GROWTH, BIOMASS, AND TRIM/CHIP TIME REDUCTION FOLLOWING APPLICATION OF FLURPRIMIDOL TREE GROWTH REGULATOR

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Abstract. Two application methods for the tree growth regulator flurprimidol were compared to untreated trees three years after treatment. Silver maple in Ohio, water and willow oak in Virginia, red oak and red maple in Maine, and Norway maple in Pennsylvania, at locations representing five different utilities, were treated with basal soil drench applications at 0.5, 0.75, and 1.0 grams of active ingredient (gai) per inch diameter at breast height (dbh) and with implant applications at 0.5 and 0.75 gai per inch dbh in 1989. Trees were revisited three years after application and assessed for growth suppression using three techniques. Measurement of the seven longest shoots in each tree were taken to the nearest inch for the growth occurring from 1989 to 1992. All trees were trimmed to utility companies' specifications, and the green biomass removed was weighed and chipped. Green biomass weight and actual trim/chip time was recorded for each tree. Significant differences were detected between the untreated trees and the treated trees; however, differences due to application techniques and dose rates were irregular and seldom significant. Overall, for the four species across all sites,there was a 63 percent reduction in shoot elongation, a 75 percent reduction in biomass, and a 55 percent reduction in trim and chip time when tree growth regulators were used.

A tremendous challenge exists for utility and private commercial arborists in managing tree growth across the country. There are approximately 3,200 electric utility companies operated by private investors, rural cooperatives, local municipalities, and county, state, and federal agencies. These companies are responsible for trimming trees under electric power lines with the ultimate objective of maintaining safe and reliable electric service. The average investor-owned utility manages over 8,000 miles of rights-of-way and trims 177,000 trees annually, at a cost of 3 to 5 million dollars. One major Northeast utility manages 15,937 miles of rights-of-way, spends over 3 million dollars on tree trimming annually, and has a tree population of over 2.5 million to maintain (19).

The number of trees to be trimmed annually is estimated at 40 to 50 million, with the cost to carry out this activity estimated at $1.5 billion. Not only do utility vegetation managers face immense problems in finding the budget and labor resources to conduct normal tree trimming, they are also under increasing scrutiny from conservation groups and homeowners as to how they actually trim trees (2). Another item that is becoming a major issue in certain parts of the country is disposal of the biomass generated from all this trimming activity. Nationally, utility line clearance alone generates approximately 50,000 tons of chipped biomass per day or 13 million tons per year (6).

The electric utility industry continually upgrades equipment and procedures to improve the effectiveness and safety of tree growth management through mechanical means. At the same time, interest is increasing in the development of nonmechanical means of controlling the growth of trees, such as tree growth regulators. Utility arborists have been investigating tree growth regulators since the early 1960s (8,9), citing benefits such as reduced power outages, more efficient trimming operations, establishment and maintenance of a trim cycle, and reduced biomass to be trimmed and discarded. Unfortunately, the early compounds created much skepticism about the efficacy of tree growth regulators because of their phytotoxicity and inconsistent results. A second generation of compounds developed in the 1980s (paclobutrazol, flurprimidol, and uniconazole) have an inherently safer mode of action (9) while retaining benefits sought by the utilities (4,7,10,11,16,18,19).

This second generation of compounds reduces growth by inhibiting production of the growth hormone, gibberellin, in the tree. Gibberellin controls the cell elongation within certain tissues. When there is an insufficient amount of gibberellin, cells still divide but do not elongate as they would normally, thus reducing shoot growth (9). Although gibberellin biosynthesis inhibitors effectively regulate tree growth, several critical issues have kept tree growth regulators from being an operational success for most utilities. These compounds are typically dissolved in alcohol and injected into trees under pressure using sophisticated equipment that requires a specially trained crew. The reaction of the tree to the alcohol carrier is often unacceptable, resulting in bark necrosis, splits, and weeping or stained holes (1,12,13). The application is often very slow, complicated, and difficult to evenly dose (5,10).

To be useful to the electric utility industry, application of tree growth regulators must be safe and efficient without requiring costly, sophisticated equipment. Application must also limit wounding and other effects detrimental to tree vigor. This paper examines new application and formulation technology that addresses these issues.

Materials and Methods

This study was conducted by ACRT, Inc., an independent utility research organization. The study began in mid-1989 with the identification of approximately 550 trees at five locations across Ohio, Pennsylvania, Maryland, Maine, and Virginia. Approximately 400 trees were identified for treatment and an additional 150 were used as untreated control trees. There was an attempt to block trees for similar crown size, tree vigor, age, diameter at breast height (dbh), and local growing conditions for the same species. At some locations this was not possible because of a lack of suitable sample trees and poor vigor of control trees. The study covered seven different species including silver maple (*Acer saccharinum*), Norway maple (*Acer platanoides*), London planetree (*Platanus x acerifolia*), red oak (*Quercus rubra*), live oak (*Quercus virginiana*), water oak (*Quercus nigra*), and willow oak (*Quercus phellos*). Trees in this study were mature and range from 10 to 30 in. dbh.

Installation. Flurprimidol was applied to all species using three application methods. The treatments included standard pressure injection, basal soil drench, and solid implant applications. All species were treated in the fall of 1989. The sycamore and two maple species were also treated in the spring of 1990. The spring applications were further divided to evaluate flurprimidol introduction at two different stages of positive root pressure and leaf transpiration. The first stage was between bud break and when the leaves were only about one-half expanded. The second stage was at later growth flush with the leaves fully expanded, but prior to next year's bud set during the active elongation period. All trees were trimmed, both treated and untreated, to standard utility specifications for line clearance. Trimming occurred approximately 2 to 3 months prior to treatment or 3 to 6 months after treatment.

Trunk injection treatments were applied using an Arborchem six-point injector. The application used a typical 6- to 8-in spacing with holes drilled 2.5 to 3 in deep at a 30° angle to accommodate the injector probes. A stock solution was prepared where each liter contained 60 grams of flurprimidol technical powder in isopropanol (16.7 ml of solution contained 1 gram of active ingredient). The appropriate amount of flurprimidol solution was applied per injection hole to provide for the tree the recommended dose of grams of active material per inch of dbh.

The basal soil drench treatments were applied to the soil at the bark/soil interface of the tree. A small trench was pulled away from the tree to hold the material and then pushed back after application (Fig. 1). The same stock solution used for injection treatments was used for the basal drench treatments. The appropriate amount of solution for the proper dose in grams of active ingredient (gai) per inch dbh was mixed with approximately 1 quart of warm water (to insure solubility) and poured at the base of the tree. The water provided enough volume to obtain even distribution of flurprimidol around the tree. The intent of this treatment was to provide active material to the suberized/nonsuberized bark interface at the soil line for transbark absorption and translocation. It was anticipated that this root uptake method would provide a more uniform distribution of product throughout the crown. All xylem vessels would be

Figure 1. Photos show application of basal soil drench (left) and tree implant (right).

potential carriers as opposed to only those vessels intercepted during the injection process. This concept is supported by previous research in this area (17).

The solid implant treatments used flurprimidol technical powder formulated with a starch binder and made into a tablet form. Two tablet doses were formulated with each tablet containing either 1.0 or 1.5 gai. The tablets were scored in the middle to allow the tablet to be broken in half to facilitate dosing at lower levels. The number of implants to apply to the tree was determined by the tree's dbh and the dose desired in ga per diameter inch. Holes were drilled in the tree with a brad point bit to facilitate the implants (Fig. 1). Placement of holes did not necessarily follow a strict spacing regimen as with standard injection. Holes were drilled just deep enough to allow placement of the implant below the bark surface. A small wooden dowel was placed over the implant to seal the hole. Implants were placed on the root flares where possible to facilitate maximum uptake while avoiding root flare sinuses, girdling roots, and bark wounds. Implants inserted in the fall were misted with distilled water prior to being plugged to facilitate the uptake process.

The implant concept was based on commercially available methods for delivering substances into trees, the observations on compartmentalization in trees espoused by Dr. Alex Shigo (14), and other research on living xylem tissue and material movement within trees (15,20,21). Based on this existing research it was clear that the xylem vessel is a self-plugging filter and that an implant had to dissolve and move from the implant site quickly. The flurprimidol implant becomes a formless powder within 30 seconds of contact with water. Research with angel-hair-packed flow chambers showed that the tablets solubilized and translocated within a 72-hour period at a flow rate of 4 gal/hr (unpublished data, Elanco laboratory). These flow rates are easily achievable in actively metabolizing and transpiring large trees (3).

Dosages were based on recommended label rates and previous experience. Maple and oak species were dosed at 0.5, 0.75, and 1.00 gai per inch dbh for the basal soil drench applications. Maple and oak species were dosed at 0.5 and 0.75 gai per inch dbh for injection and implant applications. Sycamore was dosed at 0.75, 1.00, and 1.50 gai per inch dbh for all three application treatments. Because of the higher number of implants required for sycamores, a "V" was drilled at each entry point to allow for the placement of two implants per entry hole.

Native forest-grown trees from a location in Maine were not trimmed. Rather, these trees were observed for overall effect of regulator applied as implants and were used as harvest trees for destructive analysis studies. The test species were red maple and red oak. Red maple was chosen specifically as being a possible poor compartmentalizer because the species had shown maximum injurious effects of standard injection and decay and discoloration on tests by previous researchers (13). The destructive analysis was conducted in 1991. Trees were cut across the plane of implantation and several inches above and below this plane and assessed for closure, discoloration, and any decay.

Tree assessment. Qualitative assessments were made on all 550 trees in the study for ease of application, quickness and degree of growth regulation, effects on the bark (weeping and fluxing), physiological effects, and overall tree health. In addition, destructive analysis of red maple and red oak at the Maine site were conducted to assess compartmentalization in response to treatment wounds. Tree growth regulator efficacy was evaluated quantatively for 270 trees using three separate measurements: length of regrowth of seven longest shoots, weight of the biomass removed in trimming, and time to trim and chip material removed. Pressure injected and treated but untrimmed trees in Maine were not included in these analyses. Assessments were taken in August and September of 1992 to allow for three full seasons of growth since treatment and initial trimming. The trees were again trimmed to the standard utility specifications as previously described.

Total height regrowth was evaluated by measuring the seven longest shoots for annual growth. This was an application of previous line clearance industry tree growth regulator methodology and represented those branches least regulated by the flurprimidol application. Generally, these were adventitious branches in the upper crown. The seven branches were measured for overall and annual incremental growth in length. The average length of the seven longest shoots was calculated.

The actual regrowth on an individual tree basis was measured by collecting all the biomass removed at trimming. This biomass was run through a bagging Morbark chipper (Model 175) and the chips were collected in plastic bags and weighed (Fig. 2).

Measurement of actual line-clearance, tree-trimming time included set-up time for the aerial lift, trim time per tree, and the time involved to chip trimmings. One composite time was recorded for each tree. All crews were told to follow standard trimming procedures, which in many cases included trimming for overall canopy shape, elimination of overhang, and safety elevation of lower branches. Because all trees were treated similarly and only trimmed on an as-needed basis, any degree to which the different utility line clearance practice could possibly have affected results is unknown. Some trees had so little regrowth that they were not trimmed in the 1992 evaluations.

Figure 2. Chipping and weighing of biomass removed in trimming.

Data were analyzed using analysis of variance (ANOVA) and differences between means tested using Tukey's pairwise comparisons. The analyses compared tree response to application methods, dose across application methods and dose with an application method. Certain trees were excluded from the analysis because the data were uncertain (lying well outside the normal distribution of the sample population) or missing altogether. The sycamore data set was eliminated when the majority of the trees was inadvertently trimmed in a normal operational cycle prior to data collection and trees at another location experienced an extreme drought. The live oak data set was excluded because the averages were well outside the normal distribution for the biomass weight and trim/chip time values, possibly because of different trimming practices and dissimilar untreated control trees for comparison.

Results and Discussion

Qualitative assessment. Basal soil drench and implant applicaton methods were much quicker than treatment by pressure injection and did not require special equipment or training. Pressure-injected trees showed a more immediate response than trees implanted or treated by basal soil drenches. However, the basal soil drench and the implant treatments elicited a less severe and more acceptable degree of regulation than pressure injection. The extreme suppression of leaf size, alteration of overall crown appearance, and intense leaf stacking due to suppression of internodal elongation that are characteristic of injection did not occur with the other two methods of application (Fig. 3). The early regulation stages of the basal soil drench and implant application systems appeared as a change in pigmentation patterns in the leaves with more intensification in the red and yellow pigments. A noticeable alteration in the leaf morphology followed. In year two, the leaf-stacking phenomenon was evident on the basal soil drench and trunk implant treated trees but never to the same degree as with pressure injection. Leaf size reduction was also less exaggerated than that resulting from pressure injection.

Characteristic weeping and fluxing was evident at injection holes on some of the pressure-injected trees. Field evaluation every year, for three years after application, indicated no weeping or seeping from implant holes on any species or at any site. Implant holes typically closed the same season of application. The destructive analysis of red maple and red oak trees in Maine showed maximum compartmentalization and minimum if any discoloration in the implanted trees regardless of species (Fig. 4). This evaluation indicates that the implant application has overcome the characteristic tree damage problems encountered with pressure injection investigated by previous researchers (1,12,13).

Several results were consistent across the study regardless of the application technique. It has been reported consistently in the literature that gibberellin biosynthesis inhibitors seem to cause an intensification in pigmentation in the leaves; and result in heavier bud, flower, and seed set. (8). The heavier seed set and pigment intensification were consistent throughout the study.

Flurprimidol appeared to be slow to translocate. In various years many trees across the study exhibited dual flushes of growth, with the first flush well regulated. However, the second flush exhibited a period of unregulated growth before sufficient concentrations of flurprimidol translocated to regulate growth. Even with this apparent lack of regulation noted in early internodal elongation, regrowth was still less than on unregulated trees.

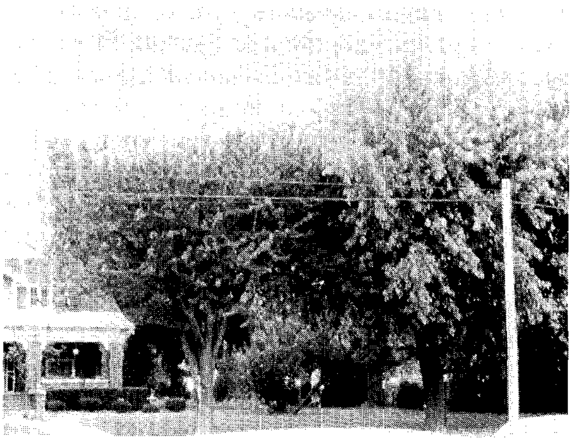

Figure 3. Typical response of alternative tree growth regulator technology two seasons after treatment. Tree on left was basal soil drenched; tree on the right was untreated check.

Quantitative assessment. Significant differences were found among treated versus untreated trees. However, differences were seldom significant among the different applications or among the different rates within each application technique. This trend held across the three measures of efficacy used in the study. There were no significant differences between the spring applications applied at one-half leaf expansion versus the applications at full leaf expansion (data not shown). There were significant differences found between the trees trimmed at or after the time of tree growth regulator treatment versus those trees that were trimmed 3 to 5 months prior to the treatment (data not shown). Trees trimmed several months prior to treatment with a tree growth regulator showed less regulation in general. This is possibly due to the reduced uptake and translocation resulting from less transpirational drag on the tree when treated.

Table 1 shows regrowth in inches and as a

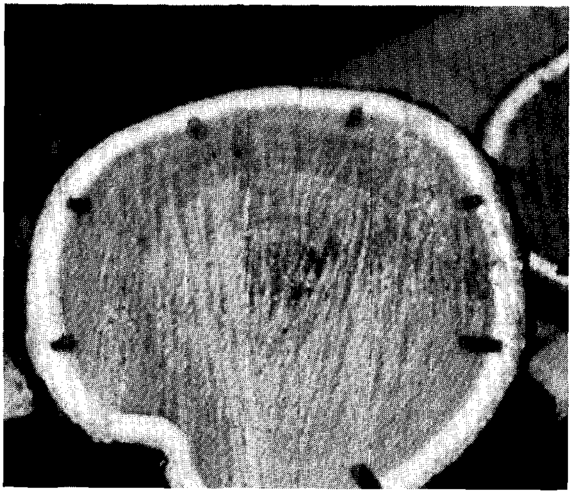

Figure 4. Cross-section of red oak shows the compartmentalization that occurs during wound closure. Photo is two seasons after treatment. Note the lack of tree damage and how well trees recover.

Table1. Regrowth, green biomass, and trim and chip time as compared to the untreated check.[1]

		Species and location							
Treatment	Dose [2]	Silver maple (Ohio)		Willow oak (Virginia)		Water oak (Virginia)		Norway maple (Pennsylvania)	
Regrowth and % of regrowth [3,6]									
Drench	0.5	86a	32	12a	32	20b	54	27b	36
	0.75	85a	31	10a	27	12b	32	16b	21
	1.0	72a	27	4a	11	4a	11	32b	43
Implant	0.5	66a	24	10a	27	37c	100	6a	8
	0.75	77a	28	30b	81	27b	73	26b	35
Control		271b	100	37b	100	377c	100	75c	100
Green biomass and % of green biomass [4,6]									
Drench	0.5	336a	38	33b	29	237b	32	25a	21
	0.75	402a	45	28b	25	484b	65	25a	21
	1.0	194a	22	27b	24	244b	33	23a	19
Implant	0.5	213a	24	8a	7	78a	10	25a	21
	0.75	274a	31	17b	15	55a	7	25a	21
Control		887b	100	112c	100	750c	100	119b	100
Trim and chip time and % of trim and chip time [5,6]									
Drench	0.5	67a	48	15b	75	100b	64	11a	39
	0.75	67a	48	13a	65	111b	71	10a	36
	1.0	36a	26	8a	40	83b	53	9a	32
Implant	0.5	56a	40	5a	25	50ab	32	10a	36
	0.75	58a	41	10a	50	28a	18	14a	50
Control		140b	100	20b	100	157c	100	28b	100

[1] Trees measured in August 1992, three growing seasons after treatment.
[2] Grams active per inch dbh.
[3] Regrowth in inches of the total of seven longest shoots measured and averaged.
[4] Pounds of biomass of each tree added together and averaged.
[5] Actual time to trim tree and chip brush in minutes (does not include dumping).
[6] Percent as compared to untreated control.
[7] Means in columns followed by the same letter are not significantly different at the 10% level using Tukey's pairwise comparisons.

percent of the untreated control of the seven longest shoots measured and averaged for all trees within a specific treatment. Among the three measurements evaluated, regrowth was the most variable, possibly because the shoots measured were those least regulated. This indicates that regrowth is not the best measure of tree growth regulator efficacy, and does not represent effect on the total crown. There were consistent significant differences between trees treated with flurprimidol and the untreated trees regardless of the application method or dose. There was not a consistent trend in differences among the applications or dose rates within applications. This lack of dose response for soil drench applications has been shown in previous research (17). Therefore after combining efficacy data, the average regrowth reduction as a percent of the untreated trees was

72% for silver maple, 64% for willow oak, 46% for water oak, and 71% for Norway maple.

Table 1 shows the average weight of the green chipped biomass removed in the trimming process in pounds and as a percent of the untreated control for trees within each treatment. The weight of the biomass removed showed the least variability among the different measures of efficacy, indicating that biomass removed is a good measure of tree growth regulator efficacy. There was always a significant difference between the treated trees and the untreated trees regardless of the application or the dose. There was not a significant trend across dose rates or among application techniques. The average reduction in weight of biomass removed across treatments and dose rates as a percent of the untreated trees was 68% for silver maple, 80% for willow oak, 71% for water oak, and 79% for Norway maple.

Table 1 shows the results of the trim and chip time analysis in minutes and as a percent of the untreated control trees. The variability existing with the trim/chip time measurement is due in a large part to the different trimming practices on the separate utilities. There was always a significant reduction in trim/chip time for treated trees regardless of treatment or the dose used. Again there was not a consistent trend across rates or among the different application methods. There was a close correlation between the biomass removed and the time it took to remove and chip it. The average reduction in trim/chip time for the treated trees across treatments and rates as a percent of the untreated trees was 59% for silver maple, 49% for willow oak, 52% for water oak, and 61% for Norway maple.

Summary and Conclusions

The trees in this study were fast-growing and acknowledged to be significant line-clearance problem species for each cooperating utility. Basal soil drench and tree implant application technologies were visually comparable in regrowth suppression to trunk pressure injection. Both of the alternative applications were less expressive in their visible degree of regulation and neither caused any detrimental long lasting effects on the tree trunk. Both appeared to take a longer time than pressure injection to show regulation in the tree crown. The alternative application methods took less time to apply and required a minimum amount of equipment and job skill training.

These alternative tree growth regulator technologies were effective in reducing growth. All treatment rates with either application technique, soil drench or implant, showed statistically significant reductions in growth and biomass production. The reduction in trim and chip time was directly related to these reductions in growth. This study shows that the best efficacy is obtained when applications are made while trees are actively growing and that trimming should be done at the time of treatment to several months after treatment.

In conclusion, flurprimidol applied as either a basal drench or solid implant was observed to be as effective during a three year period as trunk pressure injection, but without the negative side effects associated with injection. Tree growth regulators can be beneficial to a utility arborist for use on fast growing trees. They can be an important part of a cost-effective line clearance management program.

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Résumé. Deux applications du régulateur de croissance flurprimidol ont été comparées à des arbres non traités trois ans après le traitement. Les arbres—érable argenté en Ohio, chêne d'eau et chêne-saule en Virginie, chêne rouge et érable rouge au Maine, érable de Norvège en Pennsylvanie—ont été traités par injection liquide dans le sol avec des taux de 0.5 , 0.75 et 1.0 gramme d'ingrédient actif par pouce de diamètre à hauteur de poitrine (D.H.P.) et par application d'implants de 0.5 et 0.75 gramme d'ingrédient actif par pouce de D.H.P. en 1989. Les arbres ont été revisités trois ans après l'application et évalués quant à la réduction de croissance obtenue. La mesure de la longueur des sept plus longues pousses de chaque arbre a été prise de 1989 à 1992. Tous les arbres ont été élagués selon les normes des compagnies de services publics et la biomasse issue de la taille récoltée, pesée et déchiquetée. En général, pour l'ensemble des espèces (tous les sites réunis), la croissance a été réduite de 63%, la biomasse élaguée de 75% et le temps de déchiquetage de 55% par le régulateur de croissance.

Zusammenfassung. Zwei Anwendungen des Baumwachstumsregulators Fluorprimidol wurden drei Jahre nach dem Einsatz verglichen mit unbehandelten Bäumen. Silberahorn in Ohio, Wasser- und Weideneiche in Virginia, Roteiche und Rotahorn in Maine und Bergahorn in Pennsylvania wurden 1989 mit einer Applikation im Wurzelbereich von 0.5, 0.75 und 1.0 Gramm des aktiven Bestandteils (gram of active ingredient = gai) pro Zoll Durchmesser in Brusthöhe (dbh) und mit einer implantat-applikation von 0.5 und 0.75 gai/inch dbh behandelt. Von 1989 bis 1992 wurde die Länge der sieben längsten Triebe von jedem Baum gemessen. Alle Bäume wurden nach den Richtlinien der Nutzungsgesellschaft zurückgeschnitten und die entfernte grüne Biomasse wurde gewogen und zerkleinert. Generell kann man für alle vier Arten auf allen Standorten sagen, daß das Wachstum um 63%, die grüne Biomasse um 75% und die benötigte zeit zum Verkleinern um 55% durch den Wachstumsregulator reduziert wurde.