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CHEMICAL CONTROL OF TREE HEIGHT[1]

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Chinese and Japanese horticulturists developed the art of bonsai (49), whose purpose was to keep trees in pots on a size scale comparable to that of shrubs in the landscape. In modern times, horticulturists and utility companies have shown a great interest in inhibiting the growth of trees under power lines. Mechanical pruning is the most popular means of controlling the tree growth, but it can be hazardous and extremely expensive (10). The other alternative is to plant dwarf species under the power lines. Several tree species, such as *Eucommia ulmoides* D. Oliver, *Ostrya virginiana* and *Malus* spp, *Pyrus calleryana* are suitable for planting beneath power lines (Kozel, Personal communication). This would be the most appropriate long term solution to the truning of shade trees.

The use of growth regulating chemicals has expanded rapidly over the last 25 years. During this period, utility companies have sponsored several studies on the control of tree regrowth with chemicals. In addition, several chemical companies have been involved in evaluating growth-inhibiting compounds. The major thrust has been towards developing a growth inhibitor that is economical and environmentally safe, but at the same time can be applied year round under varying conditions without adverse effects on the trees (10). This paper reviews the progress made over the last three decades in the control of tree height with chemicals.

Methods of Application

Growth inhibitors are applied as foliar sprays, soil drenches, wound dressings, bark dressings, and by injection into the tree. It is important that one select the method of application that will be most economical, efficient, nonpolluting, and yet not cause undesirable side effects. Therefore, the merit of each of the application methods should be evaluated.

Foliar Application. Since the 1950's chemicals have been sprayed on trees to inhibit growth (44). This approach has been used frequently to control tree growth and has been a successful treatment method. One advantage of the treatment is that the tree is not wounded, another is that the chemical is uniformly distributed. This technique has certain ecological drawbacks such as drift of chemicals on non-target species and pollution of waters. In addition, foliar sprays require heavy equipment, significant amounts of chemicals and expensive labor costs. Certain other factors such as surfactant, humidity, temperature, chemical formulation, and concentration can result in variable response.

Bark Applications. Bark dressings have been used to introduce growth regulators into trees by some researchers (26, 33, 34). This type of treatment, unlike foliar administration, is not associated with spray drift, does not require use of heavy equipment, requires less chemical per tree, and takes less time to apply (5). Bark treatment does not result either in mechanical wounding of the tree or in contamination of the environment. Bark is difficult to permeate because of its physical and chemical composition, particularly in older trees (62). Therefore, adjuvants are needed to facilitate the transport of growth regulators into the trees. Also, treatment may result in abnormal development of cambium

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tissue (11).

Soil and root application. The root system and rhizosphere can be effective sites for application of growth regulators. Once the compound reaches the xylem, it can be uniformally transported throughout the plant. One advantage of this type of treatment is that the uptake of the growth regulator is continuous. Application of a long term supply of growth regulators to growing regions of the trees might be more effective than any other technique. One of the drawbacks of this approach is contamination of the soil. Also, it is important that growth regulators not be degraded to an ineffective form or bound in soil. This type of treatment for landscape plantings has been regarded as impractical or undesirable, although certain inhibitors can be effectively used as soil drenches (52).

Wound dressing. This treatment involves the pruning of trees to a required height. The cuts are then treated with inhibitor-fortified dressings (22). Various kinds of dressings have been tested and described in an Edison Electrical Institute report (12). The difficulty with this technique is the problem of painting all power pruner cuts from aerial buckets (2).

Trunk injection. Leonardo da Vinci, the noted artist, was one of the first to inject chemicals into trees (47). Injection techniques have been extensively used in the past to incorporate insecticides, fungicides, herbicides, and nutrients, into trees (28). Most of the early injection techniques were called "gravity feed reservoirs" (GFR) because uptake was thought to be accomplished by gravity and transpirational forces (37). During the last decade several types of pressurized injection units have been developed by several research groups (28, 30, 32, 46). All these injectors are made to inject high volumes of chemical at low concentrations into the tree. Recently, a compact portable, injection system has been designed (6). The success of this system is dependent upon injection of small volumes of growth regulators at high concentrations.

Advantages of injection technique are: (a) rapid transport of chemicals to target areas; (b) efficiency; (c) avoidance of drift and contamination of environment; (d) low hazard to the applicator; and (e) low expense (10, 64). The main disadvantage of this technique is the wounding of the trunk that may enhance the chances of disease. As a general rule, there should be no more than one wound for each 6 inches of truck diameter (60). The pros and cons of different treatment techniques have been described in detail by Stipes (62). Campana, in a recent article, elaborated on the merits of chemical injection (7).

Application time

The timing of application is a critical factor since improper timing can result in damage to the plant. Several factors influence the treatment time, such as species, stage of plant development, treatment technique, and climatic conditions. Annual variations among species in the same climatic zone are too great to depend on calendar dates of application or reliance on a single test species (52, 56, 59). Sachs et al. (56) indicated that when maleic hydrazide (MH) was applied to deciduous species before new leaves had expanded, the trees were excessively damaged. On the other hand, treatment after leaf expansion resulted in inhibition of growth without damage to the leaves. Applications made late in the growing season were ineffective in controlling the growth of deciduous species because the current year's growth may have been completed (52). In evergreen species timing of application is not very critical. However, multiple applications may be required because the growth from terminal and axillary buds may be intermittent throughout the growing season. Also, many conifers have preformed growth. These chemicals should be applied when axillary buds commence growth or after pruning (51). But deciduous trees when treated by MH at bud break are damaged excessively (49).

The application technique and climatic conditions can influence the treatment time by their effects on inhibitor activity. For the chemicals to be effective, they must be translocated to the growing regions. Whether foliarly sprayed, soil treated, bark applied or wound dressed, they have to be absorbed into the transport system of the tree before they can be effective (20). Many factors can affect this absorption, namely temperature, humidity, dosage, and formulation (61). In addition, it has been well documented that after foliar treatment absorption through young leaves is considerably greater than through mature leaves (20, 55). When injectors are used, these external factors do not affect the penetration of chemicals into trees. In the case of injected inhibitors, it has been reported that they are ineffective unless the trees are treated during spring when the leaves are well developed (39). This study again emphasized the importance of the use of developmental stages rather than calendar dates to determine the application times.

Concentrations, adjuvants, and frequency of application

These criteria are based upon species, treatment technique, developmental stage, nature of the inhibitor, and climatic conditions at treatment time. It is well known that foliar-applied compounds are more effective on greenhouse-grown plants than on field-sprayed plants. This has been attributed to the higher humidity in the greenhouse and to the relatively thin cuticles of new leaves on indoor plants (24, 58, 61). It has also been reported that multiple applications of small dosages are more effective than single applications of large doses (56). This can be attributed to losses of chemicals from the plant either by degradation or exudation. The multiple applications lead to frequent wetting of leaves that can result in greater absorption of the compound, although not always (24). Also it has been reported that decreased concentrations and increased applications can inhibit the phytotoxic effects of growth retardants (52).

The use of adjuvants with chemicals is sometimes essential to achieve the required effectiveness (20, 31). The combination of surfactants and oils can enhance the penetration of daminozide and MH and subsequently increase their effectiveness in retarding growth, although not in all species (52). But one has to be careful in the use of these surfactants because they can be phytotoxic or growth promoting, depending on the concentration used. In addition, a chemical may be either effective or ineffective, depending on the surfactant being utilized. When adjuvants are used, the concentration of applied chemicals can be lowered since more chemical is absorbed by the plant. In bark applications it is essential to use adjuvants in order to facilitate movement of chemicals into the trees, whereas in pressure injected trees the use of adjuvants will not serve any purpose.

Certain formulations of a growth regulating compound can be more effective than others (26). This has been attributed to the discrepancy that exists in the amount of active ingredient that penetrates into the tree. Not only formulation, but also treatment technique can determine the effectiveness of a growth regulating compound (e.g., bark applications in some areas require eight times the concentration of foliarly sprayed chemical) (5, 26). This can be attributed to the penetrating ability of growth regulators entering the trees through two different routes. Sachs et al. (53) indicated that high pressure trunk injection techniques appear to offer promise for rapid infusion and distribution to shoot and root systems with low concentrations of growth regulators.

The relationship of dosage to tree size is not clear. One report indicated that measurement of trunk diameter, by itself, was not an accurate reflection of tree size (50) because landscape trees are pruned frequently with a reduction of canopy size without any reduction of growth in trunk diameter. It was observed that trees with large canopies required greater dosages to inhibit growth. In another study, it was suggested that the width of band in bark applications might affect the response of the tree (5). With an increase in band width two factors are affected, the absorbing area and volume of solution applied. Other studies of the dosage/size relationship indicated that dosage could be increased in proportion to an increase in trunk diameter (39).

Species differences. In work with growth inhibitors, the evidence indicates that species response is specific. In detailed studies conducted by Cathey (8) and Frank et al. (21) on the effectiveness of various growth regulators on several species, specificity of response was quite striking. The differences in species response are probably related to differences in absorption, transport, metabolism, or site of action of the compounds (36, 52). Such investigations are needed to answer questions regarding specificity of response in tree species and can be useful in the evaluation of growth regulators for purposes of practical application.

Growth reducing chemicals

Several compounds have been tested for their effectiveness in reducing the growth of trees. Listed in Table 1 and discussed below are the compounds that have been evaluated for their usefulness in controlling the height of shade trees.

AMO 1618 (ACPC). This quarternary ammonium compound at one time appeared to be effective as a foliage spray to young, rapidly growing shoots. But various efforts to introduce the chemical via the intact bark or at pruned cuts were not successful, consequently its use was discontinued (12). In greenhouse studies conducted by Frank et al. (21), ACPC was ineffective as a growth inhibitor when foliarly applied to Chinese elm (*Ulmus parvifolia* Jacq.), green ash (*Fraxinus pennsylvanica* Marsh.) and eastern hemlock (*Tsuga canadensis* L.). Tinus (63) corroborated these findings in his studies with Siberian elm (*Ulmus pumila* L.) and green ash. Cathey (8, 9) discovered that woody species did not respond to either foliar or soil applications of this chemical. Pharis et al. (42, 43) reported that growth of Arizona cypress (*Cupressus arizonica* Greene) and coastal redwood (*Sequoia sempervirens* D. Don) were inhibited by AMO 1618 applied as a soil drench, but at the same time it did not affect the growth of coulter pine (*Pinus coulteri* D. Don).

Ancymidol (A-Rest). Greenhouse studies on seedlings have shown that ancymidol applied as a soil drench or foliar spray is an effective growth regardant for several deciduous and evergreen tree species such as maple (*Acer* spp.), birch (*Betula* spp.), Southern catalpa (*Catalpa bignonioides* Walt.), dogwood (*Cornus* spp.), elm (*Ulmus* spp.), sycamore (*Platanus* spp.), and pine (*Pinus* spp.). The height of the tree was reduced at the expense of reduced numbers of nodes and leaf size (8). In the same study, it was reported that magnolia (*Magnolia* spp.), crabapple (*Malus* spp.) and some species of pine did not respond to ancymidol. Frank et al. (21) noted that Chinese elm and eastern hemlock also were not affected by ancymidol spray treatment, whereas growth of green ash was reduced by 70%. In greenhouse studies with silver maple (*Acer saccharinum* L.), ancymidol was reported toxic to this species and the response was attributed to the methanol used as a solvent (39). In the same study it was shown that pressure injected ancymidol at a rate of 0.09 gm/tree did not inhibit the growth of American elm (*Ulmus americana* L.). Sachs et al. (53) reported that trunk implantation of 250 mg of capsulated ancymidol did not influence growth of honeylocust (*Gleditsia triacanthos* L.) trees.

Chlorflurenol or Morphactins (Maintain). This compound is available in three formulations, Maintain CF 125, Maintain A, and Maintain S. Sachs first reported in 1967 that morphactins sprayed at low concentrations (0.005 to 0.01%) completely inhibited stem elongation along with abnormal leaf and flower development (48). Later studies indicated that Maintain CF 125 applied as a foliar spray was very effective in inhibiting sprout growth and development (21, 26). It was also documented that chlorflurenol mixed with MH was very effective in inhibiting the growth of various species (21). Maintain A has been used as a tree wound dressing applied with an aerosol spray can or a paint brush. It retarded sprouting in elm, ash, locust, maple, oak and several other species (3, 26). When applied to bark, Maintain S and CF 125 reduced the growth of deciduous as well as evergreen species (5). An oil carrier was used to enhance penetration of Maintain CF 125 through the bark. It was noticed that although shoot elongation was inhibited, the sensitivity varied among species. Pressure injected Maintain CF 125, although a good regardant, caused severe phytotoxicity to field grown elm trees (40).

Chlormequat (Cycocel). The use of cycocel (CCC) as a growth limiting chemical had limited success. Asher (4) found that CCC, when applied as a soil drench to seedlings of slash pine (*Pinus elliottii* Engelm.), limited height significantly. On the other hand in studies with other conifers (Arizona cypress, Douglas fir, and coulter pine), cycocel was not effective in reducing growth

Table 1. Index of Growth Regulators Inhibiting Tree Growth.

Common name	Trade name & synonyms	Chemical name	Species inhibited
AMO-1618	Carvadan ACPC	N,N,N,2-tetramethyl-5-(1-methyl-ethyl)-4-[(1-piperidinylcarbonyl)-oxy] benzenaminium chloride	Arizona cypress, coastal redwood
Ancymidol	A-Rest EL 531	α-cyclopropyl-α-(4-methoxy-phenyl)-5-pyrimidine=methanol	Double flowered dogwood, catalpa, elm (American, Siberian), maple, paper birch, pine (white, Japanese, black) and sycamore.
Chlorflurenol	Maintain (Morphactin)	methyl 2-chloro-9-hydroxy-fluorene-9-carboxylate	Ash, big toothed aspen, black locust, elm (American, Siberian, Chinese), eucalyptus, golden willow, hickory, oak (laurel, live, post, water), pine (Monterey, scotch).
Chlormequat	CCC Cycocel	(2-chloroethyl)trimethyl-ammonium chloride	Catalpa, maple (red, Norway), red oak, red oak, American sycamore.
Chlorphonium chloride	Phosphon	tributyl (2,4-dichlorobenzyl)-phosphonium chloride	Arizona cypress, pine (coulter, slash), red oak, red maple.
Daminozide	Alar B-nine B-995 SADH	Butanedioic acid mono(2,2-dimethyl=hydrazide)	Catalpa, cottonwood, elm (American, Siberian), eucalyptus, maple (Norway, red, silver), paper birch, pine (coulter, white), white ash.
Dikegulac	Atrinal	2,3:4,6-bis-O-(1-methylethyli-dene)-L-xylo-2-hexulofurano-sonic acid, sodium salt	Ash, cottonwood, elm (American, Siberian), eucalyptus, maple, pine, sycamore
DPX-1108	Krenite	(aminocarbonyl)phosphonic acid, monoethyl ester, mono-ammonium salt	Carolina poplar, silver maple, Chinese elm, Eastern hemlock
EHPP	NIA-10637	Propylphosphonic acid, monoethyl ester	Beech, ash, aspen, crabapple, eucalyptus, elm (American, Chinese), oak (live, red), sycamore.
Fluoridamid	MBR-6033 Sustar	N-[4-methyl-3-[(trifluoromethyl)-sulfonyl]=amino]phenyl]-acetamide	Cottonwood, green ash
Maleic hydrazide	MH Slo-gro	1,2-dihydro-3,6-pyridazinedione	Ash (green, oregon, shalem, white), birch (paper, white), catalpa, dogwood, elm (American, Chinese, Siberian), Douglas fir, coastal redwood, eucalyptus, maple (Norway, red, silver), oak (black, blue, live, white), pine (white, Monterey), sycamore, willow (black, weeping).
NAA	Tre-hold	1-mapthaleneacetic acid	Ash, white birch, cottonwood, elm (American, Chinese), hickory, maple (Norway, red, silver, sugar), oak (black, water), sycamore, teak.
TIBA	Regim-8	2,3,5-triodobenzoic acid	American elm

(43). Cathey and Stuart (8, 9) found that CCC retarded the growth of maple, oak, and sycamore when applied as a soil drench. Furthermore, they reported that the compound did not persist in the soil and was more effective if applied in winter than in summer. In greenhouse studies, foliarly applied cycocel did not significantly inhibit the growth of Siberian elm, Chinese elm, green ash, and eastern hemlock (21, 63). Injected CCC was also ineffective in controlling the growth of American elm (40).

Chlorphonium chloride (Phosphon). Like CCC, Phosphon applied as a soil drench has had limited success as a growth inhibitor for trees. Its use resulted in successful stunting of Arizona cypress and coulter pine (43), and slight retardation of red maple and red oak (9). In contrast, sycamore growth was stimulated by this chemical (9). An extensive screening program with other species has not been conducted since this chemical is used only as a soil drench, a technique which is considered impractical for landscape purposes. Sachs (48) has suggested that Phosphon deserves wide spread testing under controlled irrigation conditions. Pressure injection of this chemical into trees is another way to determine its usefulness as a growth inhibitor, since it is known that it can be effective in both deciduous and evergreen species.

Daminozide (Alar;SADH). Alar has been widely used as a growth retardant for various species. The literature indicated that this compound was effective in retarding stem elongation due to shortening of the internodes. Daminozide, or other compounds with similar action, may be preferred for general use for landscape purposes since there is no 'terminal dieback' or leaf discoloration (49). Cathey (8) noted that foliar spray and soil drench applications of Alar retarded the stem growth of maple, birch, catalpa, sycamore, and elm. In the same study, it was reported that SADH was not effective in controlling the growth of *Pinus* spp. In another report, Alar retarded the growth of seedlings of Arizona cypress, coastal redwood, and coulter pine (42). Sachs et al. (55) reported that Alar, applied as a foliar spray, controlled the elongation of *Eucalyptus* and *Pinus* spp. The efficacy of this compound was influenced by humidity, geographic location and time of application. In another study, it was reported that trunk implantation of capsules containing 1 g active SADH was ineffective in inhibiting the growth of honeylocust trees (53). Tinus (63) noted that Alar inhibited the growth of Siberian elm but the toxicity to the trees was extremely high; it reduced the growth of green ash significantly but not enough to make its use worthwhile. Frank et al. (21) did not find SADH to be an effective growth retardant for Chinese elm, green ash, and eastern hemlock. Injected Alar at high concentrations has proven to be successful in retarding the growth of field grown elm, silver maple, sycamore, white pine, but not that of red oak (41). Greenhouse studies indicated that it was also effective on white ash, Norway maple, cottonwood (*Populus* spp.) but ineffective on *Eucalyptus* (41).

Dikegulac (Atrinal). Atrinal is a relatively new chemical being tested for its growth inhibiting properties. Sachs et al. (54) reported that greenhouse-grown *Eycalyptus, Fraxinus,* and *Ulmus* spp. were significantly inhibited by low concentrations (0.4%) of foliar-applied dikegulac. It was noted that even at such low concentrations there was severe tip dieback in *Eucalyptus.* Atrinal, when pressure injected into field grown trees, was found to retard growth of elm, maple, sycamore, and white pine. But at high concentrations Atrinal was phytotoxic to sycamore and white pine (41). This report also indicated that greenhouse-grown seedlings of sycamore (topped and untopped), cottonwood, red oak, white pine and eucalyptus were retarded by use of Atrinal. But two species, cottonwood and eucalyptus, developed unacceptable levels of phytotoxic symptoms.

DPX 1108 (Krenite). DPX 1108 was initially developed as a growth retardant. Later, it was discovered that at high doses in the presence of a surfactant this compound acted as a delayed action herbicide and it was subsequently named Krenite. Field studies with this compound determined that it was an extremely effective growth retardant for white ash, Carolina poplar (*Populus eugenei* L.) and silver maple. At the end of the second year, however, the mortality rate of treated species was very high (35). Greenhouse grown Chinese elm and eastern hemlock, when sprayed with this chemical, were retarded but developed slight phytotoxic symptoms (21).

EHPP (NIA 10637). Ethyl hydrogen 1-propylphosphonate can be used either as a foliar spray or as an asphalt based tree wound dressing. As a foliar spray, NIA 10637 has been found to retard growth of several field-grown tree species, such as beech (*Fagus* spp.), ash, aspen, and blue gum eucalyptus. In some cases the growth retardation lasted for over 2 years. Zimmerman (65) reported that crabapple growth was also inhibited, although leaves developed after spraying were severely malformed and this phenomenon was observed even during the second growing season. When applied as a wound dressing, NIA 10637 inhibited the sprout development in Chinese elm, poplar, ash, and maple (16). Studies with street trees growing under power lines indicated that EHPP was an effective growth inhibitor for live oak, red oak, American elm, silver maple, and sycamore (14, 18, 19). Greenhouse-grown eucalyptus seedlings appeared to be more responsive to EHPP than to MH (15). Another related compound NIA 10656 (propylphosphonic acid) has proven equally effective in retarding the growth of various tree species (15, 16, 18, 19, 38).

Fluoridamid (Sustar). This is a new chemical that has undergone limited screening. In one greenhouse study it was found to inhibit the growth of green ash by 60% over a 90 day period, but was ineffective on Chinese elm and eastern hemlock (21). Injection studies with greenhouse and field grown trees indicated that, although an effective growth retardant, it was severely phytotoxic (39-41). Embark (MBR 12325), a compound chemically related to Sustar, inhibited the growth of greenhouse grown, untopped cottonwood seedlings, whereas the growth of topped cottonwood and silver maple and untopped silver maple was unaffected (31).

Maleic hydrazide (Slo-gro). More than 20 years ago, Rai and Hamner (25, 44) discovered that MH could be used as a retardant to control the growth of shade trees. They reported that red maple, elm, and weeping willow (*Salix babylonica* L.) seedlings responded to MH foliar treatment. In the first field studies reported, foliar-applied MH inhibited growth of sycamore, elm, poplar, and eucalyptus trees (13). Also, it was noted that spraying was much less expensive for control of growth of these trees than pruning. Tinus (63) found that it was effective for control of elm height but not useful for green ash. Sachs (49) described MH as the most useful and consistent inhibitor available, and one organization treated 90,000 trees with MH in one year (3). Several workers have noted that spray treatments of MH were effective on several deciduous and evergreen species (48, 56, 63). In one report, MH was an extremely active growth inhibitor in combination with chlorflurenol (21). Maleic hydrazide injected into trees has shown considerable promise for retardation of growth of both deciduous and evergreen species (39-41).

Various studies indicated that this compound was active at low concentrations (1, 39-41, 48, 56, 63). At high concentrations it could be extremely phytotoxic. Recently, it was reported that a new formulation of MH, Royal Slo-gro, was a more effective inhibitor than other formulations. The greatest advantage of this formulation was manifested in *Pinus* spp. in which inhibition occurred without severe foliar discoloration, necrosis, or tip dieback characteristically resulting from other MH formulations (57).

Naphthyleneacetic acid (NAA). Hitchcock and Zimmerman were issued a patent in 1944 for use of NAA to control bud development (29). In extensive greenhouse studies carried out by Battelle Memorial Institute, NAA and its lower alcohol ester, ethyl NAA (ETNAA), appeared to be promising for use in retarding the growth of trees by inhibiting the sprout emergence from cut ends (12, 22). The compound is applied as a wound dressing to the cut surfaces of pruned trees. Application is restricted to the cut surfaces since, at the concentration used (1% NAA), the chemical is herbicidal if applied to the entire plant (49). Also, it was suggested that to get the highest degree of inhibition, drop-crotch pruning was essential and the number and size of cuts per tree should be kept to a minimum (12).

Battelle Memorial Institute in co-operation with 15 privately owned electric utility companies tested numerous tree dressing formulations, including 13 semi-solid inhibitor-fortified and 8 liquid inhibitor-fortified dressings. Based on this work, label approval was granted to Amchem Products, Inc. for marketing a product called Tre-Hold. This product contains 1% ETNAA formulated in an asphalt carrier. The compound NAA has also been used in a sodium salt formulation. Harris et al. (27) discovered that 1% NAA when sprayed on pruned cuts of several species inhibited resprouting. In another study it was reported that an asphalt-based aerosol formulation containing 5% NIA 10637 plus 1% ET-NAA provided outstanding activity as a sprout inhibitor on oak when applied as a pruning wound dressing (17). Lately it has been reported that application of NAA containing dressings was difficult and was not effective for control of regrowth (2).

TIBA (Regim-8). The growth regulator 2,3,5-tri-iodo-benzoic acid was first used for increasing harvestable yields of soybeans. In the course of these investigations, it was found to inhibit stem growth (23, 66). Regim-8, the dimethylamine salt of TIBA, exhibited the same property (45). In field studies conducted on American elm, it was discovered that use of pressure injected Regim-8 inhibited growth of the trees. At the same time it produced severe phytotoxic symptoms in this species (39, 40).

In addition to the growth regulators discussed above, several other compounds have been documented as effective growth retardants. Most of these come under the category of herbicides, namely, 2, 4-D; 2,4,5-T; picloram; fluorenols; and and paraquat. These herbicides, as a rule, are not considered useful for the control of stem elongation because of their phytotoxic side effects (52). Ethylene releasing compounds, such as ethephon, can also inhibit stem growth but their use can lead to defoliation.

Although extensive work has been done to find chemicals that can control tree regrowth, we must continue the search for new and more effective growth regulators. It is also important to study the interaction of such chemicals with the environment since the efficacy of growth regulators to a high degree depends on both plant and environmental factors, including plant and soil nutritional status, pH and type of soil, temperature, moisture, photoperiod, geographic location, growth rate, developmental stage and presence of other biotic and abiotic stresses.

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