TREE GROWTH REGULATOR EFFECT ON PHOTOTROPISM—ITS IMPLICATION FOR UTILITY FORESTRY

by Chad E. Sperry[1] and William R. Chaney[2]

Abstract. Pruning procedures such as V-trimming or side-trimming used by electric utilities in tree maintenance programs result in asymmetrical light exposure within tree canopies, producing the potential for phototropic growth response. The tree growth regulators (TGRs) paclobutrazol and flurprimidol are used to reduce the rate of shoot regrowth following pruning. The mode of action involves complexing of the growth retardant with cytochrome P_{450}-dependent enzymes in the metabolic pathway for gibberellins, plant hormones responsible for shoot elongation. Because cytochrome P_{450} also is a part of the blue light receptor system that controls phototropism, it was hypothesized that shoot growth, as well as phototropic curvature, would be reduced by paclobutrazol and flurprimidol. Effects of soil-applied (0, 0.5, 1, and 5 ppm) paclobutrazol and flurprimidol on shoot growth and phototropism of greenhouse-grown seedlings were found to vary among species. Neither shoot growth nor phototropic curvature in American sycamore (*Platanus occidentalis* L.) was reduced by treatment with the TGRs. In contrast, shoot growth of silver maple (*Acer saccharinum* L.) was reduced by all concentrations of both paclobutrazol and flurprimidol, whereas phototropic curvature was reduced only by flurprimidol. Phototropic curvature of etiolated zinnia (*Zinnia elegans* 'Scarlet' Jacq.) was reduced by both growth regulators.

Key Words. Tree growth regulator; paclobutrazol; flurprimidol; phototropism; utility forestry.

The tree growth regulators (TGRs) paclobutrazol and flurprimidol have a variety of benefits in utility line-clearance operations (Chaney et al. 1996). The most obvious response in trees is reduced shoot growth and, consequently, extended trim cycles (Redding et al. 1994; Mann et al. 1995). Reduction of the rate of shoot regrowth after pruning in TGR-treated trees is due to the inhibition of gibberellin biosynthesis. Gibberellins affect several physiological functions in plants but are principally responsible for the control of cell elongation and the growth in length of new shoots. TGRs act by inhibiting 3 steps in the metabolic pathway leading to gibberellins, all of which are catalyzed by cytochrome P_{450}-dependent enzymatic reactions (Rademacher 1991). The TGRs are thought to attach to the central iron atom of cytochrome P_{450}, making it inactive (Sugavanam 1984; Lürssen 1988). Cytochrome P_{450} also plays a direct role in phototropism as a part of the blue light receptor system (Galland and Senger 1988; Salisbury and Ross 1992). Hence, TGRs not only disrupt the production of gibberellin, thereby reducing growth, but they also appear to alter the photoreceptor system that controls phototropic response in plants. Paclobutrazol and ancymidol, a pyrimidine growth retardant similar to flurprimidol, have been shown to inhibit phototropism in mung bean (Konjević et al. 1989).

The inner branches in the canopies of trees that are side-trimmed or V-trimmed for utility line clearance are exposed to increased light intensity (Miller 1998). This asymmetrical exposure to light within the crown increases the likelihood of phototropic curvature and enhanced regrowth of shoots toward the power lines centered in the light-rich environment created by pruning. A study was designed to investigate the hypothesis that phototropic curvature of new shoot growth toward increased light intensities in the canopy of pruned trees will be reduced in trees treated with tree growth regulators.

MATERIALS AND METHODS

Phototropic response of American sycamore (*Platanus occidentalis* L.), silver maple (*Acer saccharinum* L.), and zinnia (*Zinnia elegans* 'Scarlet' Jacq.) were investigated. Sycamore and silver maple were grown in a greenhouse from seeds for 2.5 and 2 months, respectively. The seedlings were grown in plastic pots containing a 4:1 (v/v) mix of loamy soil/peat moss rooting medium, watered daily, and fertilized weekly with Miracle-Gro®. Paclobutrazol and flurprimidol were then applied to the soil surface so

that 10 plants each received 0.5, 1, or 5 ppm determined on the basis of dry soil weight. Twenty plants of each species were not treated to serve as controls.

Two weeks after TGR treatment, the sycamore seedlings were exposed for 1 week to a unilateral light environment consisting of a bank of 40-watt incandescent bulbs (2.0 microeinsteins/m^2/sec) in a dark room. The silver maple seedlings were introduced to the unilateral light environment 3 weeks after treatment and were observed for 10 days until measurements of curvature were recorded. Stem curvature was measured using a shadowgraph technique (Konjević et al. 1989). Each seedling was placed between an intense light source and a sheet of graph paper. The deflection from the vertical of the projected shadow of each stem was measured in degrees.

Zinnia seeds were germinated in 50-mL test tubes containing 0, 0.5, 1, or 5 ppm of either paclobutrazol or flurprimidol in water. The germinants were grown for 2 days in a growth chamber in the dark to produce etiolated seedlings. After 2 days, and before the emergence of true leaves, the etiolated seedlings were introduced to the same unilateral light environment described above. Shoot curvature was measured using the shadowgraph technique. The zinnia served as a means of standardizing the experiment because most phototropic research is done with etiolated seedlings.

Data were analyzed by analysis of variance, and difference between means was determined using the Bonferroni multiple comparison procedure at the 0.05 level.

RESULTS

The curvature of etiolated zinnia seedlings was reduced by both growth regulators (Figure 1), whereas height growth was not affected (data not shown).

Phototropic curvature in sycamore was not significantly influenced by paclobutrazol or flurprimidol at the 0.5 confidence level (Figure 2). Height growth was stimulated by 0.5 and 1 ppm paclobutrazol and by 0.5 ppm flurprimidol, whereas 5 ppm of both TGRs had no effect (Figure 3).

Shoot curvature in silver maple was suppressed at all concentrations of flurprimidol (Figure 4). In contrast, paclobutrazol had no effect on shoot curvature at the 0.05 confidence level regardless of its concentration. However, inhibition of shoot curvature was statistically significant when analyzed at the 0.1 confidence level. Silver maple height growth was suppressed by all concentrations of both compounds (Figure 5).

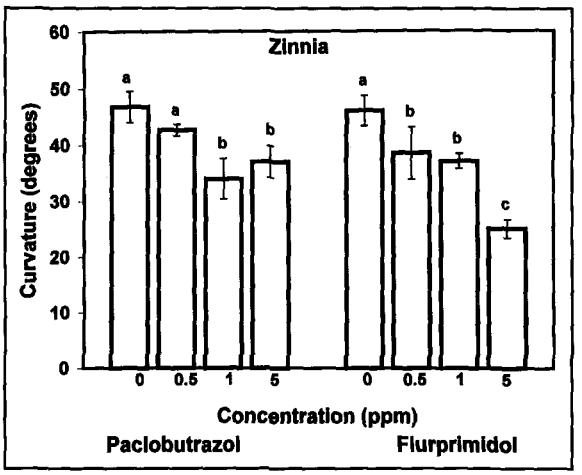

Figure 1. Influence of paclobutrazol and flurprimidol on phototropic curvature in etiolated zinnia.

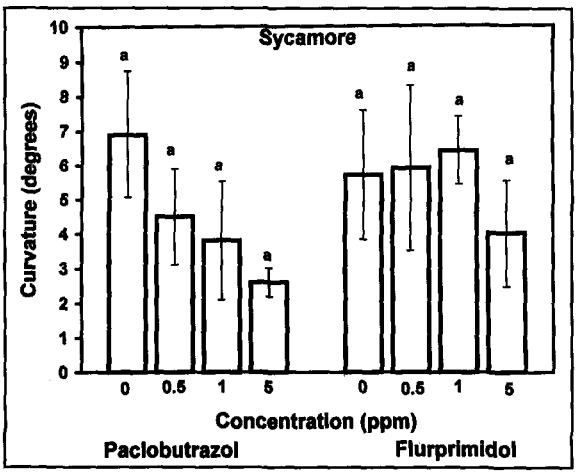

Figure 2. Effect of paclobutrazol and flurprimidol on phototropic curvature of 2.5–month-old sycamore seedlings.

DISCUSSION

Although the exact receptor involved in phototropic response is not well understood, the inhibition of curvature due to growth regulators seems to implicate cytochrome P_{450} because it is known to be affected by growth regulators and is thought to be involved with phototropism as part of the blue light receptor associ-

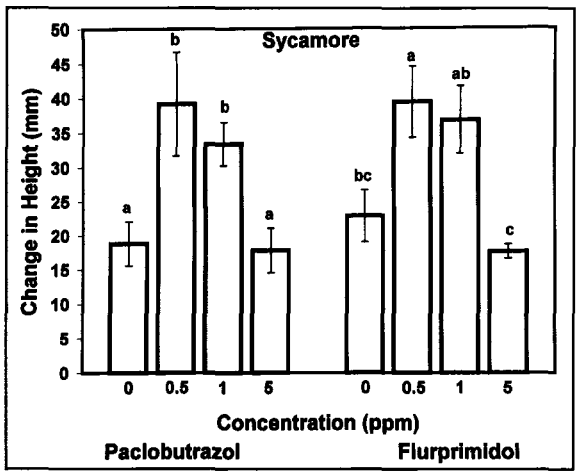

Figure 3. Effect of paclobutrazol and flurprimidol on shoot growth of sycamore seedlings.

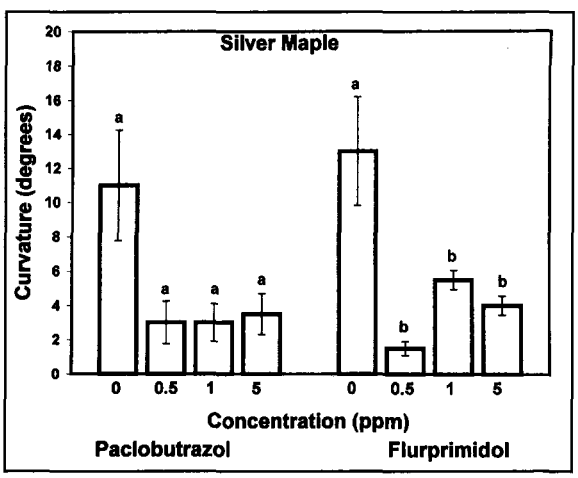

Figure 4. Effect of paclobutrazol and flurprimidol on phototropic curvature of 2-month-old silver maple seedlings.

ated with plasma membranes (Widell et al. 1983). The short time between growth regulator treatment and inhibition of shoot curvature in zinnia (2 days) suggests that the response was not a result of gibberellin biosynthesis inhibition, but rather a specific effect on a photoreceptor, presumably cytochrome P_{450} (Konjević et al. 1989). Additional support for this hypothesis is the evidence presented by Coolbaugh et al. (1978) , who showed a direct effect of ancymidol, a growth retardant similar to flurprimidol, on cytochrome P_{450} in the microsomal fraction of immature seeds of *Marah macrocarpus*.

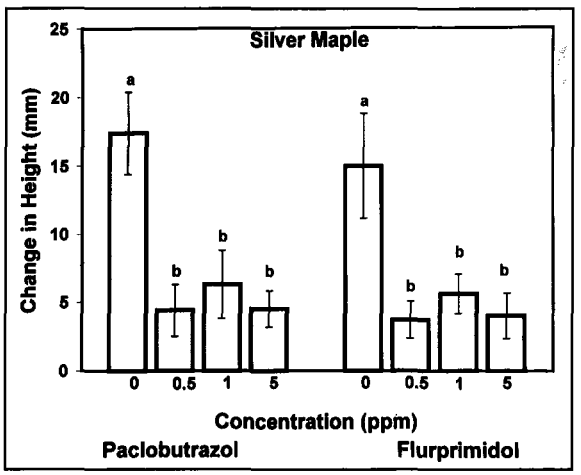

Figure 5. Effect of paclobutrazol and flurprimidol on shoot growth of silver maple seedlings.

The reduced phototropic curvature in silver maple treated with flurprimidol demonstrates a potential added benefit of the TGR in utility line-maintenance operations. At least for some tree species, the combination of reduced rates of regrowth and reduced phototropic responsiveness to unilateral lighting will increase the time required for branches to grow back into electrical conductors following trimming.

The stimulation of growth in sycamore at 0.5 and 1 ppm paclobutrazol and 0.5 ppm flurprimidol was unexpected (Figure 3). However, stimulation of growth by TGRs in zinnia and some stone fruit trees (Blanco 1987, 1988; Premachandra et al. 1996) and enhanced electron transport in isolated mitochondria exposed to low concentrations of paclobutrazol and flurprimidol (Barr et al. 1996) has been reported. The mechanism of stimulation is unknown, but it may relate to increased development of fine roots as shown in some woody species treated with paclobutrazol (Atkinson and Crisp 1983; Yelenosky 1993; Arnold and Davis 1994; Watson 1996) or enhanced release of metabolic energy for growth (Barr et al. 1996). Unpublished data from field observations and TGR label recommendations indicate that American sycamore should be treated with about one-third higher concentrations than silver maple to effectively reduce shoot growth. Additional studies should be conducted at higher concentrations of both paclobutrazol and flurprimidol on sycamore and with paclobutrazol on silver maple to determine

if the trend for TGR reduction in phototropic curvature found in this study is consistent and statistically significant.

Results of this study with seedlings indicate that TGR application may have the duel effect, in silver maple at least, of reducing both the rate of shoot regrowth and the curvature of the new shoots toward the light-rich openings created by pruning for utility line clearance.

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[1]Graduate Research Assistant and [2]Professor
Department Forestry and Natural Resources
Purdue University
West Lafayette, IN 47907

Résumé. Les procédures d'élagage qui sont utilisées par les entreprises de services électriques dans leur programme d'entretien, tels le dégagement en «V» ou latéral, donne une exposition asymétrique de la lumière à l'intérieur de la cime, créant ainsi une situation potentielle de réponse phototropique de croissance. Les régulateurs de croissance que sont le paclobutrazol et le flurprimidol sont employés pour réduire le taux d'élongation de la nouvelle pousse suite à l'élagage. Le mode d'action implique un ensemble complexe de retardateurs de croissance avec des enzymes cytochrome P_{450} dépendants qui influent sur le processus métabolique de la gibbérelline, une hormone végétale responsable de l'élongation de la pousse. Étant donné que le cytochrome P_{450} est aussi un composant du système de réception de la lumière bleutée qui permet le contrôle du phototropisme, on a posé comme hypothèse que la croissance de la pousse, tout comme celle de la courbure phototropique, seraient réduites par le paclobutrazol et le flurprimidol. Les effets d'une application sur le sol (0, 0,5, 1 et 5 ppm) de paclobutrazol et de flurprimidol sur la croissance des pousses et le phototropisme de semis cultivés en serre ont été étudiés sur plusieurs espèces. Ni la croissance de la pousse ni la courbure phototropique n'ont été réduits par l'action des régulateurs de croissance dans le cas du platane (*Platanus occidentalis*). À l'opposé, la croissance des pousses de l'érable argenté (*Acer saccharinum*) a été diminuée à toutes les concentrations de paclobutrazol et de flurprimidol, alors que la courbure phototropique ne l'a été que par le flurprimidol. La courbure phototropique d'un zinnia (*Zinnia elegans* 'Scarlet' Jacq.) a été diminuée par les deux régulateurs de croissance.

Zusammenfassung. Bestimmte Rückschnittformen, wie V-förmiger Rückschnitt oder seitlicher Rückschnitt, die von den Elektrizitätswerken in der Pflege und Unterhaltung angewendet werden, führen zu asymmetrischem Lichteinfall in die Baumkronen, was wiederum das Potential für phototropisches Wachstum erhöht. Die Wachstumsregulatoren (TGRs) Paclobutrazol und Fluorprimidol werden angewendet, um die Rate des Durchwachsens von Trieben nach dem Schneiden zu reduzieren. Die Durchführung beinhaltet eine Zusammenführung der Wachstumsverzögerer mit einem Zytochrom P_{450}-abhängigen Enzym in dem Metabolismus der Gibberelline, jener Wachstumshormone, die für das Längenwachstum der Triebe verantwortlich sind. Weil Zytochrom P_{450} auch ein Teil des Rezeptorsystems für das Blaulicht ist, welches den Phototropimus kontrolliert, wurde die Hypothese formuliert, daß das Triebwachstum ebenso wie die Phototropismuskurve durch Paclobutrazol und Fluorprimidol reduziert werden. Die Auswirkungen von bodenappliziertem (0, 0.5, 1, und 5 ppm) Paclobutrazol und Fluorprimidol auf das Triebwachstum und den Phototropismus von Gewächshauspflanzen variieren zwischen den Pflanzen. Weder das Triebwachstum noch die Phototropismuskurve bei Amerikanischen Platanen (*Platanus occidentalis* L.) wurde durch die Behandlung mit den Wachstumsregulatoren beeinträchtigt. In Kontrast dazu wurde das Triebwachstum bei Silberahorn (*Acer saccharinum* L.) durch alle Konzentrationen von Paclobutrazol und Fluorprimidol reduziert, während die Phototropismuskurve nur durch Fluorprimidol reduziert wurde. Die Phototropismuskurve von der Zinnie (*Zinnia elegans* 'Scarlet' Jacq.) wurde durch beide Wachstumsregulatoren reduziert.

Resumen. Los procedimientos de poda tales como los recortes en V o los laterales usados en los programas de mantenimiento de líneas eléctricas, provocan la exposición asimétrica dentro de la copa del árbol, produciendo el potencial para la respuesta de un crecimiento fototrópico. Los reguladores de crecimiento (TGRs, por sus siglas en inglés) paclobutrazol y flurprimidol se usan para reducir la velocidad de crecimiento de los nuevos brotes después de la poda. El modo de acción implica la complejidad de retardantes del crecimiento, con el citocromo P_{450} dependiente de enzimas en la vía metabólica de las giberelinas, hormonas responsables de la elongación de los brotes. Debido a que el citocromo P_{450} también es parte del sistema receptor de luz azul que controla el fototropismo, se planteó la hipótesis que el crecimiento de los brotes, como también la curvatura fototrópica, serían reducidos por paclobutrazol y flurprimidol. Se encontró que los efectos de paclobutrazol y flurprimidol aplicados al suelo (0.05, 1 y 5 ppm), sobre el crecimiento de los brotes y el fototropismo de brinzales de invernadero, varían entre las distintas especies. Ni el crecimiento de los brotes ni la curvatura fototrópica en sicomoro americano (*Platanus occidentalis* L.) fueron reducidos por los tratamientos con los TGRs. En contraste, el crecimiento de los brotes de arce plateado (*Acer saccharinum* L.) fue reducido para todas las concentraciones de paclobutrazol y flurprimidol, mientras que la curvatura fototrópica fue reducida solamente por flurprimidol. La curvatura fototrópica de zinnia etiolada (*Zinnia elegans* 'Scarlet' Jacq.) fue reducida por los dos reguladores de crecimiento.