

# Activity of Stem-Injected and Soil Applied Imidacloprid Against Hemlock Woolly Adelgid in the Great Smoky Mountains

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**Abstract.** Eastern hemlock (*Tsuga canadensis* [L.] Carrière) is an important component of the riparian ecosystem. Due to the widespread establishment of hemlock woolly adelgid (*Adelges tsugae* Annand)(HWA) across the range of eastern hemlock, woodland trees may be infested for extended periods (years), resulting in their decline. Imidacloprid, a systemic neonicotinoid insecticide, may be used as a strategy in forested settings to manage HWA while more long-term solutions become established, such as biological controls. Symptoms of prolonged infestation include extensive dieback and thinned canopies. In this study, trees with a diameter at breast height (DBH) of  $24.7 \pm 2.7$  SD cm in poor condition were treated with imidacloprid. Trees were treated once by trunk-injection (IMA-jet) or by soil drench in the Greenbrier area of the Great Smoky Mountains National Park, Gatlinburg, TN, USA. Changes in tree growth and HWA density were measured for 3 consecutive years. Imidacloprid-treated trees recovered, whereas the untreated trees declined. Imidacloprid treatments resulted in significantly higher 3-year mean percent growth (65.6% to 71.7% of tips) compared to the untreated controls (10.5% of tips). HWA density 3-year means in the imidacloprid-treated trees (0.10 to 1.09 per cm) likewise were statistically different to the untreated trees (2.72 per cm). The extended activity of imidacloprid-treated hemlock was attributed to storage in the symplast (xylem ray parenchyma) and to perennial needle retention. This study demonstrates that trunk-injection with IMA-jet is effective against HWA and comparable with soil drench to protect trees in the long term ( $\geq 4$  years).

**Keywords.** Hemlock Woolly Adelgid; Imidacloprid; Residual Activity; Soil Drench; Tree Injection.

## INTRODUCTION

Eastern hemlock (*Tsuga canadensis* [L.] Carrière) is an important component of the riparian ecosystem. Riparian zones are the transitional area between land and water which include soils near streams, rivers, and wetlands. Due to the widespread establishment of hemlock woolly adelgid (*Adelges tsugae* Annand) (HWA) across the range of eastern hemlock, woodland trees may be infested for extended periods (years), resulting in tree decline. Recently HWA has spread into Michigan and Nova Scotia, outside the contiguous range of hemlock (Limbu et al. 2018). HWA has a bi-voltine, parthenogenetic life cycle, where the sistens generation occurs over the winter months and the progrediens occur in the spring months. HWA undergoes aestivation as sistens in the summer months. In the southern Appalachian, the sistens occurs on hemlock from mid-July through

mid-March, and the progrediens are present from mid-March through mid-June (Coots et al. 2013). Symptoms of prolonged infestation include extensive dieback and thinned canopies.

As the HWA infestation increases, hemlock growth is inhibited. McClure (1991) reported that HWA densities  $> 4/20$  mm<sup>2</sup> of branch completely inhibit new growth in the following year. Further, as populations increase, HWA are forced to feed on older growth. When the resource is depleted, HWA mortality increases. Doccola et al. (2007) reported that HWA densities 2 to 4/linear cm were associated with decreased twig growth. In this study, we evaluated HWA per cm, cm of twig growth, and percentage of tips with growth as metrics for tree health and treatment effectiveness.

Imidacloprid, a systemic neonicotinoid insecticide, is an effective product for managing HWA (Joseph et

al. 2011). Previous work demonstrates that imidacloprid is an effective product for managing HWA when used as a soil drench (Cowles et al. 2006; Cowles 2009), but there are per-acre limits to its use for the protection of eastern hemlock. Tree injection is an option to consider when treating hemlock in environmentally sensitive areas (e.g., near streams and ponds) and is exempt from per-acre use restrictions. Trees in the Greenbrier area of the Great Smoky Mountains National Park (GRSM), Gatlinburg, TN (UTM E: 281559, N: 3957949), USA were selected for the study. The Greenbrier site is typical of the riparian zone. In an independently evaluated study at the Cornell Botanic Gardens (CBG), IMA-jet (Arborjet, Inc., Woburn, MA, USA) was successfully injected and effective in control of HWA-infested hemlock in Cascadilla Gorge, a riparian zone (Graziano 2010). However, in contrast to the CBG study [located in USDA hardiness zone 5b (−26 to −23 °C)], the Greenbrier site is in USDA hardiness zone 7a (−18 to −15 °C). Winter low temperatures and rapid temperature change have effects on the survival of HWA (Costa et al. 2004). We'd expect lower winter sistens mortality in the Southeast, and therefore see more direct effects of imidacloprid applications. This study was designed to consider the utility of tree injection in riparian areas where soil drench cannot be used and to evaluate the comparative effectiveness of two methods of tree injection over a 4-year period.

Imidacloprid and its two primary metabolites, 5-hydroxy and olefin, were detected in sap and tissue 15 and 36 months post-treatment, respectively (Coots et al. 2013). In another study, concentrations of imidacloprid and olefin were evaluated following a basal drench of imidacloprid in the GRSM, where the concentrations decreased below the  $LC_{50}$  for HWA in year 5 (Benton et al. 2015). Long-term activity therefore is attributed to imidacloprid and olefin in hemlock. In forested settings, HWA suppression has been observed at 120 ppb (0.12 µg/g) 2 years post-treatment (Cowles et al. 2006). In a 3-year study conducted at the Biltmore Estate (Asheville, NC), imidacloprid residues in tree-injected hemlock were detected at 0.2, 1.8, 2.0, and 1.4 µg/g, at 70, 435, 800, and 1165 days, respectively, compared to soil-injected imidacloprid where residues were 0.14, 0.33, 3.1, and 2.4 for the same periods (Doccola et al. 2012). In that study, trees were in similarly poor condition as in the present study. Normal resumption of growth was not

observed in the Biltmore study until 2 years post-treatment, where 72.3% and 41.7% of tip growth was observed in the tree and soil injections, respectively. Although the  $LC_{50}$  was met or exceeded at 70 days, trees recovered slowly. This observation was consistent with those reported by Webb et al. (2003), where they found that trees with significant dieback recovered only slowly, compared to hemlock that were infested, but in better condition. Untreated hemlock remained sparsely foliated and exhibited dieback.

HWA feeds in the xylem ray parenchyma cells (McClure 1991). Parenchyma is vascular tissue that grows as axial and radial tissues as a reticulated network within the xylem. It is a component of the symplast (or living tissue) and plays a role in growth, metabolism, reproduction, storage, and defense (Shigo 1991). The xylem tissue is apoplastic (nonliving) and functions to move liquid and dissolved solutes; movement of liquids is bi-directional and acropetal, with net movement upward. Long-term storage of solutes is associated with the symplast. The initial movement upward into the canopy occurs within the xylem. In deciduous trees, much of the imidacloprid is shed at leaf fall. In a study by Mota-Sanchez et al. (2009) using  $^{14}C$ -labeled imidacloprid, the researchers found that the imidacloprid accumulated in the foliage during the first season following injection into ash. However, in the second year they found imidacloprid primarily in the trunk tissues. They concluded that the movement of imidacloprid in ash trees was through the xylem. Green ash (*Fraxinus pennsylvanica* Marsh) and white ash (*F. americana* L.) shed their leaves annually, and as a consequence, much of the imidacloprid is lost from the tree. Conifers are comprised of uniseriate parenchyma characterized by a single layer (von Arx et al. 2015). Both parenchyma and foliage are the storage tissues in evergreen conifers, including hemlock. Imidacloprid is likely stored within the xylem axial and radial parenchyma. Dilling et al. (2010) found a concentration gradient within the canopy that decreased with tree height. This observation may be in part due to tree condition (tree transpiration) and to formulation used and method of application. For example, transpiration from the tree canopy is negatively affected by dieback, a sparse canopy, or in trees in a suppressed condition. These conditions may also result in imidacloprid binding to cellulose, particularly if formulations are already saturated, such as a 10% imidacloprid used in that study. However,



Benton et al. (2015) did not find significant differences in strata, but treatments in that study were applied by soil drench alone. Xylem cellulose is 44% carbon (Heukelekian and Waksman 1925), constituting an extensive adsorptive surface. The carbon adsorption coefficient of imidacloprid is ~350 (Cox et al. 1997), which suggests moderate adhesion to xylem. Pressure bomb extractions such as were conducted by Dilling et al. (2010) extract sap from the xylem tissues; whereas needle and twig tissue milling (Dilling et al. 2010; Benton et al. 2015) extract from the entire vascular tissues (xylem and parenchyma). However, Dilling et al. report that sap from needles and twigs (milled) met or exceeded the  $LC_{50}$  for HWA, whereas pressure bomb extraction (sap from xylem) did not. This differential analysis supports symplastic absorption of imidacloprid. The application of imidacloprid in an evergreen is retained over the leaf's life span and protected from photolytic degradation (Scholz and Reinhard 1999). In hemlock, needles are retained perennially (i.e., from 3 to 6 years) (Ford and Vose 2006), and may play a role in the extended activity reported.

## METHODS

This 4-year study was conducted from June 24, 2010, through May 20, 2014, in the Greenbrier area of the Great Smoky Mountains National Park, Gatlinburg,

TN (UTME: 281559, N: 3957949). Eastern hemlock (*Tsuga canadensis*) infested with hemlock woolly adelgid (*Adelges tsugae*) (HWA) were selected for study. Trees were randomized using 10 polygon locations within the Greenbrier area that: (a) were free of previous HWA chemical or biological treatments, (b) had at least 7 eastern hemlocks within the diameter range for the study (i.e., 20 to 30 cm DBH), and (c) had overall tree health within the normal parameters of HWA treatments at GRSM (a minimum 10% live crown ratio and 70% or less canopy transparency) (Schomaker et al. 2007). For each of the 10 sites, 4 treatment types (3 plus untreated control) were randomly assigned to the 7 trees within the polygon. The scarcity of untreated trees healthy enough within the region limited our ability to use a more random study design. The trees ranged in size from 20.6 to 30.5 cm DBH with a mean of 24.7 cm. Tree transparency rating was an average of 58% with live crown canopy rating of 50% (Figure 1).

Four treatments were selected to evaluate the efficacy of imidacloprid applied to the soil or by tree injection. These included Merit® soil drench (75% imidacloprid WP, Bayer Environmental Science, Clayton, NC) or trunk injection using IMA-jet (5% wt./wt. imidacloprid SL, Arborjet, Inc., Woburn, MA). Tree injections were applied using the Ecoject capsule injector (BioForest Technologies, Inc., Sault



Figure 1. Example of canopy transparency in hemlock reflects the poor growth and thinned foliage in 2011 (left), a result of HWA infestation. Overall, trees in the study were in such poor condition that no foliage samples were taken until 2012, two years after treatment. Photo (right) was taken of the same hemlock in 2013 showing increased canopy density and improved growth following tree injection with imidacloprid.

**Table 1. Treatments, methods of application, number of replicates, dosage per 2.5 cm DBH, and milliliters per injection site applied.**

Treatment	Method	Tree ID	N	Dose g/2.5 cm DBH	mL/2.5 cm DBH	mL/inject site
IMA-jet	Air Hydr/#4 Arborplug	AHA	10	0.2	4	8
IMA-jet	Ecoject	ECO	10	0.2	4	8
UTC	Untreated check	UTC	10	0	0	0
Merit 75WP	Soil drench	DRE	10	1.42	NA	NA

Ste. Marie, ON) or by Air Hydraulic injector (Arbor-jet, Inc.). Applications were made between June 24 and June 28, 2010.

The Air Hydraulic injector is a liquid delivery system that utilizes compressed air to apply formulations directly to the vascular tissue. The No. 4 Arborplug® was used in conjunction with the injector and is designed to prevent the chemistry from contacting the meristematic tissues and to minimize phytotoxicity. The Ecoject uses a refillable 8-mL-capacity canister and removable injector tip for application. Tree injections were applied at 8 mL and inserted every 15 cm of basal trunk circumference; the gram active ingredient (GAI) applied was 0.2 per 2.5 cm DBH. The basal drenches were applied within 0.6 m of the base of the hemlock trunk at 1.42 GAI per 2.5 cm DBH. Each treatment and an untreated control were replicated 10 times in a completely randomized design. A summary of the treatments is presented in Table 1. Following treatments, 4 branches (~48 cm length) were taken from each of 4 quadrants each November from the mid- to upper canopy in order to evaluate twig and foliar growth, HWA density, and percent HWA mortality. Each of the 4 samples was cut into 5 subsamples, each consisting of 3-year growth increments, from the branch terminal to the laterals. Thus each tree generated 20 subsamples each year from which to record tree responses. No branch samples were taken in the spring of 2011 due to the poor overall condition of the trees (Figure 1). We counted the number of adelgids on the 3-year branch samples and measured branch lengths. From these two metrics we calculated the number of HWA per cm of branch, and tree growth over time. We estimated the percentage of growing points per branch sample per treatment.

### Statistical Methods

For both 3-year growth (cm) and HWA per cm, the data collected on 20 subsamples in each of years

2012, 2013, and 2014 were averaged for each tree and year, and resulting means for growth and HWA counts were subjected to repeated measures analysis of variance (RM ANOVA) using PROC MIXED (SAS Inc., Cary, NC, USA). Fixed effects in the RM ANOVA model were Trt, Year, and Trt\*Year. Multivariate ANOVA, heterogeneous compound symmetry (CSH), and split plot (CS) were compared using the Bayesian Information Criterion (BIC) produced by PROC MIXED (SAS) and the model with smallest BIC was selected. The simple split plot ANOVA (with year viewed as a subplot factor) was found to be adequate for cube-root-transformed HWA counts, while the CSH model was selected for square-root-transformed 3-year growth means. Comparisons among treatment means were carried out using the LSD procedure at significance level 0.05, with results reported by year if Trt\*Year interaction was significant.

Data were transformed before carrying out analysis of variance (ANOVA) in order to achieve approximate homogeneity of variances across treatments. The arcsine transformation was applied to the proportion of terminals showing growth. ANOVA results are given for the transformed data and back-transformed treatment means are reported in graphs.

In addition, treatment comparisons were carried out separately for each year (in MINITAB Version 17, Minitab, Inc., State College, PA). The grouping information used was the Fisher LSD Method at the 95% level of confidence.

## RESULTS

### HWA per cm

Year and Treatment effects were strong ( $F_{2,68} = 37.61$ ,  $P < 0.001$  and  $F_{3,34} = 37.61$ ,  $P < 0.001$ , respectively) due mainly to higher counts for the control treatment, which decreased from 2012 to 2014. The interaction effect Trt\*Year was also significant ( $F_{6,68} = 3.75$ ,  $P = 0.002$ ).

**Table 2. Density of hemlock woolly adelgid per cm of twig from 2012 to 2014: the untreated control trees (UTC) had statistically higher HWA densities from 2012 through 2014 compared to the imidacloprid treatments applied in 2010. DRE = soil drench, AHA = Air Hydraulic tree injection, and ECO = Ecoject injector. Values presented are back-transformed from means calculated from cube-root-transformed data.**

TRT	N	2012 Mean	2013 Mean	2014 Mean	3-yr Mean
UTC	9	3.94 A	2.77 A	1.45 A	2.72 A
DRE	10	2.09 B	1.10 B	0.10 B	1.10 B
AHA	10	0.27 C	0.04 C	0.00 B	0.15 C
ECO	9	0.17 C	0.13 C	0.15 B	0.10 C

Means that do not share a letter are significantly different, Fisher's protected LSD,  $P = 0.05$ .

**Table 3. The percent of growing tips from 2012 to 2014 and 3-year mean, where the new twig growth was statistically higher in the treatments receiving either a tree injection of imidacloprid (AHA and ECO) or a soil drench treatment (DRE) of imidacloprid compared to the untreated trees (UTC) in each evaluation conducted. Means are back-transformed values from arcsine-transformed data.**

TRT	N	2012 Mean	2013 Mean	2014 Mean	3-yr Mean
AHA	10	80.4 A	72.6 A	62.0 A	71.7 A
DRE	10	74.5 A	68.6 A	63.1 A	68.7 A
ECO	10	72.3 A	67.4 A	57.0 A	65.6 A
UTC	10	15.6 B	6.5 B	9.3 B	10.5 B

Means that do not share a letter are significantly different, Fisher's protected LSD,  $P = 0.05$ .

HWA per cm remained significantly higher in the untreated controls from 2012 through 2014 compared to the imidacloprid treatments. The soil drench treatments, however, were intermediate in HWA densities until 2014, suggesting that this method required more time to affect HWA densities. Significantly lower HWA densities were consistently observed in the Air Hydraulic and Ecoject injection treatments (Table 2).

### Three-Year Growth

A significant year effect for growth was due to lower growth in 2014 ( $F_{2,68} = 35.33$ ,  $P < 0.001$ ), and the significant treatment effect was due to lower growth amounts in all years for the control ( $F_{3,34} = 6.69$ ,  $P = 0.001$ ). Trt\*Year interaction was borderline ( $F_{6,68} = 2.14$ ,  $P = 0.060$ ) but for comparison with results for HWA density, back-transformed growth means are reported for each treatment in each year.

The percent of growing points per sample per tree per sample date is presented as well as the 3-year mean. In this analysis, the imidacloprid treatments showed significant responses in growth compared to the untreated controls in all years evaluated (Table 3).

HWA mortality was statistically significant in the imidacloprid-treated trees compared to the untreated

controls in observations made in 2012 only. In the subsequent observations made in 2013 and 2014, HWA mortality remained high across all treatments (Table 4).

Regression analyses were conducted to evaluate the response in percent tip growth the year following HWA infestation in hemlock. We conducted analyses comparing the HWA per cm in 2012 and percent of twig growth in 2013 and the HWA per cm in 2013 and percent of twig growth in 2014. The regression equations are: (1) percent growth 2013 =  $89.91 - 13.76 \text{ HWA/cm 2012}$  and (2) percent growth 2014 =  $76.96 - 17.41 \text{ HWA/cm 2013}$ ;  $R^2$  were 57.7 and 56.2, respectively. In each, as HWA density increased, the percent twig growth decreased in the subsequent year. An additional analysis of the 3-year mean HWA per cm compared to 3-year mean percent twig growth resulted in a higher  $R^2$  of 73.5. The regression equation is: 3-year percent twig growth =  $91.8 - 24.21 \text{ 3-year HWA/cm}$  (Figure 2).

### DISCUSSION

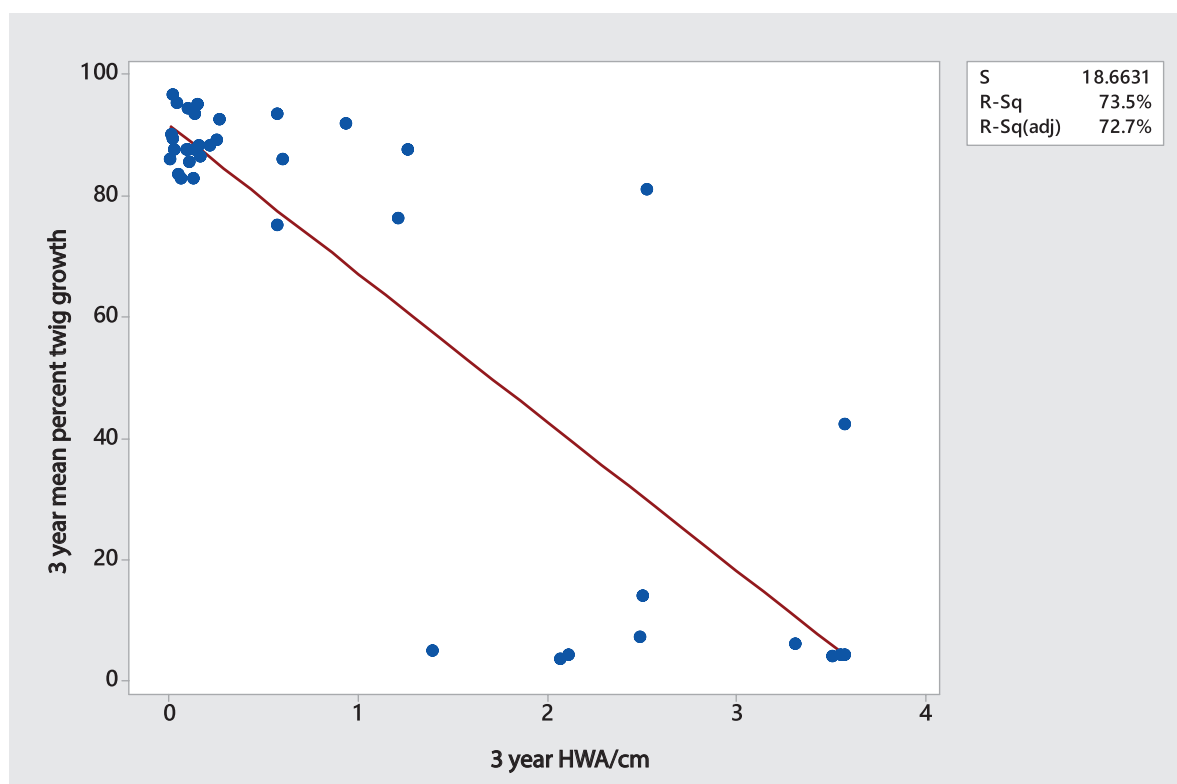
Following application, changes in annual tree growth and HWA density were measured for 3 consecutive years. Poor tree condition and insufficient growth in 2011 precluded data collection in that year. However,



**Table 4.** Proportion HWA mortality from 2012 to 2014, where we observed statistical differences in HWA mortality in the imidacloprid-treated trees (AHA, ECO, and DRE) compared to the untreated trees (UTC) in 2012. We did not observe any significance in the two subsequent years, where HWA mortality remained high across treatments. The high percent HWA mortality in the UTC is likely related to the diminished growth in those trees (i.e., reduced tip growth and twig length). AHA = air hydraulic, ECO = Ecoject, DRE = soil drench, UTC = untreated controls. Data are back-transformed following arcsine square-root transformation of the proportions.

TRT	N	2012 Mean	2013 Mean	2014 Mean
AHA	10	1.00 A	0.93 A	1.00 A
ECO	9	0.97 A	0.84 A	0.90 A
DRE	10	0.96 A	0.87 A	1.00 A
UTC	9	0.71 B	0.91 A	0.94 A

Means that do not share a letter are significantly different, Fisher's protected LSD,  $P = 0.05$ .



**Figure 2.** Regression analysis of the proportion of twigs growing, measured over 3 years (3-year mean percent twig growth), versus density of HWA, averaged over 3 years (3-year HWA/cm). The relationship shows an inverse correlation, consistent with the observations reported by McClure (1991); that is, as HWA density increases, twig growth is inhibited.

the imidacloprid treatments were effective in managing HWA infestations in the GRSM for the period of this study (4 years). Tree-injection treatments using either the Arborjet, Inc. Air Hydraulic technology or the Bio-Forest Technologies Ecoject system effectively delivered IMA-jet (5% wt./wt. imidacloprid) into the vascular tissues of eastern hemlock.

It should be noted that HWA densities greater than 2.0 per linear cm can negatively affect tree growth (Doccoła et al. 2007). After 4 years, the untreated checks had HWA densities of 2.7 per linear cm of twig; these trees remained in poor condition. Imidacloprid significantly reduced the HWA densities; for the trunk injection treatments this was dramatically

apparent in the second year following treatment, whereas for the soil drench treatment the populations were reduced gradually so that by the third year after treatment the densities were equivalent to those resulting in tree injection treatments (Table 2).

Although we report that the untreated control (UTC) trees had HWA mortality in year 4 similar to that of the imidacloprid treatments (Table 4), the percentage of growing tips degraded in the UTC. That is, the trees continued in poor health. The deteriorated resource most likely resulted in the high mortality observed in the UTC. In contrast, the imidacloprid treatments resulted in high HWA mortality, and the trees recovered. This is reflected in the 3-year mean percent new growth of imidacloprid treatments, which varied from 65.6% to 71.7%, differing significantly from only 10.5% in the UTC (Table 3).

The extended activity of trunk-injected imidacloprid has been linked to the production and persistence of imidacloprid and its olefin metabolite in the plant (Coots et al. 2013), to storage in the symplast (xylem ray parenchyma) (Turcotte et al. 2017) and to perennial needle retention. Needle retention plays a role in imidacloprid persistence as it (and its metabolites) would be shed with needle drop (Docola et al. 2012). However, in contrast to Dilling et al. (2010), we found trunk-injected IMA-jet to be as, if not more effective than soil drench. Furthermore, there were differences in the results reported for tree injection in these studies. In each study, imidacloprid residues from the mid-canopy at 24 months post-treatment at 0.15 mL AI per 2.5 cm DBH were reported by Dilling et al. at ~23.6 to 56.2 parts per billion (ppb), and by Docola et al. at 2.04 parts per million (ppm) or 205 ppb. In these studies, we observed an order of difference in the amount of imidacloprid from twig and sap tissues. Three factors may help to explain the difference in findings, which are (1) the formulation used, (2) the method of application, and (3) the tree vascular system. In each study, trees were injected using either Imicide (10% wt./wt. imidacloprid) (JJ Mauget, Co., Arcadia, CA) or (in one treatment) IMA-jet (5% wt./wt. imidacloprid) at the rate of 0.15 mL (AI) per 2.5 cm DBH. The lower solute load of the IMA-jet formulation may help to increase the uptake through the restrictive vascular tissues by protecting it from precipitation at the injection site, which we have observed with increasing imidacloprid concentrations in post-injection tree autopsies (unpublished). Uptake of

product applied by tree injection relies on transpiration from the canopy. However, we have observed differences around the hemlock bole: each injection point does not take up liquid at the same rate. We believe this is related to the variability in transpiration rates within the canopy. Tree capsule injectors (as used in the Dilling study) apply product at low pressure [~14 to 34 kilopascal (kpa)], into an injection point of 0.15 cc (0.4 cm diameter drill bit × 1.2 cm deep) and therefore are sensitive to points in the bole where movement of sap is limited. The air hydraulic applies product at higher pressure (~689 kpa), into an injection point of 2.4 cc (0.9 cm diameter drill bit × 3.75 cm deep) to deliver product and therefore is less sensitive to points in the bole where movement of sap is limited.

The imidacloprid soil drench was slower to act systemically, but has potential for long-term activity. Uptake of imidacloprid from soil drench is dependent upon available soil moisture, which is highly variable. Tree injection is not dependent upon soil moisture *per se* for movement within the vascular system. It is, however, dependent upon the environmental conditions that favor evapo-transpiration from leaf stomata. These conditions in general require a negative vapor deficit at the leaf surface. Tree injection has utility in riparian areas, near aquatic habitats, and in soils with low cation exchange capacity (CEC); soil applications on the other hand, are more appropriate in areas away from surface waters, and in soils with high cation exchange capacity (CEC).

Imidacloprid, a systemic neonicotinoid insecticide, is an effective tool to manage HWA. Previous work demonstrates that imidacloprid is an effective product for managing HWA when used as a soil drench (Cowles et al. 2006; Cowles 2009), but there are per-acre limits to its use for the protection of eastern hemlock. Tree injection is an option to consider when treating hemlock in environmentally sensitive areas (e.g., near streams and ponds) and is exempt from per-acre use restrictions. This study demonstrates that tree injection with IMA-jet is effective against HWA and comparable with soil drench to protect trees in the long term (≥ 4 years) until other long-term approaches, such as the introductions of predators, become more widely established.

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**Conflicts of Interest:**

Joseph J. Docola reports being employed to conduct product research for efficacy as Director of Research & Development for Arborjet, Inc.

**Résumé.** La pruche du Canada (*Tsuga canadensis* [L.] Carrière) est une composante importante de l'écosystème riverain. En raison de la présence largement répandue du puceron lanigère de la pruche (*Adelges tsugae* Annand) (PLP) dans l'aire de répartition de la pruche du Canada, les arbres des forêts peuvent être infestés pendant de longues périodes (années), ce qui entraîne leur déclin. Un insecticide systémique néonicotinoïde, l'imidaclopride, peut constituer une stratégie utilisée dans un contexte forestier afin de gérer PLP en attendant que des solutions à plus long terme soit développées, telle la lutte biologique. Les symptômes d'une infestation prolongée incluent le dépérissement sévère et le feuillage clairsemé. Pour cette recherche, des arbres d'un diamètre à hauteur de poitrine (DHP) de  $24,7 \pm 2,7$  SD cm en mauvais état, furent traités avec l'imidaclopride. Les arbres furent traités une fois par injection au tronc (IMA-jet) ou par trempage du sol dans la région de Greenbrier du parc national de Great Smoky Mountains, Gatlinburg au Tennessee, États-Unis. Les changements de la croissance des arbres et de la densité PLP ont été mesurés pendant trois années consécutives. Les arbres traités avec l'imidaclopride se sont rétablis tandis que ceux non-traités ont dépéri. Les traitements à l'imidaclopride ont entraîné un pourcentage moyen de croissance sur trois ans nettement supérieur (65,6 % à 71,7 % des pointes) par rapport aux témoins non traités (10,5 % des pointes). Les moyennes triennales de densité de PLP dans les arbres traités à l'imidaclopride (0,10 à 1,09 par cm) étaient également statistiquement différentes de celles des arbres non traités (2,72 par cm). L'activité prolongée des pruches traitées à l'imidaclopride a été attribuée au stockage dans le symplaste (parenchyme des rayons du xylème) et à la rétention dans les aiguilles persistantes. Cette recherche a démontré que l'injection tronciale avec IMA-jet est efficace contre le PLP et est comparable au trempage du sol pour protéger les arbres à long terme ( $\geq 4$  ans).

**Zusammenfassung.** Die kanadische Hemlocktanne (*Tsuga canadensis* [L.] Carrière) ist ein wichtiger Bestandteil des Uferökosystems. Aufgrund der weit verbreiteten Etablierung der Hemlocktannen-Gallenlaus (*Adelges tsugae* Annand) (HWA) im gesamten Verbreitungsgebiet der kanadische Hemlocktanne können Waldbäume über längere Zeiträume (Jahre) befallen werden, was zu ihrem Rückgang führt. Imidacloprid, ein systemisches Neonicotinoid-Insektizid, kann in bewaldeten Gebieten als Strategie zur Bekämpfung von HWA eingesetzt werden, während sich längerfristige Lösungen wie biologische Schädlingsbekämpfungsmittel etablieren können. Zu den Symptomen eines lang anhaltenden Befalls gehören sich ausdehnendes Absterben und ausgedünnte Baumkronen. In dieser Studie wurden Bäume mit einem Durchmesser in Brusthöhe (DBH) von  $24,7 \pm 2,7$  SD cm in schlechtem Zustand mit Imidacloprid behandelt. Die Bäume wurden einmal durch Stamminjektion (IMA-jet) oder durch Bodendurchtränkung im Greenbrier-Gebiet des Great Smoky Mountains National Park, Gatlinburg, TN, USA, behandelt. Änderungen des Baumwachstums und der HWA-Dichte wurden in drei aufeinander folgenden Jahren gemessen. Mit Imidacloprid behandelte Bäume erholten sich, während die unbehandelten

Bäume zurückgingen. Imidacloprid-Behandlungen führten zu einem signifikant höheren durchschnittlichen prozentualen Wachstum über drei Jahre (65,6% bis 71,7% der Spitzen) im Vergleich zu den unbehandelten Kontrollen (10,5% der Spitzen). Auch die 3-Jahres-Mittelwerte der HWA-Dichte bei den mit Imidacloprid behandelten Bäumen (0,10 bis 1,09 pro cm) unterschieden sich statistisch gesehen von denen der unbehandelten Bäume (2,72 pro cm). Die verlängerte Aktivität der mit Imidacloprid behandelten Hemlocktannen wurde der Einlagerung im Symplast (Xylem-Strahlenparenchym) und der mehrjährigen Nadelretention zugeschrieben. Diese Studie zeigt, dass die Stamminjektion mit IMA-Jet gegen HWA wirksam ist und vergleichbar mit einer Bodenbegrünung Bäume langfristig ( $\geq 4$  Jahre) schützt.

**Resumen.** El tsuga oriental (*Tsuga canadensis* [L.] Carrière) es un componente importante del ecosistema ripario. Debido al establecimiento generalizado del adélido (*Adelges tsugae* Annand) (HWA) a través del rango de distribución de tsuga oriental, los árboles del bosque pueden ser infestados durante periodos prolongados (años), lo que resulta en su declive. El imidacloprid, un insecticida neonicotinoide sistémico, puede utilizarse como estrategia en entornos forestales para gestionar HWA, mientras que se logran soluciones a largo plazo, como los controles biológicos. Los síntomas de la infestación prolongada incluyen muerte regresiva y copas ralas. En este estudio, los árboles con un diámetro a la altura del pecho (DBH) de  $24,7 \pm 2,7$  cm en condición pobre de salud fueron tratados con imidacloprid. Los árboles fueron tratados una vez por inyección de tronco (IMA-jet) o por zanjado del suelo en el área de Greenbrier del Great Smoky Mountains National Park, Gatlinburg, TN, EE. UU. Los cambios en el crecimiento de los árboles y la densidad de HWA se midieron durante 3 años consecutivos. Los árboles tratados con imidacloprid se recuperaron, mientras que los árboles no tratados declinaron. Los tratamientos con imidacloprid dieron como resultado un crecimiento promedio significativamente mayor al 3er año (65,6% a 71,7% de las puntas) en comparación con los controles no tratados (10,5% de las puntas). La densidad de HWA de los árboles tratados con imidacloprid (0,10 a 1,09 por cm) también resultó estadísticamente diferentes a los árboles no tratados (2,72 por cm). La actividad prolongada de imidacloprid se atribuyó al almacenamiento en el simplasto (parénquima de rayos de xilema) y a la retención perenne de la aguja. Este estudio demuestra que la inyección al tronco con IMA-jet es eficaz contra HWA, comparable con el zanjado del suelo para proteger los árboles a largo plazo ( $\geq 4$  años).