The Role of Site Conditions in Survival of Hemlocks Infested with the Hemlock Woolly Adelgid: Amelioration through the Use of Organic Biostimulants

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Abstract

Both greenhouse and field studies have shown that it is the combined stress of drought and infestation by the hemlock woolly adelgid that causes death in eastern hemlocks,. In three separate greenhouse studies it was found that the presence of adelgids alone did not cause the death of the plants over a period of 1, 2 or 5 years respectively, if they were well watered and received sufficient nutrients. Another greenhouse study found that drought hastened the death of infested hemlock seedlings. This was reflected in the rapid fall in the rate of chlorophyll fluorescence. In this study the effect of the adelgids alone was not sufficient to cause the death of the seedlings, however the added stress of drought did result in the death of the seedlings, within a period of a few weeks.

In the field, ring widths were reduced in infested trees growing on a ridge-top site, as opposed to a well-watered moist site. The results of the seedling studies are consistent with field observations that suggest hemlocks growing outside their optimal range are more susceptible to death when infested with adelgids. Also trees on ridge top sites especially with SouthWest exposures are more susceptible than trees in riparian zones.

Organic biostimulants have been shown to ameliorate the effects of adelgid feeding on eastern hemlock seedlings. These compounds are essentially, a stress vitamin-mix for plants and work particularly well on plants under water stress. Cell wall thickness, needle and cuticle thickness and ring widths in infested seedlings treated with organic biostimulants were significantly higher than infested controls.

Introduction

Seedling studies were conducted on eastern hemlock in the Greeley Greenhouse at Yale University, in order to study the following:

1. Feeding effects of hemlock woolly adelgid on seedling growth, health and vigor.
2. The combined effect of water stress and adelgid feeding on seedling physiology.
3. Bio-remedial and bio-pesticidal uses of organic biostimulants

The hypothetical bases of this study are:

a) feeding by the hemlock woolly adelgid increases probability of seedling death.
b) the addition of water stress further increases the chances of tree death.
c) regular supply of water and nutrients helps maintain health and vigor of seedlings and reduces the impact of adelgid feeding.
d) the use of organic biostimulants reduces the negative impacts of the adelgids and drought stress, by reducing insect densities and at the same time increasing tolerance to stress.

Background Information

The hemlock woolly adelgid, *Adelges tsugae* Annand (Homoptera: Adelgidae), is a well-known pest of eastern hemlock *Tsuga canadensis* (L.) (Carr.), in the hemlock-hardwood forests. This adelgid is not native to North America (McClure et al 1996) and effective controls against the spread of this pest have not been achieved. Eastern hemlock is an important component of the northern hardwood forest, and the loss of this species will have a serious impact on the flora and fauna associated with it. Hemlock is a slow growing, shade tolerant species that occupies a niche that few other evergreen species compete for. In a study done by Kelty (1989), on mixed hardwood-hemlock stands to measure productivity, it was found that hemlocks formed a dense understory beneath the hardwood overstory. In hardwood stands not containing hemlock no comparable dense understories of any species was found. The mixed stands were found to have higher yields than the pure hardwood stands, due to the additive effect of the hemlocks Kelty (1989). Although it can grow under a variety of site conditions, in regions where the hemlock grows outside its preferred habitat of relatively moist sites, death is brought about more quickly after infestation by the adelgid.

Organic biostimulants are a product of this laboratory, and are environmentally friendly, non-polluting, growth promoters for plants. These are biologically active compounds consisting of a mix of humic acids, marine algae extracts, B vitamins and two anti-oxidants vitamins C and E (Russo and Berlyn, 1990). Marine algae is a commonly used organic supplement for increasing plant growth and stress resistance (Russo and Berlyn, 1990). The addition of ascorbic acid increases the various growth responses elicited by the organic biostimulant and has resulted in a four-fold increase in leaf chlorophyll content in some cases (Berlyn et al. 1992). This may be due to an increase in cell wall and membrane permeability. The antioxidant vitamin E (alpha-tocopherol) was tested as an anti-herbivory agent in soybean plants against cabbage looper larvae, and was found to decrease herbivory (Neupane and Norris, 1991). Organic biostimulants improve root and shoot growth, increase resistance to stress, and reduce the need for high levels of nitrogen fertilization through increased efficiency of nutrient and water uptake (Russo and Berlyn, 1990). These compounds increase plant growth and vigor. Plant growth stimulants increase resistance to stresses such as low water

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potential and residual levels of certain herbicides and fungicides in soil (Berlyn et al 1993, 1993b).

Chlorophyll Fluorescence: measures the photosynthetic efficiency of photo-system II and can be used as an index of plant stress. As photons strike photo-system II, they elevate electrons in the chlorophyll molecule to a higher orbital. These electrons may return to their ground state via an electron transport system, that transfers energy between photo-systems I and II. However if any of the system components is impaired due to nutrient deficiency, water deprivation or tissue damage, it cannot transfer electrons needed to reduce CO_2 to carbohydrate in the dark reactions of photosynthesis (Kraus and Weis 1991). The un-transferred electrons return to their ground state by emitting fluorescent light. The amount of light harvested by photo-system II that is re-emitted at fluorescent wavelengths indicates the efficiency of the electron transport system between photo-system I and II. This parameter is expressed by the ratio of F_v/F_m. F_v is variable fluorescence or the difference between (F_o) the initial level of fluorescence and (F_m) the maximum level reached during measurement.

Methods and Materials

Two separate seedling studies of the effect of drought and infestation were conducted. In the first study 20 seedlings, approximately 5 years old, were divided into 4 treatments: Drought-Infested, Drought-Uninfested, Watered-Infested, Watered-Uninfested. Chlorophyll Fluorescence was used to measure plant health. Measurements were taken every week for 5 weeks since the start of the drought to determine the combined effects of adelgid feeding and drought stress on eastern hemlock seedlings.

In the second seedling study on the effect of drought and infestation on eastern hemlock seedlings approximately 200 seedlings were divided into the following treatments: Controls, Roots™, and Nitrogen. Of these 100 were infested. A subset of these seedlings was used in a drought study. The remaining 150 seedlings are still alive.

In the third seedling study 100 seedlings were divided into four treatment groups: Controls, Roots™, Control-Infested and Roots™-Infested. This study was run for 2 years. Regular measurements of height and diameter growth were taken. Destructive sampling was done at the end of the study.

The field study was conducted in Connecticut. Ten adelgid-infested and uninfested trees were selected from a ridge-top site and a similar number from an ever-moist site. Trees were cored and ring-widths measured using a microscope and a computerized ring counting program developed by one of the students here.

Results and Discussion

The results of the seedling studies and field study are given in the following graphs, which have self-explanatory sub-titles.

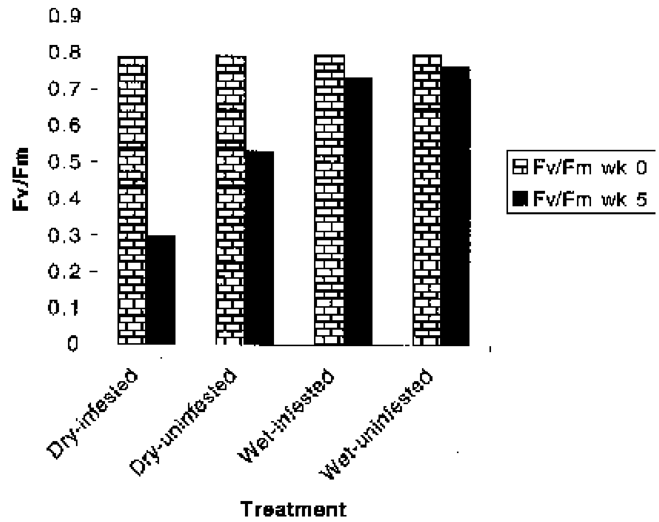

Figure 1.—Comparison of Chlorophyll Fluorescence at start and end of drought experiment.

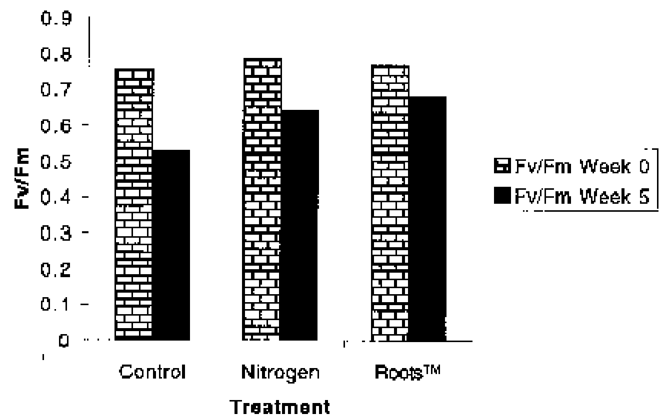

Figure 2.—Effect of Drought and Infestation on Chlorophyll Fluorescence, in seedlings treated with organic biostimulants and Nitrogen.

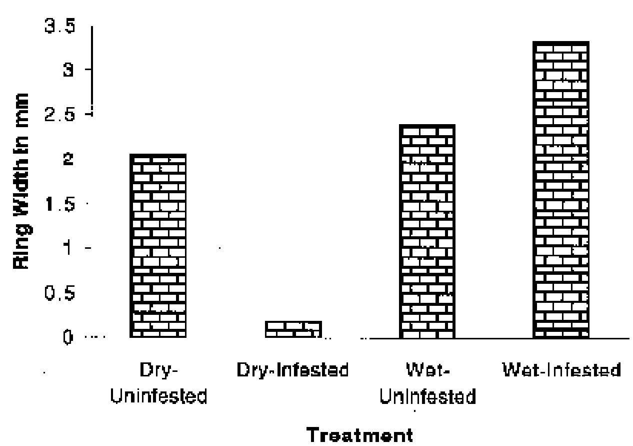

Figure 3.—In field trees, infested hemlocks on dry sites have significantly lower ring widths than uninfested trees on same sites ($p<.0001$). On wet sites infestation does not reduce ring widths.

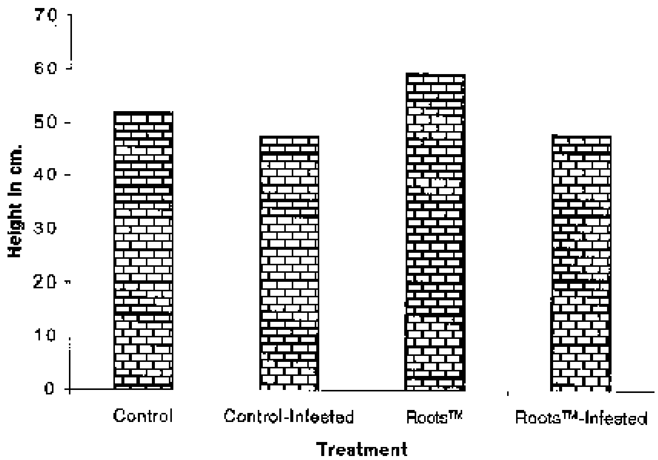

Figure 4a.—Height growth is afffected by adelgid infestation, while organic biostimulants can improve this (p=.01).

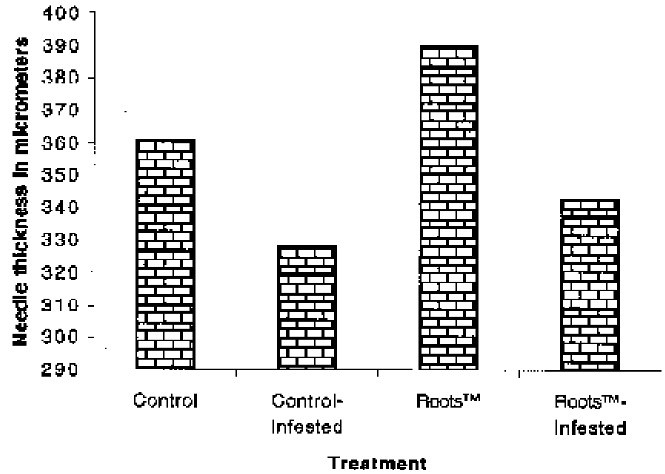

Figure 6.—Needle thickness is significantly reduced by adelgid feeding. Organic biostimulants help to mitigate this (p=.0001).

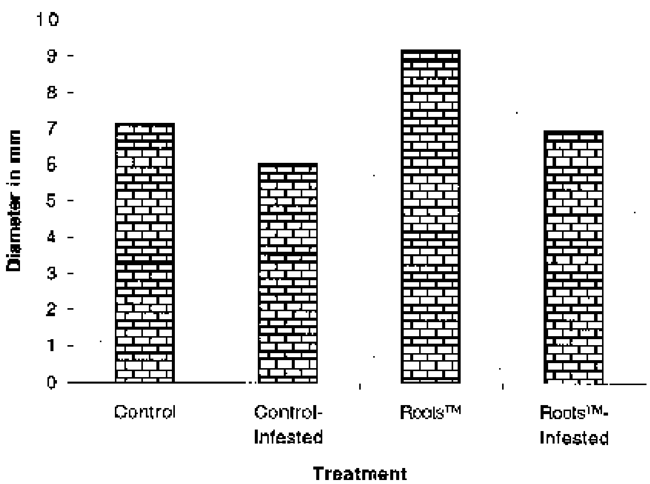

Figure 4 b.—Diameter growth is decreased by adelgid infestation, and increased by using organic biostimulants (p=.0006).

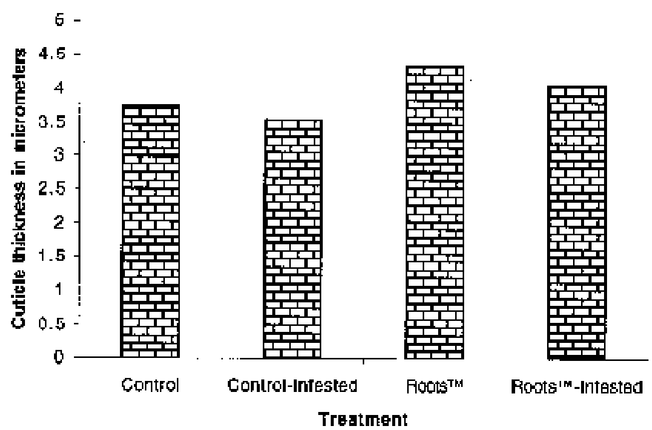

Figure 7.—Adelgid feeding significantly reduces cuticle thickness, but treatment with organic biostimulants alleviates this (p<.0001).

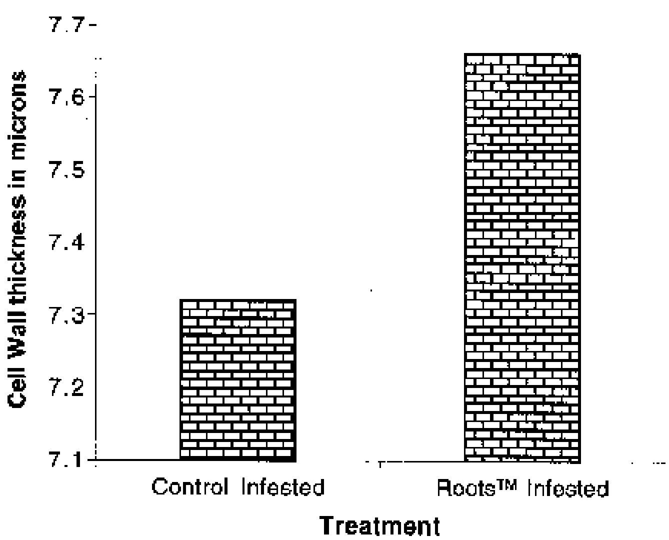

Figure 5.—Treatment with organic biostimulants significantly increases cell wall thickness in infested trees (p<.0001).

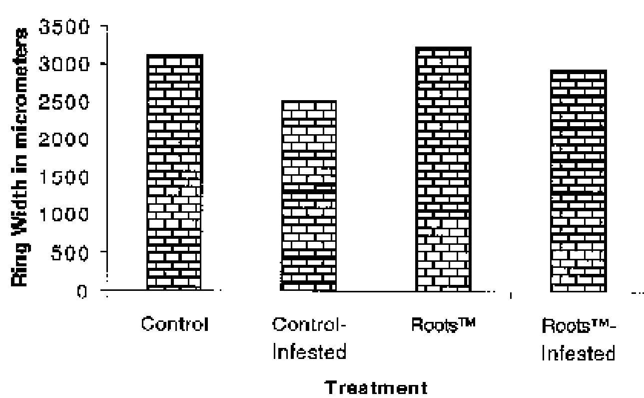

Figure 8.—Adelgid feeding reduces ring widths. Treatment with organic biostimulants reverses this trend (p=.05).

Not shown in the preceding graphs, seedlings that were used in the controlled experimental studies that were not destroyed at the end of the experiments managed to survive into their 5th year, despite heavy infestations. These seedlings are watered regularly and fertilized from time to time. This may be the key to their survival.

Figure 1 refers to the drought study conducted in 1995. Chlorophyll fluorescence is the same for all the plants at the start of the experiment. The graph shows that seedlings subjected to two stresses, water scarcity and adelgid infestation, die by week 5 as witnessed by the rapid fall in chlorophyll fluorescence. The remaining plants subjected to water stress alone, without adelgid infestations, eventually died by week 22 due to lack of water.

Figure 2 refers to the second drought study conducted in 1996, where similar findings were recorded. Death occurred around week 5 in the control-infested group of seedlings. Treatment with mineral nitrogen helped to delay death in infested and droughted seedlings for several weeks. Similarly, it was observed that treatment with the organic biostimulant Roots™ delayed the onset of death in infested seedlings also subjected to drought. The treatment with the organic biostimulant (Roots™) and the Nitrogen appears to have made these plants withstand the dual stress of infestation and drought better.

Figure 3 shows the results of the field study, which confirms the findings of the seedling study that annual growth is not affected significantly by the presence of adelgids alone, on moist sites. The addition of drought to infestation, leads to a significant drop in annual growth. Measurements of ring widths of infested trees are significantly lower in dry sites, in comparison to wet sites ($p>.0001$).

Figures 4 a and b refer to the seedling study conducted from 1994 to 1996. Height and diameter growth was significantly lowered by the presence of the adelgid. Seedlings treated with the organic biostimulant (Roots™) experienced significantly higher height growth ($p =.01$) and diameter growth ($p=.0006$), both in infested and uninfested seedlings.

Other parameters considered when measuring the effect of adelgid feeding were, cell wall, needle and cuticle thicknesses. Figures 5, 6 and 7 refer to these measurements respectively. The results of the study show that all three parameters were significantly lowered by infestation ($p<.0001$), Treatment with Roots™ caused a significant increase in these parameters, offsetting the negative effects of insect feeding ($p<.0001$). Figure 8 refers to the effect of ring widths in infested seedlings. Infested controls are the most affected by the adelgids, while Roots™ treated seedlings show the same growth as uninfested seedlings.

Recommendations for management

Eastern hemlocks infested with the Hemlock Woolly Adelgid, growing within their preferred range of ever-moist sites can survive longer than their counterparts on dry sites. Using organic biostimulants will help improve tree health and vigor, leading to increased chances of surviving attack by the hemlock woolly adelgid.

This has implications both for nursery managers and forest health managers. The organic biostimulants improve health and vigor, increase resistance to drought and insects, thereby increasing the chance of survival of seedlings, and improving recovery following insect attack. Use of organic biostimulants reduces fertilizer inputs by upto half, and can reduce pesticide loading in the environment due to the increased resistance observed in biostimulant treated plants.

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