To: Steve Contente, Bristol Town Administrator

Steve Saracino, Bristol Tree Warden

Gentlemen,

The Conservation Commission, sitting as the Tree Commission, was asked to review RI Energy's use of Tree Growth Regulators on a select group of trees in Bristol over the next few months. We discussed this topic at our meeting of May 5 and came to the following conclusion.

We'll start with the fact that none of us are experts in the use of wide spread systemic chemical treatment of trees, such as that proposed. But from what we've read, and learned from available documents and resources, the treatment proposed by RIE, which will inhibit growth of pruned trees around wires so as to limit additional needed pruning, while providing some additional benefit to the trees treated, doesn't appear to have any negative impacts that we could discern and appears to be safe for the environment. And, given the treatment will be overseen by our Tree Warden, we are satisfied this program will provide benefits to the selected trees.

We hope this input is helpful. We are happy to answer any questions you may have as to how we came to this conclusion.

Respectfully,

Tony Morettini

Chair, Bristol Conservation Commission

EXPERT REVIEWED

Forestry & Natural Resources
PURDUE UNIVERSITY

Growth Retardants: A Promising Tool for Managing Urban Trees

William R. Chaney, Professor of Tree Physiology
Department of Forestry and Natural Resources
Purdue University, West Lafayette, IN 47907

Trees and shrubs often grow too large for the available space in urban areas. In the past, costly mechanical trimming was the sole method available to arborists and utility foresters to reduce tree and shrub size. Consequently, chemical growth retardants were developed as an inexpensive approach to limit size and the growth rate of trees and, at the same time, to enhance their tolerance to the harsh environmental conditions of urban areas.

History of Tree Growth Retardants (TGRs)

Utility arborists were the first among those caring for trees to peer over the fence at agricultural and horticultural fields and ponder the potential of growth regulators used in those cropping systems as a tool for tree maintenance. Mechanical trimming, which was the sole means to combat the unrelenting growth of trees into overhead electrical wires, was a costly operation and a chemical alternative was very attractive. Hence, the electric utility industry provided funding in the late 1950s for research on chemical control of tree growth following trimming for electric line clearance. Results of that early research led to the use of napthaleneacetic acid (NAA), a synthetic auxin, painted onto the surface of pruning wounds. Although effective in reducing the regrowth of branches, coating each cut surface high in the crown of trees took a lot of time and was not cost effective. Hence, in the 1970s new TGRs and more economical application techniques were sought.

The first major breakthrough in the commercial feasibility of TGRs on a large scale was the formulation in the late 1970s of the cell elongation inhibitors, paclobutrazol, uniconazole, and flurprimidol for trunk injection. Due to their low water solubility, it was considered necessary to dissolve the new generation of growth retardants in either methyl or isopropyl alcohol. The active ingredients of these formulations were unquestionably effective in reducing tree growth. After several years of use throughout the United States in the 1980s, problems associated with trunk injection begin to appear. Cracks in the bark and cambium, weeping from injection holes, and internal wood discoloration due to the alcohol carriers led to disenchanted utility arborists and their customers. A decline in use of TGRs followed. Uniconazole was even removed from the tree care market. However, in spite of these problems, interest among utility arborists continued in a chemical tool to reduce trimming frequency and the amount of wood waste removed from trees.

Flurprimidol, sold as Cutless Tree Implants®, was pressed into tablets for insertion into shallow holes drilled in tree trunks. Concern about drilling holes into trees and the apparent compartmentalization around the tablets that prevented continued slow release of flurprimidol into the transpiration stream resulted in limited use of the implants. Hence, flurprimidol was removed from the tool kit of arborists about two years ago.

Today, only one growth retardant for use on trees remains, paclobutrazol. Satisfactory performance of paclobutrazol as a growth retardant, as well as several benefits to tree health, revealed through recent research that resulted in a rebound in use of this TGR today by some electric utilities and spurred an active expansion of the market to commercial landscapes and general arboricultural tree care.

This publication has been reviewed by:
Dr. Jeff Stringer, Un. of Kentucky; Dr. George Parker, Purdue University; Dr. Burnell Fischer, IDNR Division of Forestry; Dr. John Kershaw, Un. of New Brunswick; Mr. Ron Rathfon, Purdue University

Treatment is Easy

Paclobutrazol, formulated as Cambistat 2SC® or Profile 2SC®, is applied as a water suspension. Both formulations are approved by the EPA for soil injection or application as a basal drench. The dose rate, which is species specific, is determined by measuring trunk diameter. The water suspension of paclobutrazol can either be injected at about 150 psi into the soil to a depth of approximately 6 inches as close to the tree trunk as possible (Fig. 1) or simply poured into a shallow trench around the base of each tree (Fig. 2). The product label provides detailed information for proper application. Treatments can be made anytime the soil is not frozen or saturated with water.

Figure 1. *Soil injection method for applying paclobutrazol.*

Figure 2. *Basal or soil drench method of applying paclobutrazol.*

Actually paclobutrazol and other growth retardants with the same mode of action are currently used in the nursery industry for production of compact and hardy bedding plants and on golf courses to reduce growth of turf and the frequency of mowing fairways. The dose rate for turf is lower than that applied to trees. Consequently, the grass in a narrow ring around the base of paclobutrazol-treated trees may be notably shorter. However, this could be a benefit because the serious problem of mower and string trimmer damage to tree trucks is less likely without the need to mow close to trees. Since paclobutrazol in very immobile in soils, there is no need for concern about over-regulation of turf more than a few inches away from the treatment zone.

Mode of Action

Suppression of growth by paclobutrazol occurs because the compound blocks three steps in the terpenoid pathway for the production of the hormone gibberellin by binding with and inhibiting the enzymes that catalyze the metabolic reactions (Fig. 3). One of the main roles of gibberellins in trees is the stimulation of cell elongation. When gibberellin production is inhibited, cell division still occurs, but the new cells do not elongate. The result is shoots with the same numbers of leaves and internodes compressed into a shorter length. For many years this was considered to be the sole response of trees to treatment with paclobutrazol.

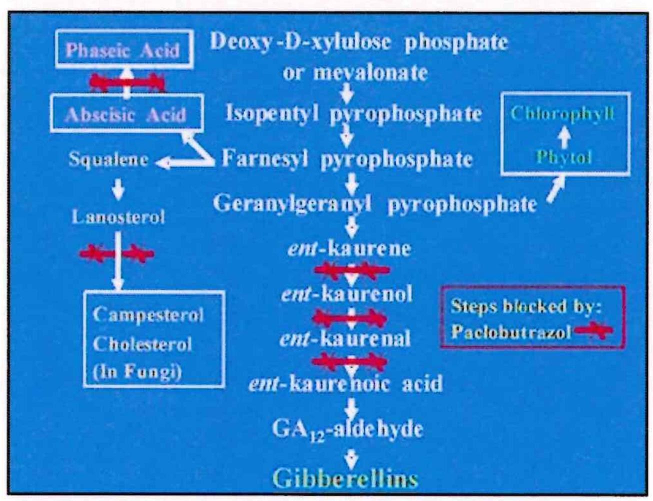


Figure 3. *Terpenoid pathway for biosynthesis of gibberellins, abscisic acid, phytol, and steroids, and path for degradation of abscisic acid. Steps blocked by paclobutrazol indicated with X—X.*

However, recent research has demonstrated that blocking a portion of the so-called terpenoid pathway causes shunting of the accumulated intermediary compounds above the blockage. The consequence is increased production of the hormone abscisic acid and the chlorophyll component phytol, both beneficial to tree growth and health (Fig. 3).

The unique structure of paclobutrazol that allows it to bind to an iron atom in the enzymes essential for the production of gibberellins also has the capacity to bind to enzymes necessary for the production of steroids in fungi as well as those that promote destruction of abscisic acid (Fig. 3). The consequence is that paclobutrazol treated trees have greater tolerance to environmental stresses and resistance to fungal diseases. Morphological modifications of leaves induced by treatment with paclobutrazol such as smaller stomatal pores, thicker leaves, and increased number and size of surface appendages on leaves may provide physical barriers to some fungal, bacterial, and insect infestations.

Growth Reduction

Shoot Growth

Although growth reduction is dose sensitive and varies widely among species, all evergreen and hardwood species, and even palms, respond in some degree to treatment with paclobutrazol. Treated trees have more compact crowns and somewhat smaller and darker green leaves, but otherwise look normal. The amount of shoot growth reduction ranges from a low of 10 percent to a high of 90 percent, with average growth reduction being 40 to 60 percent when recommended dose rates are applied. As a consequence of the reduced growth in height, there is a parallel reduction in biomass removed when trees eventually require trimming.

Cambial Growth

Although the principal focus of research with paclobutrazol has been on growth in length of shoots, reduced growth in diameter of the trunk and branches of woody plants also has been found. Expansion of cells produced by the vascular cambium also depends on gibberellins just like cells in stems and leaves. This could have significance in urban areas for trees planted in wells, above ground containers, and in the parkway between sidewalk and curb. Up to 30 percent of trees planted in the city cause sidewalk and curb damage due to expansion in girth of the trunk and roots, requiring significant portions of annual tree budgets for costly repairs. Suppression of diameter growth of tree trunks and roots at least forestalls costly damage and the creation of hazards.

Root Growth

Effects of paclobutrazol on root growth vary from enhancement to inhibition and are far from being clearly defined and understood. In almost all cases, however, the response in paclobutrazol-treated trees is an increase in root to shoot ratio. Gary Watson at the Morton Arboretum conducted one of the few studies on large mature trees exposed to paclobutrazol. Soil injection at the base of white and pin oaks caused fine root densities to be 60 or 80 percent higher, respectively, near the trunk base. It is unclear whether the responses observed in roots of treated trees are a direct effect of paclobutrazol on root growth or an indirect effect resulting from shoot growth modification and a shift in carbohydrate allocation to the roots. Root response to paclobutrazol is an important question because root growth and vigor influence not only water uptake but many other aspects of tree health.

Greener Leaves

Trees treated with paclobutrazol generally have leaves with a rich green color suggesting higher chlorophyll content (Fig. 4). There are two possible explanations for this response. One is that the leaves of both treated and untreated trees contain the same number of cells, but because the cells in leaves of treated trees are smaller, the chlorophyll is more concentrated in the reduced cell volume. In addition, however, there is evidence that the amount of chlorophyll is actually increased too because

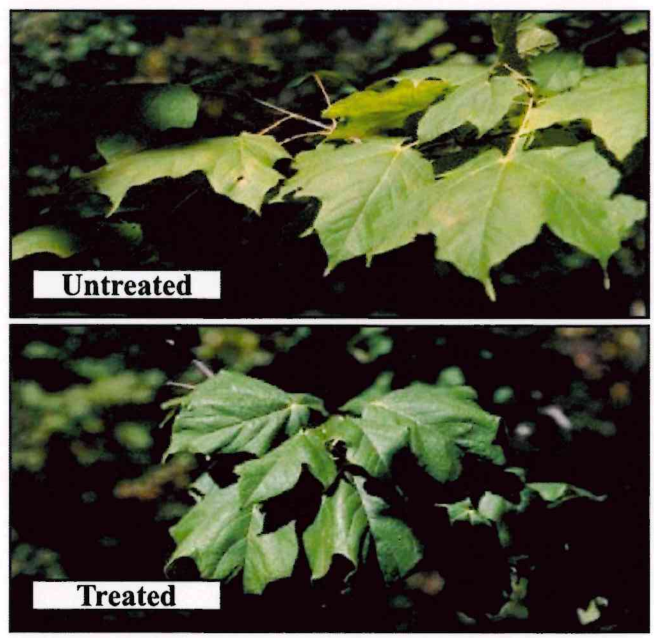


Figure 4. Sugar maple leaves from trees untreated or treated with paclobutrazol showing higher chlorophyll content (From Gary Watson).

phytol, an essential part of the chlorophyll molecule is produced via the same terpenoid pathway as gibberellins. Paclobutrazol treatment, which blocks the production of gibberellins, results in a shunting of the intermediate compounds from gibberellin synthesis to the production of even more phytol (Fig. 3). An analogy might be an accident blocking the flow of traffic on a major highway causing more drivers to divert to alternate routes.

Reduced Water Stress

In addition to interfering with gibberellin production, paclobutrazol is known to affect the synthesis of the hormone abscisic acid. Abscisic acid also is made via the terpenoid pathway (Fig. 3). Unlike the inhibiting effect on gibberellin synthesis, treatment with paclobutrazol promotes the production of abscisic acid much like it promotes the production of phytol. When gibberellin synthesis is inhibited, more precursors in the terpenoid pathway accumulate and are shunted to the production of abscisic acid.

Paclobutrazol also interferes with the normal breakdown of abscisic acid. The mode of action involves another iron containing enzyme to which the paclobutrazol will attach, preventing its activity. The combined effect on both the production and breakdown processes results in enhanced concentrations of abscisic acid in leaves. One of the functions of abscisic acid is to cause stomates to close, reducing water loss from leaves through transpiration.

Improved water relations in trees could arise from a combination of increased abscisic acid contents that physiologically reduce stomatal opening, reduced shoot growth resulting in less leaf and stem surface area for transpiration, more fine roots to absorb water, and structural changes in leaves that provide physical barriers to moisture loss. Fig. 5 shows dramatic scanning electron microscope images of thicker leaves and masses of hairs on leaf surfaces of cherrybark oaks in response to treatment with paclobutrazol.

The improvement of water relations in paclobutrazol-treated trees is an important secondary benefit of using a TGR.

Effects on Fungal Diseases

Protection from fungal diseases that attack urban trees is now recognized as another secondary benefit of using paclobutrazol. There are numerous observations of reduced incidence of common fungal diseases such as anthracnose following treatment with paclobutrazol. Karel Jacobs at the Morton Arboretum has shown

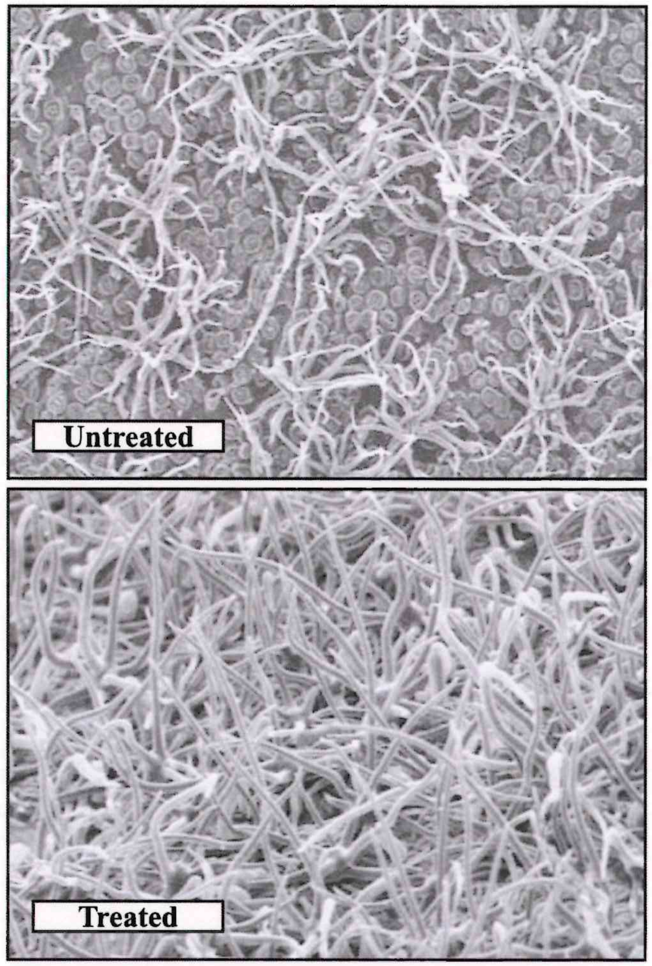


Figure 5. *Scanning electron micrographs of the lower surface of leaves of cherrybark oak untreated or treated by the soil injection method with paclobutrazol. (From Yadong Qi and William Chaney)*

paclobutrazol to significantly reduce the growth of eight fungal pathogens in laboratory cultures. More and more data from field trials is being published to substantiate the fungistatic benefit of using paclobutrazol. Bruce Fraedrich with Bartlett Tree Expert Company has recently demonstrated that even bacterial leaf scorch is markedly reduced in red oaks following a soil drench application of paclobutrazol.

The fungistatic property of paclobutrazol is due to the inhibition of steroid production in fungi, also via the terpenoid pathway (Fig. 3). This is the same mode of action that accounts for the fungistatic property of the class of fungicides known as SBIs or steroid biosynthesis inhibitors. Steroids are essential constituents of membranes.

The increased resistance of paclobutrazol-treated trees to bacteria is not thought to be a direct effect on the pathogen, but rather due to alteration in leaf surface structure (Fig. 5) or even the size of stomatal pores that make infection more difficult.

Conclusions

The many benefits of paclobutrazol can be explained based on an understanding of its ability to combine with iron containing enzymes and to inhibit, as well as foster, production via the terpenoid pathway of several important compounds for tree growth and development. Because of its many positive effects on trees, paclobutrazol is quickly evolving from use solely on trees under electric distribution lines to an important tool for commercial landscape and arboricultural practices where both growth suppression and improved tree health are desired.

Recommendation for Homeowners and Disclaimer

Commercial formulations of paclobutrazol have been registered with the EPA and are rated as General Use Pesticides. They carry a Caution Toxicity label, the lowest assigned by the EPA. Although these products may be obtained form the manufacturers for use by do-it-yourselfers, it is highly recommended and advisable that they be applied by an experienced and certified pesticide applicator who is familiar with the technology and the identification of woody plants. Any person using products mentioned in this publication assumes full responsibility for their use in accordance with current directions of the manufactures. This publication is for information only and not a promotion for any particular commercial product.

Sources of Additional and More Detailed Information.

Bai, S., W.R. Chaney and Y. Qi. 2004. Response of cambial and shoot growth in trees treated with paclobutrazol. Journal of Arboriculture 30:137-145.

Bai, S. and W. R. Chaney. 2002. Tree growth regulators affect electron transport in plant mitochondria. *Plant Growth Regulation* 35:257-262.

Bai, S. and W.R. Chaney. 2002. Treatment of mature trees and seedlings with gibberellin synthesis inhibitors affects electron transport in leaf mitochondria of parents and progeny. *Plant Growth Regulation Society of America Quarterly* 30:86-97.

Fletcher, R.A., A. Gilley, N. Sankhla, and T.D. Davis. 2000. Triazoles as plant growth regulators and stress protectants. Horticulture. Review 24:55-138.

Rademacher, W. 2000. Growth retardants: Effects on gibberellin biosynthesis and other metabolic pathways. Annual Review Plant Physiology Plant Molecular Biology 51:501-531.

Sperry, C.E. and W.R. Chaney. 1999. Tree Growth Regulator Effect on Phototropism – Its Implication for Utility Forestry. *Journal of Arboriculture* 25:43-47.

Bai, S. and W. R. Chaney. 2000. Treatment of silver maple trees with gibberellin synthesis inhibitors influences growth of progeny seedlings. *Plant Growth Regulation Society of America Quarterly.* 28:115-126.

Premachandra, G.S., C. Nagasaka, W.R. Chaney and H.A. Holt. 1996. Response of cells, callus, seeds and plants to a range of flurprimidol concentrations varies in zinnia, sunflower, green pepper, and tobacco. *Plant Growth Regulation Society of America Quarterly* 24:140-151.

Premachandra, G.S., W.R. Chaney and H.A. Holt. 1997. Gas exchange and water relations of *Fraxinus americana* L. affected by flurprimidol. *Tree Physiology* 17:97-103.

Premachandra, G.S., W.R. Chaney and H.A. Holt. 1997. Effects of mulch made from flurprimidol treated zinnia, silver maple, and white ash on growth of zinnia. *Journal of Environmental Horticulture*15:215-221.

Mann, M.P., H.A. Holt, W.R. Chaney, W.L. Mills and R.L. McKenzie. 1995. Tree growth regulators reduce line clearance trimming time. *Journal of Arboriculture* 21:209-212.

Wasniewski, T.A., W.R. Chaney and H.A. Holt. 1993. Hole angle for trunk injection of tree growth regulators and its effect on weeping, wound closure and wood discoloration. *Journal of Arboriculture* 19:131-137.

Zillmer, R.E., W.R. Chaney and H.A. Holt. 1991. Structural and biological effects of trunk injected paclobutrazol in yellow poplar. *Journal of Arboriculture* 17:261-268.

New 9/05

Integrating TGRs into Vegetation Management

Utilities experience cost savings and reduced pruning cycles with the use of tree growth regulators.

By **Jim Nesser**, *Rainbow Treecare Scientific Advancements*

Maintaining vegetation along utility rights-of-way is a critical component of providing safe and reliable power. For many years, the only tool used to accomplish this was a chain saw to remove tree limbs closest to power lines. The electric utility industry has changed rapidly in the last several years, and there are now so many vegetation management tools available it is difficult to determine which ones fit within a particular integrated vegetation management (IVM) program.

To implement an effective IVM program, utility arborists should use a wide variety of tools, including tree growth regulators (TGRs). Foresters across the country are implementing TGRs in their IVM programs to help reduce costs, increase reliability and improve stakeholder relations.

These Live oaks that were treated with paclobutrazol three years before the picture was taken. The trees now represent a cost savings for the utility, because they do not require pruning in the current cycle.

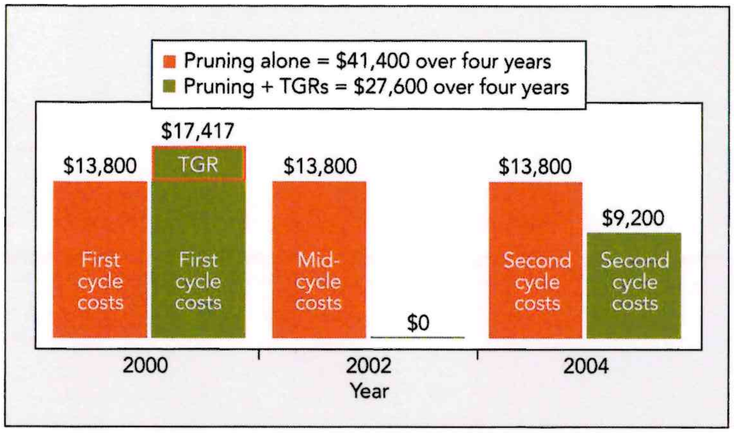
Cost Savings and Reliability

Grant Ehlen from American Electric Power (AEP) has been using TGRs for many years. When he first started using TGRs in Oklahoma, Ehlen found they provided significant cost savings by reducing pruning for the next cycle. For example, he pruned and treated 1,300 trees with paclobutrazol on one circuit. When he returned to the circuit after three growing seasons, he found only 200 of the trees needed to be pruned, resulting in a 60% cost savings.

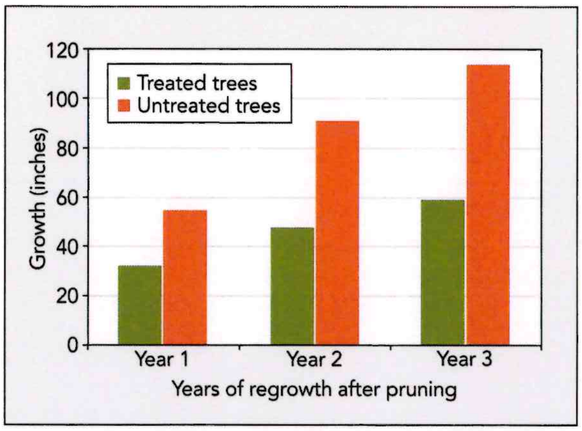
A high-cost pruning situation is another area where Ehlen used TGRs to reduce costs. Because of limited access to 100 backyard trees, Ehlen treated these trees with paclobutrazol. These trees had a history of being cycle busters, growing back into the line before the next scheduled maintenance. However, when using paclobutrazol, Ehlen saw a 35% cost reduction with these trees over four years and there was no need to prune them in the middle of the cycle.

When Ehlen moved from Oklahoma to AEP Texas, he found additional benefits of TGRs. In one instance, he had a circuit scheduled to be pruned because of a large number of outages. Due to budget constraints, the $144,000 required to prune the circuit was not readily available. Ehlen chose to spend $28,000 to treat the trees with paclobutrazol to delay the need for pruning until budget dollars were available. After the trees were treated, power reliability within the circuit improved and Ehlen was able to wait three years before pruning the circuit.

Joe Osborne with Oklahoma Electric Cooperative (OEC) also has experienced cost savings with TGRs. One of the most critical and sensitive areas in the OEC service territory is the city of Norman. Osborne originally implemented TGRs in 2007 to reduce the number of site visits he would have to make to manage the vegetation in this sensitive area.



The use of TGRs results in a 35% cost reduction over four years



TGR-treated trees show a 48% growth reduction over three years.

When Osborne later reviewed pruning requirements and associated costs in the western part of Norman, he found a 60% reduction in the amount of pruning and an estimated $39,000 cost savings over a four-year cycle after implementing TGRs in this area of the city.

Sensitive Areas

AEP Texas also has implemented TGRs in the city of McAllen. AEP forester Jesse Alvear has worked closely with McAllen urban forester Mark Kroeze to help manage the interface between public safety and the need for tree preservation based on cultural and historical needs. One example where they implemented paclobutrazol was at McAllen Miller International Airport, where several hackberries and cedars were obstructing the view of the air traffic control tower. These trees were planted in the adjoining cemetery and had significant historical value to relatives of the deceased.

Alvear and Kroeze decided to partner on this sensitive issue and brought in Edko LLC to apply Cambistat to the trees in the cemetery. The goal was to reduce the disturbance to the cemetery by extending the current annual pruning cycle, reducing the time and labor at the site, and maintaining the health of the trees. After treatment in June 2009, the trees have continued to be healthy and have not required any pruning in the three years since the project began.

Increased Worker Safety

Steve Stewart and Rob Mercer from Georgia Power implemented a TGR project on St. Simons Island, the largest of the Golden Isles along Georgia's southern Atlantic Coast. St. Simons Island brings many unique challenges to a utility forester because of its long growing season and busy tourism industry.

Georgia Power maintains most of its circuits on a three-year pruning cycle by getting at least 15 ft of clearance. However, St. Simons Island is on a two-year pruning cycle (and on an annual cycle for a few main roads). This situation causes safety concerns related to closing lanes and blocking traffic, and incurs high vegetation management costs. Stewart and Mercer chose to implement a TGR project in this area to see if they could extend the pruning cycles on the island, which would reduce their costs as well as worker and public exposure to safety risks.

The TGR project was implemented in spring 2012. Edko was hired to inventory the trees on the island and group them into three categories based on how quickly they needed to be pruned. All costs were recorded for trees that were pruned and trees treated with Cambistat. The biomass removed from the pruned trees also was weighed so biomass reduction could be evaluated over

This is a fast-growing Anaqua in south Texas. This picture was taken one year after the tree was pruned and treated with paclobutrazol. The use of TGRs ensures that this tree will not be an expensive "cycle buster" tree that needs to be pruned mid-cycle.

This picture shows a treated Live oak on the left and an untreated Live oak on the right. This picture was taken 11 months after the trees were pruned and treated with paclobutrazol.

time. Georgia Power will be looking at this site over the next couple of years to determine cost savings and how it can lengthen the pruning cycle to reduce the headaches and safety risks that come with lane closures.

Maintaining Cycles

Kevin Scott from Indiana Michigan Power has been TGRs to help maintain cycles within his system. In 2011, he had several circuits inspected that had been pruned and treated with TGRs in 2007 and 2008. The inspector determined how much clearance the spans still had in 2011. The specification Scott gave tree contractors was to prune trees to maintain clearances for three years to five years, before the trees would be pruned again during normal cyclical maintenance.

What the inspector found after looking at more than 6,500 spans of overhead power lines was 78% of the spans had at least seven years of clearance (as opposed to the three- to five-year clearance for which they were pruned) with a single application of TGRs. Of the overhead spans treated with TGRs, more than 94% of them had no clearance issues for five years after pruning. Paclobutrazol has helped Scott extend his cycles and reduce the amount of mid-cycle work needing to be done.

Rob Askine has been applying TGRs for Sacramento Municipal Utility District (SMUD) since 2000. The main benefit SMUD achieves from using TGRs is extending and maintaining its pruning cycles. Eucalyptus trees can often grow up to 10 ft in a year after they are pruned away from overhead lines; needless to say, it is difficult maintaining a three-year pruning cycle when trees grow that quickly.

SMUD has treated more than 2,100 Eucalyptus trees in the past 12 years, and its use of TGRs has been instrumental in helping the utility maintain cyclical pruning. SMUD often sees less than 1 ft of growth the year following a TGR application, and it typically sees growth control for three years to five years. The utility has seen no ill effects on the trees treated multiple times during the last 12 years.

These trees were treated with paclobutrazol three years before the picture was taken and have not been pruned since. Applications like this help SMUD easily maintain its three-year cycle.

Advancing the Industry

These are just some of the examples from around the country of utility foresters implementing TGRs into their overall IVM programs. In years past, vegetation management consisted of pruning trees away from power lines to ensure branches would not grow into the wires for three years to five years. Sometimes branches caused outages before the next pruning cycle and sometimes they did not. The process would then be repeated over and over again.

In the U.S., between $3 billion to $5 billion is spent each year on utility vegetation management, yet trees are still a leading cause of outages. Some benchmarking studies show roughly one-third of outages are caused by trees. The electric utility industry uses the system average interruption frequency index (SAIFI), the system average interruption duration index (SAIDI) and several additional formulas to determine the effectiveness of veg-

How TGRs Work

Tree growth regulator technology has been around for more than half a century. Over the past 10 years, paclobutrazol has emerged as the most effective and predictable active ingredient. The product is applied to the soil around the base of a tree and transported to the growing points of the tree during transpiration. It works by reacting in the subapical meristems of the plant to inhibit the production of gibberellins responsible for cell elongation.

When paclobutrazol is applied, the plant still has the same amount of energy available but uses less energy for vegetative growth. Since less energy is allocated to growth, the plant has more energy available for reproductive structures, fine root development, storage compounds and increased defense compounds. This change in growth leads to increased chlorophyll density, thicker leaves, more abscisic acid, and a plant more suitable to the hostile conditions of the urban forest.

etation management. By using these measures, it can be seen the average person experiences 1.1 outages per year (not including major storms) that last 1.5 hours. These figures have not improved over the last several years, and they will not improve by doing the same things that have always been done.

At one time, the most brilliant minds in the world knew the earth was flat; some experts stepped outside the box and proved the earth was round, and it changed everything. The electric utility industry can change, too, by stepping outside of the box and using TGRs, along with system analysis, pre-inspections, global positioning system, light detection and ranging technology, low-volume herbicides, dormant season spraying, aerial saw work, tree risk assessments and the many other vegetation management tools now available. TDW

Jim Nesser is the national utility sales manager for Rainbow Treecare Scientific Advancements, working with utility and application companies to enhance their vegetation management programs by implementing TGRs into IVM plans. Nesser holds a BS degree in forestry with an emphasis on hydrology and soils from the University of Minnesota. He is an ISA Certified Arborist/ Utility Specialist and has served on the Utility Arborist Association training committee for the past three years. Prior to joining Rainbow Treecare Scientific Advancements, Nesser spent seven years as a field arborist in the commercial and utility market.

Partners Updates

Utility Arborist Association

Tree Growth Regulators and Municipal-Utility Partnerships

by Jim Neeser, National Utility Sales Manager,* Rainbow Treecare *Scientific Advancements

Perception is everything! An arborist is a professional trained in the art and science of planting, caring for, and maintaining individual trees, shrubs, vines, and other perennial woody plants. Even though this is the perception of professionals in the industry, this doesn't always carry through to the general public. Utility arborists are often referred to as "tree butchers" or "a necessary evil" when they are performing their work. So what can municipal and utility arborists do to raise the standards and perceptions of the entire arboricultural industry?

To fully understand why this perception exists we must first look at the stakeholders. The municipal arborist, utility arborist, and the homeowner all have different objectives when it comes to managing a tree. Municipal arborists are primarily concerned with safety, the benefits of trees, and the health of trees. They utilize their skills to improve the health of the urban forest to provide economical, ecological, and social benefits to the people living in and visiting their communities. Utility arborists are primarily concerned with safety, delivering reliable power, reducing costs, and improving customer relations. They utilize their skills to ensure that when you flip the switch in your house, the light turns on, and that nobody is injured during the process of transporting that energy from a power plant to your home. A homeowner's objective is to have beautiful trees on his or her property and in the community. The difference in objectives is what leads to the negative perception.

What tools are being used to change the perception of utility arborists as "tree butchers"? Currently the main tools being used are professional organizations and education. Groups like the International Society of Arboriculture (ISA), Society of Municipal Arborists (SMA), and the Utility Arborist Association (UAA) all work to improve the professionalism and perception of arborists through ANSI standards, best management practices (BMPs), certifications, and programs such as "Right Tree, Right Place". Sharing information between groups at conferences and in magazine articles like this is a great way to explain the objectives of both municipal and utility arborists, as well as the Memorandum of Understanding (MOU) that was drafted and approved between the SMA and the UAA. These are great tools from an educational perspective, but not necessarily from the practical field side of arboriculture. Tree growth regulators are a valuable field tool that can be utilized by many stakeholders to accomplish multiple objectives.

Live oaks (*Quercus virginiana*) in southern Alabama eleven months after pruning. The tree on the left was treated with paclobutrazol while the tree on the right is an untreated control.

Tree growth regulator (TGR) technology has been around for over half a century. During that time, paclobutrazol has emerged as the most effective and predictable active ingredient. Paclobutrazol is used widely in both utility and commercial arboriculture. The product is applied to the soil around the base of a tree and transported to the growing points of the tree during transpiration. It works by reacting in the subapical meristems of the plant to inhibit the production of gibberellins which are responsible for cell elongation. The plant still has the same amount of energy available but is utilizing less energy for growth. Since less energy is allocated to growth, the plant has more energy available for reproductive structures, fine root development, storage compounds, and increased defense compounds. This change in growth leads to increased chlorophyll, thicker leaves, more abscisic acid, and a plant more suitable to the hostile conditions of the urban forest.

Utility arborists use paclobutrazol to reduce the amount of growth in trees near power lines. This helps reduce costs, enhance customer relations, maintain cycles, and deliver safe, reliable power. Commercial arborists utilize growth regulators to improve the health of trees, reduce maintenance costs, and improve the ability of the tree to handle urban stress.

Kevin Scott with American Electric Power (AEP) uses TGRs to build partnerships with many of the municipal arborists inside of his territory. In Fort Wayne, Indiana he works closely with City Manager of Forestry Operations Chad Tinkel. Kevin and Chad work together to determine which city trees can be removed and which trees need to be pruned. A few years ago there were a number of city trees along a boulevard that Kevin really wanted to remove to ensure safe and reliable power. Chad said that the trees could not be removed in this situation because they were critical to the overall landscape of the neighborhood.

Kevin and Chad came to the agreement that AEP would treat the trees with TGRs and the City would prune the trees using their crews. The TGRs would slow the growth of the trees and allow for less frequent pruning. The City pruned the trees so they could prune the whole tree and not just the portion which had limbs growing near the power lines. This was a good way to cost-share and come to an agreement that would satisfy both stakeholder's objectives.

Another way Kevin utilizes this tool is to improve public relations. Kevin attends City neighborhood meetings to discuss the benefits of TGRs before applications are made. This gives the residents an opportunity to see that the utility is using multiple tools to minimize the impacts on the citizens. It is also a great opportunity for the utility to meet with the homeowners in an open environment and share information about TGRs. The better the communication and more informed the homeowners, the more open and accepting they become to the objectives of the utility. Kevin conveys that utilizing TGRs results in sustained clearances which leads to longer pruning cycles and less impact on property.

A utility arborist applies paclobutrazol to reduce the amount of growth in trees near power lines.

TGR benefits also include cost savings and the reduction of pruning for the next cycle. Grant Ehlen is the forestry operations supervisor for AEP in Texas. Grant decided to look at the benefits of TGRs on an entire circuit in need of pruning; the crew pruned and treated 1,300 trees. When he returned to the circuit after three growing seasons, he found that only 200 of the 1,300 trees needed to be pruned, resulting in a 60% cost reduction.

TGRs have the unique ability to reduce the growth while improving the health of a tree. This unique ability allows this tool to meet the objectives of multiple stakeholders. By integrating TGRs into a vegetation management plan, we can build a working relationship between municipal and utility arborists. Developing partnerships is a great way to enhance the urban forest, deliver safe reliable power, and eliminate the perception that utility arborists are "tree butchers"!

SUMMARY Power outages caused by downed trees and limbs are an expensive problem for electric utility companies. These outages increase when utility foresters can not keep up with the necessary tree trimming. Paclobutrazol, a tree growth regulator, has been shown to significantly decrease the biomass removed from trimmed trees. This will enable utility foresters to maintain an acceptable trimming cycle and will also decrease the costs associated with the trimming activity and disposal of waste.

Tree Growth Evaluated 10 Years After Application of Paclobutrazol Tree Growth Regulator[1]

By P.L. Burch[2] and R.H. Wells[3]

INTRODUCTION

Tree-related power outages represent a significant expense and loss of revenue for electric utility companies. In an unpublished survey of northeastern electric utilities, Wells found that one utility had 3,012 tree-caused outages (excluding danger trees and storm work) in 1994 at an estimated cost of over $400 per outage. This utility experienced 447,652 lost revenue hours as a result of these outages. Outages increase when utility crews do not have the time to complete required trimming so as to maintain an acceptable trimming cycle. In addition, many homeowners are resistant to the frequent trimming that is required for some of the faster-growing species of urban trees. Rapidly growing species pose a particular problem when maximum line clearance is dictated by local or state regulations, or a compromise with the homeowner. Many utilities are also facing difficulty in disposing of the chips (biomass) removed from trees (1).

Tree growth regulators (TGRs) such as paclobutrazol (Profile * 2SC tree growth regulator) are being used by utility foresters to slow the growth of trees so as to enable the foresters to manage trim cycles and reduce outages. To justify the use of TGRs, utility managers have sought ways to quantify the benefits that these products deliver. Recently, researchers have attempted to quantify TGR effects by measuring tree crown area, biomass removed during trimming, and/or the time required to trim and chip the biomass (3,4). TGRs have been shown to reduce the amount of biomass removed from trees and, in doing so, reduce the amount of time needed to trim and chip the treated trees (3). Unfortunately, there are few studies that have used these techniques to measure TGR results, and the study of longest duration reported thus far is 3 years (3). Although differences between treated and untreated trees in the 3-year study were quite large, a longer-term study would provide a clearer picture of benefits.

PECO Energy has been evaluating TGRs on their system for over 20 years with the goal of obtaining long-term evaluations to help drive economic decisions. The study reported here was installed over 10 years ago and, with PECO Energy's cooperation, it enabled researchers to evaluate the utility's original study design using unbiased measurements of biomass and trim and chip time. The objectives of this study were to (a) evaluate the performance of paclobutrazol applied to the soil around fast-growing urban trees, (b) evaluate a potential rate response for paclobutrazol, and (c) evaluate the effect of application volume around the base of the tree.

MATERIALS AND METHODS

Two tree species, red maple (*Acer rubrum*) and silver maple (*Acer saccharinum*) located in a residential area of Norristown, Pennsylvania, (part of the PECO Energy system) were selected for this study. Red maple has a medium to fast growth rate (18 to 25 ft for 10 years), and silver maple has a very fast growth rate (25 to 35 ft for 10 years) (2). The study was initiated in September 1984 when trees were trimmed to PECO Energy specifications to clear the electric distribution line. The treatments were assigned as outlined in Table 1.

Initial diameter breast height (dbh) measurements averaged 9 inches for red maple and 12 inches for silver maple.

*Trademark of the SePRO Corporation.

1 Adapted from a presentation at the annual meeting of the International Society of Arboriculture, Hilton Head, South Carolina, August 15, 1995.

2 Research Biologist, Dow Elanco, Christiansburg, Virginia.

3 Formerly System Forester, PECO Energy.

TABLE 1. Species and treatment combinations for soil-applied paclobutrazol in Norristown, PA, 1984.

Species	Paclobutrazol rate (g/in. dbh)	Number of trees treated	Total application volume per tree of paclobutrazol + water (mL)
Red maple	0	3	0
Red maple	0.5	4	1500
Red maple	1.0	6	1500
Red maple	2.0	3	1500
Silver maple	0	11	0
Silver maple	0.5	5	1500
Silver maple	1.0	6	1500
Silver maple	1.0	8	3000
Silver maple	2.0	4	300
Silver maple	2.0	6	1500
Silver maple	2.0	3	3000

Paclobutrazol was applied to the soil around the target trees in November 1984 using a pressure soil injector that delivered the solution in volume increments that would allow a minimum of four injection points around the base of the trees. The TGR solution was injected at a soil depth of 6 inches as close as possible to the root collar at a delivery pressure of 150 psi. Paclobutrazol rates ranged from 0.5 to 2.0 g/in. dbh.

The untreated control trees had to be trimmed again in April of 1988 and again in August of 1990 so as to maintain line clearance, while the treated trees required no trimming at either of these dates. No biomass or any other evaluations were taken at the 1988 or 1990 dates. All trees were then trimmed to PECO Energy specifications in November 1994 (Figure 1), with green biomass for each tree being collected, weighed, and recorded (Figure 2). In addition, the time required to trim and chip the biomass was recorded for each tree. Biomass and time data were summarized using analysis of variance and mean separation by LSD at the 0.05 significance level.

Because biomass and time measurements were not taken in 1988 and 1990, estimates for the biomass removed from the untreated trees over the 10-year period were obtained by multiplying the 1994 measured response by 3. This procedure was assumed to be logical as the trees were always trimmed to the same PECO Energy specifications for clearance. However, the methods for trimming changed over the 10 years of the study. In 1984, 1988, and 1990 the whole tree was trimmed, often referred to as "rounding over," while in 1994 the directional trimming technique was used. The primary impact of this change in technique was that the whole tree method produces more trimming biomass than the directional trimming technique. Therefore, the estimates of biomass removed over 10 years for the untreated trees are probably conservative relative to the actual amount removed over the 10 years.

A 10-year percent reduction in biomass was calculated using the following formula:

$$\text{Percent reduction in biomass} = \left(1 - \frac{\text{treated tree biomass (10-yr total)}}{\text{untreated tree biomass (10-yr total)}}\right) \times 100$$

This equation represents a standard calculation used for percent reduction and/or percent control (5). No statistical comparisons were made on the percent reduction values. The relationship of biomass to trim and chip time in minutes was evaluated using simple linear regression.

RESULTS AND DISCUSSION

Biomass Reduction

In 1994 there was significantly less biomass removed from trees treated with paclobutrazol than from untreated controls; however, there were no significant differences between the rates of paclobutrazol applied. The average biomass removed from the untreated red maples in 1994 was 327 lb (Figure 3). The average biomass

FIGURE 1. *Trees were trimmed to PECO Energy specifications in November 1994.*

FIGURE 2. *The green biomass was collected for each tree and weighed.*

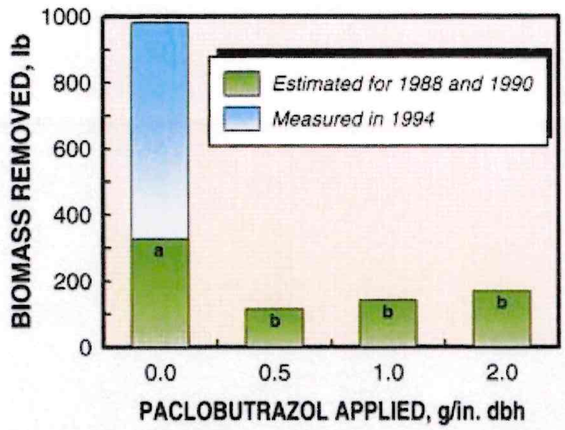


FIGURE 3. *Biomass removed over a 10-year period from red maple treated with paclobutrazol in 1984. The untreated trees were trimmed in 1988, 1990, and 1994; the treated trees were trimmed only in 1994. The estimated total for the untreated trees is equal to three times the biomass removed in 1994. LSD at 0.05 level.*

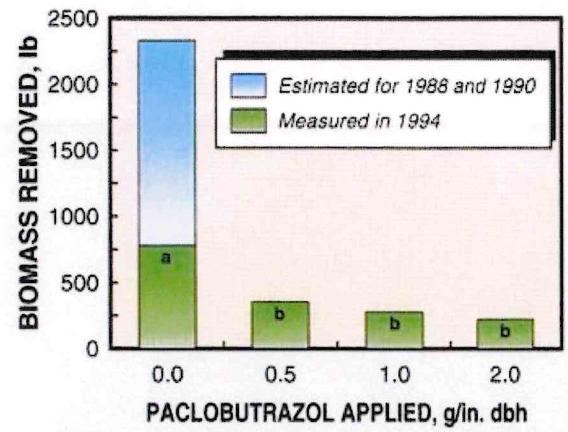


FIGURE 4. *Biomass removed over a 10-year period from silver maple treated with paclobutrazol in 1984 averaged across all volumes. Untreated trees were trimmed in 1988, 1990, and 1994; treated trees were trimmed only in 1994. Estimated total for the untreated trees is equal to three times the biomass removed in 1994. LSD at 0.05 level.*

removed from treated trees, for all rates combined, was 139 lb. The estimated amount of biomass removed from the untreated trees over the 10-year period was 981 lb. Thus the amount of biomass removed from treated trees over the 10-year period was estimated to have been reduced by 85% (Table 2).

The average biomass removed from untreated silver maples in 1994 was 778 lb (Figure 4). Again no differences were established between rates; however, all paclobutrazol treatments had biomass removals that were significantly lower than those of the untreated controls. The average biomass removed for all rates combined was 266 lb. The estimated 10-year total for biomass removed from the untreated controls was 2335 lb. The estimated percent reduction in biomass removed from the treated trees over the 10-year period was 88% (Table 2).

An 85 to 88% reduction in the amount of biomass requiring disposal can represent a significant cost savings in chip hauling and an additional benefit of reducing the amount of chips being disposed of in landfills.

TABLE 2. Estimated percent reduction in biomass over the 10 years from 1984 to 1994.

Species	Percent reduction in biomass			
	Paclobutrazol rate			
	0.5 g/in. dbh	1.0 g/in. dbh	2.0 g/in. dbh	All rates combined
Red maple	96	81	77	85
Silver maple	85	88	90	88

TABLE 3. Estimated percent reduction in trim and chip time over the 10 years from 1984 to 1994.

Species	Percent reduction in trim and chip time			
	Paclobutrazol rate			
	0.5 g/in. dbh	1.0 g/in. dbh	2.0 g/in. dbh	All rates combined
Red maple	85	75	78	76
Silver maple	85	82	91	86

Trim and Chip Time Reductions

The time taken to trim and chip the trees showed a trend among treatments similar to that of the biomass weight differences. However, despite the significant weight differences, there were no significant differences in 1994 between the times required to trim and chip treated and untreated red maple trees (Figure 5). The estimated average 10-year total for trim and chip time was 67 minutes for untreated trees versus an average treated tree total of 16 minutes. This difference represents an estimated reduction of 76% over the 10 years (Table 3). The trim and chip times for the silver maple trees more closely followed the biomass results with differences between the untreated and treated trees (Figure 6). There was also a significant difference in trim and chip times between the 2- and 1-g rates. The estimated 10-year total for trim and chip time was 134 minutes for untreated trees versus a treated tree time of 12 to 24 minutes. This represents an estimated reduction of 86% in trim and chip time over the 10 years (Table 3).

There was a strong correlation between biomass removed and trim and chip time as demonstrated by regression analysis. The correlation coefficient obtained

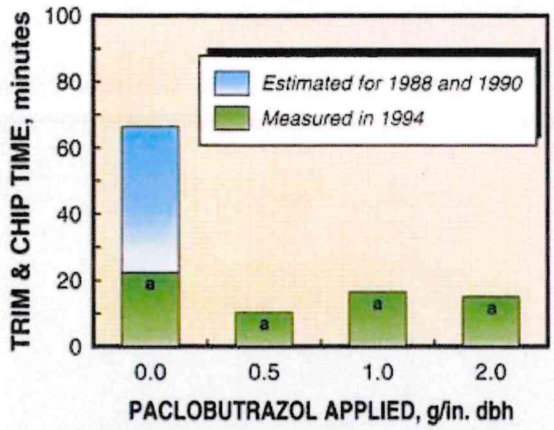


FIGURE 5. *Trim and chip time over a 10-year period for red maple treated with paclobutrazol in 1984. The untreated trees were trimmed in 1988, 1990, and 1994; the treated trees were trimmed only in 1994. The estimated total for the untreated trees is equal to three times the biomass removed in 1994. LSD at 0.05 level.*

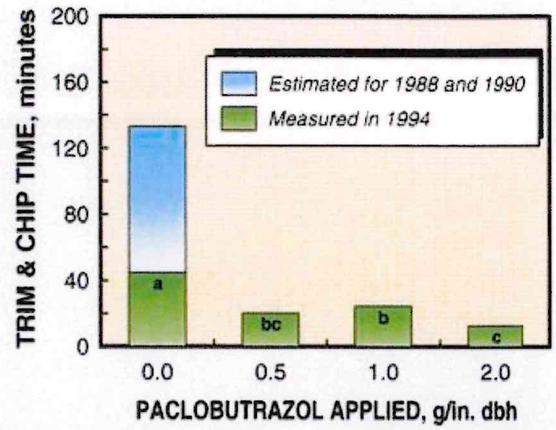


FIGURE 6. *Trim and chip time over a 10-year period for silver maple treated with paclobutrazol in 1984 averaged across all volumes. Untreated trees were trimmed in 1988, 1990, and 1994; treated trees were trimmed only in 1994. Estimated total for the untreated trees is equal to three times the biomass removed in 1994. LSD at 0.05 level.*

was 0.93 and the R-square for the simple linear model was 87% (Figure 7). This model predicts that every 100 lb of biomass removed requires approximately 5 minutes of trim and chip time. Although it is not expected that TGRs will always provide 10 years of growth suppression, these relationships demonstrate that costs of tree trimming can be reduced as reductions in tree growth and biomass removed are achieved.

Application Volume Effects

When the silver maple data were analyzed to determine effects of application rate and volume, the interaction between these two factors was significant. At 1500 mL of application volume there was a significant difference between the 1- and 2-gram rates of active ingredient per inch dbh (Figure 8). At 3000 mL of application volume the response was not different between the two rates. These results may suggest two important factors: first, paclobutrazol is more available for root uptake if the active ingredient is dispersed so as to contact more root area, and second, that subsequent rainfall and soil moisture do not move significant amounts of product from the application site to contact more root surfaces. These relationships can be further illustrated by Figure 9, which shows the 2-g rate only but compares application volumes of 300, 1500, and 3000 mL of solution. The variance decreased as the volume of application increased. The mean for biomass removal decreased as well with increasing application volume, further demonstrating the importance of the initial placement of the product. Because of the low solubility of paclobutrazol, it does not disperse with soil moisture; therefore, it appears that it cannot be applied in a manner that limits placement points.

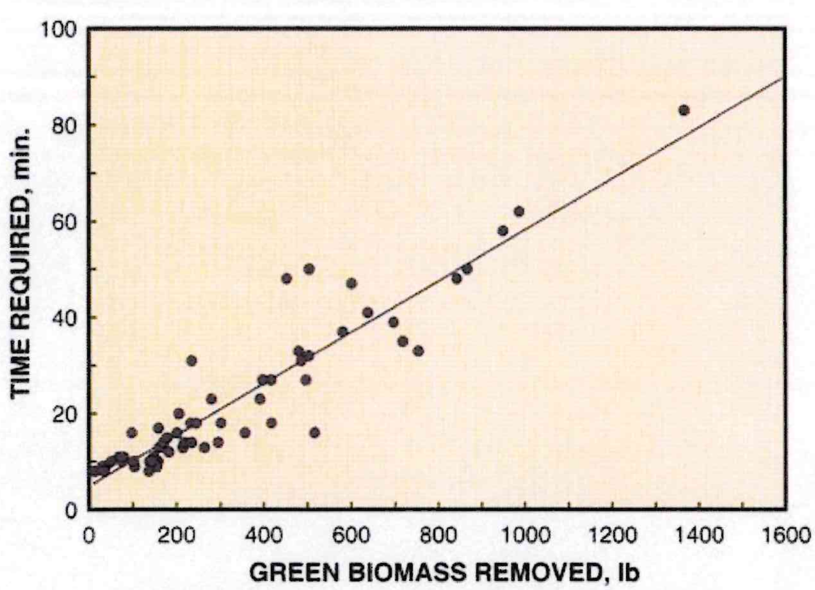


FIGURE 7. *Relationship of green biomass removed in 1994 to the time required to trim and chip in minutes. Model: Time in minutes = 5.0 + (0.053 × biomass in lb); R-square = 87%; correlation coefficient = 0.93.*

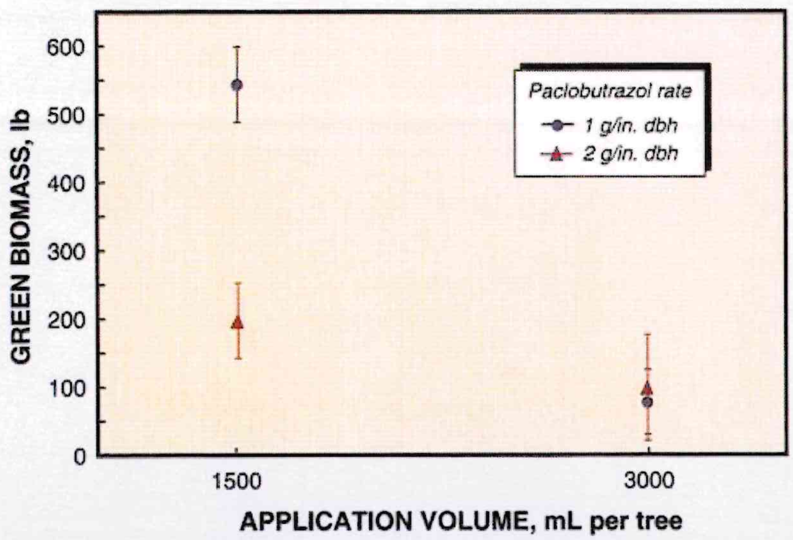


FIGURE 8. *Plot of silver maple biomass removed in lb in 1994 as affected by the interaction between the rate of paclobutrazol and the application volume.*

SUMMARY AND CONCLUSIONS

When evaluating only the amount of biomass removed in 1994, there was a significant difference between treated and untreated trees. Considering that the untreated controls were trimmed an additional two times, further separation between the treated and the untreated trees is evident. Reductions in biomass correlate well with reductions in time required to trim the trees and chip the biomass removed. Other benefits such as the reduction in hauling costs and reductions in disposal costs were beyond the scope of this study, but should correlate with the reductions in biomass. TGRs are not considered a replacement for trimming, rather as an integrated approach to help utility managers maintain a consistent trimming cycle.

The soil application method for paclobutrazol was shown to be effective in controlling tree growth. However, the effects of application volume demonstrate the importance of proper placement of the product for best results. At low application volumes there was a significant advantage to using the higher rate of application. At higher application volumes, there was no significant difference between rates. Because paclobutrazol has a very low water solubility, soil moisture cannot be considered a vector for moving the active ingredient to the tree roots. The volume and pressure of delivery should be sufficient to maximize the contact with roots for efficient uptake and utilization.

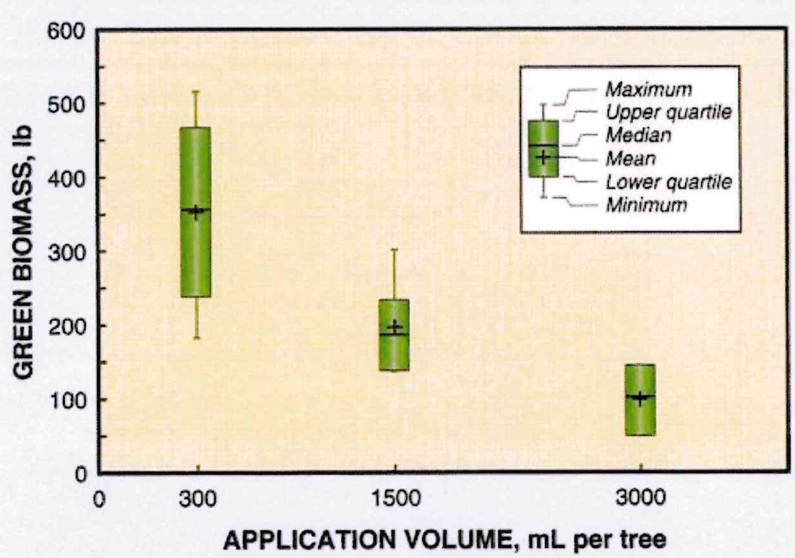


FIGURE 9. *Box and whisker plots for silver maple at the 2-gram rate of paclobutrazol. The relationship of green biomass removed in 1994 as affected by the application volume.*

ACKNOWLEDGMENTS

The authors wish to acknowledge PECO Energy for making this study possible. In addition we would like to acknowledge Henry Why, Paul Johnston, and Steven Bowen, PECO Energy, for their individual contributions to this study.

REFERENCES

1. Dayinian, M. 1993. Wood chip management. *Arborist News*. 2(2):9-13.
2. Hightshoe, G. 1978. *Native Trees for Urban and Rural America*. Iowa State University. MP 7 and 8.
3. Redding, K.D., P.L. Burch, and K.C. Miller. 1994. Growth, biomass, and trim/chip time reduction following application of flurprimidol tree growth regulator. *J. Arboriculture*. 20(1): 38–45.
4. Seiler, J.R., and P.N. McBee. 1992. A rapid technique for the evaluation of mature tree crown growth. *J. Arboriculture*. 18(6):325–328.
5. Zedaker, S.M., and J.H. Miller. 1991. Measurement of target and crop species. *Standard Methods for Forest Herbicide Research*. Southern Weed Science Society, Champaign, IL, pp. 22–40.

TREE ROOT SYSTEM ENHANCEMENT WITH PACLOBUTRAZOL

by Gary W. Watson

Abstract. Paclobutrazol 2SC (PBZ) was injected into the soil at the base of the trunk at 2 g a.i. per inch dbh. Surface fine root densities near the base of the trees were naturally higher than in the rest of the root system and were adequate to absorb the compound. PBZ treatment was effective in stimulating fine root development in pin oaks (*Quercus palustris*) and white oaks (*Quercus alba*). Pin oak fine root densities were increased significantly in high-quality topsoil. White oak fine root densities were increased significantly by PBZ alone and in combination with high-organic replacement soils. The treatment may be effective in stabilizing declining trees with insufficient fine root development.

Root development of mature landscape trees can be inadequate to support the crown (23). Root space is often more constricted in the landscape than crown space. Soil quality in the already limited root space can deteriorate over time from numerous causes, including raking leaves, which removes organic matter and nutrients; foot and equipment traffic, which compacts the soil; alkaline runoff from paved surfaces, which can raise the pH; and vigorous competition from turfgrass, which can directly reduce the number of tree fine roots in a limited root space. More directly stated, tree crowns can grow too large for the quality and quantity of root space available, resulting in decline and dieback. Root system enhancement and crown size control are 2 approaches to restoring the balance between the crown and root system.

Root system enhancement can be accomplished by improving the soil, but direct substitution or addition of soil in the root zone of existing trees will cause considerable damage to roots. Traditional surface mulch is effective for improving the soil and increasing root development over time (10), but is not a viable option in all situations. Vertical mulching, and a more extensive procedure called soil replacement (24), can also be effective in improving root development on a limited basis.

The growth regulator paclobutrazol (PBZ), a gibberellin biosynthesis inhibitor, has been shown to reduce the shoot growth of many species (6), and is commonly used to control the regrowth of trees under utility lines. This growth regulator has promise for use in the landscape wherever control of plant size is needed. Reports of its effect on root systems have been mixed. Reports range from increased root growth (1,2,6,20) to decreased root growth (2, 9,14,15), but nearly always include an increase root:shoot ratio (12,15,17). Most PBZ studies have used plants in pots or solution culture in which the PBZ is applied directly to the entire root system, so this information is of limited application to mature landscape trees. The current commercially available formulation of PBZ is applied as a basal soil injection or drench. Only a few roots at the base of the tree are in direct contact with the PBZ. Little information is available on how this type of PBZ application affects root development in the rest of the root system. Virtually nothing is known about the root response of plants in the landscape. The few published studies in which the PBZ was applied to leaves or stems of greenhouse plants reveal that root growth was generally unchanged (6,13,25) or reduced (11,16), and root:shoot ratio was increased (16,25,26) or unchanged (4,11).

Soil conditions are often a limiting factor in root growth of urban trees. If chemical enhancement of tree root systems is possible with PBZ, it is likely to be limited by soil quality. The objective of this study was to test the response of landscape tree roots to a basal application of PBZ in existing soils and improved soils.

Methods

The PBZ 2SC formulation (Profile 2SC, DowElanco, Indianapolis, Indiana) is applied as a basal soil injection or drench, within 20 cm of the trunk base. A Series 3600 Soil Injection Closed System (Springfield Specialties Co., Springfield, Pennsylvania) was used to inject the diluted (79 mL/L) solution into the soil in 250 mL aliquots for a total of 2 g of active ingredient (100 mL dilute solution) per caliper inch.

With the basal injection or drench methods listed on the label, the chemical is delivered to the upper 15 cm of soil. To confirm that a sufficient density of fine roots was present at the soil injection site, the horizontal distribution of fine roots in the upper 15 cm of soil was investigated. Core samples 15 cm deep by 6.5 cm diameter were collected at 20, 40, 60, 80, 100, 120, 240 and 365 cm from the base of 8 trees of each species that were of similar size and growing in similar conditions as the treated trees.

Experiment 1. Two rows (7 trees each) of pin oak (*Quercus palustris*) trees, between 21 and 27 cm dbh, were selected from the middle of a large, evenly spaced block of trees on the grounds of the Morton Arboretum. The 2 rows were separated by a row of unused trees. The trees were in excellent condition. One row of trees was treated with PBZ on August 28, 1989; the other row served as untreated controls.

In September 1992, fine root development was measured using root density cores. One 35 cm deep, 7 cm diameter core was taken 1.5 m from the base of each tree. Cores were cut into 5 cm segments and stored at 4°C until processing. Soil was washed from the roots, and oak roots were separated from other roots and debris by hand. Roots were digitized at 300 dpi resolution, and root surface area was measured with Image Pro for Windows software. T-tests were used to compare root densities at each soil depth ($p < 0.05$) using SigmaStat Version 2.0 for Windows.

Experiment 2. Sixteen mature white oaks (*Quercus alba*) were identified on the grounds of the Morton Arboretum. They were from 50 to 70 cm dbh with large open-grown crowns and located within 500 m of each other. All were in a state of decline as judged by the amount of dieback, tufted growth, and chlorosis in the crown.

Soil replacement in a pattern of radial trenches has been shown to increase root and crown growth (24). In this study, soil replacement was combined with PBZ treatments. There were 16 trenches around each tree, 45 cm deep and alternating between 2 and 4 m long, with the distant end of each trench positioned 7.5 m from the trunk. Alternate length trenches were necessary to prevent the near ends of the trenches from being too close together and causing excessive root damage. The trenches were filled with a 50/50 v/v site topsoil and leaf compost mix.

The 4 treatments were PBZ soil injection, soil replacement trenches (SRT), PBZ soil injection plus SRT, and control. PBZ treatments were injected on August 28, 1989, and trenches were installed in June 1990. Four trees received each treatment combination.

Fine root development was measured using the same root density coring and sample processing procedures as in Experiment 1, and at the same time. Two cores per tree (8 cores per treatment) were taken in the middle of the larger trenches, and at a similar distance from the trunk for the other treatments.

Two-way ANOVA was used to compare root density of treatments to the control ($p < 0.05$) using SigmaStat Version 2.0 for Windows. Student-Newman-Keuls Method was used as a multiple comparison procedure.

Results

Pin oak surface fine root densities were 80% higher within 60 cm of the trunk base compared to the other sampling locations (Table 1). White oak fine root densities were 60% higher within 20 cm of the trunk base. The reason for this elevated fine root density at the base of the tree is unknown, but the data show that an adequate density of fine absorbing roots are present near the base of the tree to absorb PBZ applied there.

Table 1. Horizontal distribution of pin oak and white oak fine root density (mm² fine root surface area per cm³ soil) in the upper 15 cm of soil.

	Distance (cm) from base of trunk							
	20	40	60	80	100	120	240	365
Pin oak	9.8	9.3	8.0	5.3	4.2	4.3	5.0	6.4
White oak	11.7	7.1	6.7	7.1	4.9	6.1	5.1	2.9

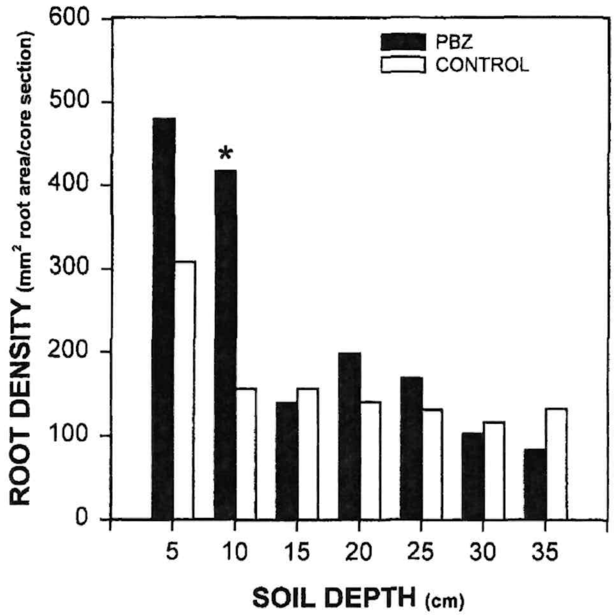


Figure 1. Fine root development of pin oaks after paclobutrazol basal injection treatment (PBZ). Roots were sampled 1 m from soil injection site. An abrupt change from organic topsoil to clayey subsoil occurs below the 10 cm sampling depth. An asterisk (*) indicates treatment value significantly different from the control at $p < 0.05$.

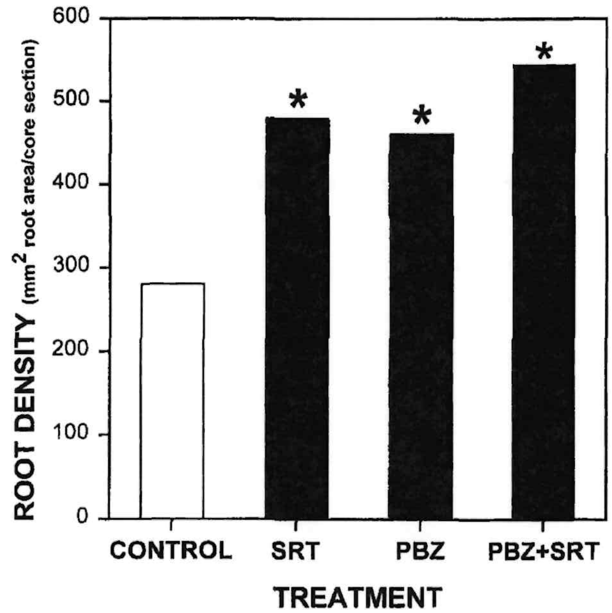


Figure 2. Fine root development of white oaks after paclobutrazol basal injection (PBZ) and soil replacement treatments (SRT). An asterisk (*) indicates treatment value significantly different from the control at $p < 0.05$.

Experiment 1. PBZ increased fine root density of pin oaks by 64% in the upper 5 cm of soil, and significantly increased the fine root density between 5 and 10 cm. At approximately 10 cm, there was an abrupt change to more dense and clayey soil horizon. Increases in root density were inconsistent and not significant in this subsoil. Increases in root densities between 15 and 25 cm depth were as much as 41%. Root density appeared to decrease between 30 and 35 cm depth (Figure 1).

Experiment 2. Root density of white oaks was increased significantly by all treatments (Figure 2). There was no significant difference among the different depths, nor was there a significant interaction between treatment and depth. As in a previous study (24), replacing the existing site soil with a soil/compost mix resulted in complete colonization of the new soil by new tree roots. The fine roots in the replaced soil were 70% denser than the undisturbed control. PBZ alone, applied in the root crown area, increased fine root density similarly in areas away from the point of application. The improved soil mix in the trenches combined with PBZ resulted in the greatest increase in fine root density, nearly double that of the undisturbed control. This greater root development (although not significantly greater than the other 2 treatments) of PBZ treated trees in high-quality soil is similar to the greater root response in the high-quality topsoil in the first experiment.

Discussion

In both experiments, fine root density was increased after application of PBZ. This technique could have application in many landscape situations for which sufficient fine root development is lacking. Fine root enhancement of the pin oaks was greatest in the high-quality topsoil and in the replacement soil trenches around the white oaks.

PBZ was applied as a soil injection near the root crown. PBZ is absorbed by roots and translocated in the xylem only, towards the branch tips (5). The stimulation of fine root development must be an indirect effect, since the chemical is never in contact with roots more than 20 cm from the base of the tree. Photosynthesis is not reduced by PBZ treatments (8,14,21). Increases in root

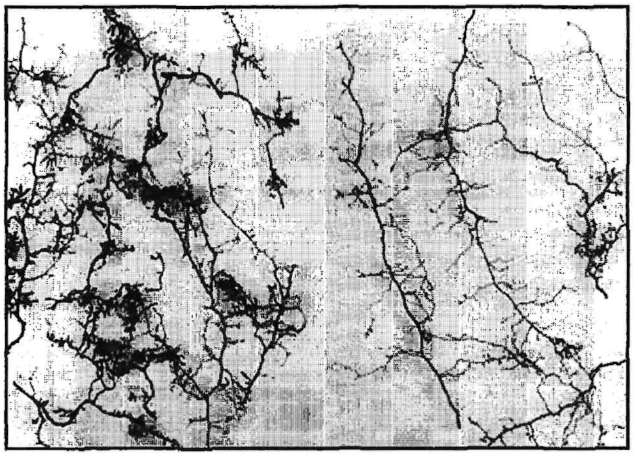


Figure 3. Pin oak fine roots from a tree treated with paclobutrazol basal injection (left) and an untreated control (right). Paclobutrazol was applied as a basal injection, and roots were sampled 1.5 m from trunk.

growth may be due to increased carbohydrate supply to roots resulting from reduced demand for growth above ground (7,20).

It could not be determined from this study if the increase in fine root density was due to an increase in root branching, elongation, or both. Visual observation suggested that the fine roots were more profusely branched (Figure 3). Increased fine root branching has been reported previously (1,9), as well as root thickening (18) and increased root initiation (6,20). Adventitious and lateral root formation processes are similar. PBZ can reduce root elongation (9,20). A smaller unsuberized length of the root tip (26) also implies slower elongation. The specific effect of PBZ on root growth and morphology is an important question in relation to future applications of this technology in the landscape. In cases in which roots have been severed and must grow long distances to reestablish the original root spread, a rapid elongation rate is very important. In contrast, where the major roots are intact, increasing the fine root density through more frequent branching could be more beneficial.

Crown response was not quantified in either experiment. The visual difference in appearance between treated and control pin oaks in Experiment 1 was negligible and limited to a slightly greener leaf color. All of these trees were healthy at the start. The first sign of crown improvement (greener color) of the white oaks was observed the second year after treatment. At the time of the root sampling, 3 years after the treatments were applied, the crowns of the declining white oaks were showing signs of improvement. Color and vigor was improving. Unfortunately, at that time, the majority of the trees included in the study were cut down for reasons unrelated to the study, and too few remained for meaningful crown development data to be collected. Of the trees that did survive, one that was treated with PBZ and replacement soil trenches continued to show crown improvement through 1995, 6 years after a single treatment. New growth was deep green and vigorous. The crown has become fuller each year (Figure 4). In 1994 and 1995, the leaves were much less scorched by mid-summer than a neighboring tree that received only SRT without PBZ (Figure 5). Leaves of PBZ treated trees were not noticeably smaller.

The increase in fine root development implies a more favorable root/crown balance and less stress in treated trees. Improved water status has been reported after treatment with PBZ (17,21). Apparent improvements in vigor, color, and drought resistance may be related to a greater capacity of the root system to absorb moisture and mineral nutrients from the soil. Reduced water use has also been reported (16,19).

Root development was not assessed until the crown began to show visible signs of improvement, 3 years after treatment. It is not known how fast the root system responded to the PBZ treatment, or which came first, crown or root improvements. The deep green leaf color characteristic of PBZ treatment persisted in both species through at least 6 years in this study. One study reports effects persisting for 10 years (3).

Both SRT and PBZ treatments were effective in increasing root development. If the existing soil around a tree is of sufficient quality to support additional root growth, then PBZ may be the treatment of choice. It is relatively inexpensive (less than US$20 per tree for the material), can be applied rapidly (less than 5 minutes per tree), causes no root damage, and benefits the entire root system. The concentration of roots at the base of the trees would seem to provide for excellent uptake. Additional data (G.W. Watson, unpublished)

Figure 4. These 2 white oak trees were treated with soil replacement trenches (top and bottom) and paclobutrazol basal injection (bottom). Photos were taken prior to treatment (left), 3 years after treatment—at the same time root systems were sampled (middle), and 6 years after treatment (right). The 2 treatments combined resulted in better crown improvement. Deadwood was inadvertently pruned from the trees during the course of the study.

Figure 5. Leaves of white oak trees treated with paclobutrazol (right) showed less marginal and interveinal leaf scorch than did untreated controls (left).

showed that American elms (*Ulmus americana*) also have fine roots concentrated at the base of the trunk, so this may occur in more than just oaks.

Because urban soils are often of poor quality, PBZ treatments may have to be combined with other soil-improving techniques. Soil replacement is costly and potentially destructive to roots and should be used only when other options are not available. Surface mulching alone can improve soil quality and increase fine root density (10,22). PBZ application combined with surface mulching may hold the greatest potential for fine root development.

These treatments are not quick cures for declining trees. It will take several years for any visible crown response to develop. Declining trees could die before the treatment would have a chance to stabilize them. PBZ treatments may prove to be more valuable as preventive maintenance on mature but still healthy trees, than on trees already in a state of decline.

Literature Cited

1. Ashokan, P.K., W.R. Chaney, and G.S. Premachandra. 1995. *Soil applied paclobutrazol affects leaf water relations and growth of American elm (Ulmus americana L.) seedlings.* Plant Growth Reg. Soc. Amer. Quar. 23: 1–12.
2. Bausher, M.C., and G. Yelenosky. 1986. *Sensitivity of potted citrus plants to top sprays and soil applications of paclobutrazol.* HortScience 21: 141–143.
3. Burch, P.L., R.H. Wells, and W.N. Kline. 1996. *Red maple and silver maple growth evaluated 10 years after application of paclobutrazol tree growth regulator.* J. Arboric. 22: 61–66.
4. Casper, J.A., and B.H. Taylor. 1989. *Growth and development of young 'Loring' peach trees after of peach seedling vegetative growth to paclobutrazol.* J. Amer. Soc. Hort. Sci. 113: 23–27.
5. Couture, R. 1982. *A new experimental growth regulator from ICI.* Proc. Growth Regulat. Soc. Amer. 9: 59.
6. Davis, T.D., N. Sankhla, R.H. Walser, and A. Upadhyaya. 1985. *Promotion of adventitious root formation on cuttings by paclobutrazol.* HortScience 20: 883–884.
7. Davis, T.D., G.L. Steffens, and N. Sankhla. 1988. *Triazole Plant Growth Regulators.* Hort. Rev. 10: 63–105.
8. DeJong, T.M., and J.F. Doyle. 1984. *Leaf gas exchange and growth responses of mature 'Fantasia' nectarine trees to paclobutrazol.* J. Amer. Soc, Hort. Sci. 109: 878–882.
9. Early, J.D. Jr., and G.C. Martin. 1988. *Sensitivity of peach seedling vegetative growth to paclobutrazol.* J. Amer. Soc. Hort. Sci. 113: 23–27.
10. Himelick, E.B., and G.W. Watson. 1990. *Reduction of oak chlorosis with wood chip mulch treatments.* J. Arboric. 16: 275–278.
11. Liyembani, S., and B.H. Taylor. 1989. *Growth and development of young peach trees as influenced by foliar sprays of paclobutrazol or XE-1019.* HortScience 24: 65–68.
12. Marquard, R.D. 1985. *Chemical growth regulation of pecan seedlings.* HortScience 20: 919–921.
13. Miller, S.S. 1982. *Growth and branching of apple seedlings as influenced by pressure- injected plant growth regulators.* HortScience 17: 775–776.
14. Rieger, M., and G. Scalabrelli. 1990. *Paclobutrazol, root growth, hydraulic conductivity and nutrient uptake of 'Nemaguard' peach.* HortScience 25: 95–98.
15. Ruter, J.M. 1994. *Growth and landscape establishment of Pyracantha and Juniperus after application of paclobutrazol.* HortScience 29: 1318–1320.
16. Ruter, J.M., and C.A. Martin. 1994. *Effects of contrasting climate and paclobutrazol on the growth and water use of two container-grown landscape plants.* J. Environ. Hort. 12: 27–32.
17. Swietlik, D., and S.S. Miller. 1983. *The effect of paclobutrazol on growth and response to water stress of apple seedlings.* J. Amer. Soc. Hort. Sci. 108: 1076–1080.
18. Tagliavini, M., and N.E. Looney. 1991. *Response of peach seedlings to root-zone temperature and*

root-applied growth regulators. HortScience 26: 870–872.

19. Wample, R.L., and E.B. Culver. 1983. *The influence of paclobutrazol, a new growth regulator, on sunflowers.* J. Amer. Soc. Hort. Sci. 108: 122–125.
20. Wang , S.Y., and M. Faust. 1986. *Effect of growth retardants on root formation and polyamine content in apple seedlings.* M. Amer. Soc. Hort. Sci. 111: 912–917.
21. Warren, S.L., F.A. Blazich, and M. Thetford. 1991. *Whole-plant response of selected woody landscape species to uniconazole.* J. Environ. Hort. 9: 163–167.
22. Watson, G.W. 1988. *Organic surface mulch and grass competition influence root development.* J. Arboric. 14: 200–203.
23. Watson, G.W. 1991. *Attaining root:crown balance in landscape trees.* J. Arboric. 17: 211–216.
24. Watson, G.W., P.D. Kelsey, and K. Woodtli. 1996. *Replacing soil in the root zone of mature trees for better growth.* J. Arboric. 22: 167–173.
25. Wieland, W.F., and R.L. Wample. 1985. *Root growth, water relations and mineral uptake of foliar sprays of paclobutrazol and GA_3.* HortScience 24: 240–242.
26. Williamson, J.G., and D.C. Coston. 1986. *Growth responses of peach roots and shoots to soil and foliar-applied paclobutrazol.* HortScience 21: 1001–1003.

The Morton Arboretum
Lisle, IL 60532

Résumé. Du paclobutrazol 2SC (PBZ) a été appliqué par injection dans le sol à la base des arbres. La densité de radicelles à la surface du sol près du tronc des arbres, là où le paclobutrazol a été injecté, était naturellement plus élevée que le reste du système racinaire et était adéquate pour l'assimilation du composé chimique. Le traitement au PBZ s'est avéré efficace pour stimuler le développement des radicelles du chêne des marais (*Quercus palustris*) et du chêne blanc (*Quercus alba*). Les densités en radicelles du chêne des marais étaient significativement accrues par l'usage du PBZ seul et par l'emploi de celui-ci en combinaison avec des sols de remplacement à forte teneur organique. Le traitement pourrait arriver à être efficace pour la stabilisation d'arbres dépérissants comportant un développement insuffisant de radicelles.

MATERIAL SAFETY DATA SHEET

Section 1: Chemical Product and Company Identification:

Product:	**ARBORLOCK™ 2SC**
Product Use:	A triazole Plant Growth Regulator for trees
EPA Reg.No.:	80697-4-2293
Company;	The Davey Tree Expert Company
	1500 North Mantua Street, Kent, OH 44240
Emergency phone:	Chemtrec: 1-800-424-9300
	The Davey Tree Expert Company, 1-952-217-3375

Section 2: Composition/Information on Ingredients:

Active Ingredient;	CAS number	w/w (%)
PACLOBUTRAZOL	76738-62-0	22.3%
Inert Ingredients, total including:		77.7%
PROPYLENE GLYCOL	57-55-6	
CLAY AND PROPRIETARY INGREDIENTS		

Section 3: Hazards Identification:

Low toxicity under normal conditions of handling and use.

Section 4: First Aid Measures:

If in Eyes: Immediately irrigate with eyewash solution or clean water, holding the eyelids apart for at least 15 minutes. Obtain immediate medical attention.
If on Skin: Take off immediately all contaminated clothing. Wash skin immediately with water followed by soap and water. Such action is essential to minimize contact with skin. Contaminated clothing should be laundered before re-use.
If Swallowed: If swallowed seek medical advice immediately and show the container, label or this data sheet, if possible. Do not induce vomiting.
If Inhaled: Remove patient from exposure, keep warm and at rest. Obtain medical attention as a precaution.

Section 5: Fire Fighting Measures:

Extinguishing media: For small fires, use foam, carbon dioxide, halon or dry powder extinguishant. For large fires, use foam or water-fog. Avoid use of water jet. Contain run-off

water with, for example, temporary earth barriers.
Protective equipment: A self-contained breathing apparatus and suitable protective clothing must be worn in fire conditions.

Section 6: Accidental Release Measures:

Wear suitable personal protection during removal of spillages. This means eye protection, chemically resistant gloves, boots and coveralls. Absorb spillage onto sand, soil, or any other suitable absorbent material. Transfer to a container for disposal. Wash spillage area with water. Washings must be prevented from entering surface water drains. Large spills should be handled according to a spill plan. Otherwise, in case of emergency call day or night, Chemtrec, 1-800-424-9300.

Section 7: Handling and Storage:

Safe Handling Advice: Avoid contact with skin and eyes. When using, do not eat, drink or smoke. Wash face and hands before eating, drinking or smoking.
Requirements for Storage Rooms: Keep in original containers, tightly closed, out of reach of children. Keep away from food, drink and animal feeding stuffs. Protect from frost. Do not store near food or within the reach of children.
Additional Information: Read the label before use.

Section 8: Exposure Controls/Personal Protections:

Ingestion: Prevent eating, drinking, tobacco usage and cosmetic application in areas where there is a potential for exposure to the material. Wash thoroughly with soap and water after handling.
Eye Contact: Where eye contact is likely, use chemical splash goggles.
Skin Contact: Where contact is likely, wear chemical resistant gloves (such as nitrile or butyl) coveralls, socks and chemical resistant footwear. For overhead exposure, wear chemical-resistant headgear.
Inhalation: A respirator is not normally required when handling this product. In case of emergency spills, use a NIOSH approved respirator with any N, R, P or HE filter.

Section 9: Physical and Chemical Properties:

Form:	Opaque Liquid
Color:	Beige to off-white
Boiling Point:	Approx. 212° F
Density:	1.08 ±0.02 grams/cubic cm at 20°C
Solubility:	Miscible

Flash Point (0°C):	Does not flash
Explosive Properties (0°C):	Not Applicable
Oxidizing Properties (0°C):	Not Applicable

Section 10: Stability and Reactivity:

Stability: Stable for more than 2 years under normal use and storage conditions. Stable to hydrolysis (pH 4-9) and not degraded by UV light.

Incompatibility: Oxidizing agents.

Hazardous Polymerization: Will not occur.

Hazardous Decomposition Products: Combustion or thermal decomposition will evolve toxic and irritant vapors.

Section 11: Toxicological Information:

(Based on Paclobutrazol Technical Data)

Acute Toxicity:

Acute oral (rats) LD_{50}: >5,000 mg/Kg

Acute dermal (rabbits) LD_{50}: > 5,050 mg/Kg

Acute inhalation (Rats): LC_{50}: >2.40 mg/L

Acute eye irritation (rabbits): Non-Irritant

Acute dermal irritation (rabbits): Non-Irritant

Skin sensitization (mice): Is not considered a sensitizer, with an index of < 3 in all groups of test animals

Section 12: Ecological Information:

(Based on Paclobutrazol Technical Data)

Ecotoxicity;

Toxicity to fish: LC_{50}	Rainbow trout: 27.8 mg/L
	Bluegill sunfish: 23.6 mg/L
	Daphnia magna: 33.2 mg/L

Unlikely to be hazardous to aquatic life

Avian dietary toxicity: LC_{50}	Mallard duck: >20,000 ppm
	Quail: > 5,000 ppm

Section 13: Disposal Considerations:

Discarded product is not considered as a hazardous waste under RCRA, 40 CFR 261.

Disposal: Do not reuse product containers. Dispose of product containers, waste containers, and residues according to local, state, and federal health and environmental regulations.

Characteristic Waste: Not Applicable
Listed Waste: Not Applicable

Section 14: Transport Information:

DOT status: Not classified
UN number: Not classified
NMFC number: 101685
Class: 065
Proper shipping name: Plant Growth Inhibitor, Modifier or Regulator
Packaging group: Not classified
Marine Pollutant: Not classified
Other applicable information: Not classified

Section 15: Regulatory Information:

Not classified as hazardous to users.
TSCA (Toxic substances control act) regulations, 40 CFR 710:
This product is a pesticide and is exempt from TSCA regulation.
CERCLA and SARA regulations (40CFR 355,370 and 372): This product does not contain any chemicals subject to the reporting requirements of SARA section 313.

Section 16: Other Information:

The information and recommendations contained herein are based upon data believed to be correct. However, ***no guarantee or warranty of any kind, expressed or implied, is made*** *with respect to the information contained herein.* The Davey Tree Expert Company *assumes no responsibility for results obtained or for incidental or consequential damages arising from the use of these data.*