Comparison of Exclusion and Imidacloprid for Reduction of Oviposition Damage to Young Trees by Periodical Cicadas (Hemiptera: Cicadidae)

ROBERT G. AHERN, STEVEN D. FRANK, AND MICHAEL J. RAUPP

Department of Entomology, University of Maryland, 4112 Plant Science Building, College Park, MD 20742

J. Econ. Entomol. 98(6): 2133–2136 (2005)

ABSTRACT Insecticides are traditionally used to control periodical cicadas (Homoptera: Cicadidae) and to reduce associated injury caused by oviposition. However, research has shown that conventional insecticides have low or variable season-long efficacy in reducing injury caused by cicadas. New systemic neonicotinoid insecticides provide excellent levels of control against a variety of sucking insects. We compared the efficacy of a neonicotinoid insecticide, imidacloprid, and a nonchemical control measure, netting, to reduce cicada injury. Netted trees sustained very little injury, whereas unprotected trees were heavily damaged. Fewer eggnests, scars, and flags were observed on trees treated with imidacloprid compared with unprotected trees; however, the hatching of cicada eggs was unaffected by imidacloprid.

KEY WORDS *Magicicada*, imidacloprid, oviposition, scarring, flagging

PERIODICAL CICADAS, *Magicicada* spp., occur throughout the eastern United States and are characterized by a prolonged subterranean developmental period that lasts either 13 or 17 yr (Marlatt 1907, Williams and Simon 1995). Periodical cicada nymphs emerge from holes in the soil beneath trees in early spring. Female cicadas injure many different species of trees by gouging slits 10–20 cm in length in bark into which they lay eggs (Smith and Linderman 1974; White 1980, 1981; Miller and Crowley 1998). Several dozen eggs are usually laid in these eggnests, and female cicadas are capable of laying several hundred eggs during their lifetime (Forsythe 1976, White 1980, Williams and Simon 1995). Injury caused by cicada oviposition is often inconsequential to large trees and generally results in pruning of branch ends and flagging. A flag is defined as a hanging, broken branch on which the leaves are dead (Smith and Linderman 1974, Miller and Crowley 1998). Young trees may be severely injured by female cicadas, and this injury may persist many years (Williams and Simon 1995, Miller 1997). Young trees are especially susceptible to injury by periodical cicadas because a large proportion of their branches are within the range of widths preferred by female cicadas for oviposition. Flags and scars are often more pronounced and noticeable on younger trees, increasing the need to minimize injury whenever possible. Landscape managers and nursery personnel are especially affected by emergence of periodical cicadas because they must protect valuable ornamental plants that are susceptible to serious injury (Miller 1997, Miller and Crowley 1998).

Insecticides are the most common tactic used to reduce injury caused by periodical cicadas, and most investigations of insecticide efficacy have been conducted in orchard systems (Forsythe 1975, Weires and Straub 1980, Hogmire et al. 1990). These studies demonstrated that several classes of insecticides, including organophosphates, carbamates, and pyrethroids, provided quick knockdown and some residual toxicity to adult cicadas. However, relatively few studies have examined the efficacy of insecticides or nonchemical approaches in reducing injury caused by ovipositing adults. A notable exception is the study by Hogmire et al. (1990) who found that only esfenvalerate provided significant protection to apple branches compared with oxamyl, methomyl, and oxythioquinox. It is noteworthy that Hogmire et al. (1990) found that netting provided the best protection from ovipositing cicadas.

In landscape settings, few studies have evaluated the efficacy of tactics to mitigate injury caused by cicadas. In a recent study, Miller (1997) found no reduction in the number of wounds per branch of mountain ash, *Sorbus* spp., when trees were untreated or sprayed with bifenthrin, cyfluthrin, carbaryl, chlorpyrifos, or fluvalinate.

Imidacloprid was the first neonicotinoid insecticide to be introduced to the landscape plant market, and it is still one of the most popular materials applied in landscapes owing to its range of activity against key Hemiptera, including lacebugs, aphids, scales, psyllids, and adelgids (Sclar and Cranshaw 1996, Gill et al. 1999, Young 2002, Webb et al. 2003). Although systemic products have been used against a variety of insect pests, there are no published accounts of the efficacy of neonicotinoids for reduction of injury by female cicadas. We were interested in determining the efficacy of chemical and nonchemical control measures to reduce cicada injury on landscape plants. Specifically, we evaluated netting as an exclusionary device to female cicadas on little-leafed linden, *Tilia cordata* P. Miller (Tiliaceae). We also evaluated a widely used and commonly recommended systemic neonicotinoid insecticide, imidacloprid, for reducing cicada injury.

Materials and Methods

Research was conducted at the University of Maryland Turfgrass Research Facility, College Park, MD, during spring and summer 2004. Periodical cicadas in brood X emerged in the College Park area during spring 2004 (Marlatt 1907). Thirty little-leafed linden trees were used in this research. Trees had been planted in 2001 in three rows of 10 trees. In 2004, the trees were uniformly 3 m in height and 7 cm diameter at breast height (dbh).

Each tree was randomly assigned to one of three treatments to establish 10 replicates of each treatment. Treatments included linden trees exposed to ambient levels of injury by female cicadas, trees treated with imidacloprid (Merit 75 WP, Bayer Corporation, Kansas City, MO), and trees covered with netting to exclude cicadas. Trees in the ambient treatment were left unprotected to estimate the natural level of injury that would accrue during the ovipositional period of cicadas. Trees in the imidacloprid treatment received 2 g of imidacloprid per 2.54-cm-dbh in 3.8 liters of water. Imidacloprid was mixed in pail and applied as a soil drench around the circumference of the tree at the root collar. Our application took place on 7 May 2004, and peak cicada emergence occurred during the last week in May and first week of June. Oviposition was first observed during the third week of May and continued until mid-July. Trees in the net treatment were covered in plastic netting (Tipper Tie-Net, Apex, NC) that had openings 1 cm in width. Nets were tied closed around the trunk just beneath the canopy and at the top of the trees. Netting was applied on 8 May 2004 and removed in 17 July, upon cessation of oviposition.

Abundance of Eggnests and Scars. Eggnests were sampled on eight branches per tree. On each tree, a high and a low branch was selected in each cardinal direction. Eggnests were counted in a 50-cm segment of each branch. Data were pooled within each tree, and a tree-specific mean was analyzed as the unit of replication. We sampled only the section >3 mm in diameter proximal to the tip of the branch, which is the portion of the branch expected to receive the greatest egg load (White 1980, Miller and Crowley 1998). Variances were heterogeneous among treatments and could not be made homogeneous with transformations. Therefore, a nonparametric Kruskal–Wallis test was used to determine the significance of treatment effect (PROC NPAR1WAY, SAS Institute 1999). Nemenyi values were calculated for means comparison using a q-distribution (Zar 1999). *Magicicada septendecim* (L.) and *Magicicada cassini* (Fisher) were both observed at the study site, but no attempt was made to distinguish oviposition wounds created by different species.

A further comparison of cicada ovipositional behavior was made between untreated trees and those treated with imidacloprid to test for propensity to sustain or terminate oviposition. Eggnests are caused when a cicada inserts its ovipositor into a branch. The result is a linear fracture in the bark with exposed fibers of wood (White 1980). Each female cicada is capable of making several dozen eggnests (White 1980). We defined scars as repeated, uninterrupted sequences of eggnests that result in a long groove. We used eggnests per scar as an indicator of the duration of an oviposition bout (White 1980), although the mechanism underlying this event was not measured directly. Two 20-cm-long branches were selected from each tree. On each of these branches the number eggnests was counted in each oviposition scar. Counts of eggnests from the two 20-cm branches were summed and then averaged for each tree. Netted trees were excluded from this analysis as none of the randomly sampled branches bore scars.

Effect of Imidacloprid on Emergence of Nymphs. The number of cicada nymphs emerging from oviposition sites was measured in the untreated and imidacloprid-treated trees. Netted trees did not contain oviposition sites. Tent-shaped sticky traps were hung on two branches per tree. Traps were positioned with the sticky area below a scar to catch the emerging nymphs as they fell. Scars of approximately equal length were selected on treated and untreated trees. Traps were 6.5 by 9.0 cm (width × length). The traps were placed on 29 July and retrieved 1 wk later. The total number of nymphs caught on each trap was pooled for each tree. Data were analyzed with a *t*-test (PROC MIXED, SAS Institute 1999).

Flagging Injury. The number of flags per tree was counted in August. Variances in the number of flags were heterogeneous among treatments and could not be made homogeneous with transformations. The number of flags per tree was analyzed with a nonparametric Kruskal–Wallis test to determine the significance of treatment effect (PROC NPAR1WAY, SAS Institute 1999). Nemenyi values were calculated for means comparison using a q-distribution (Zar 1999).

Results

The number of eggnests per 50-cm branch section was significantly different among the three treatments ($\chi^2 = 27.79$, df = 2, $P < 0.0001$) (Fig. 1). There were significantly ($P < 0.001$) more eggnests per scar (mean ± SEM) on branches on untreated trees (5.1 ± 0.8) than trees treated with imidacloprid (2.2 ± 0.2). The number of flags was significantly different among the three treatments ($\chi^2 = 16.33$, df = 2, $P = 0.0003$). Untreated trees had significantly more flags than trees treated with imidacloprid or those protected by nets (Fig. 2). The mean ± SEM number of nymphs emerg-

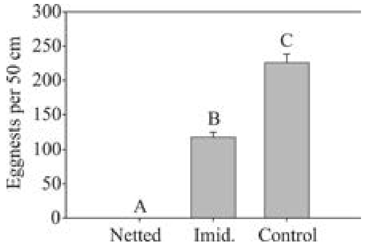

Fig. 1. Mean number of eggnests per 50-cm branch length on trees that were netted, treated with imidacloprid (imid.), and untreated. Bars that share a letter are not significantly different ($P < 0.05$) as determined by Nemenyi test.

ing from oviposition sites did not differ ($t = 0.07$, df = 18, $P > 0.9485$) between untreated (10.9 ± 3.8) and imidacloprid-treated (11.2 ± 2.6) trees.

Discussion

Female cicadas caused less oviposition injury and made fewer eggnests on trees treated with imidacloprid. We did not attempt to observe behaviors that might explain the lower numbers of damaged branches and eggnests in imidacloprid treated trees. Reduced injury and fewer eggnests could have been the result of a change in ovipositional preference or another sublethal or delayed lethal effect of imidacloprid on the cicada. Other insecticides have been reported to alter the behavior of ovipositing cicadas. Weires and Straub (1980) noted that applications of esfenvalerate caused cicadas to migrate from treated orchards, orient away from trees that were treated, and vacate treated branches after depositing unusually low numbers of eggs. Imidacloprid has been found to alter host-seeking behavior in other Hemiptera. Nauen (1995) demonstrated that the green peach aphid, *Myzus persicae* (Sulzer), avoided cabbage leaves treated with low concentrations of imidacloprid.

The label indicates that Merit may require 60 or more days for translocation (Bayer Corporation). It is possible that greater control could have been obtained by applying imidacloprid even earlier in the season.

Discoloration of foliage and flagging caused by cicadas may lead to decreased salability of young trees grown in nurseries (Smith and Linderman 1974). This type of injury has been shown to lead to customer dissatisfaction with other chewing and sucking insects in landscape systems (Sadof and Raupp 1996). We found that almost no flagging occurred on netted trees, whereas injury to unprotected trees was obvious and would likely have been objectionable to nursery operators and landscape managers. On a single netted tree, female cicadas were able to oviposit in a branch next to the net. Injury to trees treated with imidacloprid was intermediary between netted and untreated trees, although flagging and scarring on trees was apparent and may have been objectionable. It is likely that avoidance of branches treated with imidacloprid by females explains, at least in part, reduced scarring and flagging observed on trees treated with imidacloprid. Imidacloprid also may have the long-term effect of reducing root colonization by cicada nymphs because although nymph hatch was unaffected by the chemical, fewer eggs were laid in treated trees. Although our results provide evidence for the effect of imidacloprid on subsequent nymphal density, research that focuses directly on this question should be conducted in the future.

Hogmire et al. (1990) determined that netting was more economical than chemical control of cicadas at high tree densities (250 nets per ha). Although we did not measure all costs associated with our two treatments, the price of the netting to enclose a single 3-m-tall tree was $2.82, and the cost of netting 10 trees was estimated to be $28.20. To gain some perspective as to how the cost of netting might compare with an application of imidacloprid, we conducted a telephone survey with five commercial arborists in the metropolitan Baltimore–Washington region. The average cost of a single soil application of imidacloprid to a 7-cm-dbh tree was $93.33 ± $7.26 (SEM), and the cost of treating 10, 7-cm trees at the same location was $194.17 ± $41.37 (SEM). Clearly, the material cost of using netting was far less than the cost of a commercial application. However, the equivalent labor cost of a homeowner's time spent netting trees was incalculable but not trivial, because it required significant amounts of time to purchase, transport, install, and remove the nets.

In conclusion, netting proved to be a highly effective and relatively inexpensive tactic for reducing injury to small landscape trees caused by ovipositing cicadas. These results concur with findings by Hogmire et al. (1990) in fruit orchard systems. The systemic insecticide imidacloprid also provided good levels of protection from ovipositing cicadas; however, the mechanism of this protection was not resolved. That fewer eggnests occurred in each scar indicates that female cicadas may detect imidacloprid or one of its derivatives in the branch and avoid branches of treated plants. Further investigations of this phenomenon are warranted.

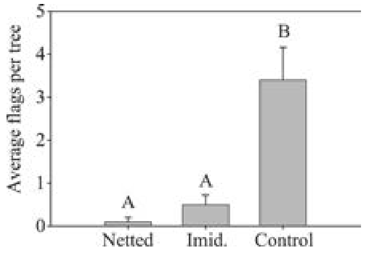

Fig. 2. Mean flags per tree on trees that were netted, treated with imidacloprid (imid.), and untreated. Bars that share a letter are not significantly different ($P < 0.05$) as determined by Nemenyi test.

Acknowledgments

We thank Mark Carroll for permission to use trees for this study. In addition, we thank Jordan Rogers, Mike Pitta, and Eddie Byrnes for assistance with data collection in the field. Lisa Vacco-Orlowski (Tipper Tie-Net) provided netting used in this study. An earlier draft of this manuscript was improved by the comments of an anonymous reviewer.

References Cited

Forsythe, H. Y. 1975. Laboratory and field evaluation of insecticides for control of periodical cicada. Ohio Agric. Res. Ext. Circ. 211.

Forsythe, H. Y. 1976. Number of seventeen-year cicada eggs per nest. Environ. Entomol. 5: 169–170.

Gill, S., D. K. Jefferson, R. M. Reeser, and M. J. Raupp. 1999. Use of soil and trunk injection of systemic insecticides to control lace bug on hawthorn. J. Arboric. 25: 38–41.

Hogmire, H. W., T. A. Baugher, V. L. Crim, and S. I. Walter. 1990. Effects and control of periodical cicada (Homoptera: Cicadidae) oviposition injury on nonbearing apple trees. J. Econ. Entomol. 83: 2401–2404.

Marlatt, C. L. 1907. The periodical cicada. U.S. Dep. Agric. Bur. Entomol. Bull. 71: 1–121.

Miller, F. D. 1997. Effects and control of periodical cicada *Magicicada septendecim* and *Magicicada cassini* oviposition injury on urban forest trees. J. Arboric. 23: 225–231.

Miller, F., and W. Crowley. 1998. Effects of periodical cicada ovipositional injury on woody plants. J. Arboric. 24: 248–253.

Nauen, R. 1995. Behavior modifying effects of low systemic concentrations of imidacloprid on *Myzus persicae* with special reference to an antifeeding response. Pestic. Sci. 44: 145–153.

Sadof, C., and M. Raupp. 1996. Aesthetic thresholds and their development, pp. 203–226. *In* L. Higley and L. Pedigo [eds.], Economic thresholds for integrated pest management. University of Nebraska Press, Lincoln, NE.

SAS Institute. 1999. SAS system for windows release 8.02. SAS Institute, Cary, NC.

Sclar, D. C., and W. S. Cranshaw. 1996. Evaluation of new systemic insecticides for elm insect control. J. Environ. Hort. 14: 22–26.

Smith, F. F., and R. G. Linderman. 1974. Damage to ornamental trees and shrubs resulting from oviposition by periodical cicada. Environ. Entomol. 3: 725–732.

White, J. 1980. Resource partitioning by ovipositing cicadas. Am. Nat. 115: 1–28.

White, J. 1981. Flagging: hosts defenses versus oviposition strategies in periodical cicadas (*Magicicada* spp., Cicadidae, Homoptera). Can. Entomol. 113: 727–738.

Webb, R. A., J. R. Frank, and M. J. Raupp. 2003. Recovery of eastern hemlock from attack by hemlock woolly adelgid following treatment with imidacloprid. J. Arboric. 29: 298–302.

Weires, R. W., and R. W. Straub. 1980. Control of the periodical cicada in Eastern New York during 1979. J. Econ. Entomol. 73: 515–519.

Williams, K. S., and C. Simon. 1995. The ecology, behavior, and evolution of periodical cicadas. Annu. Rev. Entomol. 40: 269–295.

Young, L. 2002. The efficacy of micro-injected imidacloprid and oxydemeton-methyl on red gum eucalyptus trees (*Eucalyptus camaldulensis*) infested with red gum lerp psyllid (*Glycaspis brimblecombei*). J. Arboric. 28: 144–147.

Zar, J. H. 1999. Biostatistical analysis, 4th ed. Prentice Hall, Upper Saddle River, NJ.

Received 31 May 2005; accepted 14 September 2005.