TREE GROWTH RETARDATION BY INJECTION OF CHEMICALS[1]

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Abstract. A long term study was conducted to evaluate growth retardation capabilities of potential plant growth regulators for landscape trees. These investigations were carried out in the greenhouse and at several geographic field locations with different climatic conditions. A portable, air-powered equipment system was used for injecting field trees with low volumes of highly concentrated aqueous growth regulator solutions. One- to two-year-old seedlings of approximately 25 species were tested under greenhouse conditions. Twelve chemicals were screened as potential growth retardants. The most consistently effective chemicals tested over a wide range of tree species were maleic hydrazide, dikegulacsodium, and DOWCO 391. At appropriate concentrations, these chemicals controlled sprout regrowth in most species without unacceptable phytotoxicity. Using the pressure injection technique, maleic hydrazide and dikegulac were tested for their control effectiveness on 14 species in 12 states and 17 cities. Both chemicals were successful in controlling growth of almost all species for one year. In several instances regrowth was controlled for two growing seasons following treatment. Generally, dikegulac was more consistent than maleic hydrazide in generating a growth retardation response. Field studies show that significant regrowth variability exists among trees treated with a given dosage of chemical. This variability may be attributed to environmental and/or plant factors. In order to obtain similar growth control effects for identical species located at various geographical locations, different concentrations of the same chemical may be needed.

Retrimming of trees alongside or underneath electric transmission and distribution lines is a major part of utility service continuity. Trees are trimmed at intervals of 1 to 3 years depending on growth rate and the amount of line clearance required (14). The trimming operation, although effective, can be expensive, time consuming, and hazardous (4). With these factors in mind, Edison Electric Institute undertook a 9-year (1958-1967) research project on chemical inhibition of tree growth at Battelle Memorial Research Institute (EEI Project RP 24). At the end of the project, it was concluded that additional work was needed to find a better method of chemical treatment, and additional chemicals for tree growth retardations needed evaluation (10).

Several chemicals have shown effectiveness with regard to tree sprout growth control. These growth regulating chemicals can be applied as foliar sprays (8, 15, 18, 19), wound dressings (6), bark banding (1, 11), trunk infusions (12, 13), and pressurized trunk injections (16, 17). It is important that one select the method of application that will be most economical, efficient, and nonpolluting, and yet not cause undesirable side effects. An examination of pros and cons of different application systems (3) indicates that pressurized injection into the trunk of the tree may be the most feasible technique for assuring good chemical distribution (20).

In 1974, the Electric Power Research Institute (EPRI) initiated a research project in cooperation with USDA-ARS, Nursery Crops Research Laboratory, Delaware, OH, to control regrowth of trees after pruning by injecting chemicals into trees. The research project involved greenhouse and field screening of several chemicals as potential tree growth retardants. This paper summarizes the results of studies carried out over the last 9 years to determine the possibility of commercial application of plant growth regulating chemicals to street trees.

Materials and Methods

Greenhouse studies. A survey of the growth regulation literature was conducted to identify the candidate chemicals for testing purposes. Since 1974, twelve chemicals and 25 tree species have been evaluated in the greenhouse (Table 1). The species were selected on the recommendations of electric utility company representatives based on their concern of "problem" trees in their area. Although each species was treated with a range of chemical concentrations, not every chemical was used in the treatment of every species. Thus, the treatment sequence began

1. Mention of a pesticide in this paper does not constitute a recommendation by the USDA nor does it imply registration under FIFRA. Mention of a trade mark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

Table 1. Growth regulating chemicals and woody tree species screened in the greenhouse.

Common Name	*Formulation*	*Chemical Name*	*Species Treated*
Ancymidol	A-Rest	-cyclopropyl- -(4-methoxyphenyl)-5-pyramidine = methanol	Silver maple
Chlormequat	Cycocel	(2-chloroethyl) trimethyl-ammonimum chloride	Silver maple
Daminozide	Alar	Succinic acid, 2, 2-dimethylhydrazide	Silver maple, American elm, sycamore, cottonwood, Norway maple, white ash, red oak, eucalyptus, white pine
Dikegulac	Atrinal	2,3:4,6-bis-0-(1-methyl-ethylidene)-L-xylo-2-hexulo-furanosonic acid, Na salt	Silver maple, red oak, eucalyptus, white pine, cottonwood, sycamore, poplar, white ash, water oak, black locust, black cherry, river birch, quaking aspen, melaleuca, Australian pine, redwood, black walnut
DOWCO 391X	M-4335	N, N, N-tributyl-3-(tri-fluoromethyl) benzene-thanaminum chloride	Black locust, silver maple, eucalyptus, white ash, American sycamore
DPX-1108	Krenite	Ammonium ethyl carbam-oylphosphonate	Black locust, silver maple, white ash, eucalyptus, American sycamore, red oak
Fluoridamid	Sustar 2-S	N-[4-methyl-3-[(trifluoro-methyl)-sulfonyl] = amino] phenyl] acetamide	Silver maple
FMC 10637		Ethyl hydrogen 1-propyl-phosphonate	Silver maple
Maleic hydrazide	Slo-Gro	1,2-dihydro-3, 6-pyradazinedione	Silver maple, sycamore, cottonwood, Norway maple, white oak, white ash, red oak, eucalyp-tus, white pine, poplar, hackberry, red maple, pin oak, black locust, Australian pine, black cherry, melaleaca, aspen, river birch, redwood, yellow poplar, willow
Mefluidide	Embark	N-[2,4-dimethyl-5-[(tri-fluoromethyl) = sulfonyl] amino] phenyl] acetamide	Silver maple, cottonwood
NAA	Tre-Hold	1-naphthaleneacetic acid, ethyl ester	Silver maple, black locust, white ash, sycamore, eucalyptus
UNI-P293		2,3-dihydro-5, 6-diphenyl-1,4 oxathin	Silver maple

initially with many chemicals and fewer species, gradually involving fewer chemicals and a greater number of species (14).

One-to two-year-old dormant seedlings of the listed species (Table 1) were planted in 15-cm plastic pots filled with a mixture of peat, perlite, and soil (2:2:1). The potted seedlings were placed in a greenhouse, provided with supplemental illumination, watered three times a week, and fertilized once a week to insure optimum conditions for growth and development (14). When the seedlings achieved full leaf development, approximately one-third of the foliage from the top of each plant was removed. One day after trimming, the seedlings were treated with growth regulating chemicals. A range of different concentrations of each chemical was used to determine the relative effectiveness in retarding sprout regrowth. Prior to treatment, the plants were set up in a completely randomized experimental design with 10 trees per treatment. Techniques described by Gregory (17) were used to apply the chemical. Five ml of treatment solution was added to a serum cap reservoir surrounding the stem, and the chemical was introduced by wounding the stem with a scapel, thus allowing the solution to be taken up in the transpiration stream. Distilled water was used as a treatment solution for seedlings designated as controls.

Over an 8-week period following treatment, measurements of vertical height increase, number of sprouts, sprout length and foliar phytotoxicity were collected every 2 weeks. Phytotoxicity (Foliar index rating, FI) was rated on a subjective scale from 0 to 5. Trees with phytotoxicity ratings of 3 or above were considered unacceptable for landscape purposes (14).

Field evaluation of the trunk injection technique. Starting in 1973, series of growth regulating chemicals were evaluated as commercial formulations for controlling sprout growth in mature trees. The chemicals and species used in the field testing program are listed in Table 2. The field studies included use of 11 plant growth regulating chemicals and 15 tree species. Ex-

Table 2. Summary of chemicals and species used in field testing program.

Common name	*Formulation*	*Chemical name*	*Species tested*
Ancymidol	A-Rest	-cyclopropyl- -(4-methoxyphenyl)-5-pyramidine = methanol	American elm
Chlorflurenol	Maintain CF-125	Methyl-2, 7-dichloro-9-hydroxyfluorene-9-carboxylate	American elm
Chlormequat	Cycocel	(2-chloroethyl) trimethyl-ammonimum chloride	American elm
Daminozide	Alar	Succinic acid, 2, 2-dimethylhydrazide	American elm, sycamore, Siberian elm, silver maple, red oak, white pine
Dikegulac	Atrinal	2,3:4,6-bis-0-(1-methyl-ethylidene)-L-xylo-2-hexulo-furanosonic acid, Na salt	American elm, sycamore, Siberian elm, red maple, water oak, poplar, silver maple, red oak, shamel ash, eucalyptus, sweetgum, red alder, melaleuca, white pine, hackberry, cottonwood, bigleaf maple
NIA 10637		Propylphosphonic acid	American elm
NIA 10656		Ethyl hydrogen 1-propyl-phosphonate	American elm
TIBA	Regim-8	2,3,5-triodobenzoic acid	American elm

periments on street trees were carried out with maleic hydrazide and dikegulac-sodium on 11 species at 17 locations in 12 states. Between 1973 and 1975 studies were conducted at the nursery in Delaware, OH, using the injection methods described by Himelick (9). From 1976, the field investigations were carried out employing the injection methods and equipment described by Brown (2). Using a cordless electric drill, 3 holes of 5.4 mm diameter were drilled 60 mm deep into the trunk 1 meter above the ground on all treated trees 40 cm DBH or less. For trees of large diameter, 6 holes of similar size were drilled. The number of injection sites was increased on the larger diameter trees to insure better initial distribution of the chemical. The holes were spaced equidistant around the trunk and drilled tangentially to intersect as many active xylem vessels as possible (14).

Each experiment consisted of ten trees, and treatments were assigned in a randomized complete block statistical design, with each treatment within a species having an equal distribution of DBH. For trees with a DBH of 40 cm or less, the volume (V) of chemical injected per tree was based on the square of the DBH using the formula: $V = 40 \times (DBH)^2/161$ ml. For trees larger than 40 cm DBH, V was computed on a linear relationship using the formula: $V = 410 \times DBH/40$ ml. The linear relationship was used on larger diameter trees to prevent overdosing since crown size of large trees did not increase in proportion to trunk diameter (14). All trees were topped before treatment. Control trees, although topped, did not receive an injection treatment since earlier experiments showed no significant effects of water injection. Treatments were made between three-fourths and full leaf expansion during the period April-June, using the air-powered injection system at a pressure of 14 kg/cm^2(200psi). Following injection, 3 randomly selected limb stubs on each tree in each treatment were selected for future evaluation and reference.

After leaf abscission, all sprout regrowth originating within 25 cm from the cut end of each previously marked limb was subsequently counted and measured.

From these measurements the number of sprouts, mean sprout length, and mean length of longest sprout were calculated for each tree (14). In most field studies, the condition of each tree and its foliar index rating were recorded at least once each year before fall coloration.

Results and Discussion

Both the greenhouse and field data were statistically analyzed using one-way analysis of variance and comparing the means of treated versus control trees.

Greenhouse studies. Six chemicals (daminozide, dikegulac, MH, DOWCO 391, Krenite and NAA) were effective in retarding the regrowth of various species (Table 3). The degree of response varied among species due to inherent genetic factors. Table 3 summarizes the regrowth response of several greenhouse-grown species tested with six different plant growth regulating chemicals.

One chemical, ancymidol, was insoluble in water. To overcome this problem, a mixture of methanol and phosphate buffer was used to solubilize the chemical. The solvent system proved toxic, even in the absence of ancymidol, and thus no conclusions concerning the potential ability of this compound as a growth regulant can be drawn from these studies. These preliminary tests revealed that the other five chemicals were either ineffective in controlling regrowth or, if effective, they caused excessive phytotoxicity. Therefore, further evaluation of these chemicals was discontinued.

Field studies. Early studies with trees planted in field plots near Delaware, Ohio showed that three chemicals, daminozide, maleic hydrazide (MH) and dikegulac-sodium were effective in controlling regrowth. We later found that at high concentrations daminozide was difficult to inject due to its high viscosity. In addition, cost-benefit analysis showed that daminozide application would not provide any savings when compared to mechanical pruning. Therefore, dikegulac and maleic hydrazide were selected for extensive field testing throughout the United States. Most of the subsequent experiments were conducted with city street trees, growing under utility lines. Based on the regrowth data obtained in these experiments, an estimate was made of the pruning cycle extension of treated trees as compared to control trees (Tables 4 and 5).

Table 3. Growth and phytotoxic response of various woody species to six plant growth regulating chemicals.

Chemical	Growth and phytotoxicity response [a] 0	+	++	+++	++++	−
Daminozide	White pine, eucalyptus, red oak, sycamore		Silver maple, cottonwood, Norway maple, white ash		American elm	
Dikegulac	White ash, black locust, redwood, black walnut	Eucalyptus, white pine, cottonwood, poplar, black cherry, quaking aspen	Sycamore, water oak, river birch	Silver maple, Australian pine	Red oak	
Maleic hydrazide	Cottonwood, Norway maple, redwood, red oak, aspen, melaleuca, red maple, black walnut, tilip tree	White pine, pin oak	White ash, eucalyptus, Australian pine, black cherry	Sycamore, poplar, hackberry, black locust, river birch, willow	Silver maple, white oak	
DOWCO 391	Eucalyptus	White ash	Silver maple, black locust, sycamore			
Krenite		Black locust, eucalyptus				Silver maple, white ash, sycamore
NAA		Silver maple, white ash, eucalyptus	Sycamore			

[a] The growth and phytotoxic response was classified into six categories: 0 = non-significant growth reduction with acceptable toxicity; + = significant growth reduction of 25% or less with acceptable toxicity; ++ = significant growth reduction between 25 to 49% with acceptable toxicity; +++ = significant growth reduction between 50 to 74% with acceptable toxicity; ++++ = significant growth reduction of 75% or greater with acceptable toxicity and; − = non-significant growth reduction and toxicity unacceptable.

The data showed that dikegulac generally is more effective than MH in extending the trimming cycle. An examination of the data in Table 5 leads us to conclude that geographical location and climate conditions play an important part in determining the growth response of trees to plant-growth-regulator treatment. Developmental state of the tree at treatment time also may play a significant role in influencing the subsequent growth of plants. The trimming cycle of sycamore, injected in 1977 in Philadelphia, was extended by one growing season; however, the chemicals did not produce this response in trees treated in 1980 (Table 5). These results may be attributable to the different stages of tree development at time of injection. In 1977, the trees were at half-leaf development stage and in 1980 the leaves were fully developed at treatment time. An examination of the growth data reveals that with certain treatments, even though mean growth of treated trees was less than two-thirds of the control trees, statistical analysis indicated no significant differences (5). These findings indicate large tree-to-tree variability. Such variability becomes evident

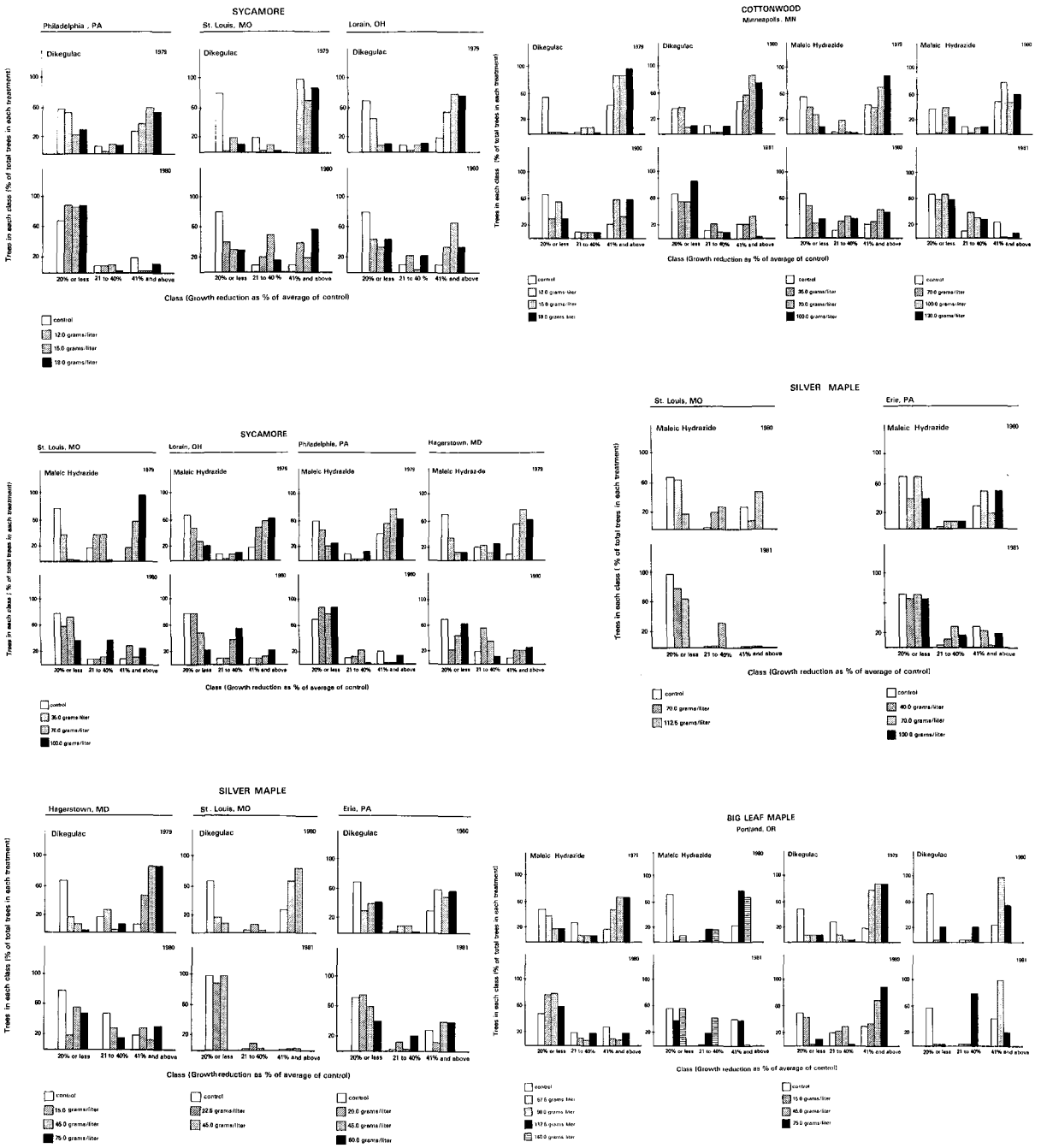
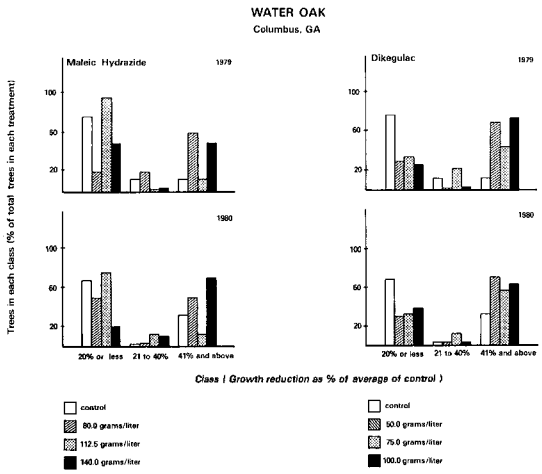
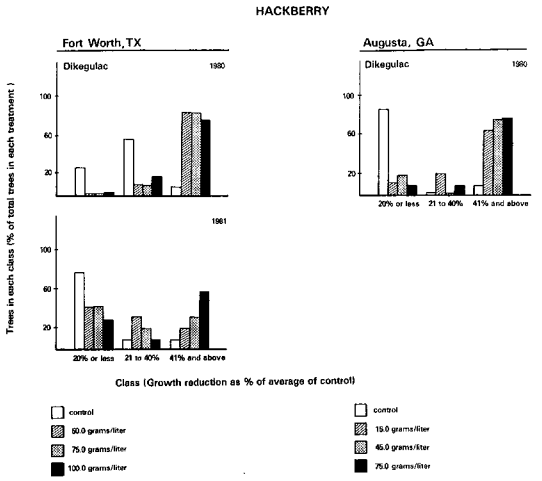


Fig. 1. Regrowth response of sycamore, silver maple, bigleaf male, cottonwood, water oak, hackberry, and red maple to injected dikegulac or maleic hydrazide at different locations. The treatments were made in the spring of first year and regrowth measurements were taken at the end of the first and second growing season following injection.





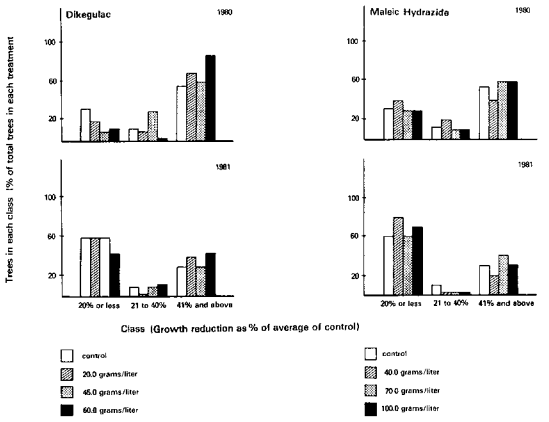


Table 4. Influence of dikegulac and maleic hydrazide on the trimming cycle of various species.

Treatment year	*Species*	*Location*	*Estimated extension of trimming cycle (years)*	
			Dikegulac	*MH*
1977	Red oak*	Lorain, OH	1	0
1977	Shamel ash	Hayward, CA	1	0
1979	Water oak	Columbus, GA	1	0
1979-80	Bigleaf maple	Portland, OR	1	0
1979-80	Cotton-wood	Minneapolis, MN	0	0
1980	Melaleuca	St. Petersburg, FL	1	1
1980	Hackberry	Augusta, GA	1	2
1980	Hackberry	Fort Worth, TX	1	1
1980	Lombardy poplar	St. Louis, MO	0	0
1980	Red maple	Stamford, CT	0	0

* Trees located in natural woodstand

Table 5. Effect of injected dikegulac and maleic hydrazide on the trimming cycle of American sycamore, silver maple, and eucalyptus at various locations.

Treatment	*Location*	*Estimated extension of trimming cycle (years)*	
		Dikegulac	*MH*
	Sycamore		
1977	Philadelphia, PA	1	1
1977	Augusta, GA*	0	0
1977	San Jose, CA	1	0
1979	St. Louis, MO	1	0
1979	Philadelphia, PA	0	0
	Silver maple		
1977	Elyria, OH	0	0
1977	Delaware, OH*	2	1
1979	Hagerstown, MD	1	0
1980	Erie, PA	0	0
	Eucalyptus		
1977	Greenfield, CA	2	2
1978	Hayward, CA	1	1
1980	St. Petersburg, FL	1	0

when one examines Fig. 1a - 1i. For experiments conducted between 1979 and 1981, the mean sprout length of untreated control trees was calculated and then assigned as 100% growth. Then the mean sprout length from each tree in each treatment (including controls) was divided into one of the following classes: 1) percent of all

trees in each treatment showing a growth reduction of 20% or less when compared against mean sprout length assigned to untreated controls (100%); 2) percent of trees with growth reduction between 21 - 40% of controls; and 3) percent of trees showing growth reduction of 41% and greater.

These graphs clearly illustrate the variability that exists among trees in a given treatment, including untreated controls. There may be several reasons for lack of uniform growth among trees: 1) inherent genetic differences in growth patterns among trees of the same species; 2) uneven distribution of chemical among limbs and trees so that certain limbs get more of the active ingredient than others; 3) since dosage is based upon DBH rather than canopy size, this may result in differences among trees of the same canopy size in the dose of growth regulator received per unit of tissue, thus contributing to tree-to-tree variability. Figure 1 also reveals that the chemicals are extremely effective in controlling growth during the first growing season following injection, however, in subsequent years their effectiveness is reduced and in several instances the tree apparently began to compensate for loss of growth during the first year.

Several factors, biotic and abiotic, must be taken into consideration in determining the proper concentration of chemical that would produce the desired results. Further research on interaction of these factors with plant growth regulators will be helpful in maximizing the potential of the injection technique for obtaining reliable and consistent growth reduction with minimal variability. The achievement of this objective will result in maximum benefit to the utility industry in their effort to control tree regrowth by commercial application of growth regulating chemicals.

Acknowledgements. The authors acknowledge funding from the Electric Power Research Institute (EPRI), Palo Alto, CA, under a cooperative agreement with the U.S. Department of Agriculture, Agricultural Research Service, designated RP 214-2 'New Methods and Chemicals to Control Regrowth in Trees'.

Literature Cited

1. Backhaus, R.A., H. Hield and R.M. Sachs. 1976. *Tree growth inhibition by bark application of morphactins.* HortScience. 11:578-580.
2. Brown, G.K. 1978. *Prototype equipment for commercial pressure-injection of aqueous growth regulators into trees.* J. Arboric. 4:7-13.
3. Campana, R.J. 1977. *Limitations of chemical injection to control Dutch elm disease.* J. Arboric 3:127-129.
4. Creed, L.D. 1975. *Tree injection method to control tree growth.* J. Arboric. 1:75-77.
5. Domir, S.C. 1982. New methods and chemicals to control regrowth in trees. EPRI Publication EL-2569, 110 p.
6. Fuller, R.G., D.E. Bell and H.E. Kazmaier. 1965. *Tree wound dressing for sprout control in pole line trimming.* Edison Electric Institute Bulletin 33:290-294.
7. Gregory, G.F. 1969. *A technique for inoculating plants with vascular pathogens.* Phytopathology 59:1014.
8. Hield, H., S.B. Boswell and S. Hemstreet. 1977 *Eucalyptus tree growth control by inhibitors applied as sprays, injection, cut painting or trunk banding.* Journal American Society for Horticultural Science 102:665-669.
9. Himelick, E.B. 1972. *High pressure injection of chemicals into trees.* Arborist's News. 37:97-103.
10. Kazmaier, H.E., D.E. Bell, R.G. Fuller and J.H. Litchfield. 1971. Final report on control of tree regrowth. EEI Publication 71-900, 127 pp.
11. Koehler, C.S. and S.S. Rosenthal. 1967. *Bark vs. foliage applications of insecticides for control of Psylla uncatoides on Acacia.* Journal of Economic Entomology. 60:1554-1558.
12. Norris, D.M. 1967. *Systematic insecticides in trees.* Annual Review of Entomology. 12:127-148.
13. Nyland, G. and W.J. Moller. 1973. *Control of pear decline with a tetracycline.* Plant Disease Reporter. 57:634-637.
14. Roberts, B.R., G.K. Brown and C.L. Wilson. 1979. New methods and chemicals to control regrowth in trees. EPRI Publication EL-1112, 95 p.
15. Sachs, R.M. and W.P. Hackett. *Chemical inhibition of plant growth.* HortScience. 7:440-448.
16. Sachs, R.M. W.P. Hackett and J. DeBie. 1974. *Growth retardation and distribution of daminozide in trunk-injected peach and nectarine trees.* HortScience. 9:33.
17. Sachs, R.M., W.P. Hackett and D. Weiser. 1973. *Soil and trunk injection of growth regulators.* HortScience. 8:275.
18. Sachs, R.M., H. Hield and J. DeBie. 1975. *Dikegulac: a promising new foliar-applied growth regulator for woody species.* HortScience. 10:367-69.
19. Sachs, R.M., W.P. Hackett, R.G. Maine, T.M. Kretchum and J. DeBie. 1970. Chemical control of plant growth in landscapes. California Agricultural Experiment Station Bulletin 844. 19 p.
20. Stipes, R.J. 1975. Chemical control of Ceratocystis ulmi - An overview Proceeding 1973 IUFRO Conference on Dutch elm disease, U.S. Forest Service, Upper Darby, PA. pp. 1-77.

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