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Effects of Mulch Made From Flurprimidol Treated Zinnia, Silver Maple, and White Ash on Growth of Zinnia[1]

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Abstract

Potential for carryover of flurprimidol in mulch derived from landscape plants and trees treated with this tree growth regulator and its effects on plants were investigated. Flurprimidol (Cutless®) was applied as a soil drench to the growing medium of greenhouse grown zinnia (*Zinnia elegans* Jacq. 'Scarlet') at six concentrations ranging from 0.0016 to 5 mg/kg (0.00000003 to 0.0001 oz/lb) and as solid tree implants (0.2 g a.i./cm diameter) (0.018 oz/in) to plantation grown silver maple (*Acer saccharinum* L.) and white ash (*Fraxinus americana* L). Shoots of zinnia were collected three weeks after treatment with flurprimidol and the leaves and one-year-old twigs of the two tree species were collected 1, 6, and 18 months after treatment. Tissues were ground into small particles and either mixed with the growing medium or applied to the surface of pots containing zinnia. Low concentrations of flurprimidol (0.0016 to 0.04 mg/kg soil) (0.00000003 to 0.0000006 oz/lb) stimulated the growth of zinnia, whereas higher concentrations (0.2 to 5 mg/kg) (0.000003 to 0.0001 oz/lb) reduced growth when applied either directly to the growing medium or as residue in mulch derived from treated plants. Mulch made from leaf or twig tissues of silver maple 6 and 18 months after treatment with trunk implants and of white ash 18 months after treatment reduced growth of zinnia.

Index words: flurprimidol, growth retardant, pesticide carryover, plant growth regulator.

Chemicals used in this study: Cutless Tree Implants (flurprimidol), [(1-(1-methylethyl)-1-(4-trifluoromethoxy) phenyl)-5-pyrimidine-methanol].

Species used in this study: silver maple (*Acer saccharinum* L.), white ash (*Fraxinus americana* L.), zinnia (*Zinnia elegans* Jacq. 'Scarlet').

Significance to the Nursery Industry

Flurprimidol (Cutless®) and other plant growth regulators are used to suppress shoot growth of landscape crops, turf grasses, and urban trees. The leaf residues and chipped wood wastes from treated plants and trees are used in home gardens and landscape situations as green manure and mulch. This study demonstrated the potential for carryover of flurprimidol at biologically active concentrations in leaves and twigs of zinnia, silver maple, and white ash when these plant residues were used as a green manure or surface mulch. Plant residues that did not contain flurprimidol also reduced growth of zinnia when applied either as a surface mulch or growing medium amendment. However, the worst case scenario was created since the plant residues were finely ground to facilitate flurprimidol and soluble extractive availability to plant roots. The larger sized plant residues and wood chips normally used as mulch or soil amendments with landscape plants should not cause any problems.

Introduction

Pesticide carryover in plant litter and soil has been shown to affect the growth of subsequently planted crops so frequently that agricultural systems involving crop rotation and herbicide usage have evolved to minimize the problem (13, 19). Fungicides applied to the foliage of wheat (*Triticum aestivum* L.) were found to accumulate in the developing seeds and to reduce their germination (10). Although lindane and chlorpyrifos applied to trees to control bark beetles accumulated in the wood and were released in smoke when the wood was burned, the amount that survived the temperatures of combustion was not considered a health hazard (3). Even second-generation exposure to rodenticides by predators, such as polecats, owls, foxes and weasels that feed on mice and rats, has been demonstrated (15).

Over 11 million cubic yards of wood chips are produced every year by tree trimming operations in urban areas (20). Because of solid waste reduction goals and recently enacted bans on landfill disposal of yard and wood wastes throughout most of the United States, about 42% of chipped wood waste is now given to homeowners and local government agencies to be used as landscape mulch (17). Steadily increasing numbers of trees growing under electric distribution wires are treated with plant growth regulators (PGRs) to reduce shoot growth following pruning for line clearance. The branches and shoots removed from the crowns of treated trees could contain a PGR because the compounds must be transported to the shoot tips to be effective. The potential for plants in landscape situations to be exposed to mulch from PGR treated trees is increasing. The effects of PGR residue on plants to which mulch derived from PGR treated trees was applied was investigated in this study.

Materials and Methods

Growth responses of zinnia to flurprimidol. Zinnia (*Zinnia elegans* Jacq. 'Scarlet') seeds were sown in vermiculite. Seedlings were transplanted 10 days later into 15 cm (6 in) diameter pots (1 seedling per pot) containing a 2:2:1 (by vol) mixture of perlite, peat moss and top soil. Each cubic meter of mix was amended with 680 g (24 oz) $Ca(H_2PO_4)_2$, 454 g (16 oz) KNO_3, 454 g (16 oz) $MgSO_4$, 3.6 kg (7.9 lb) ground limestone and 57 g (2 oz) Peter Frit Industries trace element No. 555.

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Seven days after transplanting, flurprimidol was dissolved in isopropyl alcohol and applied to the soil surface of each pot (after diluting in 300 ml of water) to give concentrations of 0.0016, 0.008, 0.04, 0.2, 1.0 or 5.0 mg/kg (0.00000003, 0.00000015, 0.000006, 0.000003, 0.00002 or 0.0001 oz/lb) (weight a.i./weight of soil mixture). An untreated control and an isopropyl alcohol only treatment also were included. There were five replications of each treatment.

Seedlings were grown in a randomized complete block design on benches in a greenhouse at Purdue University, West Lafayette, IN, in May under ca. 28C (82F) daytime maximum and 23C (73F) nighttime minimum temperatures. Pots were irrigated daily. One-half liter (17 oz) of Hoagland's solution was applied to each pot every week as an additional nutrient supply (7). Axillary buds were removed continuously to prevent branching. Plant height and leaf length and width were measured at weekly intervals for three weeks beginning seven days after flurprimidol application. Leaf area was determined using a regression equation with the independent variables leaf length and width.

Experiment 1—Effect of mulch made from flurprimidol treated zinnia on growth of zinnia. Incorporation into soil mixture of shoot tissue from plants grown for 43 days with flurprimidol. Zinnia plants from the previous experiment, which were grown for 43 days with different concentrations of flurprimidol applied to the potting mixture, were harvested at the flowering stage. The above-ground portion of the plants was freeze-dried at –50C (–58F) and ground in a Wiley mill with a 20 mesh screen. Flurprimidol in the tissues was determined using the analytical procedure described below. Ten g (0.4 oz) of ground zinnia tissue were mixed with the potting medium (same mixture as used in the previous experiment) in 15 cm (6 in) diameter pots. An untreated mulch control (no flurprimidol) and a no-mulch control (only potting mixture) also were included. Seven-day-old zinnia seedlings, ca. 25 cm (9.8 in) tall, were transplanted into the pots (1 seedling per pot). There were five replications of each treatment. The seedlings were grown in a randomized complete block design on greenhouse benches with growing conditions as described in the previous experiment.

Experiment 2—Incorporation into soil mixture or surface application of mulch from plants grown for 31 days with flurprimidol. Mulch was made from flurprimidol treated (0, 0.0016, 0.008, 0.04, 0.2, 1.0 and 5.0 mg/kg) (0.00000003, 0.00000015, 0.000006, 0.000003, 0.00002 or 0.0001 oz/lb) zinnia plants as described in the previous experiment except that they were harvested 38 days after transplanting and 31 days after treatment. Ten g (0.4 oz) of ground zinnia tissue for each of the concentration treatments were mixed with the potting medium in 15 cm (6 in) diameter pots for the soil incorporation treatments. Pots were filled with only potting medium for the surface-mulch treatments. Seven-day-old zinnia seedlings were transplanted into the pots (1 seedling per pot). Ten g (0.4 oz) of mulch were uniformly spread on the surface of the pots for the surface-mulch treatments 10 days after transplanting. An untreated-mulch control and a no-mulch control also were included. There were five replications of each treatment. The seedlings were grown in a greenhouse in a randomized complete block design with growing conditions as described in the previous experiments. Plant height was measured at weekly intervals beginning 10 days after transplanting.

Effect of mulch made from flurprimidol treated silver maple and white ash trees on growth of zinnia. Silver maple (*Acer saccharinum* L.) (12–20 cm (4.6–7.7 in) dbh) and white ash (*Fraxinus americana* L.) (17–26 cm (6.6–10.4 in) dbh) were treated with solid flurprimidol implants (Cutless® Tree Implants, DowElanco, Indianapolis, IN) in early spring using manufacturer recommended procedures and rates (0.2 g a.i./cm (0.018 oz/in) dbh). All trees were drilled with a 1-cm (0.38 in) diameter brad point bit and a 1 g (0.04 oz) a.i. tablet was inserted into the holes of treated trees. Control trees were drilled only. The diameter range of the silver maples resulted in 3 or 4 implant holes per tree, whereas white ash required 3, 4, or 5 holes. The trees were growing in plantations at the Eli Lilly Research Laboratory and the DowElanco Farm in Greenfield, IN. Eight trees of each species (5 treated and 3 untreated controls), stratified so that each harvest would have an equal number of trees of the same size and number of treatment holes, were cut 1, 6, and 18 months after treatment. Leaves and twigs with buds were collected separately, freeze-dried and ground to pass a 6 mm mesh screen. Mulch made from twigs was mixed with the potting medium at a ratio of 1:3 (by vol) and mulch made from leaves was mixed at a ratio of 1:2. Eight-day-old zinnia seedlings were transplanted into the pots (1 seedling per pot). An untreated-mulch control of leaves or twigs and a no-mulch control also were included. Each treatment was replicated five times. The seedlings were grown in a greenhouse in a randomized complete block design with growing conditions as described in the previous experiments. Plant height was measured at weekly intervals for five or six weeks beginning 17 days after transplanting. Total leaf area was calculated and shoot and root dry weights were measured at the end of the experiment.

Samples of the potting mixture were collected using a cork-borer at the time of transplanting and at two week intervals thereafter from untreated-mulch control and no-mulch control pots of white ash to evaluate changes in pH. Four g (0.1 oz) of the air dried potting media samples were mixed with 12 ml (0.4 oz) of deionized water and shaken for 30 min before pH was measured.

Analysis of flurprimidol in mulch made from flurprimidol treated zinnia, silver maple and white ash. Tissues were shaken in 80% methanol for one hour and the extract filtered into an evaporation flask. Methanol was removed at 38–40C (100–104F). The remaining water fraction was partitioned in dichloromethane (DCM) and the DCM layer was removed and evaporated to dryness. The residue was dissolved in DCM and poured onto a Florisil column. The column was washed with 5 ml (0.2 oz) of anhydrous ether and hexane (1:1 by vol). Flurprimidol was eluted with a 5 ml (0.2 oz) mixture of anhydrous ether and methanol (97:3 by vol) and evaporated to dryness under a clean, dry air stream. Samples were further purified using C18 columns, washed with 20 ml (0.7 oz) of 40% methanol, and the flurprimidol eluted from the column with 10 ml (0.3 oz) of 60% methanol. The eluent was evaporated to dryness and the residue dissolved in 50 ml methanol. Four ml of the final sample were injected to a Hewlett Packard GC 5890A with a HP mass selective detector 5970 and a HP 7673A autosampler (Hewlett Packard, Wilmington, DE). A DB-17 fused silica capillary column (30m × 0.32 mm; J & W Scientific, Folson, CA) with helium as the carrier gas was used. Carrier gas flow rate was 32 ml/min. The temperature for chromatography was 250C (482F)

for both injector and detector. The initial column temperature was 170C (338F) for 1 min followed by a 3C (37F)/min increase to a final temperature of 230C (446F) with a 5-min hold time. Electron ionization was at 70 eV with a scan range of m/e 40–320. Under these conditions, flurprimidol retention time was 10.5 min.

Flurprimidol concentrations in the samples were quantified using standard solutions. Recovery rate of flurprimidol in the extraction and purification procedure was estimated to be 80% using untreated mulch samples spiked with known concentrations of flurprimidol. This correction factor was used to adjust the data presented.

Data for all the experiments were analyzed using analysis of variance (ANOVA) and differences among means determined at the 0.05 level using Duncan's multiple range test.

Results and Discussion

Growth responses of zinnia to flurprimidol. Height growth of zinnia was reduced by isopropyl alcohol (IPA) in water at the concentration used (3.3 ml/liter) (0.5 oz/gal) as the solvent for flurprimidol (Fig. 1). Height growth was significantly greater for plants grown with the lower concentrations of flurprimidol (0.0016, 0.008 and 0.04 mg/kg soil mass) (0.00000003, 0.00000015, and 0.000006 oz/lb soil mass) compared to the IPA treatment and was similar to that of the untreated control. Growth stimulation at these lower concentrations of flurprimidol was sufficient to negate the growth inhibition caused by IPA alone. Height growth was reduced by higher concentrations of flurprimidol (0.2, 1, and 5 mg/kg) (0.000003, 0.00002 and 0.0001 oz/lb). The height of zinnia treated with 5 mg/kg (0.0001 oz/lb) was 53% less than the height of untreated control plants. Total leaf area of zinnia had the same relationship to flurprimidol concentrations as height growth of the plants (data not shown). Leaf area was reduced by concentrations of flurprimidol greater than 0.2 mg/kg (0.000003 oz/lb), but it too was stimulated by treatment with 0.0016, 0.008 and 0.04 mg/kg (0.00000003, 0.00000015 and 0.000006 oz/lb) flurprimidol.

These results show that low concentrations of flurprimidol stimulate growth of zinnia, substantiating similar results we previously reported for zinnia (12). No other evidence of growth stimulation has been reported before with the exception of an incidental observation made by Arnold and Davis (1) that 800 mg/liter (0.13 oz/gal) paclobutrazol applied to the foliage of Chinese chestnut (*Castanea mollissima* Blume) increased internode elongation. In addition, paclobutrazol at rates up to 16 mg (0.0006 oz) a.i./20 cm (7.9 in) pot applied as a soil drench to golden pothos [*Epipremnum aureum* (Linden & André) Bunt.] almost doubled leaf size (4). The growth inhibition observed with flurprimidol, however, has been reported for several ornamental and orchard trees, woody shrubs, and floriculture crops (2, 5, 8, 9, 11, 16, 18, 21).

Experiment 1—Effect of mulch made from flurprimidol treated zinnia on growth of zinnia. Incorporation into soil mixture of mulch from plants grown for 43 days with flurprimidol. Plant height of the mulch control (no flurprimidol) was less than the no-mulch control indicating that mulch treatment itself had a growth inhibiting effect (Fig. 2). Addition of mulch may have caused a nutritional imbalance due to a change in the carbon-nitrogen ratio in the potting mixture. For agricultural crops, it is recommended that chemical nitrogen be added in an amount equal to 1.2% of the weight of the mulching material (14). In accordance with this recommendation, 0.12 g (0.004 oz) of nitrogen should have been added to each pot to prevent nitrogen deficiency due to bacterial decomposition, since 10 g (0.4 oz) of mulch was incorporated into each pot. Adequate nitrogen should have been available, however, because 0.5 liter (17 oz) of Hoagland's solution was added each week for seven weeks, resulting in 0.73 g (0.03 oz) of nitrogen per pot. Nevertheless, the weekly additions of small amounts of nitrogen to a potting mixture already high in organic matter may still have allowed a carbon-nitrogen imbalance to exist.

Toxic substances in the mulch may also have been a problem. Bark, wood, and foliage of some plants contain substances toxic to other plants, particularly young ones. A mulch containing toxins is more likely to cause problems if the mulch particles are small, as in sawdust. Any toxic effects are further accentuated if a high proportion of the roots are in the surface soil and in close contact with the fine mulch (6). Both finely ground and soil incorporation of the mulch in this study increased the potential for effects of any toxins in the mulch.

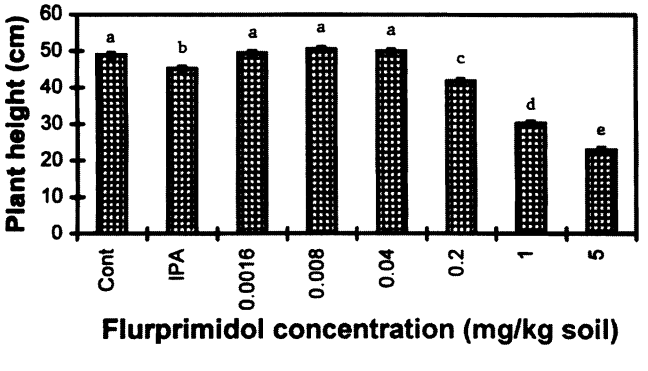

Fig. 1. Effects of different concentrations of flurprimidol on height of zinnia 21 days after flurprimidol application (Cont., untreated control; IPA, isopropyl alcohol control). Flurprimidol was dissolved in IPA, diluted with water and applied to the soil surface seven days after transplanting. Values with the same letter are not significantly different according to Duncan's multiple range test, p = 0.05.

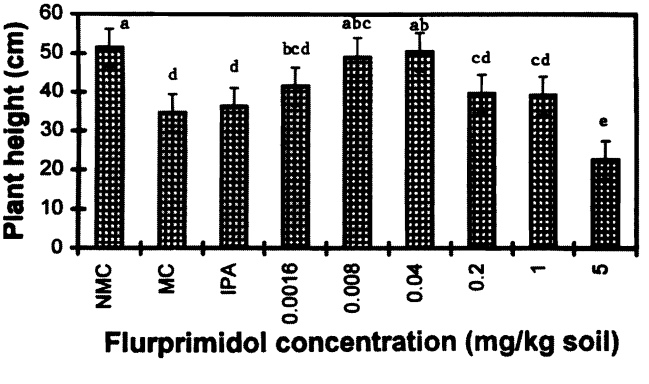

Fig. 2. Effects of mulch made from flurprimidol treated zinnia on height of zinnia seven weeks after transplanting (NMC, no-mulch control; MC, mulch control; IPA, isopropyl alcohol control). Ten g of ground zinnia tissue was mixed with the potting medium before transplanting. Values with the same letter are not significantly different according to Duncan's multiple range test, p = 0.05.

Table 1. **Flurprimidol in mulch and whole plants of zinnia grown with various concentrations of flurprimidol for 43 days.**

Flurprimidol treatment (mg/kg soil)	Flurprimidol concentration		Total recovered[y] (%)
	In mulch (ng/g dry wt)	In whole plant[z] (µg/plant)	
5	4070a[x]	33.2a	0.5
1	3778a	34.3a	2.3
0.2	2894b	29.4b	9.8
0.04	592c	6.7c	11.1
0.008	257c	3.1cd	25.4
0.0016	162c	1.9d	80.2
0	0d	0e	0

[z]Quantity in whole plant was calculated using combined shoot and root dry weights.

[y]Total recovered was calculated as the amount of flurprimidol found in the whole plant as a percentage of the amount applied to the soil.

[x]Values followed with the same letter are not significantly different according to Duncan's multiple range test, p = 0.05.

Height growth of plants treated with mulch from IPA grown zinnia did not differ significantly from mulch control plants. Mulch made with 0.008 and 0.04 mg/kg (0.00000015 and 0.000006 oz/lb) flurprimidol treated zinnia showed a stimulation in growth compared to mulch control plants. Mulch from plants treated with the highest concentration of flurprimidol (5 mg/kg) (0.0001 oz/lb) inhibited height growth. The growth stimulation and growth inhibition by mulch made of zinnia treated with lower and higher concentrations of flurprimidol, respectively, illustrate a response similar to that observed in the previous experiment with direct application of flurprimidol to the potting mixture. The results suggest that flurprimidol absorbed by zinnia was accumulated in plant tissues in its biologically active form.

There was a progressive increase in the concentration of flurprimidol in the mulch, ranging from 0 to 4,070 ng/g, that was positively correlated with the amount of flurprimidol applied to the soil medium in which the plants used to make the mulch were grown (Table 1). A similar trend also occurred when flurprimidol was expressed as the absolute quantity per plant. The amount of flurprimidol (µg/plant) was determined by multiplying the combined shoot and root dry weight by the concentration of flurprimidol (ng/g) in the mulch determined by GC-MS analyses. The amount of flurprimidol absorbed by the plants expressed as a percentage of that applied to the soil was greater at lower concentrations compared to higher concentrations (Table 1). For example, 80.2% of the flurprimidol applied to the soil was absorbed by the plants treated with 0.0016 mg/kg (0.00000003 oz/lb), whereas only 0.5% was absorbed at the 5 mg/kg (0.0001 oz/lb) treatment rate. Although the percentage absorbed was lower at the higher treatment rates, it is important to note that the total amount of flurprimidol absorbed tended to be greater at the higher treatment rates.

The amount of flurprimidol added to each pot mulched with ground tissue from zinnia treated directly with 5 mg/kg (0.0001 oz/lb) flurprimidol, the only treatment that had an inhibitory carryover effect (Fig. 2), was equivalent to an application of 0.08 mg (0.000012 oz) flurprimidol/kg (lb) growing medium. This concentration was calculated from the results of the flurprimidol analysis (4,070 ng/g, Table 1), the amount of mulch used (10 g) (0.4 oz), and the mass of potting medium (500 g) (18 oz). The concentration of flurprimidol applied via the mulch was between direct application concentrations of flurprimidol that stimulated (0.04 mg/kg) (0.000006) and inhibited (0.2 mg/kg) (0.000003) zinnia growth (Fig. 1).

Experiment 2—Incorporation into soil mixture or surface application of mulch from plants grown for 31 days with flurprimidol. Application of mulch (MC, untreated control) itself caused a reduction in height growth in both mixed and surface applied mulch treatments (Fig. 3A,B). Stimulation of height growth, compared to the untreated mulch treatment, was observed when tissue from zinnia grown at 0.0016 and 0.008 mg/kg (0.00000003 and 0.00000015 oz/lb) flurprimidol was incorporated into the potting medium, whereas no stimulation was observed in surface-mulch treatments. Height growth was inhibited with higher concentrations of flurprimidol treated mulch in both mixed and surface mulch treatments. The results showed that surface application of mulch also inhibited height growth, but the effect was less than occurred when the mulch was mixed into the potting medium. For example, the mulch control reduced growth by 33 and 12% in the mixed and surface mulch treatments, respectively, compared to the no mulch control. The same relationship occurred for mulch derived from zinnia grown at 5 mg/kg (0.0001 oz/lb) flurprimidol; growth reduction was 73% when mixed into the potting medium and 57% when applied to the surface. Availability to plant roots of flurprimidol in the mulch, and the potential impact on the carbon-nitrogen ratio and release of toxic substances were probably greater when the mulch was incorporated in the rooting medium.

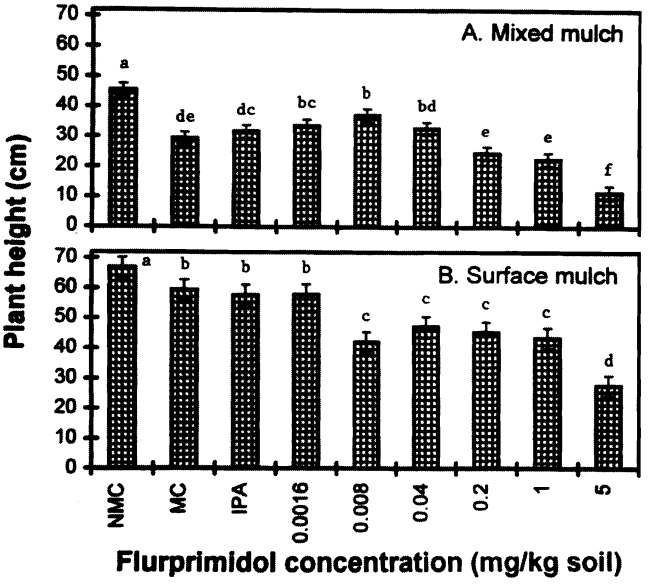

Fig. 3. Effects of mixed (A) and surface-applied (B) mulch made from flurprimidol treated zinnia on height of zinnia 38 days after transplanting (NMC, no-mulch control; MC, mulch control; IPA, isopropyl alcohol control). In the mixed mulch treatment, 10 g of ground zinnia tissue were incorporated with the potting medium before transplanting and in the surface application 10 g of ground zinnia were placed on the surface of each pot 10 days after transplanting. Values with the same letter are not significantly different according to Duncan's multiple range test, p = 0.05.

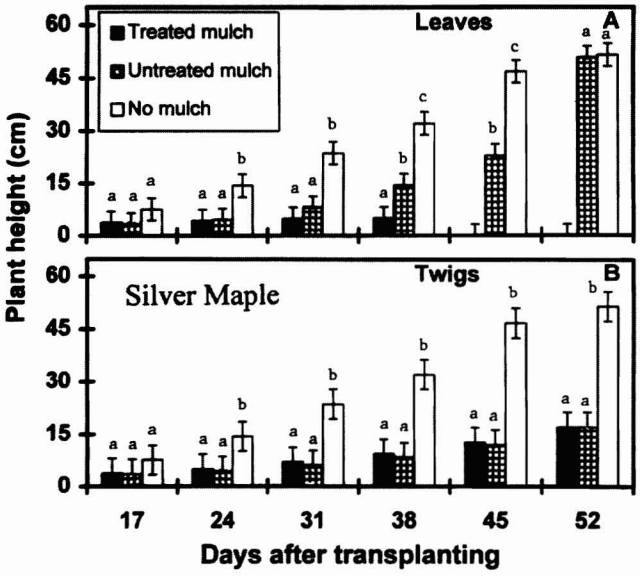

Fig. 4. Effects of mulch made from silver maple leaves (A) and twigs (B) collected 1 month after flurprimidol treatment on height of zinnia measured at weekly intervals. Plants in flurprimidol treated leaf mulch had died by 45 days after transplanting. Values with the same letter are not significantly different according to Duncan's multiple range test, p = 0.05.

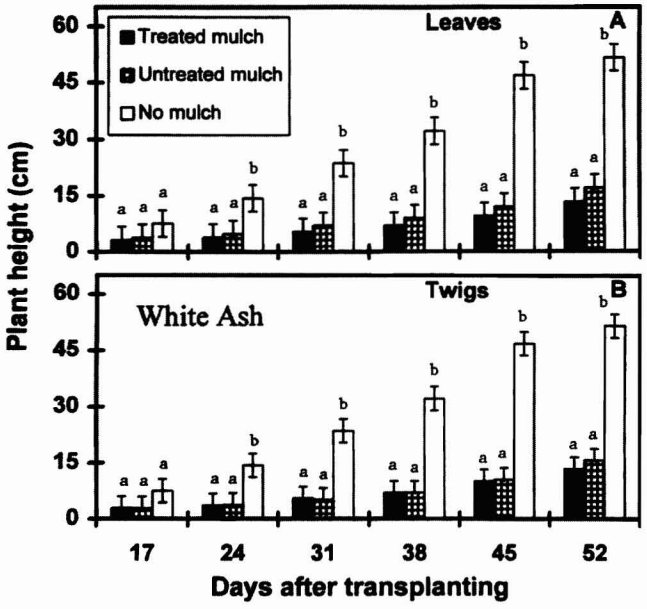

Fig. 5. Effects of mulch made from white ash leaves (A) and twigs (B) collected 1 month after flurprimidol treatment on height of zinnia measured at weekly intervals. Values with the same letter are not significantly different according to Duncan's multiple range test, p = 0.05.

Effects of mulch made from flurprimidol treated silver maple and white ash on growth of zinnia. Although inhibition due to mulch derived from both flurprimidol treated and untreated trees occurred as soon as 24 days after transplanting, inhibition due to flurprimidol in the mulch did not occur until 38 days after transplanting in the flurprimidol treated silver maple leaf mulch treatment (Fig. 4A). All five plants exposed to the flurprimidol treated leaf mulch had died by 45 days after transplanting, suggesting that the flurprimidol was at a toxic level in the mulch. Mixing mulch derived from silver maple twigs and white ash leaves and twigs into the potting medium, regardless of whether or not it was from a flurprimidol treated or untreated tree, had the same inhibiting effect as mulch derived from zinnia described in the previous experiments (Fig. 4B and 5).

A decrease in height growth of zinnia occurred 52 days after transplanting into growing medium containing mulch made from leaves or twigs of silver maple trees treated for 6 months with flurprimidol implants. A similar response was not observed in white ash twigs, which were collected 6 months after the flurprimidol treatment (data not shown). White ash leaves were not available for collection 6 months after the treatment due to early leaf drop in the autumn.

Reduction in height growth by mulch made from leaves and twigs harvested 18 months after treatment was observed in both silver maple and white ash (Figs. 6 and 7). For silver maple leaves, a significant reduction in height growth was observed as early as 31 days after transplanting (Fig. 6A); however, in twigs it was observed only 45 days after transplanting (Fig. 6B). In white ash a significant reduction in height growth was observed 45 days after transplanting in leaf mulch (Fig. 7A) and beginning 38 days after transplanting in twig mulch (Fig. 7B). The effects on height growth of zinnia observed in this study suggest that flurprimidol was

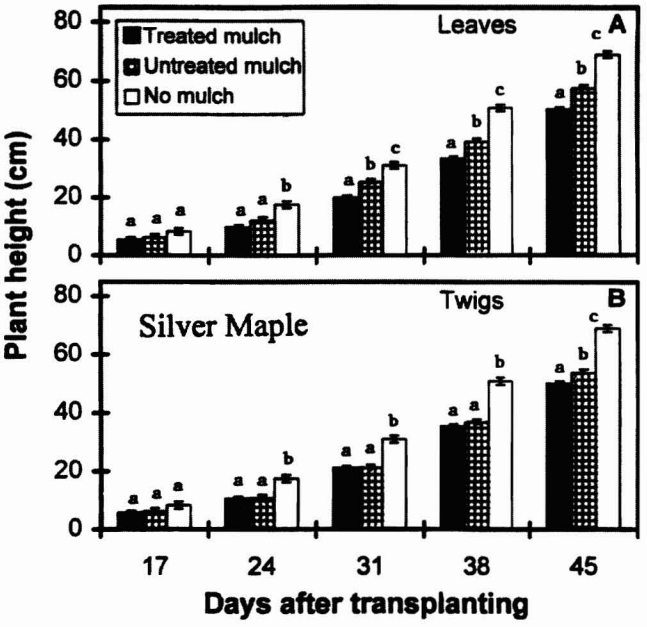

Fig. 6. Effects of mulch made from silver maple leaves (A) and twigs (B) collected 18 months after flurprimidol treatment on height of zinnia measured at weekly intervals. Values with the same letter are not significantly different according to Duncan's multiple range test, p = 0.05.

translocated from trunk implants to leaves and twigs of the trees for two growing seasons after treatments, and that it either remained in these tissues in a biologically active form or was continually supplied from the implant reservoir in the trunk. Because of the deciduous habit of the trees used, con-

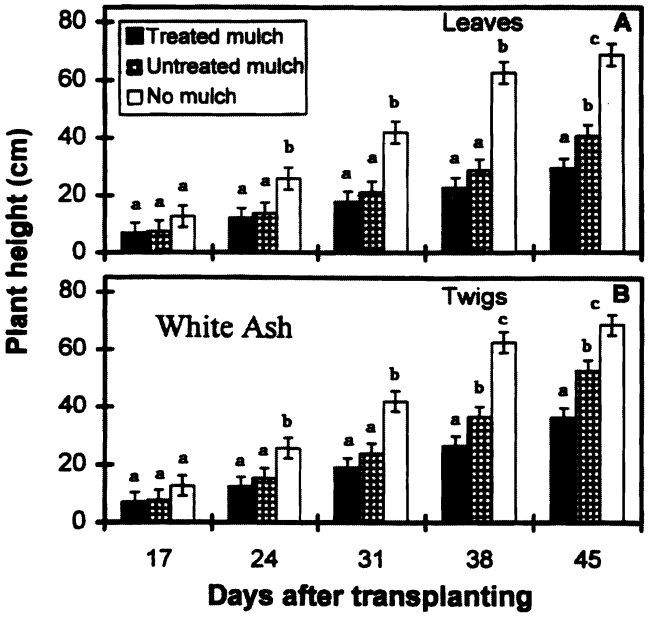

Fig. 7. Effects of mulch made from white ash leaves (A) and twigs (B) collected 18 months after flurprimidol treatment on height of zinnia measured at weekly intervals. Values with the same letter are not significantly different according to Duncan's multiple range test, p = 0.05.

tinued translocation of flurprimidol to the leaves in the second growing season (18 months after treatment) was essential.

The concentrations of flurprimidol applied via the leaf or twig mulch in the treatments that inhibited growth ranged from 0.02 to 0.0016 mg/kg (0.000003 to 0.00000003 oz/lb). These concentrations were calculated as before from the tissue analyses (Table 3), the weight of mulch used per pot [60 g (2.1 oz) of twigs, 1:3 by vol, or 130 g (4.6 oz) of leaves, 1:2 by vol]. Although these secondary treatments of flurprimidol all inhibited growth, the calculated flurprimidol concentrations fall between direct application treatment rates that stimulated (0.0016 mg/kg to 0.04 mg/kg) (0.00000003 to 0.000006 oz/lb) the growth of zinnia (Fig. 1).

Total leaf areas and root:shoot ratios of zinnia 45 days after transplanting into rooting medium mixed with mulch made from silver maple or white ash leaves and twigs harvested 18 months after flurprimidol treatment are shown in Table 2. Although treatment with leaf or twig mulch from both tree species resulted in a reduction in total leaf area, there was not a significant effect due to mulch from trees treated with flurprimidol implants compared to that from untreated trees (Table 2). Application of flurprimidol has been shown to reduce leaf expansion in apple seedlings and bean plants (5). However, the concentration applied was higher than that potentially available to plants in this study.

Flurprimidol treated mulch did not affect root weight (data not shown); however, the root:shoot ratio was higher due to the inhibition of shoot growth when mulch made from silver maple twigs and white ash leaves from flurprimidol treated trees was mixed in the rooting media (Figs. 6 and 7). Flurprimidol has been found to increase root weight and root:shoot ratio of apple seedlings (5).

The pH of the potting media gradually increased about one pH unit during the course of the experiment in all three

Table 2. Total leaf area and root:shoot ratio of zinnia 45 days after transplanting into rooting medium mixed with mulch made from silver maple or white ash leaves and twigs from control trees and trees treated with flurprimidol implants for 18 months.

	Total leaf area (cm^2)		Root:shoot ratio	
	Type of mulch			
Treatment	Leaves	Twigs	Leaves	Twigs
	Silver maple			
Treated mulch	600a[z]	617a	0.44a	0.36a
Untreated mulch	667ab	660ab	0.38a	0.26b
No-mulch control	710b	710a	0.41a	0.41a
	White ash			
Treated mulch	563a	511a	0.39a	0.32a
Untreated mulch	615a	586a	0.27b	0.28a
No-mulch control	755b	755b	0.36a	0.36a

[z]Values in columns for a tree species followed by the same letter are not different according to Duncan's multiple range test, p = 0.05.

types of potting mixtures (data not shown). The Hoagland's solution, which was added weekly to the pots, was adjusted to pH 7. Although there were significant differences in pH among the three different potting mixtures, the differences were not greater than one-third of a pH unit at any sampling date, and not considered substantial enough to account for the effects of the mulch treatment on zinnia growth.

Flurprimidol reached the leaves and terminal shoots in both white ash and silver maple within one month of its application in the spring (Table 3). The concentrations of flurprimidol in leaves and twigs were less 6 and 18 months after treatment than one month after treatment. White ash leaves were not available for collection 6 months after treatment due to early leaf fall in the autumn of that year. Comparison of the flurprimidol concentrations found in the leaves and twigs showed higher concentrations in both of these tissues in sil-

Table 3. Flurprimidol concentrations in mulch made from leaves and twigs of flurprimidol treated silver maple and white ash trees at 1, 6 and 18 months after the treatment.

	Time after treatment					
	1 month		6 months		18 months	
	Type of mulch					
Tree species	Leaves	Twigs	Leaves	Twigs	Leaves	Twigs
	ng/g dry weight					
Silver maple	93.3Aa[z]	97.3Aa	39.6b	37.1Ab	23.5Ab	12.5Ab
White ash	62.7Ba	52.9Ba	Nd[y]	19.5Aab	12.6Ab	12.9Ab

[z]Means in columns followed by the same upper case letter and means in rows followed by the same lower case letter are not significantly different according to Duncan's multiple range test, p = 0.05. Values are means of 5 mulch samples made from 5 trees.

[y]ND; not detected since leaves were not available for collection due to early leaf-fall in the autumn.

ver maple than in white ash one month after treatment (Table 3). Thereafter the concentrations were similar, suggesting either a more rapid metabolism of flurprimidol or a slower rate of translocation of the compound in white ash than silver maple trees.

The results of these experiments demonstrate that flurprimidol residues can exist in plant tissues at concentrations sufficient to affect the growth of other plants when flurprimidol treated plants are used as a mulch. However, the worst case scenario was created and the potential for effects was enhanced in this study by using powdered or finely ground tissue that enhanced the likelihood of leaching and uptake by roots. In a typical utility tree maintenance program using tree growth regulators, only a portion of the trees being trimmed would have been treated with a tree growth regulator, resulting in substantial dilution of the quantity of PGR in the chips produced. The mulch material also would be much larger in size, reducing the rate of leaching and release of any PGR residues. Consequently, the carryover effects could be growth stimulation rather than growth inhibition. Further studies are needed to investigate the stability of flurprimidol in woody residue and the potential for its effects on plants in the landscape if the mulch used consisted of the wood chip size and the flurprimidol concentrations that would typically result from an electric line clearance trimming operation.

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