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ADVANCES IN TREE GROWTH CONTROL BY TRUNK INJECTION[1]

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Abstract. A study was made of new methods and chemicals for controlling regrowth in trees. As part of this research program a portable, air-powered equipment system was developed for injecting low volumes of concentrated aqueous chemical solutions into trees for sprout regrowth control. Using young seedlings in the greenhouse, 10 chemicals were screened for their effectiveness in controlling regrowth on 24 tree species. Laboratory studies were also conducted to determine the translocation and metabolic behavior of certain radio-labelled chemicals in young seedlings. Using the trunk injection technique, measurements of sprout regrowth were made on mature trees of several species during the period 1973-78. Of the growth regulators tested, daminozide, dikegulac and maleic hydrazide consistently caused reductions in sprout growth. In general, high concentrations were more effective in controlling regrowth than were low concentrations for equal volumes of the same chemical.

The management of trees along powerline rights-of-way is a persistent problem for electric utility companies and one of considerable economic importance as well. Growth that can potentially contact a powerline is removed by manual pruning, an operation which must be repeated at intervals of 1 to 3 years, depending on the growth rate of the particular species.

Application of chemical growth retardants has been suggested as a possible alternative to costly mechanical pruning techniques currently in use. Although foliage application of growth retardants has met with some success, certain undesirable side-effects often accompany such treatments. Direct introduction of chemicals into trees via trunk injection offers obvious ecological advantages over existing spray techniques as an economical means of managing vegetation along utility rights-of-way.

Development of a Portable Injection System

Controlling tree regrowth by chemical injection involves repeated treatments of the same tree every few years. Since most treated trees will be in public view, either on private property or along urban streets, the injection procedure must not disfigure the tree nor render the tree susceptible to secondary infection. These conditions must be satisfied in addition to meeting the requirements for safety, effectiveness, and economy.

The injection equipment developed in this research program makes use of the advantage of small diameter, force-fit injectors and low volumes of concentrated growth regulator solutions (Brown, 1978). The small diameter injectors are easily inserted into and removed from pre-drilled holes in the trunk, and they operate safely without leakage if inserted to an adequate depth. Each injector has its own injection circuit, injection cylinder and pneumatic power control circuit. The stainless steel injection circuit is a combination design for conversion of low air pressure to high water pressure. The liquid end displaces a maximum volume of 40 ml per cycle and can be adjusted to any volume between 0 and 40 ml by manipulating a stroke adjustment control. When

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more than 40 ml per injector are required, multiple cycles of the injection cylinder are used.

Although the entire system is enclosed in an aluminum sheet metal housing for minimum weight, all parts of the injection circuit itself are either stainless steel or plastic for protection against corrosive chemical solutions. The supply of growth-regulating chemical is stored in a plastic tank located within the injector system housing. The supply tank can be easily refilled or removed for draining and flushing. The air supply for operating the system is carried in a portable air tank connected to the injection system via a pneumatic quick coupler. The portable air tank can be quickly recharged from a larger air tank carried on a service truck.

The injection system has been field tested since 1976 using a wide variety of tree species growing in diverse geographical locations. In field experiments involving more than 1100 trees, and with injection pressures up to 200 psi, the equipment has operated without problems. The completed prototype equipment system is estimated to have a retail cost of less than $1500. The equipment and methods described in this report are expected to be used commercially within the next few years, particularly since results of field research have shown that trunk-injected chemicals can significantly reduce tree growth and sprout development in mature trees (Brown *et al.*, 1977).

Greenhouse Evaluation of Chemicals

In an effort to determine the relative effectiveness of numerous growth retarding chemicals for controlling sprout growth in a wide variety of tree species, various concentrations of each chemical were tested on young, containerized seedlings in the greenhouse. Using the technique described by Gregory (1969), individual growth regulators were introduced into each seedling by wounding the stem with a sharp scalpel. Observations on vertical height increase, number of sprouts, sprout length, and overall plant appearance were noted approximately 8 weeks after treatment (Ufferman *et al.*, 1979). In most of the later studies, the seedlings were harvested and measurements of root weight, shoot weight and root-shoot ratio were made to determine the influence of chemical treatment on seedling growth and development.

In greenhouse tests conducted since 1974, commercial formulations of ancymidol (A-Rest), chlormequat (Cycocel), daminozide (SADH, Alar), dikegulac (Atrinal), fluoridamid (Sustar), FMC 10637, maleic hydrazide (MH, Slo-Gro), mefluidide (Embark), napthaleneacetic acid (NAA, Tre-Hold), and UNI-P293 have been tested on a wide variety of tree seedlings including silver maple, American elm, sycamore, cottonwood, Norway maple, white ash, red oak, eucalyptus, white pine, poplar, water oak, black locust, black cherry, river birch, quaking aspen, melaleuca, Australian pine, redwood, hackberry, red maple, pin oak, aspen, yellow-poplar and willow. Using the manufacturers' recommended dosage as a guide, a range of chemical concentrations was tested in each experiment. In total, 10 growth-regulating chemicals were screened in the greenhouse using 24 species representing a cross-section of "problem" trees from throughout the U.S.

Some of the early experiments conducted in the greenhouse showed that several of the chemicals under test were either ineffective in controlling regrowth or exhibited undesirable side-effects on growth and/or foliar appearance. For these reasons, and because solubility was a problem with some chemicals, most tests were conducted with only two growth regulants, maleic hydrazide and dikegulac. The most consistent index of sprout growth control for seedlings in the greenhouse was vertical height increase. The number of sprouts was relatively unaffected by chemical treatment in these experiments.

The best regrowth control with maleic hydrazide occurred at the highest concentrations, with significant reductions in all species tested except white ash and redwood. However, phytotoxicity was a consideration in several species including black locust, Australian pine, black cherry, sycamore, aspen, poplar, river birch, and hackberry. Dikegulac, primarily but not exclusively, at the higher concentrations effectively controlled regrowth in sycamore, Australian pine, white ash, water oak, yellow-poplar, silver maple, river birch, and black cherry seedlings; however, phytotoxicity was a problem with the latter three species. Dikegulac was not considered to be effective in controlling regrowth of black locust, melaleuca, aspen, and redwood seedlings at any of the concentrations tested in the greenhouse.

Field Evaluation of the Trunk Injection Technique

Based on the results of chemical evaluations made in the greenhouse, studies were initiated in the field to determine the effectiveness of trunk injection on mature trees.

1973 Experiments. Water solutions of commercial formulations of ethrel (Ethephon), ancymidol, and chlorflurenol (Maintain CF-125) were injected into the trunks of American elm saplings in May and June to evaluate their effectiveness in reducing sprout regrowth (Roberts *et al.*, 1979a). In general, chemical treatments made in June were more effective in controlling sprout growth and less likely to cause phytotoxicity than were comparable treatments made in May. Chlorflurenol was the most effective chemical tested for controlling sprout growth in American elm.

1974 Experiments. Commercial formulations of daminozide, ancymidol, chlormequat, chlorflurenol, TIBA (Regim-8), maleic hydrazide, and fluoridamid (Sustar 2-S) were evaluated on 135 American elm trees during 1974 (Brown *et al.*, 1977). The trees were topped in early April, leaving a substantial number of limb stubs to accentuate sprouting. The injection system used in these experiments was an early design which utilized three modified lag bolts (5/8 × 3-inch) connected via a common pressure manifold system to a 20-gallon hydraulic sprayer. The injections were completed during the first 2 weeks of June, after full leaf expansion. The condition of each tree and its general foliar appearance were recorded each year at the end of the growing season but before fall coloration. After leaf abscission, all sprout regrowth within 10 inches of the end of each cut limb was measured.

After the 1974 growing season, five of the original chemicals tested (daminozide, chlorflurenol, TIBA, maleic hydrazide and fluoridamid) proved to be effective in reducing sprout regrowth in American elm at the concentrations used in these studies. The same trees were observed again during the next growing season (1975) and similar results were noted. In 1976, sprout regrowth data were collected for only daminozide and maleic hydrazide since the manufacture of fluoridamid was discontinued, and the remaining treatments had no longer reduced regrowth or had resulted in death of the trees. Both daminozide and maleic hydrazide continued to be effective in reducing sprout growth in American elm during 1976 when compared to untreated controls. By the end of 1977, although there were still significant differences between treated and untreated elms, the rate of regrowth was comparable for all trees.

1975 Experiments. The same formulations of daminozide and maleic hydrazide used in the 1974 treatments, but at three concentrations each, were injected in American elm and American sycamore during 1975 (Brown *et al.*, 1977). The injection equipment used in 1975 was the same as that used in 1974. The volume of chemical solution injected per tree was based on trunk diameter at breast height (dbh). Seventy trees from each species were topped before injection in May and June after full leaf expansion. The experiments in these studies were statistically designed so that each chemical treatment had an equal distribution of dbh. The effects of injection on sprout growth and tree condition were recorded as previously described.

The analysis of regrowth data for 1975 showed that at least one concentration of each chemical significantly reduced sprout growth for both species tested. Although some concentrations of maleic hydrazide were excessively phytotoxic and some concentrations of daminozide were relatively ineffective, the low and medium concentrations of maleic hydrazide, as well as the high concentration of daminozide, exhibited satisfactory sprout regrowth control in elm and sycamore over the range of dbh tested. During the following year, 1976, sprout growth was still significantly reduced in American elm with the high concentration of daminozide, and on sycamore with the medium concentration of maleic hydrazide. After the third growing season, 1977, only the medium concentration of maleic hydrazide remained effective; by 1978, there was no residual effect of growth regulator treatment on either species.

1976 Experiments. Water solutions of daminozide and maleic hydrazide, plus an experimental chemical, dikegulac, each at three concentrations, were pressure-injected into 100 trees each of Siberian elm, silver maple, American sycamore and red oak. For these experiments, and all subsequent field studies, the portable, air-powered injection system described earlier was used. The trees in this study were topped in April prior to injection during May and June. As in previous field experiments, the condition of each tree and its general foliar appearance were recorded each year before fall coloration. Regrowth measurements were taken after leaf abscission in the fall, and included all sprout growth within 10 inches of the cut end on elm and sycamore, within 20 inches on red oak, and within 36 inches on silver maple.

After the first growing season, sprout regrowth in elm, maple, and sycamore was effectively reduced by at least one concentration of each chemical. In general, higher concentrations were more effective than lower concentrations of the same chemical. However, at the concentrations used in these experiments, none of the chemicals reduced sprout growth in red oak. Observations made on the same trees after two growing seasons revealed that sprout growth on maple and sycamore was still significantly reduced when compared to the controls. Because the Siberian elms (treated and untreated) were severely damaged by winter weather, no additional data are available on this species. Surprisingly, the highest concentration of dikegulac did reduce sprout on red oak during the second year, even though no effect was apparent the first year. In 1978, three growing seasons after treatment, the highest concentration of dikegulac still showed some sprout growth reduction in sycamore and oak, while the highest concentration of maleic hydrazide was still effective in silver maple.

Time of year for injection. To determine the most suitable time of year for injection, treatments with daminozide were made on American elms at 2-month intervals starting in February, 1976. As expected, the time required to introduce chemicals into the tree was longer in the winter months and appeared to correlate well with the physiological state of the tree at the time of injection. In general, treatments made during the dormant period were not as effective in controlling subsequent regrowth as were treatments made in the spring.

Injection of topped and untopped trees. To determine the relative effectiveness of injecting topped or untopped trees, 40 American elms were treated with maleic hydrazide in May, 1976. Half of the trees had been topped in April before treatment, while the remaining trees were left untopped. After one growing season, all of the chemically treated trees showed reduced sprout growth, and there was no significant difference in growth between trees topped prior to injection and trees left untopped.

Injection wound closure. To study injection wound closure and to get some idea of the benefits derived from treating wounds to promote healing, the injection holes made in the 1975 studies with American elm, American sycamore, and silver maple were covered with grafting wax, sprayed with wound dressing, or left untreated. Measurements of wound closure made two growing seasons after treatment suggest that applications of grafting wax or wound dressings do not appreciably enhance the healing process in most trees. Smooth bark species such as silver maple may have a tendency to exhibit vertical bark splitting after injection, but this does not appear to be a major problem if the injection holes are small (less than ¼-inch diameter).

1977 Eperiments. Commercial formulations of dikegulac and maleic hydrazide, each at three concentrations, were selected for further evaluation on a variety of tree species in California, Georgia, Ohio, and Pennsylvania. A total of 610 trees, including American sycamore, silver maple, red oak, shamel ash, and eucalyptus, were treated after full leaf expansion in the period April-June, 1977 (*Roberts et al.*, 1979b). Four of the studies involved treatments made on municipally owned street trees. Except for about one-half of the eucalyptus treatments, all trees were topped prior to injection by cutting major limbs. Following injection, three randomly selected limb stubs in each tree were identified for treatment evaluation at the end of the growing season as previously described. All injections were made with the portable, air-powered injection system.

With the exception of one experiment with sycamore in Georgia, both dikegulac and maleic hydrazide significantly reduced sprout regrowth after one growing season in all species tested. In general, higher concentrations were more effective in controlling regrowth than were lower concentrations of the same chemical. However, higher concentrations of both chemicals, particularly dikegulac, were more likely to cause unfavorable foliar appearance. Regrowth control was generally similar for identical species tested with the same chemical at different geographic locations. Two growing seasons after treatment, 1978, the results were essentially the same but the street tree experiment with silver maple was no longer showing significant differences in growth rate. Sprout regrowth in the remaining species was reduced more effectively by higher concentrations of dikegulac.

1978 Experiments. Since some difficulty was experienced in injecting higher concentrations of chemical into eucalyptus during the 1977 treatments, and since many of the trees in the original experiment were topped after injection rather than before, 50 previously untreated eucalyptus in a different location were treated in March, 1978. These trees were injected with two concentrations each of aqueous solutions of dikegulac and maleic hydrazide. Sprout regrowth and foliar appearance were measured as previously described.

After a single growing season, the highest concentration of dikegulac and both concentrations of maleic hydrazide resulted in significantly less sprout regrowth when compared to untreated controls. These data verify the earlier results with eucalyptus and suggest that sprout growth in this species is controlled equally well whether injection is completed before or immediately following the trimming operation.

The Fate and Residual Characteristics of Injected Chemicals

In order for growth retardants to be registered by the U.S. Environmental Protection Agency (EPA), it is essential to determine the metabolic fate of such chemicals after they have been injected into the tree. For this purpose, studies were conducted to determine the translocation pattern and formation of metabolites, if any, in selected tree species injected with radio-labeled daminozide and maleic hydrazide (Domir, 1978). One-year-old seedlings of silver maple, American sycamore, American elm, and red oak were planted in sand and later transferred into half-strength nutrient solution. Two weeks later, the seedlings were injected with ^{14}C-daminozide and ^{14}C-maleic hydrazide. The seedlings were harvested at periodic intervals up to 1 month after treatment and then separated into roots, stems, and leaves. Individual plant parts were then extracted with aqueous methanol and aliquots of each extract were checked for radioactivity using various forms of chromatography. Biochemical studies were also initiated to determine the metabolic fate of injected growth regulators.

Within 1 day after treatment, both daminozide and maleic hydrazide were detected in all parts of the plant, indicating a rapid transport of ^{14}C material both acropetally and basipetally. Minimal quantities of ^{14}C-daminozide were exuded from the seedlings into the nutrient solution. In the case of maleic hydrazide, however, up to 18% of the ^{14}C activity was exuded into the nutrient solution except that no exudation was detected in red oak. These results further indicate that whereas most of the radioactivity is extractable from plant tissue, a significant portion (up to 20% of that injected) is present in the bound form, particularly in the stem.

Using various forms of chromatography we determined that daminozide was not converted to a metabolite in any of the species tested. However, maleic hydrazide was metabolized into another chemical form in all of the species studied. In silver maple and American sycamore, this metabolite was identified as a sugar conjugate of maleic hydrazide. The identity of the metabolite in red oak and American elm remains unknown.

Cost Analysis

At current prices, we estimate the average cost of trunk injection to be about $2 per tree. This figure is based on the use of a portable, air-powered injection system with an original equipment cost of $1500, an equipment life of 3 years, and an annual equipment repair cost of $250. Assuming that an average of 45 trees can be treated per day over a total of 60 working days, the equipment cost is $0.31 per tree.

To estimate labor cost, we selected a 20 inch diameter tree to be representative of the average tree size in our field treatments. The volume of solution required for a 20 inch tree is 513 ml. Previous experience with trees this size suggests that the approximate time required for preparation and treatment is 10 minutes. Assuming a wage of $10 per man, the average labor cost per tree for trunk injection becomes $1.67.

Aqueous formulations of dikegulac and maleic hydrazide have shown the most promise for controlling sprout regrowth in our research program. The current distributor cost for maleic hydrazide is $9.50 per gallon. Assuming the tree size and volume requirement indicated above, the average chemical cost per tree for maleic hydrazide would be about $0.11. The cost of dikegulac, an experimental chemical, is unknown at this time, but it is anticipted that the eventual market price will be competitive with other growth-regulating chemicals such as maleic hydrazide.

To get some idea of the potential savings derived from trunk injection we estimate that it costs an average of $10 to trim each tree in a "typical" line-clearing operation. If growth control chemicals such as maleic hydrazide are applied following trimming, the cost per tree is about $12 Assuming a 1-year trimming cycle without chemical treatment, and a reduction in regrowth equivalent to 1 year of growth with chemical treatment, the annual costs with and without trunk injection become $6 and $10, respectively. Thus a potential savings of $4 per tree, or 40%, might be achieved by using the trunk injection technique.

Current Status

Several aqueous formulations were originally tested for their effectiveness in controlling sprout regrowth in trees. As mentioned previously, we are currently working with two growth-regulating chemicals in our research program. One of these materials, dikegulac, is an experimental compound that has been tested for use as a chemical pinching agent and growth control compound for numerous woody ornamentals. The other material, maleic hydrazide, is a heterocyclic plant growth regulator that has been used successfully as an agricultural chemical for many years, particularly as a sucker control agent for tobacco. Maleic hydrazide is currently registered for use as a growth regulating chemical for deciduous trees by foliar application only. Maleic hydrazide is not now registered for use via trunk injection. Dikegulac is registered for use.as a foliar spray to retard the growth of numerous woody ornamentals but, like maleic hydrazide, is not now registered for use via trunk injection.

In 1977, the U.S. EPA issued a rebuttable presumption against registration (RPAR) for products containing maleic hydrazide. The commercial formulation of maleic hydrazide, Slo-Gro, with the diethanolamine salt of maleic hydrazide as a major constituent, was included on the list of RPAR compounds. Subsequent to the EPA notification, the primary manufacturer of commercial formulation submitted technical evidence to rebut the presumption of risk indicated by the RPAR announcement. Additional information on the economic, social, and environmental benefits derived from the use of this compound has also been submitted to EPA for consideration. At the present time it is anticipated that EPA will publish a position statement on the registration of maleic hydrazide-containing compounds sometime during 1979.

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ABSTRACTS

BAUMGARDT, J.P. 1979. **Utilizing tree by-products.** Grounds Maintenance 14(5): 22, 26, 92, 94, 96.

A few years ago the debris from pruning and tree removal would have been heaped into a great pile and then burned. Burning bans and, later, air pollution controls necessitated the use of machinery to grind waste wood so burning could be avoided. Today, highly specialized machines quickly shred limbs or grind stumps, creating a heap of shredded wood. Logs may be sold as firewood or used in grounds maintenance operations, but what is to be done with mounds of wood chips and sawdust? Wise use of this residue can benefit the landscape at a minimal cost.

NIELSEN, D.G. 1979. **Integrated control strategies established for tree insects.** Weeds, Trees and Turf 18(5): 20-22, 25-26.

Integrated Pest Management (IPM) is a current and popular approach utilizing pest control techniques that optimize production of maintenance efficiency while minimizing adverse environmental side effects. IPM is not new but was abandoned by many producers and landscape managers with the advent of petroleum based synthetic organic pesticides in the 1940's. Today, IPM is an approach to improve efficient use of all available tactics, including conventional pesticides only when necessary. Few programs have been developed to optimize control efficiency against pests of trees and shrubs. However, IPM can be implemented against some of the most common and destructive pests of woody ornamentals in the landscape and the nursery. A few examples are presented here to illustrate how these strategies are formulated based on thorough knowledge of the pests involved and tactics available for combating them.

VAN ARSDEL, E.P. 1979. **Symptoms and conditions of environmental tree disease.** Weeds, Trees and Turf 18(6): 16-20, 23, 26, 28-29.

Environmental diseases are those caused by the adverse effects of the environment on the tree. The adverse environmental conditions can be physical or chemical and can affect the plant directly or through the soil, water, or air. Direct physical disturbances can be mechanical injuries to the above-ground part of the tree, but more commonly they are to the roots because people are not much aware of the part of the tree that is underground. Physical changes in the level or drainage of the soil are often harmful. Harmful chemicals can be in the soil, the water, the air, or may be applied by people. Physical changes in the atmosphere are adverse weather (e.g., early or late frost), or sudden changes in the microenvironment (e.g., changes in a nearby structure), or the introduction of chemicals (air pollution). Environmental maladies involve several species of plants more often than infectious or biological diseases do, and they often stop at the property ownership lines.