Novel Barriers to Prevent Dogwood Borer (Lepidoptera: Sesiidae) and Rodent Damage in Apple Plantings

ARTHUR M. AGNELLO,[1,2] DAVID P. KAIN,[1] JEFFREY GARDNER,[3] PAUL D. CURTIS,[4]
MICHAEL L. ASHDOWN,[4] AND MICHAEL P. HOFFMANN[3]

J. Econ. Entomol. 107(3): 1179–1186 (2014); DOI: http://dx.doi.org/10.1603/EC14040

ABSTRACT We evaluated a combination of noninsecticidal alternatives to control trunk-damaging dogwood borer, *Synanthedon scitula* (Harris), consisting of novel barrier technologies, used alone or in combination with mating disruption. Barrier formulations evaluated included fibrous barriers of nonwoven ethylene vinyl acetate (EVA) and nonfibrous barriers of rubberized paint (elastomer) used in building coatings. To examine efficacy of dogwood borer control in orchards, all barrier trials were replicated in field tests, both in combination with mating disruption and without it. Trunk inspections to determine whether mating disruption and barriers effectively reduced actual tree infestation showed pheromone disruption significantly reduced infestation compared with the untreated check, but was not as effective as trunk handgun sprays of chlorpyrifos. EVA trunk barriers were effective in preventing borer infestation compared with untreated trees. The elastomer did not differ from the check or the EVA treatment. There was no interaction between disruption and barrier treatments. Barrier field life and durability was assessed over 2 yr by comparing degradation over time due to weathering and other environmental effects including animal damage. The EVA persisted and remained more intact than the elastomer, but was in need of reapplication after 2 yr. Barriers were also screened for efficacy against voles in small-plot trials in nonorchard locations with known high vole pressure; they were tested either alone, combined with a repellent (thiram), or, in the case of the elastomer only, combined with an abrasive (sand). Only the EVA significantly lowered vole chewing damage relative to the untreated checks.

KEY WORDS *Synanthedon scitula*, mating disruption, trunk barrier, elastomer, ethylene vinyl acetate

An increase in the acreage of apple trees grown on dwarfing rootstocks, which have a tendency to form aggregations of root initials or burrknots, has led to an increase in problems from dogwood borer, *Synanthedon scitula* (Harris), which infests rootstocks through these burrknots (Rom and Brown 1979). This insect is an important wood-boring apple pest in eastern North America (Riedl et al. 1985, Warner and Hay 1985, Kain and Straub 2001, Bergh and Leskey 2003, Kain et al. 2004, Carter 2009, Agnello et al. 2013). In a statewide survey of dwarf apple orchards in New York, ≈60% of the trees had suffered damage by borers and ≈32% of the trees were actively infested (Kain et al. 2004). Dogwood borer infestations in apples have been associated with decreased vigor and even tree death (Riedl et al. 1985) and the lifespan of tart cherry trees is estimated to be reduced by one-third by dogwood borer infestation (Kain and Agnello 1999). Borer injury may also provide infection pathways for fungal or bacterial pathogens, such as rootstock fire blight (Orton and Adams 1915). Dogwood borer is also the major insect pest of flowering dogwood, a valuable ornamental species, causing losses to homeowners, municipalities, and nursery operators (Hartman et al. 1997).

The dogwood borer overwinters as a larva concealed within a burrknot. In spring, it feeds on burrknot tissue until it pupates in May. In early to mid-June, the adults (clear-wing moths) emerge, mate, and lay eggs. In New York, there is typically one brood of larvae in the summer that feed through the fall until they go into hibernation. Most insecticides such as acetamiprid (Agnello et al. 2013) control only the summer larvae and require multiple applications. In contrast, chlorpyrifos controls both overwintering and summer larvae with one application (Kain and Straub 2001, Kain et al. 2002, Wise and Gut 2002). However, chlorpyrifos is under increasing scrutiny by regulatory agencies and may not be available in the future (Kain et al. 2004). In practice, growers are reluctant to apply trunk sprays to control borers because, to be effective, sprays must be applied with a handgun applicator,

---

[1] Department of Entomology, Cornell University, New York State Agricultural Experiment Station, 630 West North Street, Geneva, NY 14456.

[2] Corresponding author, e-mail: ama4@cornell.edu.

[3] Department of Entomology, Cornell University, Comstock Hall, Ithaca, NY 14853.

[4] Department of Natural Resources, Cornell University, Fernow Hall, Ithaca, NY 14853.

Fig. 1. Apple tree trunks covered by nonwoven EVA fiber barriers, North Huron, NY.

which entails considerable labor and potential for worker exposure.

A potential alternative to insecticides is the use of trunk barriers. Hoffmann et al. (2001) demonstrated that in situ generated fibrous barriers significantly reduced maggot damage to broccoli and onion plants and provided control comparable with insecticides. Curtis et al. (2002) showed that in situ generated fibers of ethylene vinyl acetate (EVA), a common medical and food grade plastic, applied to sweet corn, were effective in preventing bird damage to corn ears. More recently, work by Kain et al. (2010) compared various trunk treatments and showed that sprayable fibrous barriers were highly effective in preventing dogwood borer infestation in apples. In that study, filaments of EVA were directly sprayed onto the rootstock portion of apple trunks to provide a breathable net-like barrier (Fig. 1). Dogwood borer infestation was reduced from 19% in untreated controls to 0% in treated apples. Furthermore, these barriers lasted sufficiently long to indicate a use to prevent rodent damage in orchards.

Another alternative to using insecticides to control dogwood borer is mating disruption, which uses inundative release of the insect's sex pheromone to make it difficult for males to find females, thus hampering mating. Previously, commercially available dogwood borer sex pheromone dispensers were not very effective, owing to the presence of a geometric isomer produced as a contaminant in the manufacturing process that was antagonistic to the male moths (Leskey et al. 2009). Recently, a dogwood borer sex pheromone blend without the contaminant, which is much more effective than those previously available, was developed by Zhang et al. (2005), and is now commercially available. However, the effectiveness of mating disruption can be compromised in situations where planting size or shape and high population pressure allows the immigration of mated females (Cardé and Minks 1995).

Voles (*Microtus* spp.) also cause significant damage to agricultural and ornamental crops (Conover et al. 1995), including orchards (Byers 1984) and nurseries (Bromley et al. 1992). Voles damage trees by gnawing the bark and vascular tissue of trees (Pearson and Forshey 1978). Byers (1974) found that in U.S. orchards alone, vole damage can result in annual economic losses of US$40 million.

In general, rodent control is usually accomplished by habitat modification, repellents or toxicants, exclusion with mouse guards, and trapping. Habitat modification typically consists of using herbicides or tillage to reduce the vegetative cover on the orchard floor (Merwin et al. 1999); chemical control typically relies on zinc phosphide or anticoagulant rodenticides, but these are expensive and can be hazardous to nontarget species (Byers 1984). A few repellents, including those based on capsaicin and the fungicide thiram, are registered for use on voles (Agnello et al. 2013), but neither ingredient provides satisfactory long-term protection.

Recent work by Curtis et al. (2002) indicates that using abrasive barriers to deter rodent feeding is feasible. For example, Nolte et al. (2003) demonstrated that beavers were prevented from feeding on saplings merely by coating them with a latex–sand mixture; this is a simple approach that could be easily mechanized for commercial applications in orchards. Deterrent plastic barriers affixed to the lower portion of apple tree trunks are commonly used to prevent vole damage during the winter in northern apple growing areas. However, the barriers most commonly used (plastic spiral "mouse guards") have been implicated in an increase in trunk borer infestation because they create an environment of relatively high humidity and low light around the trunk that is conducive to elongation of the root initials that make up burrknots, providing a food substrate attractive to trunk borers (Leskey and Bergh 2005). Mouse guards may also protect borer larvae from insecticide sprays and natural enemies. Because of borer problems, many growers have stopped using mouse guards to prevent rodent feeding and are relying instead on chemical control methods.

The research described herein was conducted to evaluate a combination of noninsecticidal tactics for preventing trunk damage by dogwood borer larvae and voles. Novel deterrent barrier materials, used either alone or in combination with pheromone mating disruption, were evaluated for their effect on dogwood borer infestation; we additionally evaluated their utility against vole damage.

Materials and Methods

Dogwood Borer. The candidate deterrent formulations evaluated were fibrous barriers made of nonwoven EVA, and nonfibrous barriers made of an elastomeric paint used in commercial building coatings. To examine the efficacy of dogwood borer control in commercial orchards, all the barrier trials were replicated in large-scale field tests, both with and without dogwood borer mating disruption. Three commercial high-density apple orchards on dwarfing rootstock located in North Huron, NY, were selected based on historical infestation with dogwood borer at varying levels: Huron, mixed varieties on M.9 rootstock,

Fig. 2. Application of EVA barriers using a hot-melt spray gun, North Huron, NY.

planted in 2004, 4.2 cm trunk diameter at 30 cm height; Lummisville, mixed varieties on M.9 rootstock, planted in 2007, 3.7 cm trunk diameter at 30 cm height; Hilltop, mixed varieties primarily on B.9 rootstock, except for one variety (Braeburn) on M.26 rootstock, planted in 2002, 5.7 cm trunk diameter at 30 cm height.

The experiment was a split-plot design with orchard as block, two pheromone levels as the main plots, and three barrier levels as subplots. Each orchard site consisted of one 4-ha section designated for pheromone mating disruption, and an adjacent section approximately the same size where pheromones were not applied. Each barrier treatment (EVA, elastomer, and untreated check) was randomly replicated three times in each subplot and each replicate consisted of 40 trees (2 adjacent rows by 20 adjacent trees per row) at Huron and Lummisville, and 30 trees (3 adjacent rows by 10 adjacent trees by row) at Hilltop.

Barriers were applied to trunks in late spring before the start of the dogwood borer flight, to a height of 60 cm from the soil surface, to provide protection from feeding damage by smaller rodents as well as rabbits able to access the trees from on top of snow cover during the winter. The EVA (Elvax 205W, DuPont, Wilmington, DE) fibers were generated using a hot melt adhesive unit (Dynamini, ITW Dynatec, Hendersonville, TN) fitted with a hand-held spray head (DG II, ITW Dynatec), and applied on 7–8 June 2011 (Fig. 2). The elastomeric paint (Max-Stretch, Ames Research Laboratories, Jefferson, OR), was applied on 24–25 May 2011 with a commercial paint sprayer (Titan XT 440, Titan Tool, Plymouth, MN). For mating disruption, before the beginning of the yearly dogwood borer flight, twist-tie dispensers containing dogwood borer sex pheromone (Isomate DWB, Pacific Biocontrol, Vancouver, WA) were deployed at a rate of 247 dispensers per hectare between 25 and 27 May 2010, 11 and 26 May 2011, and 27 April to 18 May 2012. Mating disruption by itself was evaluated in these plots beginning in 2010, 1 yr before the barriers were applied, and so was in place for three successive seasons by the end of this study.

To provide an indication of whether mating disruption could be taking place, wing-type pheromone traps (Pherocon 1C, Trécé, Adair, OK) were deployed on 25–27 May 2010, 1 June 2011, and 22 May 2012. These were baited with rubber septa containing the new dogwood borer pheromone blend developed by Zhang et al. (2005), and deployed in each pair of disrupted–nondisrupted orchards before the beginning of the dogwood borer adult flight each season. Three traps were hung in each plot with one at the end most distant from the other of the pair, one in approximately the center of each plot, and one at least 33 m from the edge of the adjacent plot. Traps were inspected at least once per week through late September or early October each year and numbers of captured moths recorded. In the nonpheromone main plots at each orchard site, a grower-standard treatment of chlorpyrifos was applied and replicated to serve as a benchmark control. For this treatment, five plots of 10 trees each in the nonpheromone sections received a runoff trunk spray of chlorpyrifos (Lorsban 4 EC, Dow AgroSciences, Indianapolis, IN) at 1.4 liters Lorsban 1.4 EC: 379 liters of water, applied to the graft union and rootstock portion of the tree trunks on 10 June 2010, 15 June 2011, and 18 July 2012, using a Nifty Pul-Tank sprayer (Rears Manufacturing Co., Eugene, OR).

Trunk inspections to determine whether mating disruption and the barrier formulations were effective in reducing actual tree infestation were conducted between 21 and 24 September 2010 (no barriers in place, mating disruption only), 19 and 23 September 2011, and 24 and 26 September 2012. On each of the dates in 2011 and 2012, barriers were removed from 10 trees randomly selected from within each replicate, and their burrknots were examined for freshly produced frass, an indication of active infestation. All burrknots in the combined 10-tree subsample were counted and examined for the presence of fresh frass. The percentage of burrknots infested was determined; treated trees were also checked for any apparent phytotoxic effects of the barriers. Data recorded for each treatment were the number of burrknots present and the number of burrknots infested at the time of examination. Because the split-plot design sacrifices precision in estimating main plot effects (mating disruption), additional trees within the main plots were evaluated for dogwood borer infestation. In this case, the experimental design comparing the effect of pheromone alone became a randomized complete block design, and sampling of an additional 100 trees with no barrier treatments was conducted in an X-shaped pattern; the additional sampled trees were categorized as edge, intermediate, and interior areas of the plots, so that any locational effects of the pheromone could be identified.

Barrier field life and durability was assessed on a regular basis during the 2-yr study by taking an extensive series of photos of a set of designated trees (the same trees were used throughout) roughly every 4 mo (8 July and 8 November 2011; 5 April, 31 July, 4 December 2012, and 1 May 2013) and visually comparing the extent of their degradation over time due to weathering and other environmental effects, including animal damage. Barriers on each of 10 trees per subplot were rated as 100% intact or exposing <10%, 11–25%, 26–50%, >50%, or 100% of the trunk surface.

Voles. The two barrier materials were also screened for efficacy against meadow voles (*Microtus pennsylvanicus* (Ord)) in small-plot trials in nonorchard locations with known high vole pressure; they were tested either alone, combined with a repellent, thiram (Defiant 75W, Taminco, Atlanta, GA), and, in the case of the elastomer only, combined with sand as an abrasive (Quikrete Commercial Grade Sand–Medium, Quikrete, Atlanta, GA). Fresh pieces of apple tree branches cut to 31 cm length were used to simulate young apple tree stems. Approximately 29 cm of each stem was treated with one of five possible barrier materials, or left untreated as a control: EVA, elastomer alone, elastomer mixed with sand, elastomer + thiram (100 ml: 16 g of Defiant), and thiram alone (16 g of Defiant + 17 ml of sticker [ClearSpray, Cleary Chemical, Dayton, NJ] + 100 ml of water). The EVA was applied using the hot-melt unit as for the dogwood borer treatments, and the elastomer and thiram-only (plus sticker) treatments were brushed onto the apple stems to get complete coverage.

Six stems, one of each treatment, were randomly attached to a 10.2 by 10.2 by 121.9 cm piece of pressure-treated lumber. On 18 November 2011, six replicate pieces of lumber with the barrier-treated apple stems were placed in a row at each of the three nonorchard sites near Ithaca, NY, having preferred habitats for voles and showing past evidence of vole activity: in an unmaintained field, on the fallow edge of agricultural fields adjacent to a clump of black walnut trees, and in an area of unmowed lawn near a field research laboratory. The apple wood was inspected on 1 and 14 December 2011, 9 January, 9 and 28 February, and 23 March 2012; presence or absence of vole damage was noted, and if present, the number of centimeter of stems exhibiting damage measured.

Statistical Analysis. Because AOV assumptions were violated and the data were not amenable to transformation, analyses were conducted using a generalized linear mixed model logistic regression (PROC GLIMMIX; SAS Institute Inc. 2008, Cary, NC). Before analysis, burrknot infestation counts were converted to binomial data comprising the number of burrknots infested among total number of burrknots within the sampled trees. The data from each year were analyzed separately using mating disruption and trunk barrier as fixed effects, and orchard site and the interaction of mating disruption with orchard site as random effects.

Subsequently, to test solely for main plot effects, count data for the number of infested burrknots were analyzed using a generalized linear mixed model logistic regression with mating disruption and the interaction of mating with location within the orchards as fixed effects; orchard was the random effect. In addition, a repeated measures logistic regression was conducted to test for main plot effects over time, with the three individual orchard sites as the subjects of repeated sampling because all data were collected from the same three orchard sites for the years 2010–2012 (PROC GENMOD; SAS Institute Inc. 2008).

Table 1. Pheromone trap captures of dogwood borer male moths in plots treated with Isomate DWB pheromone dispensers, North Huron, NY, 2010–2012

Site of treatment	Mean yearly total moths per trap		
	2010	2011	2012
Huron			
Pheromone	0.0	0.0	1.3
Check	835.3	305.7	261.7
Lummisville			
Pheromone	0.0	0.0	0.0
Check	344.0	169.7	68.0
Hilltop			
Pheromone	0.0	0.0	0.0
Check	290.7	77.0	204.0

In addition, to compare dogwood borer infestation among trees with chlorpyrifos-treated trunks, mating disruption, and no mating disruption, mixed model logistic regression was again used (PROC GLIMMIX; SAS Institute Inc. 2008). The analyses were conducted within a year with the three treatments as fixed effects and the orchard site as the random effect. Burrknot infestation counts were converted to binomial data comprising the number of burrknots infested among total burrknots. Count data were summed for each treatment plot within orchard and year.

Barrier longevity ratings were subjected to a repeated measures analysis of variance (PROC GENMOD; SAS Institute Inc. 2008), with the experimental units being 10-tree means for each rep and block on each date ($n = 108$).

For the analysis of vole damage, the numbers of apple twigs exhibiting damage were subjected to logistic regression (PROC LOGISTIC; SAS Institute Inc. 2008) to determine the odds of damage occurring in the different barrier treatments.

Results

In 2010, moth captures began on 28 May, with sustained flight occurring in all sites by 10 June; peak trap numbers occurred in July. Trap shutdown, a measure of communication disruption, was 100% in all pheromone-treated plots, while the average total capture for the season in the nonpheromone plots ranged from 290.7 to 835.3 moths per trap (Table 1). During the 2011 season, a few moths were captured in traps in the nonpheromone plots beginning 3 June, with sustained catch beginning 10 June. The peak trap catch occurred roughly from mid- to late July. Trap shutdown was again 100% in all pheromone-treated plots, and the average total capture for the season in the nonpheromone plots ranged from 77.0 to 305.7 moths per trap (Table 1). In 2012, the first moth capture in all plots was on 30 May. There appeared to be two flights this season, owing to unusually high early spring temperatures. The first peak trap catch occurred in mid- to late June, and the second was in mid- to late August. Traps were monitored through 4 October, but trap

Table 2. Trunk burrknot infestation rates by dogwood borer in trees with EVA or elastomeric paint barriers, North Huron, NY, 2011–2012

Treatment	2011		2012	
	Proportion infested	Odds ratio estimate[a,b]	Proportion infested	Odds ratio estimate[a,b]
EVA	0.020	0.302a	0.053	0.653a
Elastomer	0.035	0.573ab	0.063	0.859a
UTC	0.061	1.00b	0.075	1.00a

[a] Means followed by the same letter are not significantly different ($P < 0.05$).

[b] Odds of treatments being infested in relation to the untreated control.

Table 3. Trunk burrknot infestation rates by dogwood borer in trees under mating disruption or receiving chlorpyrifos trunk sprays, North Huron, NY, 2010–2012

Treatment	Proportion infested	Odds ratio estimate[a,b]
2010		
Disrupted	0.047	0.51b
Nondisrupted	0.089	1.00c
Chlorpyrifos	0.006	0.06a
2011		
Disrupted	0.036	0.45b
Nondisrupted	0.072	1.00c
Chlorpyrifos	0.003	0.04a
2012		
Disrupted	0.088	0.57b
Nondisrupted	0.145	1.00c
Chlorpyrifos	0.024	0.15a

[a] Means followed by the same letter are not significantly different ($P < 0.05$).

[b] Odds of treatments being infested in relation to the nondisrupted treatment.

capture ended, except for a few outliers, on 19 September. Trap shutdown was essentially 100% in all pheromone plots, as one site (Huron) caught a mean seasonal total of 1.3 moths per trap compared with 68.0–261.7 (at Huron) moths per trap in the nonpheromone plots (Table 1).

In 2011, the trunk barrier treatments had a significant effect on the likelihood of borer infestation ($F_{2,48} = 6.60$; $P < 0.0029$). The odds of infestation occurring in the EVA treatment were ≈0.37 of those in the untreated check, while in the elastomer treatment the odds were ≈0.57 of those in the check (Table 2). The odds of infestation occurring in the main plots with mating disruption present were ≈0.58 of those in plots not receiving mating disruption pheromone, but this was not significant at $\alpha = 0.05$ ($F_{1,48} = 3.75$; $P < 0.0586$), and there was no interaction of the barrier treatments with mating disruption ($F_{2,48} = 0.49$; $P < 0.6168$). In 2012, there were no significant differences either because of mating disruption ($F_{1,48} = 2.60$; $P > F = 0.2596$) or barrier treatments ($F_{2,48} = 1.34$; $P < 0.2725$; Table 2), nor was there an interaction between mating disruption and barrier treatments ($F_{2,48} = 0.11$; $P < 0.8941$).

To lend greater precision to main plot effects, a separate repeated measures logistic regression of main plot effects alone was conducted using additional trunk infestation data (as described in Materials and Methods). Differences between least squares means for this separate analysis indicated that mating disruption applied over the 3 yr reduced the odds of burrknot infestation by ≈50% (odds ratio = 0.5082; $z = -11.28$; $P < 0.0001$).

In comparing the effectiveness of mating disruption with chlorpyrifos trunk sprays, inspections in 2010 showed the odds of infestation in the chlorpyrifos spray plots were 12% of the odds in the mating disruption plots ($t = -2.85$; $P >$ t $= 0.0062$, and the odds of infestation occurring in the nondisrupted plots were 1.96 times higher than that in the mating disruption plots ($t = 3.60$; $P >$ t $= 0.0007$); all differences were significant (Table 3). In 2011, the odds of infestation in the chlorpyrifos plots were 9% of those in the mating disruption plots ($t = -2.44$; $P >$ t $= 0.0182$), and the odds of infestation occurring in nondisrupted plots were 2.22 times those of the plots under mating disruption ($t = 3.75$, $P >$ t $= 0.0005$); all differences were significant (Table 3). However, for both of these years, there was no significant effect of location within the orchard on infestation level, and no interaction of disruption with location in the orchard. In 2012, odds of infestation in trees sprayed with chlorpyrifos were reduced ≈75% compared with those in trees under mating disruption ($t = -3.98$, $P < 0.0002$), and odds of infestation in nondisrupted plots were ≈1.8 times those in disrupted plots ($t = 3.86$, $P < 0.0003$). In this year of the study, location within the orchard significantly affected borer infestation rate ($F_{2,12} = 5.54$, $P < 0.0198$), with the odds of infestation in the edge areas of the orchard being ≈1.5 times greater than in the interior and intermediate areas; there was no interaction between mating disruption and within-orchard location.

The assessments of different barrier treatments for the prevention of vole damage to apple stems showed that, although all the candidate treatments tested reduced chewing damage relative to the untreated control, there was a significant difference only in the EVA-treated stems. The logistic regression showed that the odds of stems in the EVA treatment having chewing damage were ≈8% of those in the control group ($\chi^2 = 4.61$, $P > \chi^2 = 0.0319$; Fig. 3).

Barrier longevity ratings showed greater barrier durability for EVA fibers than for the elastomeric trunk coatings over the 2-yr period of this study ($z = 4.48$; $P < 0.0001$), although the degree and nature of the weathering damage varied somewhat by site, with both treatments showing substantial amounts of degradation by the end of the second year (Figs. 2a and b). By the final inspection in May 2013, 23 mo after application, the proportion of trees having EVA barriers still completely intact ranged from ≈47% at the Huron site to 3.3% at the Lummisville site. In contrast, none of the elastomer barriers were in this category, but the proportion of trees in the next highest group (trunks 1–10% exposed) followed the same site trend, ranging from 33% at Huron to 7% at Lummisville. Furthermore, only the Lummisville site contained trees with the EVA barriers completely stripped away

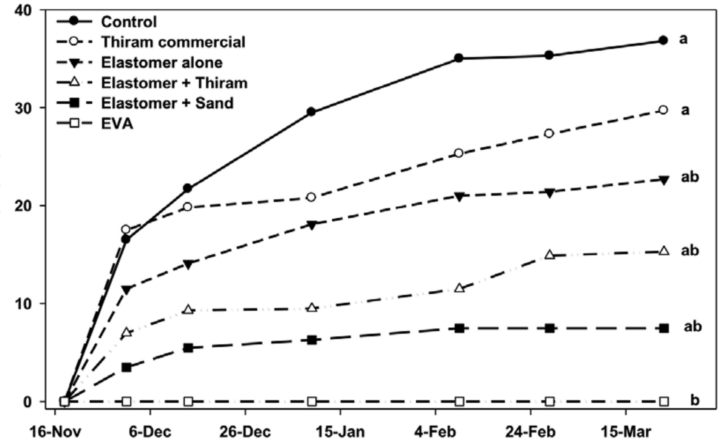

Fig. 3. Vole chewing damage on apple stems treated with different candidate barrier materials during the winter of 2011–2012, near Ithaca, NY.

to expose 100% of the bark, presumably caused by animal feeding or foraging activity; this phenomenon increased from November 2011 (3.3%) to May 2013 (20%). In many cases, remnants of the removed EVA barrier could be found lying in the immediate area of the tree.

Discussion

Apple growers are increasingly concerned with the impacts of borers on dwarf apple trees; these trees, which are grown on size-controlling (dwarfing) rootstocks, have a tendency to develop burrknots, aerial aggregations of root initials, on the rootstock portion of the trunk. Dogwood borer infests apple tree trunks by ovipositing on these burrknots, and their feeding damage often results in loss of tree vigor and shortened tree life. Barriers to dogwood borer oviposition may represent an effective, efficient, physical control method. Riedl et al. (1985) and Kain et al. (2004) have assessed latex paint, both full strength and diluted with equal parts water, and applied by either spraying or brushing on. Their findings showed some effectiveness against new infestations during the season of application, but unsatisfactory persistence in subsequent years, often because the paint did not continue to adhere well to the burrknot tissue, and began to deteriorate quickly in winter. Kain et al. (2010) compared several barrier materials, including nonwoven EVA fibers, which provided good protection during the first year, but was not significantly different from the untreated check the second season.

In the current study, an elastomeric paint product and EVA were evaluated in combination with pheromone mating disruption to determine if this approach extended protection. Our results showed that the EVA barrier treatment had significantly lower infestations of borers than did the untreated (no barriers) check; the proportion of trunks infested in the elastomer treatments was higher than in the EVA plots, but the treatments were not significantly different from either the EVA treatment or the check (Table 2). Furthermore, infestation levels were not affected by the interaction between barrier treatments and the mating disruption. In regard to the mating disruption treatment alone, the pheromone effectively shut down trap captures of dogwood borer male moths and resulted in a lower likelihood of infestation; however, the infestation levels were still statistically greater in trees under mating disruption than in trees receiving trunk sprays of chlorpyrifos, even after three successive years of pheromone mating disruption (Table 3). Of the barrier formulations tested against voles, only the EVA treatment showed a significant reduction in damage relative to the controls (Fig. 3).

EVA barrier durability was significantly better than the elastomer barriers nearly 2 yr after being applied (Fig. 4); early observations of barrier weathering condition indicated that the elastomer might not have been holding up as well as EVA, as some cracks and openings were starting to be seen after only 1 yr of field life.

An overall assessment of the value of implementing any of these management tactics in a commercial orchard would need to take into account not only their potential efficacy in preventing trunk damage, but also their cost in time and materials. Chlorpyrifos trunk sprays remain the most effective treatment against borers, but the time and effort to apply them, along with potential regulatory restrictions, detract from their utility, and they will not prevent rodent damage. Pheromone disruption significantly reduced dogwood borer infestation compared with untreated orchards, but was less effective than chlorpyrifos trunk sprays, and did not show a cumulative increase in efficacy over a 3-yr period. The fibrous EVA trunk barriers showed the most promise for preventing trunk damage caused by both dogwood borers and voles, but its period of effectiveness was shorter than the multiyear time scale that had been anticipated. Furthermore, the need for specialized application equipment would diminish the practicality of this option. Also, we did not

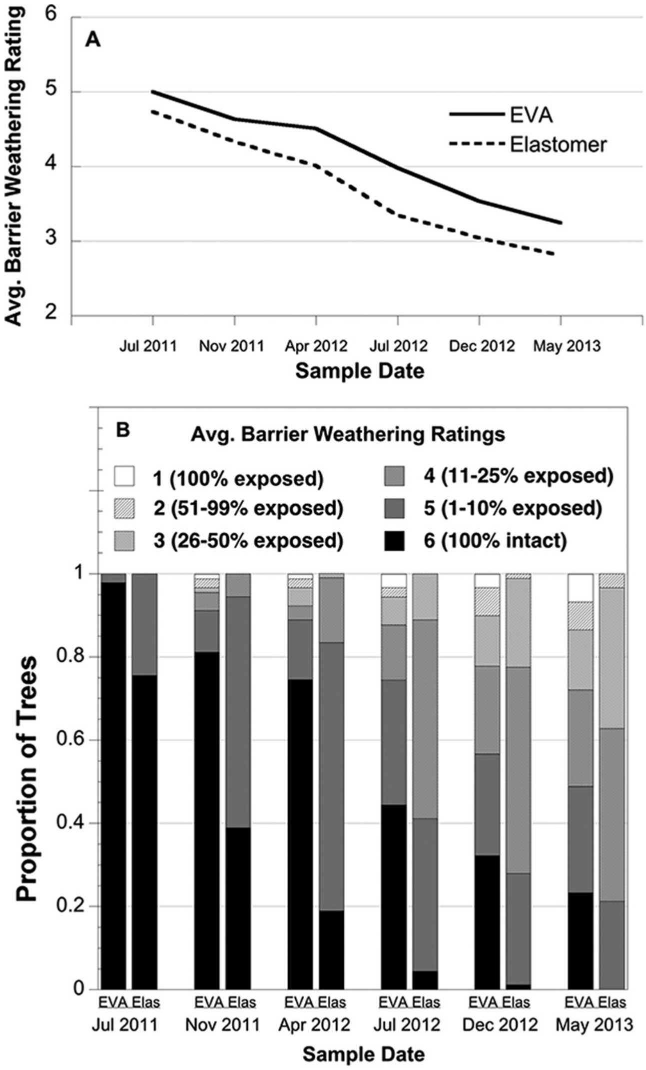

Fig. 4. Degradation progress of two barrier treatments showing (A) overall average ratings and (B) proportion of trees in the different weathering categories across all sites from July 2011 to May 2013. EVA = ethylene vinyl acetate fibers; Elas = elastomeric paint.

see improved infestation prevention when barriers and pheromone disruption were combined. We do believe this technology is compatible with conventional farm practices and could be implemented, but some modifications to the technique would need to be made (e.g., a thicker sprayed coating) to extend the protective life of the barrier, so that reapplication would not be necessary annually.

We believe that continued research on this methodology could eventually offer new tools to replace hand applications of a hazardous insecticide, thus reducing worker and nontarget exposure, while providing a level of control that is currently lacking.

Acknowledgments

Jacqueline Mattick, Courtney Sekulic, Elizabeth Swartele, Dylan Tussey, Cortni McGregor, and Kristin McGregor were responsible for weekly trap inspections and plot maintenance, infestation assessments, data collation, and data entry. We are grateful to J. D. Fowler, Fowler Farms, Wolcott, NY, and Paul Wafler, Wafler Farms North Huron, NY, for allowing us to conduct this study in their orchards; Aijun Zhang for providing improved dogwood borer pheromone lures; and to Jason Barry, Cornell Statistical Consulting Unit, for his assistance with the statistical analyses. This research was supported by U.S. Department of Agriculture Special Research Grants Program–Pest Management Alternatives Award 2010-34381-21306, and by the New York State Apple Research and Development Program.

References Cited

Agnello, A. M., R. Gardner, M. Helms, A. Landers, D. Rosenberger, K. Cox, J. Carroll, T. Robinson, D. Breth, D. Kain, et al. 2013. 2013 Pest Management Guidelines for Commercial Tree-Fruit Production. Cornell Coop. Extension, Ithaca, NY. p. 248. (http://ipmguidelines.org).

Bergh, J. C., and T. C. Leskey. 2003. Biology, and ecology, and management of dogwood borer in eastern apple orchards. Can. Entomol. 135: 615–635.

Bromley, P. T., M. Parker, and W. T. Sullivan Jr. 1992. Controlling vole damage in commercial orchards and ornamental nurseries. N. C. Agric. Ext. Serv. Publ. 472.

Byers, R. E. 1974. Pine mouse control in apple orchards. Ann. West Va. State Hort. Soc. Meet. Mt. Grow 335: 3–13.

Byers, R. E. 1984. Control and management of vertebrate pests in deciduous orchards of the eastern United States. Hortic. Rev. 6: 253–285.

Cardé, R. T., and A. K. Minks. 1995. Control of moth pests by mating disruption: Successes and constraints. Annu. Rev. Entomol. 40: 559–585.

Carter, K. 2009. Integrated pest management for apples. Ontario Ministry of Agriculture, Food & Rural Affairs Publ. 310. Queen's Printer for Ontario, Toronto, ON.

Conover, M. R., W. C. Pitt, K. K. Kessler, T. J. Dubow, and W. A. Sanborn. 1995. Review of human injuries, illnesses, and economic losses caused by wildlife in the United States. Wildlife Soc. Bull. 23: 407–414.

Curtis, P. D., E. D. Rowland, and G. L. Good. 2002. Developing a plant-based vole repellent: Screening of ten candidate species. Crop Prot. 21: 299–306.

Hartman, J. R., M. L. Witt, W. M. Fountain, R. E. McNiel, M. F. Potter, and R. T. Jones. 1997. The flowering dogwood. Coop. Ext. Serv. ID-67, Univ. Kentucky, Lexington. p. 4. (http://www.ca.uky.edu/agc/pubs/id/id67/id67.pdf).

Hoffmann, M. P., T. P. Kuhar, J. M. Baird, J. Gardner, P. Schwartz, and A. M. Shelton. 2001. Non-woven fiber barriers for control of cabbage maggot and onion maggot (Diptera: Anthomyiidae). J. Econ. Entomol. 94: 1485–1491.

Kain, D. P., and A. M. Agnello. 1999. Pest status of American plum borer (Lepidoptera: Pyralidae) and fruit tree borer control with synthetic insecticides and entomopathogenic nematodes in New York State. J. Econ. Entomol. 92: 193–200.

Kain, D., and R. W. Straub. 2001. Status of borers infesting apple burr knots and their management in New York orchards. NY. Fruit Q. 9: 10–12.

Kain, D. P., R. Straub, and A. Agnello. 2002. Evaluation of various trunk sprays to control borers infesting burrknots, 2001. Arthropod Manage. Tests 27: A42.

Kain, D. P., R. W. Straub, and A. M. Agnello. 2004. Incidence and control of dogwood borer (Lepidoptera: Sesiidae) and American plum borer (Lepidoptera: Pyralidae) infesting burrknots on clonal apple rootstocks in New York. J. Econ. Entomol. 97: 545–552.

Kain, D. P., M. P. Hoffmann, J. Gardner, and A. Agnello. 2010. Physical barriers to prevent dogwood borer (Lepidoptera: Sesiidae) infestation of apple burrknots. J. Entomol. Sci. 45: 35–43.

Leskey, T. C., and J. C. Bergh. 2005. Factors promoting infestation in newly planted, non-bearing apple orchards by dogwood borer, *Synanthedon scitula* (Harris) (Lepidoptera: Sesiidae). J. Econ. Entomol. 98: 2121–2132.

Leskey, T. C., J. C. Bergh, J. F. Walgenbach, and A. Zhang. 2009. Evaluation of pheromone-based management strategies for dogwood borer (Lepidoptera: Sesiidae) in commercial apple orchards. J. Econ. Entomol. 102: 1085–1093.

Merwin, I. A., J. A. Ray, and P. D. Curtis. 1999. Orchard groundcover management systems affect meadow vole populations and damage to apple trees. HortScience 34: 271–274.

Nolte, D. L., M. W. Lutman, D. L. Bergman, W. M. Arjo, and K. R. Perry. 2003. Feasibility of non-lethal approaches to protect riparian plants from foraging beavers in North America. Wildlife Damage Management, Internet Center for U.S. Dep. Agric. National Wildlife Research Center - Staff Publications.

Orton, C. R., and J. F. Adams. 1915. Collar-blight and related forms of fire-blight. Penn. State College Agr. Exp. Sta. Bull. 136: 23.

Pearson, K., and C. G. Forshey. 1978. Effects of pine vole damage on tree vigor and fruit yield in New York apple orchards. HortScience 13: 56–57.

Riedl, H., R. W. Weires, A. Seaman, and S. A. Hoying. 1985. Seasonal biology and control of the dogwood borer, *Synanthedon scitula* (Lepidoptera: Sesiidae) on clonal apple rootstocks in New York. Can. Entomol. 117: 1367–1377.

Rom, R. C., and S. A. Brown. 1979. Factors affecting burrknot formation on clonal *Malus* rootstocks. HortScience 14: 231–232.

SAS Institute. 2008. SAS/STAT 9.2 user's guide. SAS Institute, Cary, NC.

Warner, J., and S. Hay. 1985. Observations, monitoring, and control of clearwing borers (Lepidoptera: Sesiidae) on apple in central Ontario. Can. Entomol. 117: 1471–1478.

Wise, J. C., and L. J. Gut. 2002. Trunk sprays for control of dogwood borer, 2000–2001. Arthropod Manage. Tests 27: A56.

Zhang, A., T. C. Leskey, J. C. Bergh, and J. F. Walgenbach. 2005. Sex pheromone of the dogwood borer, *Synanthedon scitula.* J. Chem. Ecol. 31: 2463–2479.

Received 29 January 2014; accepted 31 March 2014.