



**Outreach**

Warnell School of Forestry & Natural Resources

**UNIVERSITY OF GEORGIA**

## Optimized Insecticide Dosage for Hemlock Woolly Adelgid Control in Hemlock Trees

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### Overview

Hemlock woolly adelgid (HWA) (*Adelges tsugae*) is killing hemlock trees in the eastern United States (Figure 1, 2). This invasive insect is native to Japan and has been in the eastern United States since the 1950's. HWA feed by sucking fluids from hemlock twigs just at the base of the needles (Figure 3), depleting the tree of needed energy reserves. Large swaths of hemlock forests have been decimated by HWA, and millions of hemlocks have died (Figure 4).

Both eastern (*Tsuga canadensis*) and Carolina (*Tsuga caroliniana*) hemlock are susceptible to HWA attack. The few native HWA predators are not impacting populations, although work continues with classic biocontrol of HWA to establish more effective predators. In addition, hemlocks in the eastern US lack resistance to HWA. As a result, HWA populations can increase very quickly. A hemlock twig can have hundreds of HWA covering it. Tree death can occur in as little as three years as trees are overwhelmed by unrestrained growth of adelgid populations.



Figure 1. HWA on eastern hemlock.



Figure 2. HWA on eastern hemlock branches. USDA Forest Service, Region 8, Bugwood.org



**Figure 3.** HWA feeding on twig near the base of hemlock needles.



**Figure 4.** Thousands of hemlocks have been killed by HWA. Photo: Will Blozan, Appalachian Arborists

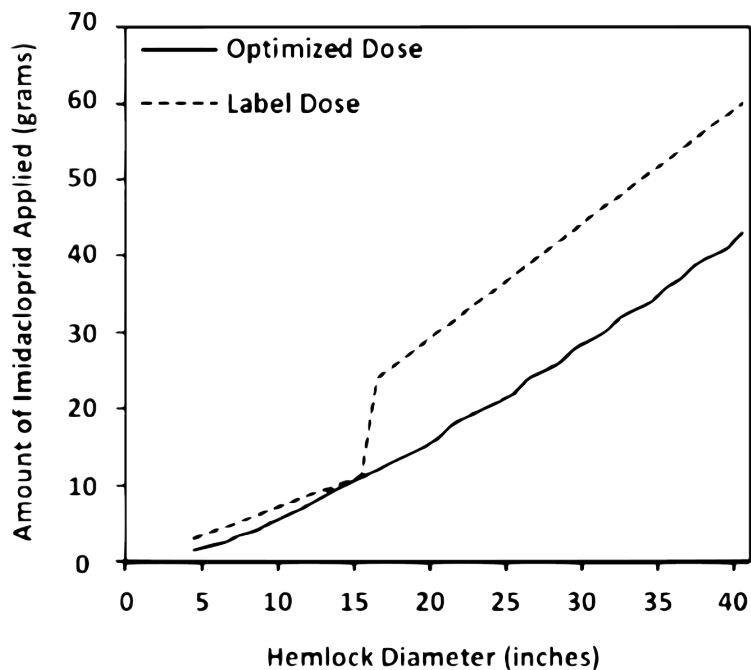
Efforts are underway to establish specialist adelgid predators from Asia and the northwestern United States to biologically suppress adelgid populations. However, insecticides will be needed to keep hemlocks healthy until these predators become established. Hemlock pest management is important for federal and state lands, urban forests, and private property. Large HWA management programs have been initiated to reduce HWA populations and preserve hemlock forest health. For example, Great Smoky Mountains National Park (GRSM), which has the largest HWA management program in the U. S., has treated over 250,000 individual hemlocks with the insecticide imidacloprid. Imidacloprid treatments are the most commonly used and effective method of suppressing HWA.

### **Insecticide Use**

Imidacloprid, a neonicotinoid insecticide, works systemically, which means that the insecticide moves within the tree in sap. Applications can be made to the soil near the base of the hemlock or directly to the tree trunk. As the tree draws up water from the soil, imidacloprid is moved with the water up to the canopy where HWA feeds. A systemic insecticide application reduces the chance of unintended insecticide impacts compared to spraying an entire hemlock canopy with a contact insecticide. Also, HWA populations can be suppressed for numerous years following one imidacloprid treatment. A study from the University of Tennessee and GRSM showed that HWA populations were suppressed for seven years after one imidacloprid treatment. An optimized dosage recommendation, based on the relationship between tree diameter and insecticide concentrations in foliage, was an outcome of this research program (Benton et al. 2016a).

## Optimized Dosage Recommendation

The new optimized recommendation both reduces insecticide use for large trees and provides a precise dosage for any specific size of hemlock tree, based on the tree's diameter at breast height (DBH). The dose according to the pesticide label (label dose) doubles the amount of imidacloprid that is applied per inch DBH for trees greater than 15 inches DBH (Figure 5, dashed line). For example, a 16 inch DBH tree would receive twice as much pesticide per inch as a 15 inch DBH tree following the product label dose instructions.



**Figure 5.** Amount of imidacloprid applied to hemlocks using the optimized and label doses.

The new dosage recommendations were developed using the concentration of insecticidal compounds present in hemlock foliage five years after imidacloprid treatments. Hemlocks given new dosage rates are expected to have enough insecticide in the foliage to reduce HWA populations at least five years after a single application. For larger hemlocks, less imidacloprid can be applied per tree when using the new dosage recommendation, while still providing at least five years of HWA protection (Figure 5, solid line). The suggested

amount of imidacloprid is specific for each tree's size, so each hemlock will receive an optimal dose for that exact diameter tree. This is a precision insecticide recommendation, not a "one size fits all" solution.

Using less imidacloprid on trees still provides effective HWA suppression for numerous years, but will allow additional trees to be treated on each acre, financial savings, and less insecticide being introduced to the forest.

## Imidacloprid Application Instructions

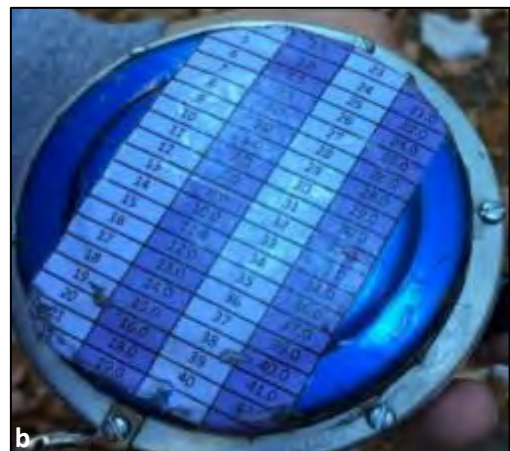
The amount of product needed for each DBH size class can be written directly on a DBH tape or Biltmore stick (Figure 6a, b), which eliminates having to do calculations in the field. Once the trunk diameter is measured, check the amount of product to apply, and apply.

Imidacloprid dosage guidance is provided for the following soil application methods: basal drench, soil injection, and slow-release CoreTect tablets (Table 1). Separate tables and instructions for each application method are included for easy use in the field (see end of this document).

While trunk injection applications are possible, soil applications of imidacloprid provide more consistently successful results. Imidacloprid can be purchased as a water soluble packet (WSP) or as a flowable formulation (Imidacloprid 2F). WSP and flowable recommendations are based on a 1 gram active ingredient (g a.i.) per 1 fluid ounce of mixture (see mixing instructions on page 6). Soil injection and basal drench applications can be made using either WSP or flowable products. Soil injection recommendations are given for both the Kioritz Injector and the 1-Two Root Injector. While Kioritz Injectors are no longer being produced, they are still widely used.

Imidacloprid is sold by numerous companies and can be purchased at competitive prices. Local home improvement stores and online vendors sell imidacloprid, but check the active ingredients of the product to be sure that it only contains imidacloprid. The optimized dosage recommendations are for imidacloprid products, and using a product with other active ingredients will result in an incorrect dosage of imidacloprid. Please check your state's rules on pesticide use. Imidacloprid is a restricted use insecticide in some states, which means that it can only be applied by a certified pesticide applicator.

| Inches DBH | Amount of diluted imidacloprid |           |
|------------|--------------------------------|-----------|
| 2 0 16 oz  | 2 1 18 oz                      | 2 2 19 oz |
| 171        | 191                            | 211       |
| 296        | 332                            | 368       |
| 401        | 450                            | 500       |
| 480        | 542                            | 603       |
| 542        | 616                            | 691       |



**Figure 6.** Optimal dosage amount can be written directly on a Biltmore stick (a) or attached to DBH tape for easy use in the field (b).

**Table 1. Application Options for Optimal  
Imidacloprid Dose for Eastern Hemlock**

| Inches DBH              | Total g a.i. <sup>1</sup><br>per Tree | Number of Fluid Ounces   |                 | Number of injector<br>pumps            |  | Number of<br>Tablets |
|-------------------------|---------------------------------------|--------------------------|-----------------|--|--|----------------------|
|                         |                                       | Water soluble<br>packets | Imidacloprid 2F | Kioritz Injector<br>1/6 oz per<br>pump | 1-Two Root<br>Injector<br>1/4 oz per<br>pump | CoreTect             |
| 4                       | 1.3                                   | 1.5                      | 1.5             | 8                                      | 5  | 3                    |
| 5                       | 1.9                                   | 2                        | 2               | 11                                     | 8  | 4                    |
| 6                       | 2.5                                   | 2.5                      | 2.5             | 15                                     | 10   | 5                    |
| 7                       | 3.3                                   | 3.5                      | 3.5             | 20                                     | 13   | 7                    |
| 8                       | 4.0                                   | 4                        | 4               | 24                                     | 16   | 8                    |
| 9                       | 4.9                                   | 5                        | 5               | 29                                     | 19   | 10                   |
| 10                      | 5.7                                   | 6                        | 6               | 34                                     | 23   | 11                   |
| 11                      | 6.6                                   | 7                        | 7               | 40                                     | 26   | 13                   |
| 12                      | 7.5                                   | 8                        | 8               | 45                                     | 30   | 15                   |
| 13                      | 8.5                                   | 9                        | 9               | 51                                     | 34   | 17                   |
| 14                      | 9.5                                   | 10                       | 10              | 57                                     | 38   | 19                   |
| 15                      | 10.5                                  | 11                       | 11              | 63                                     | 42   | 21                   |
| 16                      | 11.6                                  | 12                       | 12              | 69                                     | 46   | 23                   |
| 17                      | 12.6                                  | 13                       | 13              | 76                                     | 51   | 25                   |
| 18                      | 13.7                                  | 14                       | 14              | 82                                     | 55   | 27                   |
| 19                      | 14.9                                  | 15                       | 15              | 89                                     | 59   | 30                   |
| 20                      | 16.0                                  | 16                       | 16              | 96                                     | 64   | 32                   |
| 21                      | 17.2                                  | 18                       | 18              | 103                                    | 69   | 34                   |
| 22                      | 18.4                                  | 19                       | 19              | 110                                    | 73   | 37                   |
| 23                      | 19.6                                  | 20                       | 20              | 117                                    | 78   | 39                   |
| 24                      | 20.8                                  | 21                       | 21              | 125                                    | 83   | 42                   |
| 25                      | 22.0                                  | 22                       | 22              | 132                                    | 88   | 44                   |
| 26                      | 23.3                                  | 24                       | 24              | 140                                    | 93   | 47                   |
| 27                      | 24.6                                  | 25                       | 25              | 147                                    | 98   | 49                   |
| 28                      | 25.9                                  | 26                       | 26              | 155                                    | 103  | 52                   |
| 29                      | 27.2                                  | 28                       | 28              | 163                                    | 109  | 54                   |
| 30                      | 28.5                                  | 29                       | 29              | 171                                    | 114  | 57                   |
| 31                      | 29.8                                  | 30                       | 30              | 179                                    | 119  | 60                   |
| 32                      | 31.2                                  | 32                       | 32              | 187                                    | 125  | 62                   |
| 33                      | 32.5                                  | 33                       | 33              | 195                                    | 130  | 65                   |
| 34                      | 33.9                                  | 34                       | 34              | 204                                    | 136  | 68                   |
| 35                      | 35.3                                  | 36                       | 36              | 212                                    | 141  | 71                   |
| <b>Maximum per acre</b> |                                       | <b>181</b>               | <b>181</b>      | <b>1086</b>                            | <b>724</b>                                   | <b>362</b>           |

<sup>1</sup>grams active ingredient

The maximum amount of imidacloprid that can be applied per acre each year is 0.4 lb of active ingredient. The WSP and flowable products must be diluted with water prior to application; Table 1 lists the maximum number of fluid ounces per acre that may be applied to reach the 0.4 lb of active ingredient limit when using the mixing instructions given below. The maximum per acre amount that can be applied using the Kioritz injector and the 1-Two Root Injector are listed in Table 1 as the number of pumps for each injector.

**Mixing instructions\***

**Water soluble packets:** Add a 1.6 oz. WSP to a container. Fill with water to form a final volume of 34 fl. oz. The final volume of the suspension in the container (WSP + water) should be 34 oz. Table 2 lists dilution volumes if multiple WSPs are used for a suspension. Note: Add water until a final volume of the WSP + added water is the volume listed in the table. Continue to agitate the container while making applications to ensure the imidacloprid remains suspended in the fluid.

**Imidacloprid 2F (flowable):** Add 18 fl. oz. of Imidacloprid 2F to a container. Fill with water to obtain a final volume of 1 gallon (128 fl. oz.). The final volume of the suspension (Imidacloprid 2F + water) should be one gallon.

| Table 2. Final Suspension Volumes for WSPs |                               |
|--|-------------------------------|
| Number of WSPs                             | Final suspension volume (oz.) |
| 1  | 34                            |
| 2  | 68                            |
| 3  | 102                           |
| 4  | 136                           |
| 5  | 170                           |

\*Products must be diluted as instructed to ensure that hemlocks receive the proper dose.

**Application Instructions**

**Soil drench and soil injection** - Brush away the top layer of organic material (the “duff” layer) in the immediate area where soil drench and soil injections are being applied. Imidacloprid binds to organic material in the soil. Treatments are more effective if this layer is removed while the imidacloprid solution is being applied. Once the solution has been absorbed by the soil, the top organic layer can be replaced.

- *Soil drench* – The imidacloprid suspension should be applied to the soil within 18 inches of the hemlock trunk. Pour the solution evenly around the base of the tree. Do not pour the suspension all in one location. Do not pour the suspension on the hemlock trunk.

- *Soil injection* – Product labels list different soil injection application approaches (e.g. grid system, circle system, basal system). A basal application to the soil has proven to be very efficient, but application further from the trunk may be necessary to reach roots when trees are close to aquatic areas (see Caution, below). Follow the label instructions for the approach of choice.

**CoreTect™** pellets – Brush away the top layer of organic material. Bury CoreTect pellets in the soil 2 - 5 inches below the soil surface within 6 – 24 inches of the trunk. Space the pellets evenly around the hemlock trunk. Completely cover the pellets with soil.

**Caution:** Soil applications should NOT be made within 10 feet of a stream channel, lake, pond, or wetland. Do not use soil applications on rocky outcrops where there is very little soil around the base of the hemlock. Do not make soil applications immediately after rainfall or during a drought. The soil should be moist, not saturated, for maximum effectiveness.

*It is important to always read any pesticide label before use. Use the product strictly according to the label directions. It is particularly important to follow all safety precautions. Trade and brand names are used only for information. The University of Georgia does not guarantee nor warrant published standards on any product mentioned; neither does the use of a trade or brand name imply approval of any product to the exclusion of others, which may also be suitable.*

### **Further Reading**

- Benton, E. P., J. F. Grant, R. J. Webster, J. R. Nichols, R. S. Cowles, A. F. Lagalante, and C. I. Coots. 2015. Assessment of imidacloprid and its metabolites in foliage of eastern hemlock multiple years following treatment for hemlock woolly adelgid, *Adelges tsugae*, in forested conditions. *Journal of Economic Entomology* 108: 2672 – 2682.
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- Benton, E.P., J F. Grant, R. J. Webster, R. S. Cowles, A. F. Lagalante, R. J. Nichols, and C. I. Coots. 2016b. Hemlock woolly adelgid abundance and hemlock canopy health numerous years after imidacloprid basal drench treatments: Implications for management programs. *Journal of Economic Entomology* 109: 2125 – 2136.

- Coots, C., P. L. Lambdin, J. Grant, and R. Rhea. 2013. Spatial and temporal distribution of residues of imidacloprid and its insecticidal 5-hydroxy and olefin and metabolites in eastern hemlock (Pinales: Pinaceae) in the southern Appalachians. *Journal of Economic Entomology* 106: 2399 – 2406.
- Cowles, R. S., M. E. Montgomery, and C. A. S.-J. Cheah. 2006. Activity and residues of imidacloprid applied to soil and tree trunks to control hemlock woolly adelgid (Hemiptera: Adelgidae) in forests. *Journal of Economic Entomology* 99: 1258 – 1267.
- Dilling, C., P. Lambdin, J. Grant, and R. Rhea. 2010. Spatial and temporal distribution of imidacloprid in eastern hemlock in the southern Appalachians. *J. Econ. Entomol.* 103: 368 – 373.
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- Mayfield, A. E., III, B. C. Reynolds, C. I. Coots, N. P. Havill, C. Brownie, A. R. Tait, J. L. Hanula, S. V. Joseph, and A. B. Galloway. 2015. Establishment, hybridization and impact of *Laricobius* predators on insecticide-treated hemlocks: Exploring integrated management of the hemlock woolly adelgid. *Forest Ecology and Management* 335: 1 – 10.
- McClure, M. S. 1991. Density-dependent feedback and population cycles in *Adelges tsugae* (Homoptera: Adelgidae) on *Tsuga canadensis*. *Environmental Entomology* 20: 258 – 264.
- Young, R. F., K. S. Shields, and G. P. Berlyn. 1995. Hemlock woolly adelgid (Homoptera: Adelgidae): Stylet bundle insertion and feeding sites. *Annals of the Entomological Society of America* 88: 827 – 835.

### Citation

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## Optimal Imidacloprid Dose Water Soluble Packets

| Inches DBH                 | Number of Fluid Ounces | Inches DBH | Number of Fluid Ounces |
|----------------------------|------------------------|------------|------------------------|
| 4                          | 1.5                    | 20         | 16                     |
| 5                          | 2                      | 21         | 18                     |
| 6                          | 2.5                    | 22         | 19                     |
| 7                          | 3.5                    | 23         | 20                     |
| 8                          | 4                      | 24         | 21                     |
| 9                          | 5                      | 25         | 22                     |
| 10                         | 6                      | 26         | 24                     |
| 11                         | 7                      | 27         | 25                     |
| 12                         | 8                      | 28         | 26                     |
| 13                         | 9                      | 29         | 28                     |
| 14                         | 10                     | 30         | 29                     |
| 15                         | 11                     | 31         | 30                     |
| 16                         | 12                     | 32         | 32                     |
| 17                         | 13                     | 33         | 33                     |
| 18                         | 14                     | 34         | 34                     |
| 19                         | 15                     | 35         | 36                     |
| <b>Maximum oz per acre</b> |                        | <b>181</b> |                        |

Water soluble packet mixing instructions: Add a 1.6 oz. WSP to a container. Fill with water to form a final volume of 34 fl. oz. The final volume of the suspension in the container (WSP + water) should be 34 oz.

Application instructions: Brush away the top layer of organic material (the “duff” layer) in the immediate area where soil drench is being applied. Apply the imidacloprid suspension on the soil within 18 inches of the hemlock trunk. Pour the solution evenly around the base of the tree.

| <b>Optimal Imidacloprid Dose</b> |                               |                   |                               |
|----------------------------------|-------------------------------|-------------------|-------------------------------|
| <b>Imidacloprid 2F</b>           |                               |                   |                               |
| <b>Inches DBH</b>                | <b>Number of Fluid Ounces</b> | <b>Inches DBH</b> | <b>Number of Fluid Ounces</b> |
| 4                                | 1.5                           | 20                | 16                            |
| 5                                | 2                             | 21                | 18                            |
| 6                                | 2.5                           | 22                | 19                            |
| 7                                | 3.5                           | 23                | 20                            |
| 8                                | 4                             | 24                | 21                            |
| 9                                | 5                             | 25                | 22                            |
| 10                               | 6                             | 26                | 24                            |
| 11                               | 7                             | 27                | 25                            |
| 12                               | 8                             | 28                | 26                            |
| 13                               | 9                             | 29                | 28                            |
| 14                               | 10                            | 30                | 29                            |
| 15                               | 11                            | 31                | 30                            |
| 16                               | 12                            | 32                | 32                            |
| 17                               | 13                            | 33                | 33                            |
| 18                               | 14                            | 34                | 34                            |
| 19                               | 15                            | 35                | 36                            |
| <b>Maximum oz per acre</b>       |                               | <b>181</b>        |                               |

Imidacloprid 2F mixing instructions: Add 18 fl. oz. of Imidacloprid 2F to a container. Fill with water to obtain a final volume of 1 gallon (128 fl. oz.). The final volume of the suspension (Imidacloprid 2F + water) should be one gallon.

Soil drench instructions: Brush away the top layer of organic material (the “duff” layer) in the immediate area where soil drench is being applied. Apply the imidacloprid suspension on the soil within 18 inches of the hemlock trunk. Pour the solution evenly around the base of the tree.

## Optimal Imidacloprid Dose Kioritz Injector

| Inches DBH                    | Number of Injector Pumps | Inches DBH  | Number of Injector Pumps |
|-------------------------------|--------------------------|-------------|--------------------------|
| 4                             | 8                        | 20          | 96                       |
| 5                             | 11                       | 21          | 103                      |
| 6                             | 15                       | 22          | 110                      |
| 7                             | 20                       | 23          | 117                      |
| 8                             | 24                       | 24          | 125                      |
| 9                             | 29                       | 25          | 132                      |
| 10                            | 34                       | 26          | 140                      |
| 11                            | 40                       | 27          | 147                      |
| 12                            | 45                       | 28          | 155                      |
| 13                            | 51                       | 29          | 163                      |
| 14                            | 57                       | 30          | 171                      |
| 15                            | 63                       | 31          | 179                      |
| 16                            | 69                       | 32          | 187                      |
| 17                            | 76                       | 33          | 195                      |
| 18                            | 82                       | 34          | 204                      |
| 19                            | 89                       | 35          | 212                      |
| <b>Maximum pumps per acre</b> |                          | <b>1086</b> |                          |

Imidacloprid 2F mixing instructions: Add 18 fl. oz. of Imidacloprid 2F to a container. Fill with water to obtain a final volume of 1 gallon (128 fl. oz.). The final volume of the suspension (Imidacloprid 2F + water) should be one gallon.

Water soluble packet mixing instructions: Add a 1.6 oz. WSP to a container. Fill with water to form a final volume of 34 fl. oz. The final volume of the suspension in the container (WSP + water) should be 34 oz.

Kioritz Injector instructions: Brush away the top layer of organic material. Product labels list different soil injection application approaches (e.g. grid system, circle system, basal system). Follow the label instructions for the approach of choice. **One pump = 1/6 oz**

## Optimal Imidacloprid Dose 1-Two Root Injector

| Inches DBH                    | Number of Injector Pumps | Inches DBH | Number of Injector Pumps |
|-------------------------------|--------------------------|------------|--------------------------|
| 4                             | 5                        | 20         | 64                       |
| 5                             | 8                        | 21         | 69                       |
| 6                             | 10                       | 22         | 73                       |
| 7                             | 13                       | 23         | 78                       |
| 8                             | 16                       | 24         | 83                       |
| 9                             | 19                       | 25         | 88                       |
| 10                            | 23                       | 26         | 93                       |
| 11                            | 26                       | 27         | 98                       |
| 12                            | 30                       | 28         | 103                      |
| 13                            | 34                       | 29         | 109                      |
| 14                            | 38                       | 30         | 114                      |
| 15                            | 42                       | 31         | 119                      |
| 16                            | 46                       | 32         | 125                      |
| 17                            | 51                       | 33         | 130                      |
| 18                            | 55                       | 34         | 136                      |
| 19                            | 59                       | 35         | 141                      |
| <b>Maximum pumps per acre</b> |                          | <b>724</b> |                          |

Imidacloprid 2F mixing instructions: Add 18 fl. oz. of Imidacloprid 2F to a container. Fill with water to obtain a final volume of 1 gallon (128 fl. oz.). The final volume of the suspension (Imidacloprid 2F + water) should be one gallon.

Water soluble packet mixing instructions: Add a 1.6 oz. WSP to a container. Fill with water to form a final volume of 34 fl. oz. The final volume of the suspension in the container (WSP + water) should be 34 oz.

1-Two Root Injector instructions: Brush away the top layer of organic material. Product labels list different soil injection application approaches (e.g. grid system, circle system, basal system). Follow the label instructions for the approach of choice. **One pump = 1/4 oz**

## Optimal Imidacloprid Dose CoreTect™

| Inches DBH                      | Number of Pellets | Inches DBH | Number of Pellets |
|---------------------------------|-------------------|------------|-------------------|
| 4                               | 3                 | 20         | 32                |
| 5                               | 4                 | 21         | 34                |
| 6                               | 5                 | 22         | 37                |
| 7                               | 7                 | 23         | 39                |
| 8                               | 8                 | 24         | 42                |
| 9                               | 10                | 25         | 44                |
| 10                              | 11                | 26         | 47                |
| 11                              | 13                | 27         | 49                |
| 12                              | 15                | 28         | 52                |
| 13                              | 17                | 29         | 54                |
| 14                              | 19                | 30         | 57                |
| 15                              | 21                | 31         | 60                |
| 16                              | 23                | 32         | 62                |
| 17                              | 25                | 33         | 65                |
| 18                              | 27                | 34         | 68                |
| 19                              | 30                | 35         | 71                |
| <b>Maximum pellets per acre</b> |                   | <b>362</b> |                   |

CoreTect™ application instructions: Brush away the top layer of organic material. Bury CoreTect pellets in the soil 2 - 5 inches below the soil surface within 6 – 24 inches of the trunk. Space the pellets evenly around the hemlock trunk. Completely cover the pellets with soil.