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This publication includes lecture notes of papers presented at the 2010 GREEN EXPO Turf and Landscape Conference. Publication of these lectures provides a readily available source of information covering a wide range of topics and includes technical and popular presentations of importance to the turfgrass industry.

This proceedings also includes research papers that contain original research findings and reviews of selected subjects in turfgrass science. These papers are presented primarily to facilitate the timely dissemination of original turfgrass research for use by the turfgrass industry.

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Dr. Ann Brooks Gould, Editor
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SYSTEMIC INSECTICIDES FOR TREE AND SHRUB CARE

Richard S. Cowles[1]

Various sucking and chewing insect pests can damage the aesthetics of ornamental plantings, or even kill the plant material. Protecting these plants from damage can require use of insecticides. Systemic insecticides have important characteristics that often make them especially effective. When systemic insecticides are applied to one part of the plant (such as the roots), they are transported in sap to other plant parts. Because the currently registered systemic insecticides are transported upwards, plants can then be effectively treated to manage certain pests without having to spray the foliage. Furthermore, products applied evenly around the base of a plant are transported to all parts of the plant, and more complete control of insect pests is possible than with foliar sprays. One other major advantage to using systemic products is that they can be delivered in ways (through soil injection, soil drench, trunk injection, or trunk sprays) that lead to the residues only being present inside the plant tissue, which then implies reduced exposure of people, beneficial predators and parasites to insecticides.

Systemic insecticides of the neonicotinoid class are available with a spectrum of solubility and mobility characteristics for use in managing insect pests in trees and shrubs. Mobility of products is listed here in decreasing order: dinotefuran (Safari) = acetamiprid (TriStar), thiamethoxam (Flagship), and imidacloprid (Merit and many equivalent generic products). The first two products are so mobile that when applied to the soil or as a bark spray, they appear rapidly (within days or weeks) in the foliage of the treated plants. Imidacloprid is relatively slowly transported in trees, and it may take months for its residues to show up in foliage following a soil or bark spray application.

Solubility and mobility also influence the ability of these products to reach concentrations that are lethal to target pests. Although only transported upward in the xylem tissues, enough insecticide is transported back-and-forth between xylem and phloem that insects with sucking mouthparts that tap directly into any part of the vascular system to feed are easily killed. My observation has been that systemic insecticides are effective for any of the honeydew producing pests. For example, xylem-feeding glassy winged sharpshooters, which produce an extremely watery honeydew, and phloem-feeding aphids, whiteflies, soft scales, and mealy bugs, which produce large amounts of sugary honeydew, are usually easily killed with systemic insecticides. Adelgids produce tiny amounts of honeydew, but are also readily killed by systemic insecticides. Armored scales are a special challenge to control with systemics. They feed on parenchyma or mesophyll tissues, rather than tapping into the vascular system. Armored scales can only be targeted effectively with the most soluble of systemic products, such as dinotefuran or acetamiprid; in general, imidacloprid has been ineffective against armored scales.

Other groups of pests can be effectively managed with systemic insecticides. The dosage of insecticide required to kill these pests may be greater than with the sucking insect pests, but the effective dosage is specific to the plant/pest/insecticide combination. My rule of thumb is that leaf beetles (Family Chrysomelidae: e.g., lily leaf beetle, viburnum leaf beetle, etc.), leaf miners (of all insect orders), and sawfly caterpillars are readily controlled with systemic insecticides. Weevils and externally feeding lepidopteran (moth or butterfly) caterpillars are poorly controlled with the currently registered neonicotinoid insecticides.

Systemic insecticides have risen to prominence for quarantine or "slow the spread" treatment of trees to protect them from being attacked by bark beetles or borers. Recent introductions of foreign species, such as the Asiatic longhorned beetle and emerald ash borer (EAB), threaten many species of trees in urban and non-urban forests. The amount of insecti-

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cide required to kill an Asian longhorned beetle larva is orders of magnitude greater than what is required to kill sensitive sucking insects (Nauen et al., 1998, Poland et al., 2006a). The greatest benefit of these systemic insecticides in quarantine programs is to kill the adult beetles when they feed on foliage prior to egg laying (Poland et al., 2006b). The idea is generally to remove infested trees (and destroy the larvae inside by chipping the trees) while at the same time treating surrounding trees so that any adult beetles left in the neighborhood are within a sea of toxic trees and die before laying eggs.

One additional insecticide is used to combat EAB. Emamectin benzoate (TreeÄge) has a different mode of action than the other insecticides described in this article, has very low water solubility, and has only been applied through tree injection. Once in the tree, this product is effective for killing EAB larvae within the tree for 2 to 3 years (Smitley et al., 2010). Because there is little hope of eradicating EAB from North America, our best hope for preserving ash trees is to protect them while the infestation front moves past and eliminates nearby unprotected trees. To protect ash trees, soil or trunk applications of dinotefuran, or soil applications of imidacloprid can keep trees relatively healthy, even though these insecticides are not 100% effective at killing larvae. Because it is costly, injection of emamectin benzoate on a 2- or 3-year schedule (a 2-year schedule would be important for the largest trees) could be reserved for protecting ash trees during the peak years of local infestation risk. Surprisingly, ash trees can survive (once they are treated) even when up to 30% of the crown shows signs of die-back (Herms et al., 2009). Of course, those dead branches don't recover and should be pruned out, and preventive systemic insecticide treatments can protect trees from this damage. Urban ash trees can provide significant benefits in shading buildings that can be measured as savings in utility bills (from not having to use as much air conditioning). Generic imidacloprid products are inexpensive enough that annual imidacloprid treatments to protect trees from infestation by EAB can be less costly than the utility cost savings that the trees provide (McPherson and Rowntree, 1993).

My earliest work with imidacloprid in trees was in 1991, when it was still an experimental compound. Starting with those first trials, and continuing to the present, I have observed two or more years of benefit when targeting highly susceptible pests (aphids, lace bugs, and adelgids) in many species of trees (Cowles et al., 2006; Cowles, 2009). The nagging question was: Are there multiple years of control because the product has killed all the pests, and it takes a while for the tree to become reinfested, or are there insecticidal residues present in the tree for multiple years? This question could only be answered once tools for analyzing residues improved enough to measure part per billion concentrations. Together with Dr. Anthony Lagalante (Department of Chemistry, Villanova University), I have found that imidacloprid is transformed in hemlock trees very efficiently into the metabolite called imidacloprid olefin (Cowles and Lagalante, 2009). Other researchers have found that the olefin metabolite is about 15 times more active than the imidacloprid parent compound (Nauen et al. ,1998). The imidacloprid and the olefin concentrations peak about 20 months after a soil application. The imidacloprid concentrations in tissues then decline, but the olefin concentrations decline more slowly (Cowles and Lagalante, 2009). Typically, a single soil application of imidacloprid can be expected to provide 5 to 7 years of protection from hemlock woolly adelgid (HWA) in hemlock trees. So, to answer the question posed earlier, both possible explanations are correct. Imidacloprid and its olefin metabolite are present at insecticidal concentrations within the tree tissues for multiple years. This compounds mortality over several generations, which can lead to extirpation of the pest population from those treated trees. Once trees in an area have been protected with systemic insecticides, it may take several years more before they become reinfested. Therefore, when using imidacloprid to manage these very sensitive pest species, the decision to re-treat trees with an insecticide should be based on observations that the pest population is once again increasing. Because imidacloprid moves so slowly in hemlock trees, customers should be informed that they won't see the full benefit from a soil injection or bark spray application for up to two years.

The duration of control of pest populations is dependent on the size of the tree, the dosage of insecticide applied, and the condition of the tree at the time of application. The relationship between the minimum effective dosage of insecticide and a tree's size is not as straightforward as might be expected from reading the pesticide label. Labels provide instructions for dosing trees in direct proportion to the diameter of the tree. However, the product is being diluted in the volume of living tissue of the tree, which is approximately proportional to the cube of the tree's diameter (Cowles, 2010). Therefore, label directions greatly overdose small trees, and very large trees may be inadequately dosed. Overdosing hemlocks (and other species of trees) with imidacloprid generally results in outbreaks of spider mites, and so fine-tuning the dosage to match the size of the tree makes both good biological and economic sense.

The role of tree condition at the time of treatment has only recently become apparent. When a tree is highly stressed, it may no longer be transpiring as effectively as a healthy tree. This may happen when HWA have caused loss of needles and tip die-back, or when the feeding of borers has injured the tree's vascular system directly. In either case, reduction of transpiration will limit the ability of the tree to transport insecticide dissolved in the sap from the base of the tree through the trunk and to the foliage (Ford et al., 2007). The adage "an ounce of prevention is worth a pound of cure" is certainly true when using systemic insecticides. Being able to get effective absorption and translocation of systemic insecticides when a tree is healthy can mean that less insecticide in the long run has to be used to keep that tree healthy. Waiting until a tree shows signs of damage or stress from infestation may jeopardize being able to bring that tree back to full health (Jesse Webster, GSMNP, *personal communication*).

Rapidity of pest population reduction and the duration of control are factors that govern which insecticides fit the situation best. In the northern United States, infrequent harsh winters cause significant mortality of HWA. This gives hemlock trees a temporary reprieve and they can regain some vigor. Therefore, a slow-acting but long-lasting treatment with imidacloprid can be sufficient to maintain hemlock tree health. However, elongate hemlock scale has become more important, and this pest is not controlled with imidacloprid. Dinotefuran (for immediate control of adelgids and scales) and imidacloprid (for multiple year benefit in managing HWA) can be combined to manage both pests effectively. In the southern United States, winters are never cold enough to cause such a set-back in adelgid populations, and so large trees can die within about 4 years following initial infestation (Will Blozan, *personal communication*). Because imidacloprid residues accumulate so slowly in foliage, imidacloprid treatment of large, heavily infested trees in the South may not be effective quickly enough to save the health of the trees. In situations where immediate pest suppression is desired, a contact acting foliar spray (such as horticultural oil) or using a faster acting systemic insecticide like dinotefuran may be necessary to preserve the trees. In the Great Smoky Mountain National Park, trees may be extremely difficult to access, and it may make sense to combine quick-acting dinotefuran with the long-lasting imidacloprid in one treatment to improve the outcome and to minimize the labor required to conserve these trees. The complementary nature of these two products over time, and their different spectrum of activity suggest that their use in combination can be beneficial.

Loss of honey bees to Colony Collapse Disorder (CCD) has caused heightened scrutiny of factors that could contribute to their overall health. Even though evidence clearly implicates interactions between parasitic Varroa mites and the honey bee viruses they vector as the likely cause of CCD (Cox-Foster et al., 2007), public sentiment and fears that systemic insecticides may be involved with CCD could jeopardize the future of these products. Furthermore, to be systemic, an insecticide must have significant water solubility, which implies some risk of water pollution and leaching to groundwater. Therefore, practitioners should be aware of these environmental concerns and should use systemic products for tree and shrub care in a manner that minimizes the risk to pollinators and to aquatic resources. Some steps that can be taken include (1) use the lowest dosage necessary, (2) treat plants only when needed [don't re-treat plants until called for], (3) apply products either as a basal bark spray, which greatly limits soil contamination, or a very shallow subsurface soil injection, which maximizes binding to organic matter in soil and prevents leaching, and (4) limit treatments of plants visited by pollinators to application immediately after bloom with products that are expected to degrade over one season (dinotefuran or acetamiprid). Systemic insecticides provide extraordinary benefits for managing insect pests in trees and shrubs. Let's use these products wisely.

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Mention of specific trade names does not constitute an endorsement of that product to the exclusion of any other similar product. Always read and follow label directions.