2, whereas Pherocon AM boards have a total surface area of only 214 cm^2. The greater surface area of Rebell traps could increase the probability of fly captures compared to Pherocon boards,

The objectives for this study were to: 1) compare the attractiveness of host fruit concentrates on Pherocon AM boards with and without ammonium acetate for *R. mendax* and *R. cingulata*, 2) determine the optimal method of ammonium acetate deployment (plastic dispenser versus pre-baited Pherocon AM boards) for *R. mendax*, and 3) determine the relative effects of trap dimension and trap surface area on captures of *R. cingulata*.

MATERIALS AND METHODS

Field sites. Field experiments with fruit and ammonium acetate attractants were conducted during the 2002 field season in a non-commercial blueberry planting located in southwest Michigan (Allegan Co.) and non-commercial cherry orchards in northwest (Leelanau Co.) and southwestern (Van Buren Co.) Michigan. The blueberry site was a *ca.* 2 ha 'Jersey' planting used in past field studies (Stelinski and Liburd 2001) due to the presence of a resident *R. mendax* population. The southwestern cherry site was a recently abandoned *ca.* 2 ha planting of 'Montmorency' tart cherries. The northwestern cherry site was a *ca.* 5 ha planting of 'Montmorency' tart cherries that had not been commercially managed for at least five years.

Lures. Cherry and blueberry concentrates were obtained from Milne Fruit Products, Inc (Prosser, WA). For the cherry concentrate 5% tart cherry concentrate (Brix 68 g sugar/100 ml; lot # JEL-02-092-MI), 5% sweet cherry concentrate (Brix 68 g sugar/100 ml; lot # MFP-92-074-M3), and 85% water were blended. Because of the high sugar content, ethanol (5% v:v) was also added to preserve freshness under field conditions. Milne Fruit Products removed all non-soluble components, including sugars, from the blueberry concentrate; therefore it was not necessary to add ethanol to this purified essence. Five ml of each concentrate was dispensed into 2.5 cm x 5.0 cm plastic bags and heat-sealed. A 6.4 cm long cotton wick was inserted into the dispenser prior to sealing to draw the concentrate out for release. Fruit concentrate dispensers were then attached to the top of traps with 0.6 cm binder clips.

Ammonium acetate lures consisted of plastic yellow dispensers (Great Lakes IPM, Vestaburg, MI) that were filled with 2 g of solid ammonium acetate (Sigma

Aldrich, St. Louis, MO) immediately before deployment. A single dispenser was attached to the upper corner of the Pherocon AM trap with a yellow twist tie.

***R. mendax* lure comparisons**. Five treatments were compared in a randomized complete block design with six replicates. Treatments consisted of Pherocon AM yellow boards prebaited with ammonium acetate (2 g) and protein hydrolysate (0.5 g) (Great Lakes IPM), and Pherocon AM yellow boards baited with the following lures: 1) blueberry concentrate, 2) ammonium acetate, 3) blueberry concentrate and ammonium acetate, 4) nothing (control). Traps were hung at the optimum height within blueberry bushes ca. 15 cm below the uppermost canopy and in a vertical orientation on the south side of the blueberry bushes with foliage and fruit cleared in a ca. 0.5 m radius (Liburd et al. 2000). Traps were separated by at least 15 m, with 10 m between blocks. Each week *R. mendax* were removed and counted by sex, and treatments rotated within each block to account for positional bias. Treatments and traps were replaced biweekly for an 8 wk period.

***R. cingulata* lure comparisons.** Two trapping experiments were conducted during the 2002 field season. In the first experiment, conducted at the northwest site, the trapping systems evaluated were yellow Rebell traps (Great Lakes IPM, Vestaburg, MI) baited with: 1) cherry concentrate, 2) solid ammonium acetate, 3) cherry concentrate and ammonium acetate, and 4) nothing (control). In the second experiment, conducted at the southwest site, the same lures compared at the northwest site were evaluated in combination with yellow Pherocon AM boards rather than Rebell traps. The experimental design was a randomized complete block with five replicates for the Rebell systems and six replicates for the Pherocon AM systems. Traps were separated by at least 20 m, with 30 m between blocks.

Traps were hung vertically on the south side of trees with foliage cleared in a 0.5 m radius from the traps. No fruit was present on trees at either site during the 2002 field season due to spring frosts. Traps were separated by at least 20 m and maintained as described above in blueberries.

To determine the effects of trap size and dimension on captures of *R. cingulata* flies, three trap designs were compared in a randomized complete block experiments at the southwest site. There were six replicates of each of three treatments: 1) a Pherocon AM board hung vertically, 2) two Pherocon AM boards unfolded and attached back to back such that sticky sides faced out, and 3) a Rebell trap. The total surface areas coated with Tanglefoot for each trap design were *ca.* 214 cm^2, 428 cm^2, and 642 cm^2, respectively.

Statistical Analysis. For each experiment, data were square root-transformed $(x + 0.5)^{1/2}$ prior to analysis with ANOVA followed by means separation using Fisher's least significant difference (LSD) test (SAS Institute 1998). Treatment means were considered different at $P = 0.05$.

RESULTS

R. mendax. Analysis of the blueberry trapping experiment results indicated a significant effect due to treatment ($F = 10.69$; df = 4, 20; $P < 0.05$). Pherocon AM boards pre-baited with ammonium acetate and protein hydrolysate, unbaited Pherocon AM boards with ammonium acetate chargers, and unbaited Pherocon AM boards with ammonium acetate chargers and blueberry essence captured significantly more *R. mendax* flies compared to boards baited with other lures, but were not significantly different from each other (Table 4.1). Fly captures on traps baited with blueberry essence did not differ significantly from those on unbaited traps.

R. cingulata. Direct comparisons of four trapping systems based on the Pherocon AM board revealed that the treatment effect was significant ($F = 9.7$; df = 3, 15; $P < 0.05$). Significantly more *R. cingulata* flies were captured on traps baited with ammonium acetate, cherry concentrate or a combination of the two compared to an unbaited trap (Table 4.2). The mean number of flies captured on boards baited with either ammonium acetate or cherry concentrate was not significantly different. However, the use of ammonium acetate in combination with cherry concentrate increased fly captures; significantly more flies were captured on traps baited with this dual system than on those baited only with the cherry concentrate. Although there was not a significant difference between the mean number of flies captured on the Pherocon AM boards baited with the combination of lures or only with ammonium acetate, the former captured *ca.* 30% more flies than the latter. The number flies captured on boards baited with cherry concentrate was also significantly higher than those captured on unbaited (control) boards, which suggests that cherry concentrate may have an additive effect when used with ammonium acetate to attract flies.

The response of *R. cingulata* to ammonium acetate and cherry concentrate lures in combination with Rebell traps differed from that observed on Pherocon AM boards, although there was a significant treatment effect ($F = 9.79$; df = 3, 12; $P < 0.005$). Significantly fewer flies were captured on unbaited Rebell traps or traps baited with cherry concentrate in comparison to traps baited with ammonium acetate (Table 4.3). The addition of a cherry concentrate lure did not increase fly captures on the Rebell traps. Similarly, there was no significant difference between the mean number of flies captured on ammonium acetate and ammonium acetate plus cherry concentrate-baited traps. Approximately twice as many flies were captured on traps baited with either ammonium acetate treatment compared to other treatments.

In comparisons of trap types for capture of *R. cingulata*, the mean number of flies on Rebell traps (108.5 ± 9.9) was significantly greater than the mean number of flies captured on a single Pherocon AM board (23.5 ± 5.5) or two Pherocon AM boards (25.8 ± 6.8) joined together to form a trap of similar size and shape as the Rebell trap ($F = 91.5$; df = 2, 10; $P < 0.05$).

Table 4.1. Effect of different lures on seasonal captures of adult *R. mendax* on Pherocon AM traps.

Lure type	Mean ± SEM flies per trap
Ammonium acetate (dispenser) + blueberry concentrate	66.3 ± 12.2a
Ammonium acetate + protein hydrolysate (impregnated in adhesive)	63.0 ± 11.8a
Ammonium acetate	58.2 ± 15.0a
Blueberry concentrate	18.8 ± 4.9b
None	15.5 ± 2.9b

Means within each column followed by the same letter are not significantly different, ($P > 0.05$, Fisher's Protected LSD Test). Untransformed values are shown.

Table 4.2. Effect of different lures on weekly captures of adult *R. cingulata* captured on Pherocon AM traps.

Lure type	Mean ± SEM. flies per trap
Ammonium acetate + cherry concentrate	51.7 ± 9.4a
Ammonium acetate	37.2 ± 9.9ab
Cherry concentrate	28.7 ± 5.1b
None	15.8 ± 4.5c

Means within each column followed by the same letter are not significantly different, ($P > 0.05$, Fisher's Protected LSD Test). Untransformed values are shown.

Table 4.3. Effect of different lures on weekly captures of adult *R. cingulata* captured on Rebell traps.

Lure type	Mean ± SEM no. flies per trap
Ammonium acetate	43.6 ± 9.2a
Ammonium acetate + cherry concentrate	32.8 ± 9.9a
Cherry concentrate	16.0 ± 3.4b
None	17.4 ± 4.8b

Means within each column followed by the same letter are not significantly different, ($P > 0.05$, Fisher's Protected LSD Test). Untransformed values are shown.

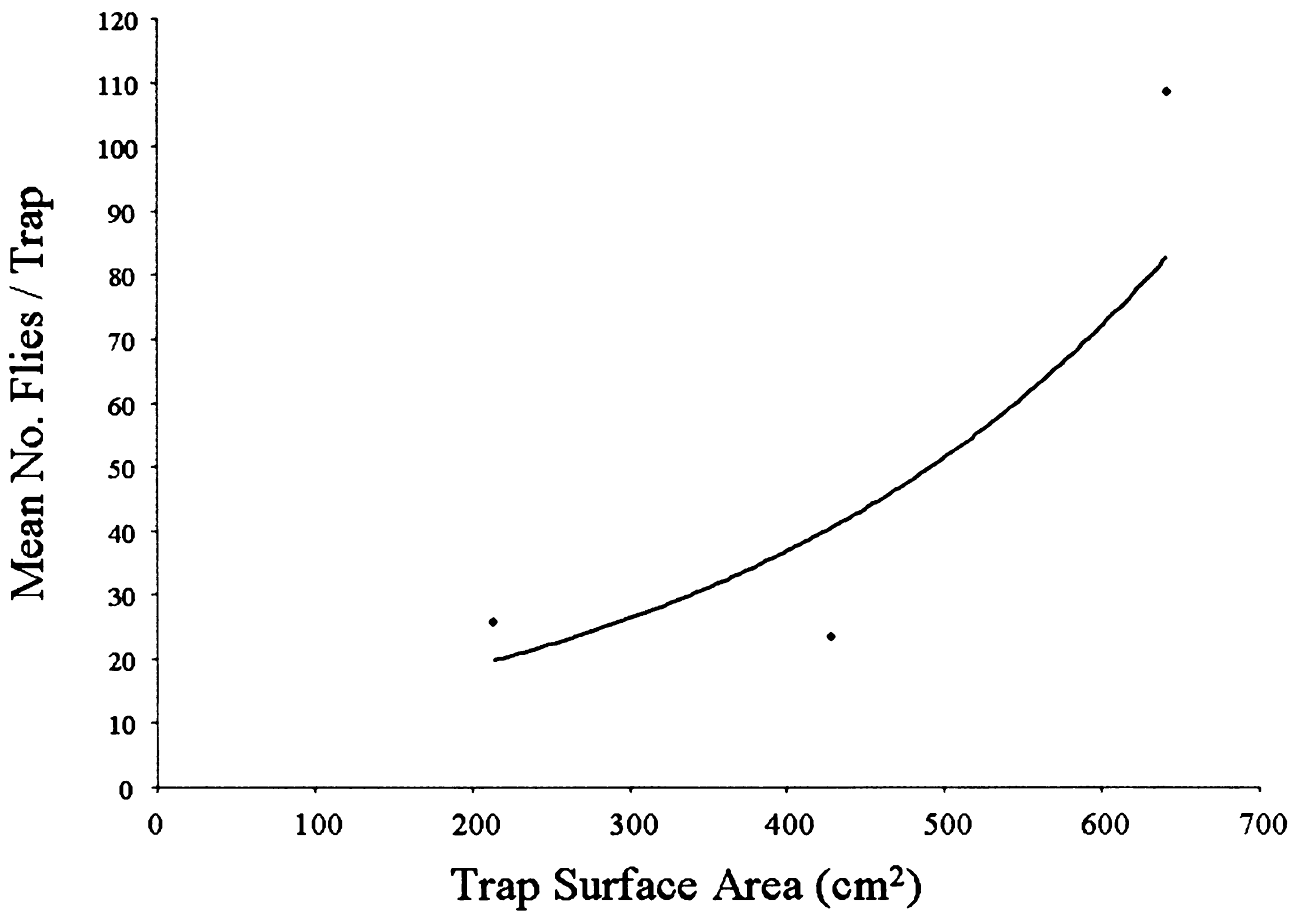

Figure 4.1. Seasonal captures of adult *R. cingulata* on traps with different surface areas (214, 428, and 642 cm^2).

DISCUSSION

Ammonium acetate significantly increased fly catches in all three experiments, in agreement with the findings of a previous study (Liburd et al. 2001). This indicates that an attractive olfactory lure is an important component of any trapping system for maximizing *Rhagoletis* capture. *Rhagoletis* flies, like most Tephritids, require a protein meal following emergence. Ammonium acetate represents an attractive food source because ammonium is an important component of the flies' natural protein source, avian fecal matter. However as the season progresses, flies spend a decreasing proportion of time feeding and more time searching for mates and, in the case of females, oviposition sites (Smith 1984). If volatiles emitted by cherries or blueberries are acting to attract *R. cingulata* and *R. mendax*, respectively, to their hosts, as shown for other *Rhagoletis* flies (Linn et al. 2003, Fein et al. 1982, Reissig 1982), then fruit volatile lures may be more important during the latter half of the growing season to accurately monitor population levels.

The addition of cherry concentrate to Pherocon AM boards or Rebell traps increases their attractiveness to *R. cingulata*. This result was slight and not significantly different from control (no lure) Pherocon AM boards. However, when used in combination with an ammonium acetate lure, an additive effect of the concentrate did increase fly captures. A similar effect was not seen in the captures of flies on ammonium acetate baited Rebell traps when cherry concentrate was added. Other studies with the Rebell trap have shown its high efficacy in capturing the black cherry fruit fly, *R. fausta* (Liburd et al. 2001), and the European cherry fruit fly, *R. cerasi* (Russ et al. 1973), compared to Pherocon AM boards. Liburd et al. (2001) speculated that the three-dimensional structure of the Rebell trap visually stimulates flies over a larger field as they move through the host canopy because the trap is visible from all angles of fly approach. Although a direct comparison between Rebell traps and Pherocon AM boards was not made, the results indicate that the addition of ammonium acetate and/or cherry concentrate to Pherocon AM boards makes the attractiveness of this trap equivalent to the Rebell trap. Similar results for ammonia-baited Pherocon AM boards were obtained by Liburd et al. (2001).

Cherry and blueberry concentrates did not consistently increase fly captures when used alone, suggesting that the volatile composition, concentration, or release rate of the concentrate lures are either insufficient host fruit mimic or that flies do not rely on cherry fruit odor for locating host fruits. However, cherry concentrate did numerically increase captures of *R. cingulata* on Pherocon AM boards. This suggests that there is potential for identifying attractive cherry fruit volatiles and that some level of an attractive volatile or volatiles are present in the lure used in this study. This finding is significant because growers and pest management consultants are unlikely to adopt Rebell traps due to the constraints of cost, labor-intensive deployment, and maintenance. Augmentation of Pherocon AM boards currently in use with attractive volatile lures or fruit concentrates would be a feasible economic means of enhancing traps catches. Further studies on the volatile components fruits, particularly host fruits remaining on the tree after harvest, are necessary to determine whether a blend such as described for apple maggot (Fein et al. 1982, Reissig 1982) could exist for *R. cingulata* before such a lure can be developed to improve trap attractiveness. To this end, laboratory and field choice assays should investigate fly response to fruit odors. If flies are attracted by an olfactory cue emitted by their host, they should exhibit higher levels of visitation to these fruit. Additionally, the specific individual volatiles and fly responses to these individual components need to be evaluated via GC-EAD to identify specific behaviorally-active chemical components, as described for apple and hawthorn fruits for *R. pomonella* (Fein et al. 1982, Linn at el. 2003).

R. mendax responded similarly to Pherocon AM boards baited with ammonium acetate dispensers or with ammonium acetate and protein hydrolysate incorporated into the Tangle-trap. Pre-baited traps are a therefore a better choice for monitoring this species because although the cost of the pre-baited traps is higher compared to unbaited traps and ammonia dispensers, the labor requirements are lower because lure deployment and maintenance are not needed initially.

My data indicate that the surface area of Rebell traps is not entirely responsible for the effectiveness of Rebell traps, as the relationship between increasing surface area is non-linear (Figure 4.1). It is likely that the three-dimensional structure of the Rebell trap is the source of its superior performance over Pherocon AM boards. Future studies should be done to evaluate the effect of trap shape by directly comparing the response of flies to Pherocon boards arranged in the Rebell formation and Rebell traps.

SUMMARY AND CONCLUSIONS

This research indicates that there is potential for the adoption of baited spinosad (GF-120) for control of *Rhagoletis* flies. The results obtained from 2002 and 2003 experiments demonstrate that spinosad bait is effective at controlling larval infestation of fruit, but less effective than unbaited spinosad (SpinTor) at controlling populations of adult *Rhagoletis* flies. Commercial implementation of spinosad bait will require improvements in the formulation of the product. Specifically, enhancements in attractiveness and rain fastness should improve its efficacy and practicality as an alternative to conventional insecticide sprays.

With the registration of selective insecticide chemistries for control of *Rhagoletis* pests of fruit crops, it is necessary to reevaluate the timing of insecticide applications. Specifically, targeting the 8-10 day pre-oviposition period was adequate for contact insecticides. However, as these insecticides are replaced by selective chemistries reliant on behavior of flies, particularly those related to feeding, spray guidelines will need to require initial sprays immediately after the first capture of a fly within the target crop when flies are spending the greatest amount of time feeding. Therefore, the deployment of highly attractive traps is critical to ensure the earliest possible capture of flies following emergence.

Position, design and attractiveness are key components of an effective trapping system. Optimal trapping of adult flies is particularly important for capturing flies early in their emergence, as a more effective trap will be more likely to detect fly presence at lower population levels. The results of the 2002 and 2003 cherry trapping studies showed the importance of placing traps high in the canopy for maximum capture of *R. cingulata*. Furthermore, it appears that the three-dimensional structure of Rebell traps, rather than surface area are responsible for their efficacy, although future studies must be done to evaluate this directly. The results of the 2002 experiment indicate that the attractiveness of Rebell traps is not enhanced by the addition of ammonium acetate or fruit concentrate lures. However, these traps are economically less feasible than Pherocon AM boards and are therefore less abundantly used among growers and pest management consultants. The utility of the more preferable Pherocon boards can be enhanced through the addition of ammonium acetate alone or with a fruit concentrate lure.

Enhancement of trap attractiveness to *R. mendax* was not observed for Pherocon boards baited with blueberry essence or blueberry essence and ammonium acetate. Fruit lures that emit an attractive bouquet of host volatiles may have potential for use to enhance trap captures, as described by work done on other *Rhagoletis* species (Linn et al. 2003, Fein et al. 1982, Reissig 1982). However, the results obtained in the cherry and blueberry studies do not strongly indicate this possibility. It is likely that the fruit lures used did not release the correct volatiles or proportion of volatiles necessary to elicit fly responses. Thorough analyses of volatile emissions from ripe and unripe fruits must be completed and the resulting volatiles individually tested for olfactory receptor and behavioral responses from flies before trapping studies can be used as an efficient assessment fruit-based attractive lures.

APPENDIX

Appendix 1

Record of Deposition of Voucher Specimens*

The specimens listed on the following sheet(s) have been deposited in the named museum(s) as samples of those species or other taxa, which were used in this research. Voucher recognition labels bearing the Voucher No. have been attached or included in fluid-preserved specimens.

Voucher No.: 2004-9

Title of thesis or dissertation (or other research projects):

Comparison of Monitoring Strategies and Evaluation of Spinosad Formulations for Management of Key *Rhagoletis* Species

Museum(s) where deposited and abbreviations for table on following sheets:

Entomology Museum, Michigan State University (MSU)

Other Museums:

Investigator's Name(s) (typed)

Kirsten S. Pelz

Date December 06, 2004

*Reference: Yoshimoto, C. M. 1978. Voucher Specimens for Entomology in North America.
Bull. Entomol. Soc. Amer. 24: 141-42.

Deposit as follows:

Original: Include as Appendix 1 in ribbon copy of thesis or dissertation.

Copies: Include as Appendix 1 in copies of thesis or dissertation.
Museum(s) files.
Research project files.

This form is available from and the Voucher No. is assigned by the Curator, Michigan State University Entomology Museum.

Appendix 1.1

Voucher Specimen Data

Page_1_of_1_Pages

Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
Rhagoletis pomonella (Walsh)	Michigan Allegan Co. Fennville 20 July 2003 Host: on apple tree					10	10		MSU
Rhagoletis mendax Curran	Michigan Allegan Co. Douglas 20 July 2003 Host: on blueberry bush					10	10		MSU
Rhagoletis cingulata (Loew)	Michigan Van Buren Co. Coloma 25 June 2002 Host: on cherry tree					10	10		MSU

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

Kirsten S. Pelz

Date December 6, 2004

Voucher No. 2004-9

Received the above listed specimens for deposit in the Michigan State University Entomology Museum.

6 Dec 2004

Curator Date

LITERATURE CITED

LITERATURE CITED

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