Incidence and Control of Dogwood Borer (Lepidoptera: Sesiidae) and American Plum Borer (Lepidoptera: Pyralidae) Infesting Burrknots on Clonal Apple Rootstocks in New York

DAVID P. KAIN,[1] RICHARD W. STRAUB,[2] AND ARTHUR M. AGNELLO[1]

J. Econ. Entomol. 97(2): 545–552 (2004)

ABSTRACT Surveys were conducted in the major apple growing regions of New York state to determine the incidence of borers infesting burrknots on clonal apple rootstocks. Dogwood borer, *Synanthedon scitula* (Harris), was generally prevalent throughout the state, but American plum borer, *Euzophera semifuneralis* (Walker), was limited to western New York apple orchards near infested stone fruit trees. Insecticides evaluated in the field for efficacy against both borers were chlorpyrifos, endosulfan, indoxacarb plus oil, methoxyfenozide, fenpropathrin, and kaolin clay. Also, white latex paint was tested alone and mixed with chlorpyrifos. One application of chlorpyrifos applied at the petal fall developmental stage was equivalent to chlorpyrifos applied at petal fall and again in mid-July, and it provided season-long control of dogwood borer and American plum borer. One application of chlorpyrifos applied any time between the half-inch green developmental stage and petal fall, or after harvest the previous season, controlled both overwintered and summer brood larvae of dogwood borer. Multiple applications of fenpropathrin, indoxacarb plus oil, and endosulfan applied during the dogwood borer flight period controlled the summer brood.

KEY WORDS *Euzophera semifuneralis*, *Synanthedon scitula*, burrknots, survey, control

BURRKNOTS ARE AGGREGATIONS OF root initials that can develop on the aboveground portion of all commercial size-controlling clonal apple rootstocks. Infestations by larvae of the dogwood borer, *Synanthedon scitula* (Harris), have been related to the presence of burrknots (Rom and Brown 1979, Riedl et al. 1985, Warner and Hay 1985). The initial point of entry is usually the burrknot, where newly hatched larvae commence feeding on root initials. Examinations of apple orchards in western New York and the Hudson Valley (Riedl et al. 1985) revealed that 70% of trees on size-controlling rootstocks had burrknots and that an average of 40% of the burrknots in any particular orchard were infested by borers. High numbers of burrknots was positively correlated with increased borer infestation. Borers recovered included dogwood borer and American plum borer, *Euzophera semifuneralis* (Walker), with dogwood borer the predominant species. Results of tree trunk surveys of tart cherry and peach, conducted during 1994 and 1995 in western New York, the Hudson Valley, and on Long Island, determined that American plum borer is the prevalent tree-boring insect pest in tart cherry in western New York, but not in the other two regions (Kain and Agnello 1999). During the 1998 and 1999 growing seasons, several apple orchards in western New York expressing burrknots were found to be heavily infested with American plum borer. It is likely that infested tart cherry trees are reservoirs of American plum borer, from which other susceptible crops (i.e., apples with burrknots) may become infested. Reports by growers, agents, and nurserymen suggest that borer infestations are increasing throughout the Northeastern, Mid-Atlantic, and Michigan apple production areas. We deemed it necessary to determine the prevalence and species distribution of borers in apple orchards to alert growers to the need for control measures. Moreover, because the flight periods of dogwood borer and American plum borer do not coincide, it is important to determine which of the two species is present in a given production region before precise timing of insecticide applications can be recommended.

Dogwood borer has one flight per season that peaks in mid-July in New York. For control of dogwood borer, recent New York Extension recommendations suggested insecticide applications in early to mid-July (Agnello et al. 2000). Because American plum borer has only recently been identified as a pest of apple in western New York, the efficacy of insecticides against this pest in apple burrknots is unknown. American plum borer has two flights per season in New York, peaking in late May and mid-July. Therefore, first generation American plum borer larvae are not affected by insecticide application directed at dogwood

[1] Department of Entomology, New York State Agricultural Experiment Station, Geneva, NY 14456.

[2] Department of Entomology, New York State Agricultural Experiment Station, Hudson Valley Laboratory, 3357 Rt. 9W, Highland, NY 12528.

borer in the summer. Treatments for American plum borer on both tart cherry and peach are recommended at petal fall, with a subsequent application during mid- to late July if infestation levels remain high (Kain and Agnello 1999). However, petal fall application alone can provide season-long control of American plum borer and lesser peachtree borer in cherry (Biddinger 1989). Yonce (1980) also determined that a single application of chlorpyrifos early in the growing season controlled peachtree and lesser peachtree borers in peach. Although a single application of chlorpyrifos should provide season-long control of the numbers of both borer species we would expect to find in apple, the optimum timing of such a treatment is not known. During 2000, we evaluated various postbloom timings of chlorpyrifos applications against dogwood borer and American plum borer. Regulatory changes have largely eliminated postbloom use of chlorpyrifos on apple, except for trunk sprays directed at borers. In the event that future regulatory changes may eliminate postbloom chlorpyrifos for trunk sprays and because petal fall is an inconvenient time to apply trunk sprays, in 2001 and 2002 prebloom applications of chlorpyrifos and other insecticides were evaluated against dogwood borer. White latex paint, reported as being somewhat effective against borers (Riedl et al. 1985, Warner and Hay 1985) was tested alone and mixed with chlorpyrifos.

Materials and Methods

Orchard Surveys, 2000–2001. Thirty apple orchards planted to mixed cultivars on various dwarfing rootstocks were surveyed in either spring or fall, when borers were overwintering and could be easily found, in western New York, the Hudson Valley, the Champlain Valley and the Albany area. Data were collected on the extent of burrknot expression, the degree to which burrknots were infested by borers, relative abundance of borer species in each orchard, and the extent of borer damage in infested orchards. In each orchard, 50 trees were examined for incidence of burrknots, and those found were inspected for the presence of freshly produced frass, indicating recent borer activity. The level of bark damage on each tree was classified on a rating of 0–5: 0, no damage; 1, burrknot tissue feeding only, <50% consumed; 2, burrknot tissue feeding only, >50% consumed; 3, feeding outside of burrknot; 4, feeding outside of burrknot, 25–50% trunk girdled; and 5, feeding outside of burrknot, >50% trunk girdled. Up to 10 trees having fresh frass were examined for larvae, which were identified as dogwood borer or American plum borer to determine their relative abundance (Peterson 1967). It was noted whether mouseguards of any type were affixed to tree trunks in each orchard. The surrounding area within ≈0.8 km was surveyed by driving access roads to determine the presence or absence of stone fruit (tart cherry or peach) orchards in the vicinity.

Efficacy Trials, 2000. Within two commercial orchards in Wayne County, New York (Fowler and Wafler orchards, Huron), chlorpyrifos (Lorsban 50 W, Gowan, Yuma, AZ), at 0.34 kg ([AI])/379 liters (Fowler) or 0.68 kg ([AI])/379 liters (Wafler) was applied at either the petal fall developmental stage, in midsummer, or at both petal fall and again in midsummer and compared with an untreated control. Sprays were applied on 17 May and 7 July in the Fowler orchard, and on 22 May and 17 July in the Wafler orchard. This treatment regime was designed to compare the effectiveness of chlorpyrifos when applied earlier than recommended and when applied at the currently recommended time period. Midsummer application of insecticides effectively controls dogwood borer (Riedl et al. 1985, Warner and Hay 1985) but not first generation American plum borer and overwintering larvae of either species. Insecticide emulsions were applied as a coarse spray by handgun, by using a Nifty-Pul-Tank sprayer (Rears Manufacturing Co., Eugene, OR) operated at 10,547 g/cm^2 pressure (150 psi). Approximately 250 ml of solution was sprayed directly on the burrknots of each tree. At the Fowler orchard, treatments were applied to three row by ≈15 tree (M.9/'McIntosh') plots, replicated four times. On 28 June and 11 October, 10 trees from the middle of each plot were examined for fresh frass, indicating live borers were present. At the Wafler orchard, treatments were applied by the grower, by using a handgun sprayer, to three entire rows (≈186 m in length) (Mark/'Empire', Mark/'Gingergold', or M.9/'Gingergold'), replicated three times. Control was evaluated in late June to determine the efficacy of treatments against the first brood of American plum borer and again in the fall to determine efficacy against the summer broods of both species. Fifty (28 June) or 25 trees (11 October) from the middle of each plot were examined for fresh frass. Trees were considered infested if any fresh frass was present, regardless of the number of burrknots per tree. During October, all infested trees in each plot were sampled for live larvae to determine the number and species present. Treatments were completely randomized at both locations.

Efficacy Trial, 2001. A field trial was conducted at the Wafler orchard to evaluate prebloom applications of chlorpyrifos compared with postbloom applications of other insecticides and white latex paint. Nine treatments were tested: 1) chlorpyrifos (Lorsban 4 emulsifiable concentrate [EC], Dow AgroSciences LLC, Indianapolis, IN), 1.36 kg ([AI])/379 liters applied at "half-inch green" (HIG); 2) chlorpyrifos (Lorsban 4 EC), 1.36 kg ([AI])/379 liters applied at "pink"; 3) chlorpyrifos (Lorsban 4 EC), 1.36 kg [AI])/379 liters applied at "petal fall" (PF); 4) chlorpyrifos (Lorsban 4 EC), 1.36 kg ([AI])/379 liters plus paint (Magic Easy Spread flat white exterior latex, Yenkin-Majestic Paint Corp., Colombus, OH), 33% (vol:vol), applied at HIG; 5) indoxacarb (Avaunt 30 wettable granule (WG), DuPont, Wilmington, DE), 0.051 kg ([AI])/379 liters plus horticultural oil (Sunspray 6E, Sunoco, Philadelphia, PA), 1% (vol:vol) applied at PF; 6) indoxacarb (Avaunt 30 WG), 0.051 kg ([AI])/379 liters plus horticultural oil, 1% (vol:vol) applied at PF and again in mid-July; 7) endosulfan (Thiodan 3 EC, Gowan), 0.34 kg ([AI])/379 liters applied at PF, 18 July and 15 August; 8) white latex paint (33% [vol: vol]) applied at HIG; and 9) untreated. Insecticide and paint emulsions were applied as in 2000. Treatments were arranged randomly in three row by 15 tree plots and were replicated three times. All trees were M.26/'Empire' and expressed numerous burrknots. All burrknots on 10 trees from the middle row of each plot were examined for freshly produced frass, as described previously, on 27 June and 11 September. Trees displaying any amount of fresh frass were considered actively infested regardless of the number of burrknots per tree. Infested trees were examined for live larvae and the number of larvae per tree was recorded.

Efficacy Trial, 2002. In 2002, a field trial was conducted at the Wafler orchard to evaluate the efficacy of chlorpyrifos (Lorsban 4 EC), 1.36 kg ([AI])/379 liters applied postharvest (15 October, 2001), and main season use of more recently introduced insecticides, including methoxyfenozide (Intrepid 2 flowable [F], Dow Agrosciences LLC), 0.113 kg ([AI])/379 liters applied at tight cluster (19 April) and 17 July, kaolin clay (Surround 95% wettable powder [WP], Engelhard Corporation, Iselin, NJ), 21.54 kg ([AI])/379 liters applied 28 June, 17 July, and 9 August, fenpropathrin (Danitol 2.4 EC, Valent U.S.A. Corporation, Walnut Creek, CA), 0.091 kg ([AI])/379 liters applied 27 June, 17 July, and 9 August, and indoxacarb (Avaunt 30 WG), 0.051 kg ([AI])/379 liters plus horticultural oil, 1% [vol:vol] applied 17 July and 9 August. Aforementioned treatments were compared with a standard treatment of chlorpyrifos (Lorsban 4 EC), 1.36 kg ([AI])/379 liters, applied at tight cluster (19 April) and an untreated control. Insecticide emulsions were applied in the same manner as in 2001. Treatments were arranged randomly in three row by 15 tree plots and were replicated three times. All burrknots on 10 trees from the middle row of each plot were examined for freshly produced frass, as described previously, on 27 June and 11 September.

Statistical Analysis. For survey data, relationships among number of larvae, burrknots, and damage were determined by regression analysis (SuperANOVA version 1.11, Abacus Concepts 1991). Differences in infestation levels in relation to the presence of stone fruits or mouseguards were determined using one-tailed *t*-tests (Microsoft Excel 98, Microsoft 1998). For efficacy trials, data regarding the presence or absence of fresh frass were analyzed using a logit model with categorical factors and robust variance estimation to account for correlation among individuals (trees) within experimental units (StataCorp 2001). The initial logit model compared each treatment to an untreated control with significant differences based on an asymptotic z statistic having a probability of ≤ 0.05. Treatment means and 95% confidence intervals were calculated using the estimated logit model and then back-transformed to proportions. These confidence intervals were based on the standard errors of the predicted mean for each treatment.

Larval counts were normalized using a square root transformation, and transformed data were subjected to analysis of variance (ANOVA). Differences among treatments were determined using Fisher's protected least significant difference (LSD) test (SuperANOVA version 1.11, Abacus Concepts 1991).

Results and Discussion

Orchard Surveys, 2000–2001. The results of surveys in 30 apple orchards are presented in Table 1. Borer larvae can penetrate apple bark through any type of wound. Burrknots may mimic wounds by provision of the exposed soft tissue of root initials. Burrknots were present in all orchards surveyed and on an average of 56% (range, 18–98%) of trees in each orchard. On average, 32% (range, 0–94%) of trees with burrknots were actively infested with borers. Also, regression analysis showed that the greater the proportion of trees with burrknots (x) the higher proportion of trees with burrknots that were infested by borers (y): ($y = 0.821x - 0.132$, $r^2 = 0.394$, $P = 0.0002$) (residual mean square error = 0.051, standard error intercept = 0.113, standard error burrknots = 0.187). Not all trees with damage were actively infested; 59% of trees with burrknots were either actively infested or showed evidence, in the form of feeding damage, of previous infestation. There was a correlation between damage rating (x) and the percentage of trees with burrknots that were infested (y): ($y = 0.357x + 0.019$, $r^2 = 0.706$, $P = 0.0001$) (residual mean square error = 0.025, standard error intercept = 0.048, standard error damage rating = 0.043). Bark damage to stone fruits causes gummosis, which attracts female American plum borer moths (Biddinger 1989). Similarly, fresh feeding on apple may affect subsequent damage by stimulation of oviposition.

Mouseguards are devices used to prevent voles, mice, and other rodents from feeding on bark on the lower portion of the tree trunk. They typically consist of a cylinder of a perforated or woven metal material, such as hardware cloth, or plastic. Mouseguards may be loose-fitting or may wrap fairly tightly around the trunk (plastic spiral type). Mouseguards inhibit penetration of herbicides around the bases of trees, leading to weedy conditions within the mouseguard. Furthermore, light penetration is lower and humidity is higher inside the mouseguard. These factors have been implicated in increased growth of burrknots (Rom and Brown 1979). Whether mouseguards conform loosely or more tightly to the burrknot area, anecdotal reports have suggested that they contribute to increased levels of trunk infestation by borers. In eight apple orchards where mouseguards were present, borers actively infested 42% of the trees. Where mouseguards were absent, 30% were actively infested. Statistically, in trees with burrknots, the proportion that were actively infested was no greater, and numbers of dogwood borer larvae were no higher, when mouseguards were present compared with when they were absent (Table 2). Interestingly, there is evidence that dogwood borer larvae are more abundant in the trunks of dogwood, *Cornus florida* (L.),

Table 1. Incidence of dogwood borer (DWB) and American plum borer (APB) infestations in New York apple orchards, 1999–2001

Location	Block	Proportion of trees: With burrknots	Proportion of trees: Infested[a]	Proportion of trees: With damage[a]	Average damage rating[b]	Larvae per 10 infested trees: DWB	Larvae per 10 infested trees: APB	Mouseguards	Stone fruit within 0.8 km
Wayne Co.	1	0.66	0.58	0.58	0.61	7	0	No	No
Wayne Co.	2	0.68	0.76	0.76	1.26	12	0	No	No
Wayne Co.	3	0.94	0.94	0.96	2.64	12	12	Yes	Yes
Wayne Co.	4	0.82	0.46	0.46	0.63	0	15	Yes	Yes
Wayne Co.	5	0.98	0.94	0.94	2.18	9	7	Yes	Yes
Wayne Co.	6	0.78	0.56	0.84	1.56	15	2	No	Yes
Wayne Co.	7	0.30	0.00	0.00	0.00	0	0	Yes	Yes
Wayne Co.	8	0.52	0.27	0.35	0.50	6	0	Yes	No
Wayne Co.	9	0.78	0.62	0.77	1.44	17	0	No	Yes
Wayne Co.	10	0.88	0.16	0.39	0.43	8	1	No	Yes
Champlain	1	0.50	0.15	0.16	0.15	1	0	Yes	No
Champlain	2	0.52	0.34	1.00	1.18	3	0	Yes	No
Champlain	3	0.28	0.00	3.78	0.69	0	0	No	No
Orleans	1	0.60	0.23	0.58	1.46	1	7	No	Yes
Orleans	2	0.90	0.05	0.22	0.27	2	1	No	No
Orleans	3	0.20	0.12	0.80	0.62	3	0	No	No
Orleans	4	0.40	0.02	0.60	0.43	1	0	No	No
Hudson Valley	1	0.38	0.50	0.95	1.35	10	0	No	No
Hudson Valley	2	0.40	0.23	0.85	0.61	8	0	Yes	No
Hudson Valley	3	0.32	0.42	0.88	1.00	6	0	No	No
Hudson Valley	4	0.40	0.16	0.45	0.30	9	0	No	No
Hudson Valley	5	0.18	0.08	0.33	0.12	1	0	No	No
Hudson Valley	6	0.48	0.18	0.50	0.48	9	0	No	No
Hudson Valley	7	0.62	0.23	0.39	0.73	10	0	No	No
Hudson Valley	8	0.44	0.20	0.55	0.45	11	0	No	No
Albany	1	0.80	0.58	0.78	1.13	12	0	No	Yes
Albany	2	0.38	0.11	0.16	0.26	4	0	Yes	Yes
Albany	3	0.68	0.35	0.94	1.56	13	0	No	No
Albany	4	0.50	0.00	0.24	0.38	0	0	No	No
Average		0.56	0.32	0.59	0.84	6.2	1.6	NA	NA

NA, not applicable.
[a] Proportion of trees with burrknots that were infested or damaged; proportion does not include trees with no burrknots.
[b] 0, no damage; 1, burrknot tissue feeding only, <50% consumed; 2, burrknot tissue feeding only, >50% consumed; 3, feeding outside of burrknot; 4, feeding outside of burrknot, 25–50% trunk-girdled; and 5, feeding outside of burrknot, >50% trunk girdled.

trees with greater exposure to sunlight (Potter and Timmons 1981).

Consistent with the results of a 1994–1995 survey of borers infesting stone fruits (Kain and Agnello 1999), American plum borer larvae were not found in regions other than western New York (Wayne and Orleans counties) (Table 1). Furthermore, American plum borer larvae were rarely found infesting burrknots on apple trees in western New York except in orchards in proximity to stone fruit plantings ($P < 0.01$) (Table 2). Mechanically harvested tart cherry orchards, which are concentrated in western New York, may serve as reservoirs of American plum borer for infestation of nearby susceptible orchards. Therefore, it was appropriate to evaluate separately the effect of mouseguards on American plum borer infestation levels in those western New York apple orchards that were near stone fruit plantings separately from those that were not. In the former case, the number of American plum borer larvae was higher in trees with mouseguards than in those without (Table 2). In this survey, American plum borer cocoons were occasionally found attached to the insides of plastic spiral mouseguards. On tart cherry trees, American plum borer larvae com-

Table 2. Comparison of the effect of tree guards and proximity to stone fruit plantings on dogwood borer (DWB) and American plum borer (APB) apple infestation parameters

Parameter	Mean (range): With mouse-guards	Mean (range): Without mouse-guards	Mean (range): With stone fruit	Mean (range): Without stone fruit	P	t	df
Proportion infested	0.37 (0–0.94)	0.29 (0–0.76)			0.314	0.4976	11
No. DWB	4.3 (0–12)	7.4 (0–17)			0.068	−1.5635	18
No. APB (near stone fruit)[a]	8.5 (0–15)	3.0 (0–7)			0.097	1.5588	4
No. APB[a]			5.4 (0–15)	0.2 (0–1)	0.009	2.9388	7

One-tailed t-test.
[a] Comparisons based on orchards in western New York only.

Table 3. Efficacy of various treatments against dogwood borer and American plum borer infestations in apple 2000

Orchard	Treatment	kg (AI)/379 liters	Application date	Proportion actively infested trees: Mean[a]	95% CI	SEM	$P > z$	Mean (±SEM) larvae/tree[a]
				June evaluation				
Wafler	Chlorpyrifos 50 W	0.34	17 May	0.01a	0.01–0.03	0.46	0.000	
	Chlorpyrifos 50 W	0.34	17 May, 7 July	0.04a	0.02–0.06	0.26	0.000	
	Chlorpyrifos 50 W	0.34	7 July	0.25b	0.18–0.33	0.21	0.011	
	Untreated			0.40b	0.32–0.49	0.18		
				Oct. evaluation				
	Chlorpyrifos 50 W	0.34	17 May	0.05a	0.02–0.15	0.60	0.000	0.0a
	Chlorpyrifos 50 W	0.34	17 May, 7 July	0.02a	0.01–0.06	0.44	0.000	0.03a (0.02)
	Chlorpyrifos 50 W	0.34	7 July	0.01a	0.00–0.07	0.86	0.000	0.0a
	Untreated			0.67b	0.46–0.82	0.44		0.72b (0.10)
				June evaluation				
Fowler	Chlorpyrifos 50 W	0.34	17 May	0.05a	0.01–0.26	0.96	0.102	-
	Chlorpyrifos 50 W	0.34	17 May, 7 July	0.08a	0.03–0.18	0.51	0.092	
	Chlorpyrifos 50 W	0.34	7 July	0.33a	0.13–0.61	0.61	0.911	
	Untreated			0.30a	0.08–0.69	0.85		
				Oct. evaluation				
	Chlorpyrifos 50 W	0.34	17 May	0.05ab	0.01–0.23	0.88	0.014	0.0a
	Chlorpyrifos 50 W	0.34	17 May, 7 July	0.08a	0.04–0.13	0.32	0.00	0.0a
	Chlorpyrifos 50 W	0.34	7 July	0.05a	0.02–0.13	0.52	0.00	0.0a
	Untreated			0.35b	0.22–0.51	0.34	-	0.33b (0.10)

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

monly attach their cocoons to the inside of outer bark that has separated from the wood of the trunk after the inner bark has been consumed. American plum borer larvae may prefer the concealed but spacious site provided by loose bark common on infested standard-sized tart cherry trees. However, large areas of separated bark are not common on dwarf apple trees, and larvae may find mouseguards to be attractive sites for pupation for the same reason as they do separated bark. Although it seems that American plum borers are attracted to the environment behind mouseguards, they were only found in orchards that were in proximity to infested stone fruit trees, regardless of the presence of mouseguards. Conversely, dogwood borers seem to neither prefer nor require this kind of environment and were found as commonly in trees with and without mouseguards.

These survey results indicate that in New York the proportion of trees in a given orchard on size-controlling rootstocks, and the proportion of those trees that are infested by borers, has remained similar to those levels in New York in the early 1980s (Riedl et al. 1985). The perception that borer problems have increased may be related to increased acreage of apple trees on size-controlling rootstocks that are susceptible to burrknot development; acreage increased ≈25% from 1985 to 1996 (Schooley 1990, 1996).

Efficacy Trials, 2000. The data from experiments conducted in 2000 were analyzed separately for each site and each assessment period (June and October). At both sites, a single petal fall (17 May) application of chlorpyrifos yielded season-long control of borers generally comparable with split applications applied at petal fall and in mid-July (Table 3). Because of synchrony with the first flight of American plum borer, the petal fall timing was expected to control this species' first generation larvae. Control of overwintered larvae of either species was not anticipated, and it was expected that frass produced by overwintered dogwood borer larvae, which continue to be observed throughout June, would be present at the time of the first evaluation (28 June). However, in plots receiving an application of chlorpyrifos at petal fall, a lower proportion of trees sampled exhibited fresh frass compared with those that did not receive chlorpyrifos at that time. In the Fowler orchard, overlapping mean confidence intervals indicated that differences were not significant, but z statistics suggested that differences were marginally significant and that the petal fall application was effective. Differences were significant according to both statistical analyses in the Wafler orchard. Therefore, we conclude that, in addition to protecting burrknots from newly hatched American plum borers, the petal fall application of chlorpyrifos penetrated the burrknot, and killed overwintered larvae. Mid-July sprays, although controlling borers for the remainder of the season, obviously allowed feeding damage by both species from petal fall through the time of treatment. At the October evaluation, American plum borer and dogwood borer were present in both orchards; in the Fowler orchard the control had 10 American plum borer and two dogwood borer larvae, and in the Wafler orchard the control had 10 American plum borer and 44 dogwood borer larvae. At the October evaluation, evidence of fresh frass and number of larvae actually found (Fowler orchard $F = 12.52$; df = 3, 156; $P = 0.0001$; and Wafler orchard $F = 65.84$; df = 3, 296; $P = 0.0001$) suggest that early spring treatments not only killed overwintered larvae of both species but also persisted

Table 4. Efficacy of various treatments against dogwood borer infesting apple 2001

Treatment	kg (AI)/379 liters	Application date	Proportion actively infested trees				Mean (±SEM) larvae/tree[a]
			Mean[a]	95% CI	SEM	$P > z$	
			June evaluation				
Chlorpyrifos 4EC	1.36	24 April	0.07a	0.01–0.29	0.89	0.000	0.03a (0.03)
Chlorpyrifos 4EC + paint	1.36 33% (v/v vol:vol)	24 April	0.13a	0.04–0.35	0.64	0.000	0.17ab (0.08)
Chlorpyrifos 4EC	1.36	5 May	0.17a	0.12–0.23	0.20	0.011	0.03a (0.03)
Chlorpyrifos 4EC	1.36	23 May	0.53b	0.48–0.59	0.11	0.013	0.20ab (0.07)
Indoxacarb 30 WG + horticultural oil	0.051 1% (v/v vol:vol)	23 May	0.50b	0.41–0.59	0.19	0.009	0.40bc (0.11)
Indoxacarb 30 WG + horticultural oil	0.051 1% (v/v vol:vol)	23 May, 18 July	0.60bc	0.50–0.69	0.20	0.086	0.70cd (0.15)
Endosulfan 3EC	0.34	23 May, 18 July, 15 Aug.	0.63bc	0.40–0.82	0.48	0.307	0.67cd (0.16)
Paint	33% (v/v vol:vol)	24 April	0.63bc	0.43–0.80	0.43	0.280	0.67cd (0.17)
Untreated			0.77c	0.60–0.88	0.41		0.90d (0.19)
			Sept. evaluation				
Chlorpyrifos 4EC	1.36	24 April	0.07a	0.01–0.29	0.89	0.000	0.07a (0.05)
Chlorpyrifos 4EC + paint	1.36 33% (v/v vol:vol)	24 April	0.03a	0.01–0.16	0.86	0.000	0.03a (0.03)
Chlorpyrifos 4EC	1.36	5 May	0.13ab	0.04–0.35	0.64	0.000	0.13a (0.06)
Chlorpyrifos 4EC	1.36	23 May	0.03a	0.01–0.16	0.86	0.000	0.03a (0.03)
Indoxacarb 30 WG + horticultural oil	0.051 1% (v/v vol:vol)	23 May	0.40b	0.31–0.50	0.20	0.000	0.50bc (0.13)
Indoxacarb 30 WG + horticultural oil	0.051 1% (v/v vol:vol)	23 May, 18 July	0.23b	0.18–0.29	0.16	0.000	0.23ab (0.08)
Endosulfan 3EC	0.34	23 May, 18 July, 15 Aug.	0.33bc	0.10–0.69	0.76	0.029	0.43bc (0.12)
Paint	33% (v/v vol:vol)	24 April	0.47bc	0.33–0.61	0.29	0.009	0.53c (0.12)
Untreated			0.77c	0.60–0.88	0.41		1.33d (0.21)

CI, confidence interval.

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

long enough to control dogwood borer and second generation American plum borer larvae hatching in midsummer (Table 3).

Efficacy Trial, 2001. The efficacy of chlorpyrifos against both borer species when applied at petal fall in 2000 prompted the evaluation of earlier timings that may conform to proposed regulatory guidelines. Because larvae of American plum borer were absent from plots selected for trials in 2001, data on that species could not be obtained. In June evaluations (Table 4), prebloom chlorpyrifos sprays at half-inch green (24 April), with or without white latex paint, and at pink (5 May) provided significantly better control of overwintered dogwood borer compared with treatments applied postbloom, based on evidence of fresh frass. Although a relatively high incidence of fresh frass was evident in the chlorpyrifos petal fall treatment, numbers of larvae were comparable with those in prebloom treatments, suggesting that larvae had been active before treatment and were controlled thereafter ($F = 7.507$; df = 8, 261; $P = 0.0001$).

In the September evaluations, all chlorpyrifos treatments except the 5 May application had significantly fewer actively infested trees compared with other treatments. In addition, all chlorpyrifos treatments had significantly fewer larvae compared with all other treatments except indoxacarb applied at petal fall (23 May) and mid-July ($F = 14.509$; df = 8, 261; $P = 0.0001$). This suggests that the efficacy of early season applications of chlorpyrifos persisted through mid-July, when the dogwood borer flight typically peaks. In general, for both evaluation dates, the use of white paint to coat burrknots was ineffective in preventing or reducing dogwood borer infestations. Moreover, the addition of white paint to chlorpyrifos did not contribute to efficacy of either treatment. Endosulfan, the only previously recommended postbloom insecticide in New York (Agnello et al. 2000), applied three times (petal fall, 18 July, and 15 August), was only slightly more effective than the untreated control. Although indoxacarb did not seem to be effective against overwintered dogwood borer larvae, both indoxacarb treatments resulted in significantly fewer infested burrknots and larvae compared with the control. In addition, indoxacarb applied at petal fall plus mid-July was statistically comparable with chlorpyrifos treatments in terms of larval counts.

Efficacy Trial, 2002. In the 20 June evaluation, the postharvest application of chlorpyrifos (15 October 2001) was significantly more effective than the untreated control and equivalent to the prebloom application in terms of both proportion of burrknots infested and number of dogwood borer larvae ($F = 13.718$; df = 6, 14; $P = 0.0001$) (Table 5). Methoxyfenozide, the only other treatment applied prebloom (at tight cluster, 19 April) against overwintering larvae, was different from the untreated control, but not as effective as the prebloom chlorpyrifos treatment. Fenpropathrin, kaolin clay, and indoxacarb treatments, none of which were applied before the June evaluation, were also different from the untreated control, obviously due to natural variation.

Table 5. Efficacy of various treatments against dogwood borer infesting apple 2002

Treatment	kg (AI)/ 379 liters	Application date	Proportion actively infested trees				Mean (± SEM) larvae/tree[a]
			Mean[a]	95% CI	SEM	$P > z$	
			June evaluation				
Chlorpyrifos 4EC	1.36	15 Oct., 2001	0.07ab	0.01–0.29	0.90	0.000	0.07a (0.67)
Chlorpyrifos 4EC	1.36	19 April	0.03a	0.01–0.16	0.87	0.000	0.03a (0.33)
Fenpropathrin 2.4EC	0.091	27 June, 17 July, 9 Aug.	0.47b	0.27–0.68	0.45	0.005	0.63b (0.22)
Methoxyfenozide 2F	0.113	19 April, 17 July	0.50b	0.41–0.59	0.19	0.000	0.70bc (0.09)
Kaolin clay 95 WP	21.54	28 June, 17 July, 9 Aug.	0.53b	0.39–0.67	0.30	0.002	0.60b (0.10)
Indoxacarb 30 WG	0.051						
+ horticultural oil	1% (v/v vol:vol)	17 July, 9 Aug.	0.57b	0.42–0.70	0.30	0.006	0.67bc (0.09)
Untreated			0.77c	0.71–0.82	0.16		1.23c (0.15)
			Oct. evaluation				
Chlorpyrifos 4EC	1.36	15 Oct. 2001	0.10ab	0.02–0.41	0.93	0.006	0.10a (0.10)
Chlorpyrifos 4EC	1.36	19 April	0.03a	0.01–0.16	0.87	0.000	0.03a (0.03)
Fenpropathrin 2.4EC	0.091	27 June, 17 July, 9 Aug.	0.20ab	0.12–0.31	0.30	0.000	0.20ab (0.00)
Methoxyfenozide 2F	0.113	19 April, 17 July	0.43bc	0.18–0.73	0.63	0.234	0.53bc (0.24)
Kaolin clay 95 WP	21.54	28 June, 17 July, 9 Aug.	0.50bc	0.27–0.73	0.51	0.333	0.67bc (0.24)
Indoxacarb 30 WG	0.051						
+ horticultural oil	1% (v/v vol:vol)	17 July, 9 Aug.	0.07a	0.03–0.15	0.45	0.000	0.10a (0.06)
Untreated			0.67c	0.43–0.84	0.50		0.93c (0.23)

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

In the October evaluation, both chlorpyrifos treatments, and the indoxacarb and fenpropathrin treatments were significantly better compared with the untreated control in terms of percentage of trees infested and the number of larvae found ($F = 5.562$; df = 6, 14; $P = 0.0039$). Neither methoxyfenozide nor kaolin clay differed significantly from the control. In the 2002 trial, indoxacarb applications were timed to better coincide with the flight period of dogwood borer, and this treatment resulted in control equivalent to prebloom chlorpyrifos.

In New York State, dogwood borer is a ubiquitous and predominant borer infesting burrknots on size-controlling apple rootstocks. In contrast, the American plum borer is more of a problem in apple orchards located near infested tart cherry and peach orchards, especially in those orchards with spiral plastic mouseguards on the trunks of trees. In addition, American plum borer is a significant pest of apple only in western New York, because of the concentration of mechanically harvested, infested tart cherry trees that serve as a reservoir of the pest in that region.

Chlorpyrifos applied as a coarse trunk spray at a rate of 0.34–1.36 kg AI/379 liters at any time between half-inch green and petal fall apparently killed overwintered larvae and also provided control of the summer broods of both American plum borer and dogwood borer in our tests. Chlorpyrifos applied after harvest in 2001, at a rate of 1.36 kg AI/379 liters, also killed overwintering dogwood borer larvae and provided adequate control of the subsequent summer brood. Season-long control of wood-boring larvae by using chlorpyrifos has been noted in other studies (Yonce 1980, Biddinger 1989, Kain and Agnello 1999). Chlorpyrifos residues are short-lived on foliar plant surfaces, primarily due to volatilization, but when chlorpyrifos is applied to bark, residues may persist for up to 15 mo, possibly due to sorption to dead bark tissue. (Racke 1993)

The present registration of postbloom chlorpyrifos use on apples is conditional and its future availability is uncertain. Our results indicate that there are viable alternatives to current recommendations for control of trunk borers in apple, including prebloom and postharvest application of chlorpyrifos, and preventative application of indoxacarb, fenpropathrin, and endosulfan during the dogwood borer flight period. Yet to be determined is the point at which chemical control is warranted; research to determine the effects of borer feeding on seasonal yield and growth of apple trees is needed.

Acknowledgments

We thank Deborah Breth (Cornell Cooperative Extension) for alerting us to damage by American plum borer in western New York, the growers who allowed us to survey orchards, and the following individuals who aided in various aspects of the project: Peter Jentsch (Cornell University, Hudson Valley Laboratory); and Mike Fargione, Kevin Iungerman, Deborah Breth, and Steve Hoying (all Cornell Cooperative Extension). We also thank Paul Wafler and John Fowler for providing orchards in which to conduct efficacy trials. We thank Jan Nyrop for assistance with statistical analysis. This research was financially supported by Dow Agrosciences, E. I. DuPont de Nemours Corp., and the New York State Apple Growers Association.

References Cited

Abacus Concepts. 1991. SuperANOVA, version 1.11. Abacus Concepts, Berkeley, CA.

Agnello, A. M., W. F. Wilcox, D. A. Rosenberger, T. L. Robinson, J. Schupp, P. D. Curtis, D. I. Breth, and S. A. Hoying. 2000. Pest management guidelines for commercial tree-fruit production, 2000. Cornell University Press, Ithaca, New York.

Biddinger, D. J. 1989. The biology and control of the American plum borer (Lepidoptera: Pyralidae) on tart cherries in Michigan. M.S. thesis, Michigan State University, East Lansing.

Kain, D. P., and A. 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.

Microsoft. 1998. Microsoft Excel 98. Microsoft, Redmond, WA.

Peterson, A. 1967. Larvae of insects. An introduction to Nearctic species. Part 1: Lepidoptera and Hymenoptera, 6th ed. The Ohio State University Press, Colombus, OH.

Potter, D. A., and G. M. Timmons. 1981. Factors affecting predisposition of flowering dogwood trees to attack by the dogwood borer (*Synanthedon scitula*). HortScience 16: 677–679.

Racke, K. D. 1993. Environmental fate of chlorpyrifos. Rev. Environ. Contam. Toxicol. 131: 1–154.

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.

Schooley, R. 1990. New York fruit tree survey 1990. NY Agric. Stat. Serv., NY Dept. Agric. Markets, NY.

Schooley, R. 1996. New York fruit tree and vineyard survey 1996. NY Agric. Stat. Serv., NY Dept. Agric. Markets, NY.

StataCorp. 2001. Stata statistical software: release 7.0. Stata Corporation, College Station, TX.

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.

Yonce, C. E. 1980. Effectiveness of chlorpyrifos for control of *Synanthedon pictipes* and *S. exitiosa* in peach orchard tests of young trees with emphasis on timing applications. J. Econ. Entomol. 73: 827–828.

Received 18 June 2003; accepted 11 December 2003.