N O T E

Efficacy of Imidacloprid and Dinotefuran Applied as Soil Drenches or Trunk Sprays for Managing *Adelges tsugae* (Hemiptera: Adelgidae) on Mature Hemlock Trees in a Forest[1]

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Tsuga canadensis (L.) Carrière (eastern hemlock) and *T. caroliniana* Engelm (Carolina hemlock) are threatened by *Adelges tsugae* (Annand) (Hemiptera: Sternorrhyncha: Adelgidae), an introduced insect pest. *Adelges tsugae*, or the hemlock woolly adelgid, is native to southern Japan and was first observed in Virginia in the 1950s. It now is a serious pest of hemlock in 17 states in the eastern United States often killing infested trees in native forests stands (Gouger 1971, Scientific Tree Topics 3: 1 - 9; Souto et al. 1996, Pg. 9 - 15 *In* Proceedings: of the First Hemlock Woolly Adelgid Review, U.S. Dep. Agric. FS FHTET-96 - 10; Havill et al. 2006, Ann. Entomol. Soc. Am. 99:195 - 203).

Currently, the only viable method of *A. tsugae* management is with insecticides. The systemic activity of imidacloprid has been successful against *A. tsugae* when applied to the soil, trunk, or foliage of hemlock trees (Steward and Horner 1994, Arthropod Manage. Tests 19: 348; Webb and Raupp 2003, J. Arboric. 29: 298 - 302; Cowles et al. 2006, Pg. 169 - 172 *In* Proceedings: Third Symposium on Hemlock Woolly Adeligd in the Eastern United States, U.S. Dep. Agric. FS FHTET-2005 - 1), and several imidacloprid products are labeled for *A. tsugae* management.

Dinotefuran also is active against *A. tsugae*, and Safari™(Valent U.S.A. Corporation, Walnut Creek, CA), a commercial product containing this active ingredient, is registered for HWA management through a Section 24(c) Special Local Needs (SLN) label. Dinotefuran is systemic, and its uptake by and distribution within hemlock trees are reported to be more rapid than those of imidacloprid (Corbel et al. 2004, J. Med. Entomol. 41: 712 - 717; Cowles et al. 2006, Pg. 169 - 172 *In* Proceedings: Third Symposium on Hemlock Woolly Adeligd in the Eastern United States, U.S. Dep. Agric. FS FHTET-2005 - 1).

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Pentra-Bark® (Quest Products Corp., Linwood, KS) is a nonionic organosilicone wetting agent designed to improve penetration through bark of water-based formulations of fungicides, insecticides, plant growth regulators, and micronutrients. Use of this surfactant with either imidacloprid or dinotefuran may facilitate movement of these insecticides directly into the vascular transport system.

The objectives of this study were 2-fold: (1) to compare the efficacy of imidacloprid and dinotefuran for management of *A. tsugae* in a natural environment and (2) to determine the effect of application method on insecticide efficacy. Two application methods were compared: soil drenches and trunk sprays in combination with the surfactant Pentra-Bark.

Four insecticide treatments (i.e., two commercial products each applied by two methods) and a nontreated control were used in this study: soil drench with imidacloprid (Marathon®II; OHP Inc., Mainland, PA); soil drench with dinotefuran (Safari 20SG; Valent U.S.A. Corp., Walnut Creek, CA); trunk spray with imidacloprid plus Pentra-Bark ; (4) trunk spray with dinotefuran plus Pentra-Bark; and (5) nontreated control. The study was conducted in the DuPont State Forest (NC Division of Forest Resources) in Henderson Co., using a completely randomized design with 5 single-tree replications in each treatment. All 25 trees selected for the study were eastern hemlocks that were 20 - 21 cm diam. at breast height (dbh). Trees receiving soil drench applications were at least 50 m apart to prevent cross contamination from the insecticides, and trees receiving trunk spays were at least 1.8 m apart. Each tree in the study was marked with an aluminum tag, so it could be located easily for sampling over the course of the study.

All treatments were applied on 12 October 2007. The amount of insecticide used in each treatment was based on tree dbh. Soil drenches were applied at the recommended rates on product labels: 1.2 g of active ingredient (AI)/2.54 cm of dbh. For each insecticide, 9.6 g of AI was placed in 30.3 L of water and the mixture was poured directly around the base of the trunk of each tree out to a distance of approx. 30 cm. The amount of product used for each tree was 40 mL of Marathon II or 48 g of Safari 20 SG. Prior to application, the duff layer around the base of the tree was removed to enhance percolation of the insecticide into the soil.

Trunk sprays were applied at a rate of 1.7 g of AI/2.54 cm of dbh, for a total of 13.6 g of AI per tree. The total amount for all 5 trees in each treatment was prepared in a single batch: the imidacloprid treatment contained 284 mL of Marathon II, 3.8 L of water, and 88.7 mL of Pentra-Bark, and the dinotefuran treatment contained 340.2 g of Safari 20SG, 3.8 L of water, and 88.7 mL of Pentra-Bark. After each mixture was prepared, 756 mL was placed into each of five 1.2-L hand-pump spray bottles (Ace®, Professional Hand Sprayer, Oak Brook, IL) to ensure that each tree received an equal volume. On each tree, the trunk was sprayed from a height of 10 cm to 180 cm above the soil surface until the pump sprayer was emptied.

To evaluate mortality of *A. tsugae*, trees were sampled before, and at 26 (06 November 2007), 51 (01 December 2007), and 176 (25 May 2008) after treatments were applied. Although pretreatment samples were collected in October 2007, mortality assessments at this time were considered to be inaccurate because *A. tsugae* just were beginning to come out of aestivation. A pole pruner was used to collect branch samples from 3 different heights above ground from each tree: low (1 m), medium (4 m), and high (7 m). For each tree, a 4-L plastic bag was filled with hemlock branches from each height. After samples from all trees were collected, they were returned to the laboratory and stored overnight in an environmental chamber (18°C, 60% RH, 24:0

[light:dark] photoperiod). On the following day, 100 *A. tsugae* were selected: 34 from branches at the low height and 33 from branches at the middle and upper heights. *Adelges tsugae* were examined under a dissecting microscope (20×) and rated as either alive (active) or dead (inactive). If no activity was obvious, *A. tsugae* were touched with a dissecting pin in an attempt to elicit movement prior to rating them as alive or dead. The number of *A. tsugae* rated as dead was used to calculate percent mortality for each tree.

Analysis of variance (ANOVA; PROC GLM, SAS 9.3, SAS Institute Inc, Cary, NC, 2008) was used to determine if there were significant differences in mean *A. tsugae* mortalities among treatments. If significant differences occurred among treatment means, orthogonal contrasts were used to independently compare effects of insecticide AI and application method. The total number of dead *A. tsugae* for each treatment in each month was the response variable in these analyses. Due to violations of normality and homogeneity of variances, a ranking procedure was used (PROC RANK, SAS 9.3) that assigned ranks to the observations in the data set based on mortality values. An ANOVA (PROC GLM) of the ranks resulted in a nonparametric analysis of the treatment effects.

Orthogonal contrasts provide an independent partitioning of the overall treatment effect, i.e., each contrast relates to an independent question and can be interpreted individually, regardless of the overall treatment test significance. Therefore, even though the overall tests for treatment effect on mortality ($F = 1.47$; df = 4; $P = 0.246$) (Table 1) were not significant on day 26 (see below), the dinotefuran versus imidacloprid contrast was, in fact, significant ($F = 4.17$; df = 4; $P = 0.054$) (Table 1).

Treatment efficacy varied over time (Table 1). There was no significant difference among treatments in *A. tsugae* mortality 26 after treatment ($F = 1.47$; df = 4; $P = 0.246$); however, significant differences among treatments were observed at both 51 ($F = 10.29$; df = 4; $P < 0.001$) and 176 after treatment ($F = 5.64$; df = 4; $P = 0.003$). *Adelges tsugae* mortality was significantly higher on trees treated with dinotefuran compared with those treated with imidacloprid on all 3 sample dates: 26 days ($F = 4.17$; df = 4; $P = 0.054$), 51 days ($F = 29.91$; df = 4; $P < 0.001$), and 176 days ($F = 15.90$; df = 4; $P = 0.001$) after treatment. There was significantly higher mortality on treated trees than on the nontreated control trees at both 51 ($F = 6.93$; df = 4; $P = 0.016$) and 176 ($F = 6.26$; df = 4; $P = 0.021$) days posttreatment. However, application method had no significant effect on *A. tsugae* mortality with either insecticide on any of the sample dates. Therefore, both trunk sprays and soil drenches were equally effective at delivering these two insecticides.

Because *A. tsugae* populations are density dependent upon the nutritional quality of their host trees, populations decline as tree health deteriorates (McClure et al. 2001, *In* Hemlock Woolly Adelgid, U.S. Dep. Agric. FS FHTET-2001 - 03). The region of North Carolina where the field sites were located had been in drought conditions for 7 out of the previous 10 years. The Palmer drought severity index (PDSI) uses precipitation and temperature data to determine the level of drought for a specific geographical region. The index is scaled from -4 to +4, with negative numbers representing different severity levels of drought (-1 = drought, -2 = moderate drought, -3 = severe drought, and -4 = extreme drought). The PDSI for this region of North Carolina in 2007, when this study was conducted, was between severe and extreme drought (Fig. 1). This may have impacted uptake and distribution of the systemic insecticides applied to the trees. Tree stress also may have caused some of the mortality of *A. tsugae* observed.

Table 1. Percent mortality of *Adelges tsugae* on hemlock trees at 26, 51, and 176 days after application that were not treated (controls) or received one of four insecticide treatments: trunk spray with dinotefuran plus Pentra-Bark, soil drench with dinotefuran, trunk spray with imidacloprid plus Pentra-Bark®, and soil drench with imidacloprid.

		No. days after application[a]					
		26		51		176	
Insecticide	Application method	Mean	±SE	Mean	±SE	Mean	±SE
Control		53.0	17.8	60.6	11.8	39.0	17.8
Dinotefuran	Trunk spray	69.4	9.0	94.0	2.5	97.8	2.0
	Soil drench	84.6	7.7	100.0	0	99.4	0.6
Imidacloprid	Trunk spray	52.2	7.4	60.5	11.2	57.7	17.6
	Soil drench	59.2	13.3	63.0	14.6	49.0	19.2
One-way ANOVA[b]		*F* value	*P* > *F*	*F* value	*P* > *F*	*F* value	*P* > *F*
Treatments		1.47	0.246	10.29	<0.001	5.64	0.003
Contrasts:[c]							
Control versus treatments		0.75	0.398	6.93	0.016	6.26	0.021
Dinotefuran versus imidacloprid		4.17	0.054	29.91	<0.001	15.90	0.001
Dinotefuran – Trunk spray versus soil drench		0.85	0.366	3.22	0.088	0.22	0.646
Imidacloprid – Trunk spray versus soil drench		0.11	0.748	0.080	0.781	0.14	0.708

[a] Treatments were applied in Oct 2007 and were evaluated in Nov and Dec 2007 and May 2008. Percent mortality values are means ± standard errors (SE) from five replicate trees for each treatment; 100 *Adelges tsugae* were counted on each tree.
[b] One-way analysis of variance (ANOVA) on the ranked mortality values with 4 degrees of freedom for treatments.
[c] Single-degree-of-freedom orthogonal contrasts.

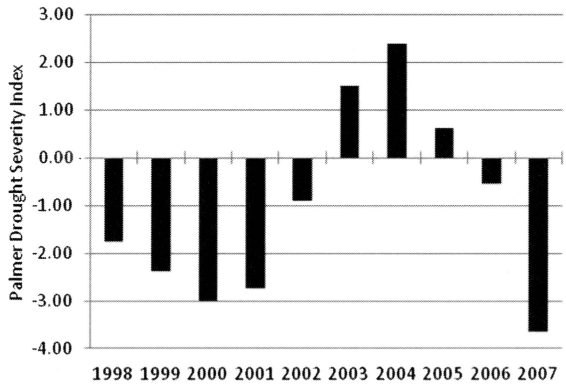

Fig. 1. The Palmer drought severity index from 1998 - 2007 for the region of North Carolina where study sites were located.

Although Imidacloprid soil drench treatments have been reported to be slow acting, they control *A. tsugae* over multiple years (Silcox 2002, Pg. 280 - 287 In Proceedings: Symposium on the Hemlock Woolly Adelgid *In* Eastern North America, U.S. Dept. of Agric., Morgantown; Cowles et al. 2006, Pg. 169 - 172 *In* Proceedings: Third Symposium on Hemlock Woolly Adeligd in the Eastern United States, U.S. Dep. Agric. FS FHTET-2005 - 1). Our data suggest that under the conditions existing when this study was conducted, dinotefuran caused both greater and more rapid mortality of *A. tsugae* than imidacloprid. If dinotefuran provides more rapid control than imidacloprid, then it may be possible to combine both insecticides as a treatment recommendation for *A. tsugae* due to their complimentary nature. Although the dinotefuran trunk spray provided high levels of *A. tsugae* mortality in this study (Table 1), it is unclear whether this can be attributed to the addition of Pentra-Bark to the application mixture. Treatments of both imidacloprid and dinotefuran as trunk spray applications without Pentra-Bark would be necessary to determine if this surfactant facilitated uptake through the bark and improved overall efficacy.

On each evaluation date, *A. tsugae* mortality levels were not significantly different for the 2 application methods for each insecticide (Table 1). Therefore, trunk sprays should be the preferred application method in forest settings because this method uses less water and less insecticide than soil drenches, negating the need for tank trucks or large amounts of water. Trunk sprays also allow for a more efficient, economical, and targeted application of the insecticide because it is being applied directly to the tree trunk. With trunk sprays, there would be a minimal amount of pesticide reaching the soil, which would reduce potential runoff into streams or other sensitive areas, and reduce potential adverse effects on litter dwelling earthworms.

Research has shown that when imidacloprid is applied to soil that it can provide effective multiyear control of *A. tsugae* (Steward and Horner 1994, Arthropod Manage. Tests 19: 348; Cowles et al. 2006, Pg. 169 - 172 *In* Proceedings: Third Symposium on Hemlock Woolly Adeligd in the Eastern United States, U.S. Dep. Agric. FS FHTET-2005 - 1). The 2 primary methods for applying imidacloprid to soil are drenches and injections, both of which have drawbacks. Soil drenches require access to large quantities of water, necessitating the use of a tank truck or other method of water transport to treatment sites, which limits applications in forest to areas near roads. The Kioritz applicator (Kioritz Corp., Tokyo, Japan) used for soil injection is relatively expensive, prohibiting its use by individual property owners. If trunk spray applications using Pentra-Bark, or a similar surfactant, can be validated as an effective means of delivering these insecticides to hemlock trees, then this would enable applicators to treat hemlocks without the need of access to large quantities of water or purchasing specialized equipment.

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