Does Imidacloprid Reduce Defoliation by Japanese Beetles on Linden for More Than One Growing Season?

Steven Frank, Robert Ahern, and Michael J. Raupp

Abstract. Laboratory feeding trials confirmed that leaves from little-leaf linden treated with imidacloprid were eaten by Japanese beetles far less than those from untreated trees. Field studies revealed that soil applications of imidacloprid significantly reduced the degree of severe defoliation caused by Japanese beetles in the year that the insecticide was applied and also in the next year. These findings indicate that imidacloprid is a useful tool for arborists in reducing defoliation by this important pest.

Key Words. Defoliation; feeding deterrence; imidacloprid; IPM; Japanese beetle; linden; plant health care.
and at the time of insecticide application in 2004, they were uniformly 3 m (9.9 ft) tall and 7 cm (2.8 in) diameter breast height (DBH). At the end of the study in 2006, trees were approximately 4 m (13.2 ft) tall and 9 cm (3.6 in) DBH. Trees were surrounded by several acres of turfgrass that served as a source for Japanese beetles that readily colonized and consumed leaves of the study trees.

Each tree was randomly assigned to one of two treatments to establish ten replicates of each treatment. Treatments included the application of imidacloprid (Merit® 75 WP; Bayer Corp., Kansas City, MO) and remaining trees left untreated. Trees in the imidacloprid treatment received 2 g (0.07 oz) of imidacloprid per 2.54 cm (1.02 in) DBH in 3.8 L (1 gal) of water. Imidacloprid was mixed in a plastic pail and applied as a soil drench around the circumference of the tree at the root collar within 1 m (3.3 ft) of the trunk. Application took place on 7 May 2004, approximately 1 month before the appearance of Japanese beetles.

**Feeding Deterrence**

It was the goal of this study to determine if leaves from trees treated with imidacloprid were consumed less than leaves from untreated plants. To assess this, we removed single leaves of the same phonological age, specifically the first fully expanded leaf on a branch with an active meristem, from each treated and each untreated tree. The area of each leaf was measured with a Li-Cor® LI-3100C area meter (LI-COR Biosciences, Lincoln, NE). The leaf was placed in a large Petri plate lined with moistened filter paper. Japanese beetles were collected from untreated linden trees at the study site. A single beetle was randomly assigned to a Petri plate containing either a treated or untreated leaf and allowed to feed for 24 hr. At the end of the feeding interval, beetles were removed and the leaf area was once again measured. The amount of leaf area consumed by each beetle was estimated by subtracting the leaf area remaining from the leaf area at the start of the assay.

**Defoliation**

We assessed the ability of imidacloprid to mitigate defoliation severe enough to reduce the aesthetic quality of lindens growing in a landscape as perceived by a homeowner or urban forester. In a previous study Raupp et al. (1988) demonstrated a direct relationship between levels of defoliation and perception of injury to arborvitaes attacked by the evergreen bagworm, *Thyridopteryx ephemeraeformis*. When defoliation by bagworms reached 50%, more than 95% of people agreed that the plants were damaged and that control was warranted. This and other studies such as those by Sadof and Raupp (1987), Coffelt and Shultz (1990), and Sadof and Raupp (1997) confirmed the finding that 50% defoliation was regarded as damaged by more than 90% of people surveyed. To provide an unambiguous definition of defoliation, we chose 50% or more defoliation of an individual leaf to be an indicator of severe damage.

To estimate the efficacy of imidacloprid in preventing severe damage, we examined 80 leaves on each tree treated with imidacloprid and those untreated. At each of four cardinal points, north, east, south, and west, we examined one shoot in the upper half of the tree and one shoot in the lower half of the tree. Ten leaves were examined on each shoot and the number of leaves recorded with 50% or more of their leaf area missing. Defoliation was quantified in the second week of August in 2004, 2005, and 2006 when feeding by Japanese beetles was nearly complete. The response variable used for our statistical analysis was the proportion of leaves severely damaged. Severe damage was expressed as the proportion of leaves in a sample of ten that sustained 50% or more defoliation.

**Statistical Analyses**

Data from the feeding deterrence assays were not normal and could not be normalized through transformation. Variances were not homogeneous. Therefore, amounts of leaf area consumed by beetles eating leaves from untreated and treated trees were compared with a Kruskal-Wallis nonparametric analysis of variance (Zar 1999; Statistix® Analytical Software, Tallahassee, FL).

We studied not only the effect of imidacloprid on Japanese beetle feeding, but also if the application of imidacloprid affected the pattern of damage caused by Japanese beetles as they fed. These data were analyzed as a split, split plot with cardinal direction and leaf position (height) in the canopy as subplots. Proportional data were transformed with the arcsine square root to satisfy the assumptions for analysis of variance as suggested by Zar (1999). The proportions of severely damaged leaves per tree were analyzed with the general linear models procedure (Statistix Analytical Software) in 2004 and 2005. A Tukey test was used to separate treatment means following the analysis of variance (Statistix Analytical Software). In 2006, Japanese beetle populations were very low at our study site and imidacloprid treatments could not be examined for interactive effects with tree height and cardinal direction. We could examine only the direct effect of imidacloprid on severe damage caused by Japanese beetles. Data collected in 2006 did not meet assumptions for analysis of variance and transformations of these data failed correction for normality. Therefore, differences in amounts of severe damage on treated and untreated trees were compared with a Kruskal-Wallis nonparametric analysis of variance (Zar 1999; Statistix Analytical Software).

**RESULTS AND DISCUSSION**

**Feeding Deterrence**

Japanese beetles consumed significantly less leaf tissue on leaves from trees treated with imidacloprid (*P* < 0.0001,
Defoliation in the Field

As a result of dramatically different levels of Japanese beetle abundance and associated damage during all 3 years, we analyzed data from each year independently. The application of imidacloprid significantly reduced the proportion of severely damaged leaves in 2004 and 2005 (2004, $P < 0.0002$, $F_{1,9} = 37.16$; 2005, $P < 0.0001$, $F_{1,9} = 40.09$). In 2004, the proportions of severely damaged, as measured by leaves with 50% or more of their area missing, leaves on treated trees and untreated leaves were $0.07 \pm 0.01$ and $0.23 \pm 0.03$, respectively. In 2005, the proportion of severely damaged leaves on treated and untreated trees were $0.28 \pm 0.03$ and $0.74 \pm 0.03$, respectively. Populations of Japanese beetles during 2006 were very low and the resultant damage was negligible. Most leaves had less than 5% leaf surface area damaged by Japanese beetles on treated and control trees. The proportion of severely damaged leaves did not differ significantly between those treated with imidacloprid and those untreated ($P < 0.55$, $\chi^2 = 0.34$). The proportions of severely damaged leaves on treated and untreated trees were $0.02 \pm 0.001$ and $0.02 \pm 0.001$, respectively.

In 2004, there was no significant interaction between the application of imidacloprid and the height of leaves in the canopy of the tree. This indicates that defoliation related to feeding by Japanese beetles was consistent between high- and low-canopy branches within each insecticide treatment. However, in 2005, there was a significant insecticidal treatment by height interaction ($P < 0.0003$, $F_{1,72} = 14.63$) (Figure 1). In 2005, leaves in the lower canopy of trees treated with imidacloprid sustained very low levels of injury, whereas approximately 50% of leaves in the upper canopy of treated trees were severely damaged.

In both years, defoliation was significantly affected by the height of the leaves in the tree canopy with a clear pattern for greater levels of defoliation in the upper canopy ($2004, P < 0.0001$, $F_{1,72} = 97.73$; 2005, $P < 0.0001$, $F_{1,72} = 34.87$) (Figure 1). This result supports and confirms observations made previously by Fleming (1972) and Rowe and Potter (1996). Rowe and Potter (1996) suggested that Japanese beetles aggregate in the upper canopy of trees as they orient to the silhouette of their hosts during colonization. Once feeding begins, the release of floral and fruit-like volatile compounds such as linalool and aliphatic esters attracts ever-increasing numbers of beetles to the upper canopy of the tree (Loughrin et al. 1996, 1997).

An interaction between direction and insecticidal treatment ($P < 0.016$, $F_{3,54} = 3.76$) governed the degree of defoliation in 2004 (Figure 2). Defoliation was suppressed and similar at all cardinal points on trees treated with imidacloprid, but severe defoliation was more common on western exposures than on northern ones. No such pattern was observed in 2005 when levels of defoliation exceeded 74% and the degree of defoliation was uniformly distributed around the canopies of both treated and untreated trees (Figure 2). It is not clear why defoliation was more intense on western exposures and less so on northern or other exposures. Beetles may have initially colonized the western sides of trees from surrounding habitats. Feeding would increase volatile release and attract other beetles to these portions of the trees (Rowe and Potter 1996; Loughrin et al. 1996, 1997).

During both 2004 and 2005, we observed dead beetles beneath the canopies of trees treated with imidacloprid but not beneath untreated trees. Moreover, Japanese beetles were observed on the foliage of treated trees expressing symptoms of poisoning, including trembling, uncoordinated movement, and arrested movement. Soil applications of imidacloprid reduced defoliation in the year of application and at least 1 year thereafter.
IMPLICATIONS FOR ARBORICULTURE

Imidacloprid can significantly reduce the amount of feeding associated with Japanese beetles. Laboratory feeding trials clearly showed that Japanese beetles consumed significantly less leaf tissue when trees were treated with imidacloprid. Field studies revealed that severe defoliation caused by the feeding of Japanese beetles was greatly reduced by the application of imidacloprid. This reduction was seen during the year of application in which severe defoliation on treated trees was approximately 70% lower than on untreated ones. In the next year, when Japanese beetles were more abundant and defoliation was generally greater, imidacloprid continued to provide a 62% reduction in severe defoliation. This extended period of protection should reduce the necessity for multiple insecticide applications for management of Japanese beetles on lindens and, likely, other amenity trees attacked by this important pest.

Acknowledgments. We thank Chris Tierno and Kate Laskowski for assistance with the collection of data. We also thank Bayer Environmental Science for providing the imidacloprid used in the study.

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Résumé. Les essais alimentaires en laboratoire confirment que les feuilles du tilleul à petites feuilles traitées avec l’imidacloprid étaient moins dévorées par les scolytes japonais que celle d’arbres non traités. Les études sur le terrain ont révélé que les applications sur le sol d’imidacloprid ont significativement diminué le degré de sévérité de la défoliation causée par les scolytes japonais dans l’année où l’insecticide a été appliqué ainsi que l’année subséquente. Ces découvertes indiquent que l’imidacloprid constitue un outil utile pour les arboriculteurs afin de réduire la défoliation par cet important parasite.


Resumen. Ensayos de laboratorio confirmaron que las hojas de tilo tratadas con imidacloprid fueron consumidas mucho menos por escarabajos japoneses que las de árboles no tratados. Estudios de campo revelaron que las aplicaciones al suelo de imidacloprid redujeron significativamente el grado de defoliación severa causada por los escarabajos en el año en que el insecticida fue aplicado, y también en el siguiente. Estos hallazgos indican que imidacloprid es una herramienta útil para los arboristas para reducir la defoliación por esta importante plaga.