Feasibility of Adding Surfactants to Slow-Release Herbicide Tablets for Container-Grown Landscape Plants[1]

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Abstract

Slow-release tablets made of dicalcium phosphate containing a herbicide and a surfactant were evaluated for weed growth. The addition of 1-2% surfactant to herbicides having a very low water solubility, such as Gallery (isoxaben), Surflan (oryzalin), Ronstar (oxadiazon), and Goal (oxyfluorfen), and for comparison, to Dual (metolachlor), markedly enhanced the release of herbicide and enlarged the area of weed inhibition. The surfactants that produced the best results were Triton X-100 and X-77. Tablets placed on the surface of containers filled with Metro Mix 350 or a pine bark-peat moss-sand medium, under intermittent mist in the greenhouse, or under sprinklers outdoors, produced up to 15 cm (6 in) diameter circular areas of weed control, around a single tablet. Initial release of herbicide from tablets was rapid upon exposure to moisture and the area of activity became close to maximum within a few days after placing the tablet on the soil surface. Tablets placed on surface produced larger areas of activity than when buried. The tablets retained their shape after 3 months of outdoor exposure.

Index words: Dicalcium phosphate, low water solubility, area of growth inhibition, bioassy plant

Weed species used in this study: *Agrostis stolonifera* L. 'Seaside', *Brassica nigra* L. Koch 'Green Wave', *Amaranthus retroflexus* L., *Lolium multiflorum* Lam.

Herbicides used in this study: Dual (metolachlor) [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)acetamide]; Gallery (isoxaben) [N-[3-(1-ethyl-1-methylpropyl)-5-isoxazolyl]-2,6-dimethoxybenzamide]; Surflan (oryzalin) [4-(dipropylamino)-3,5-dinitrobenzenesulfonamide]; Ronstar (oxadiazon) [3-2,4-dichloro-5-(1-methylethoxy)phenyl]-5-(1,1-dimethylethyl)-1,3,4-oxadiazol-2-(3H)-one; and Goal (oxyfluorfen) [2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl)benzene].

Significance to the Nursery Industry

Most herbicides currently recommended for weed control in container grown nursery stock such as Surflan, Ronstar, and Goal are characterized by very low water solubility.

This limitation can be partially overcome by adding a surfactant to the herbicide. By addition of a 1–2% surfactant to a dicalcium phosphate and herbicide tablet, the release of herbicide and the area of weed control around the tablet is considerably increased. The surfactants that produced the best results were Triton X-100 and X-77.

Tablets of herbicide and surfactant evaluated on growth media used in commercial practice, in the greenhouse and outdoors, produced weed-free areas up to 15 cm (6 in) around the tablet. The application of one or several tablets on the media surface, according to the size of the container, could provide an alternative to spraying or granular application presently in use. The long range benefit of tablet application for weed control resides in its potential to reduce the run-off of herbicides into drainage water.

Introduction

Preemergence herbicides are widely used in container-grown landscape plants. Repeated applications of herbicides are often necessary to keep the crop weed-free during the entire growing season (5, 14). Therefore, controlled-release systems have aroused interest in container culture. Expectations for greater efficiency and safety in comparison to conventional herbicide formulations are based on the following assumptions. First, the rate of herbicide in a controlled-release formulation is higher than that required for a single conventional application, but much less than for the repeated applications required to achieve a similar prolonged control period (3, 4). Secondly the herbicide not released remains unavailable for leaching and dissipation (9, 12, 17). Many of the controlled-release formulations developed were produced as granules, i.e. concrete like particles up to 2-3 mm (.008-.012 in) diameter. However, it is important to note that the application of granules on container-grown plants, generally applied as an over-the-top treatment, presents several problems, including the lack of uniformity in the distribution of the active ingredient on the container surface; and an appreciable fraction of the applied herbicide falls between the pots, directly on the soil, which may contribute to pollution of surface and sub-surface water.

A different approach was followed by Smith and Verma (13, 18). They prepared controlled-release tablets (i.e. flat pieces of compressed material, generally 1 to 2 cm diameter (0.4-0.8 in) containing sufficient herbicide to control weeds in a relatively large area using 1 to 3 tablets placed on the container surface. Initially, they used plaster of paris as the porous inert matrix, but subsequently replaced it with dicalcium phosphate. Dicalcium phosphate has the advantage of keeping the form of the tablet when wet and can be produced mechanically by dry pressing (13, 18, 19).

Weed control achieved by dicalcium phosphate tablets containing Lasso (alachlor), Dual (metolachlor) or Sencor/

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Lexone (metribuzin) was comparable to or better than conventional application of commercially available formulations (9, 11, 15). Tablets with herbicides having a low water solubility gave insufficient results (9, 11, 15, 16, 19). Unfortunately, many herbicides which are currently recommended for container grown nursery crops have a very low solubility in water (5, 14).

Due to the interesting features of the dicalcium phosphate tablet as a controlled-release carrier, an attempt was made to add surfactants to the system, based on the following assumptions. The release of the herbicide from the tablet is basically a diffusion process, triggered by water, and is a function of the water solubility of the active compound (3, 4). Once released, the extent of the movement of the herbicide in the soil depends on characteristics of the chemical, the soil, and the water regime (20). It has been shown that certain surfactants were able to increase the apparent solubility in water of herbicides, and to enhance their leaching in soil (1, 2, 6).

The objectives of these studies were to determine the activity of tablets containing herbicides having a very low water solubility (0.7 to 2.4 ppm) with various surfactants added to the tablets. Release of the herbicides were measured by bioassay.

Materials and Methods

Tablets consisted of a filler, dicalcium phosphate (91 to 97%), a binder, magnesium stearate (2%), herbicide in formulated or technical grade (1 to 5%) and, in certain combinations, surfactant (1 to 2%). After thorough mixing of ingredients, tablets were punched with a Stokes Single Punch Tablet Machine, model F, using the technique described by Smith, Gorski and Moore (15). Tablets were 12 mm (.047 in) in diameter, 2-4 mm (.008-.016 in) thick and weighed 1.0 to 1.5 g, according to composition. In a given batch the weight was very uniform varying by less than 1%.

The herbicidal material incorporated in the tablets was either technical Dual (95.4%), Gallery (92.2%), and Surflan (97%) or formulated Surflan AS 40, Ronstar WP 50, and Goal 1.6E. Following surfactants were added: 'Dash' (a proprietary BASF blend of surfactants); Tween 20 (polyoxyethylene sorbitate monolaureate); Tween 80 (polyoxyethylene sorbitan monooleate); Triton X-100 (octyl phenoxy polyethoxyethanol); or X-77 (alkylarylpolyoxyethylene glycols, free fatty acids and isopropanol). Details on the composition of the tablets are presented in Table 1.

Herbicide release was studied in the greenhouse and outdoors. Containers were filled with Metro Mix 350 (MM), a proprietary growing medium containing vermiculite, peat moss, processed bark ash and sand, or with a pine bark-peat moss-sand mixture (6:3:1 by vol) (BPS), a growing medium developed for landscape plants at the Department of Horticulture, Ohio State University, Columbus. The average organic matter content of MM and BPS mixtures were 6.6% and 16.5%, respectively; their cation exchange capacity, 6 and 8 meq/100 g, and their pH, 6.7 and 4.4, respectively.

In the greenhouse, 15 (6 in) or 18 cm (7.2 in) diameter pots filled with MM were placed under intermittent mist (8 sec every 16 min). Outdoors, 18 cm (7.2 in) diameter pots filled with MM or BPS were kept in the open and watered by sprinkler irrigation, as required. As a general procedure, a tablet was placed on the soil surface at the center of the pot and seeds of a sensitive bioassay plant—Creeping bentgrass, Black mustard, Redroot pigweed or Italian ryegrass were densely oversown. An initial watering was applied soon after sowing. After several days, the seeds emerged

Table 1. Composition of tablets.[z]

Tablet designation	Herbicide	Herbicide formulation	Per tablet %	Per tablet mg ai	Surfactant	Per tablet %
M1	Dual	Techn. 95.4%	1	12.2	—	—
M1-X1	Dual	Techn. 95.4%	1	11.5	X-77	1
IT1	Gallery	Techn. 92.2%	1	12.3	—	—
IT1-X1	Gallery	Techn. 92.2%	1	12.9	X-77	1
IT5	Gallery	Techn. 92.2%	5	59.9	—	—
OS1	Surflan	Surflan AS40	1	6.0	—	—
OS1-X1	Surflan	Surflan AS40	1	5.5	X-77	1
OS5	Surflan	Surflan AS40	5	26.4	—	—
OT1	Surflan	Techn. 97%	1	13.1	—	—
OT1-X1	Surflan	Techn. 97%	1	14.1	X-77	1
OT5	Surflan	Techn. 97%	5	66.0	—	—
R1	Ronstar	Ronstar WP50	1	5.4	—	—
R1-X1	Ronstar	Ronstar WP50	1	5.6	X-77	1
R1-TR1	Ronstar	Ronstar WP50	1	6.5	Triton X-100	1
G1	Goal	Goal 1.6 E	1	2.3	—	—
G5	Goal	Goal 1.6 E	5	10.8	—	—
G1-X1	Goal	Goal 1.6 E	1	2.4	X-77	1
G3-X1	Goal	Goal 1.6 E	3	6.6	X-77	1
G3-X2	Goal	Goal 1.6 E	3	6.4	X-77	2
G1-D1	Goal	Goal 1.6 E	1	2.3	Dash	1
G1-TW1	Goal	Goal 1.6 E	1	2.3	Tween 20	1
G1-TE1	Goal	Goal 1.6 E	1	2.3	Tween 80	1
G1-TR1	Goal	Goal 1.6 E	1	2.3	Triton X-100	1

[z]The tablet mixture contains: 93–97% Ca diphosphate, 2% Mg stearate, 1–5% technical or formulated herbicide, 1–2% surfactant. The average weight of tablets varied with each formulation, from 1.1 to 1.5 g/tablet.

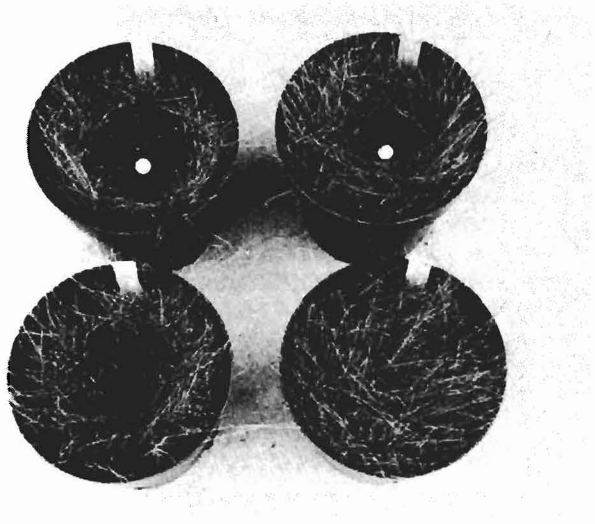

Fig. 1 Area of inhibition produced by tablets of oxyfluorfen placed on the surface (A,B) or 2 cm (0.75 in) below surface (C,D), as assessed by bentgrass. Right: G1 tablet (Goal only) (B,D); left: G1-X1 tablet (Goal & Surfactant X-77) (A,C).

and formed a solid mat except for a clearcut circle of growth inhibition around the tablet. At each observation, two measures of the diameter of the area of inhibition were taken and averaged.

Changes were made in the standard procedure in the following studies. In the placement and timing studies (Table 5), tablets were buried 2 cm (0.8 in) below the media surface. Seeds of bentgrass were sown at various intervals after placing the tablet on the surface (watering followed the tablet placement) in comparison to 0 interval which was sown immediately. In surfactant studies, surfactants in a 1% aqueous solution were sprayed on the surface before placing the tablets and compared to tablets containing the surfactant (Table 4).

All experiments were conducted with 4 or 5 replications in a randomized complete block design. Data were analyzed by Duncan's multiple range test.

Results and Discussion

All herbicide tablets placed on the soil surface, oversown with weed seeds and watered, produced a clearcut circular area of weed inhibition, indicating a symmetrical release from the tablet (Fig. 1).*

Effect of surfactants. The main results of experiments with five herbicides, comparing the effects of tablets loaded with herbicide and surfactant X-77 to tablets with herbicide only, are shown in Table 2. Without surfactant, the area of inhibition produced by water-soluble Dual was larger than that of the low-soluble herbicides Gallery, Surflan, Ronstar and Goal. With all herbicides, the addition of 1% surfactant X-77 significantly increased the area of activity. In comparison to the 1% herbicide tablets, the addition of surfactant increased the diameter of the area of inhibition by approximately 33% for Dual, and by 170 to 300% for the other herbicides. The actual size of the area of activity of tablets with low-soluble herbicides + surfactant was larger than that of Dual alone. The herbicidal material from which the tablets were prepared, technical or formulated, appears to influence performance. Tablets of Surflan made from 40% formulated material (OS) produced a larger area than tablets made of technical material (OT), in spite of their lower content in active ingredient (Tables 1,2). Comparing the areas of inhibition produced by 1% and 5% tablets (Table 2), the difference was negligible when technical material had been used (IT1), IT5; OT1,OT5), but with formulated material (OS1,OS5; G1,G5) the inhibition of 5% tablets was significantly greater. Product formulations have proprietary composition, but are known to include surface-active substances, which apparently enhance the release of herbicide from the tablet.

Several surfactants were evaluated as additives to Goal and Ronstar, under greenhouse conditions (Table 3). Triton X-100 was the most effective in enlarging the area of weed inhibition, followed by X-77 whereas Dash, Tween 20 and Tween 80 were less effective. Weed inhibition from Triton X-100 was better than X-77, observed on containers kept outdoors (Table 6).

In order to explore the role of surfactants on the release of herbicide from the tablet and its lateral movement, 3 surfactants (Tween 20, Tween 80, X-77) were sprayed on the soil surface prior to applying Surflan tablets without surfactant (OT1). Surflan tablets without surfactant were compared to tablets containing X-77 (OT1-X1) that were placed on non-sprayed soil (Table 4). The surfactants sprayed on the surface had no effect on the emergence of the bioassay plant (ryegrass). While the OT1-X1 tablets, containing both herbicide and surfactant, produced an area of inhibition much larger than OT1 tablets, the area of activity of OT1 tablets was not increased by the surfactants sprayed on the soil.

Table 2. Area of weed inhibition around herbicide tablets, with or without surfactant[z]

Herbicide	Tablets[y]	Bioassay plant	Diameter (mm) of inhibition area[y]		
			1% H	1%H+1%X	5%H
Dual	M1,M1-X1	RG	57 b[x]	76 a	—
Gallery	IT1,IT1-X1,IT5	MD	20 b	65 a	25 b
Surflan	OS1,OS1-X1,OS5	RG	32 d	86 a	48 c
Surflan	OT1,OT1-X1,OT5	RG	26 e	73 b	28 de
Ronstar	R1,R1-X1	PW	15 b	60 a	—
Goal	G1,G1-X1,G5	BG	41 c	110 a	74 b

[z]Single tablets placed on soil surface at center of 16 cm (6 in) dia. pot, and oversown with seeds of bioassay plant (BG—Creeping bentgrass, MD—Black mustard, PW—Redroot pigweed, RG—Italian ryegrass). Separate experiment for each herbicide, in the greenhouse.

[y]Content of tablets detailed in Table 1. 1%H, 5%H—1% or 5% herbicide; 1%H+1%X—1% herbicide + 1% surfactant X-77.

[x]For each herbicide, followed by different letters indicate significant differences (5%), by Duncan's multiple range test.

Table 3. Effect of surfactants added to tablets of oxyfluorfen and oxadiazon on the inhibition area around the tablets, assessed by bentgrass or pigweed[z]

Herbicide	Surfactant	Tablet[y]	Bioassay	Diameter (mm) of inhibition area
Goal	—	G1	BG	43 d[x]
Goal	Dash	G1-D1	BG	41 d
Goal	Tween 20	G1-TW1	BG	45 cd
Goal	Tween 80	G1-TE1	BG	54 c
Goal	X-77	G1-X1	BG	73 b
Goal	Triton X-100	G1-TR1	BG	124 a
Goal	X-77	G1-X1	PW	68 ab
Goal	Triton X-100	G1-TR1	PW	88 a
Ronstar	X-77	R1-X1	PW	51 b
Ronstar	Triton X-100	R1-TR1	PW	79 a

[z]Single tablets placed on soil surface at center of 16 cm (6 in) dia. pots, and oversown immediately with seeds of Creeping bentgrass (BG) or Redroot pigweed (PW). Experiment conducted in the greenhouse.

[y]Content of tablets detailed in Table 1. Except G1, all tablets contained 1% of surfactant.

[x]Diameter of inhibition area for BG or for PW followed by different letters indicate significant differences (5%) by Duncan's multiple range test.

Table 4. Effect of surfactant sprayed on soil surface or added to tablet of oryzalin, on the inhibition area around the tablet, assessed by ryegrass[z]

Surfactant			
Incorporated In tablet	Sprayed On surface	Tablet[y]	Diameter (mm) of inhibition area
X-77	—	OT1-X1	60 a[x]
—	—	OT1	15 b
—	Tween 20	OT1	16 b
—	Tween 80	OT1	18 b
—	X-77	OT1	19 b
—	Tween 20	—	0 c
—	Tween 80	—	0 c
—	X-77	—	0 c

[z]Single tablets with or without sufactant were placed on soil surface which was sprayed, or not, with 1% aqueous of surfactant, and oversown immediately with Italian ryegrass. Experiment conducted in the greenhouse.

[y]Content of tablets detailed in Table 1.

[x]Diameter of inhibition area followed by different letters indicate significant differences (5%) by Duncan's multiple range test.

It has been shown that adding certain surfactants to a herbicide solution will increase the apparent water solubility of the herbicide, enhance the herbicidal activity when applied on foliage and increase the depth of leaching in soil (1,2,6). However, no clear correlation was found between the increase in solubility, the enhanced foliar activity and the greater movement in soil. The increase in solubility of herbicides due to surfactants may be very marked; for example, with Karmex (diuron), the apparent solubility passed from 42 ppm in pure water to 189 ppm in a 1% X-77 solution (6). Increased solubilization of Karmex and other herbicides (2,6) was also recorded with Triton X-100 and Tween 20. All the surfactants evaluated in this work were non-ionic. It is not clear which physical or chemical property could be responsible for the enhanced release from tablets. The results of the above experiment (Table 4) indicate that the effect of the surfactant added to the tablet is probably not due to changing the hydrophobic characteristics of the media surface, which would thus enhance the movement of low-soluble herbicides, but, rather by increasing the solubilization, and hence, the initial release from the tablet.

Placement and timing. Tablets placed below the soil surface produced circular areas of inhibition, markedly smaller than when placed on the surface (Fig. 1) (Table 5). Since the release of herbicide in a uniformly moist medium is symmetrical around the tablet, the largest possible area of activity is formed in the plane containing the tablet. When a tablet is placed under the surface, the semi-spherical volume of release produced above the tablet may intersect with the surface, and the section area will be inversely related to the depth of the tablet. Downward leaching from irrigation may further reduce the presence of herbicide on the surface. Since weeds in containers are mainly due to seeds born by

Table 5. Diameter of inhibition area around oxyfluorfen tablets placed on surface and below soil surface, assessed by bentgrass oversown immediately, 1 and 2 weeks later.[z]

		Diameter (mm) of inhibition area		
		Bentgrass sown weeks after tablet		
Tablet[y]	Placement of tablet	0	1	2
G1	on surface	35 c[x]	38 c	37 c
	below surface	0 d	0 d	0 d
G1-X1	on surface	82 a	82 a	81 a
	below surface	57 b	65 b	60 b

[z]Single tablets placed on soil surface or 2 cm (0.75 in) below soil surface at center of 18 cm (7 in) dia. pots. Experiments were conducted in the greenhouse under mist.

[y]Content of tablets detailed in Table 1.

[x]Diameter of inhibition area followed by different letters indicate significant difference (5%) by Duncan's multiple range test.

wind or water, it is the top layer which must be protected by preemergence herbicide (7) and this can best be achieved by placing the tablet on the surface.

All tablets included in this work retained their physical integrity after continuous exposure on soil surface up to 3 months, in the greenhouse and in the open.

The timing of the release and lateral expansion of herbicide from the tablet was examined by oversowing the soil surface with a sensitive species at various dates after placing the tablets (Table 5). It appears that the inhibition area rapidly reaches its definite size and no significant increase occurs beyond that of day 0, when oversown immediately (Fig. 2).

These results with Goal were corroborated by similar experiments with Dual, Gallery and Surflan (not detailed). The assessment used in these experiments, based on the germination of oversown seeds delineates the area where the herbicide concentration is equal or above that inhibiting root or shoot development, at approximately 1 to 3 days after sowing (since the herbicides tested have no effect before root/shoot protrusion).

Following the placement of the tablet and watering, an active and rapid release process apparently takes place. The events occurring in the tablet upon exposure to water have not been documented. Herbicide release can be a process of solubilization of herbicide molecules by water penetrating into the tablet, and increased solubility induced by a surfactant (1,6).

Subsequently, the herbicide is probably moved by diffusion along a gradient of concentration, from the tablet outwards. The extent of the lateral movement might be determined by equilibrium between diffusion forces, soil/water conditions and dissipation factors, such as volatilization and leaching (20). It is important that effective weed-control can be achieved in an area close to the maximum soon after applying the tablet.

Outdoor experiments. Experiments were carried out in the open under conditions close to commercial nursery practice, and compared to results from the greenhouse (Table 6). Several tablets with Goal produced larger areas of inhibition outdoors than in the greenhouse (Table 6). Comparing 2 mediums, Metro Mix 350 (MM) and a bark-peat-

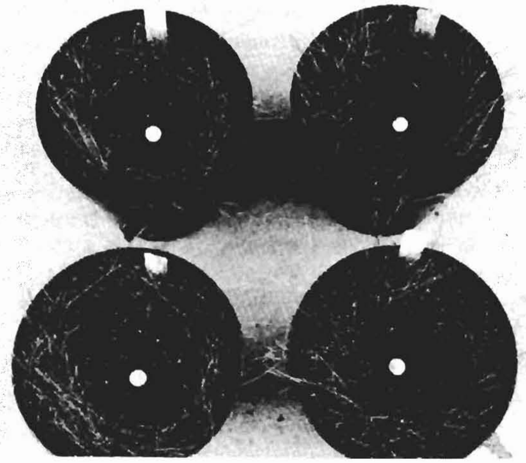

Fig. 2 Area of inhibition produced by tablets of oxyfluorfen, assessed by bentgrass oversown immediately (C,D) or after 2 weeks (A,B). Right: G1 tablet (Goal only) (B,D); left: G1-X1 tablet (Goal & Surfactant X-77) (A,C).

sand mix (BPS), no clear differences were noted, in spite of the greater organic matter content of BPS than MM (16.5% vs 6.6%, resp). The largest areas of activity, approximately 15 cm (6 in) diameter, were produced by G1-TR1 and G3-X2 tablets (containing respectively 1% oxyfluorfen + 1% Triton X-100 and 3% oxyfluorfen + 2% X-77). Gallery and Ronstar tablets, assessed by pigweed, gave smaller areas of inhibition, indoors and outdoors (Table 6). It is of practical significance, that under outdoor conditions, with great diurnal variations in air and soil moisture, and on two growth mixtures used in practice, the release and activity of the herbicide followed a pattern similar to that recorded under controlled greenhouse conditions.

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Table 6. Diameter of inhibition area produced by various tablets in greenhouse and outdoors, on Metro Mix 350 and Bark-Peat-Sand mix assessed by bentgrass and pigweed.[z]

		Diameter (mm) of inhibition area		
		Greenhouse	Outdoors	
Tablet[y]	Bioassay	MM	MM	BPS
G1-X1	BG	82 c[x]	121 c	120 c
G3-X1	BG	98 abc	134 bc	129 c
G3-X2	BG	107 ab	150 a	149 ab
G1-TR1	BG	117 a	149 ab	145 ab
OS1-X1	BG	86 bc	100 d	122 c
R1-X1	PW	60	45	59
IT1-X1	PW	—	53	53

[z]Single tablets were placed on soil surface at center of 16 cm (6 in) dia. pots (greenhouse) or 18 cm (7 in) dia. pots (outdoors) and oversown with Creeping bentgrass (BG) or Redroot pigweed (PW). In greenhouse, under intermittent mist, all pots were filled with Metro Mix 350 (MM); outdoors, under sprinkler irrigation, the pots were filled with MM or Bark-Peat-Sand mixture (BPS).

[y]Content of tablets detailed in Table 1.

[x]Results with BG in the greenhouse and outdoors were analyzed separately. Diameter of inhibition area in each experiment, followed by different letters indicate significant difference (5%) by Duncan's multiple range test. Diameters with PW were not significant.

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Paclobutrazol Inhibits Growth of Woody Landscape Plants[1]

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Abstract

Paclobutrazol, applied as a spray or drench, suppressed growth of 8 woody landscape species. Magnitude of growth inhibition was directly correlated with application rate, whereas both magnitude and duration of growth inhibition was influenced by application method. Generally, paclobutrazol when applied as a drench suppressed growth to a greater degree than did spray applications. Flowering or fruiting of 3 species was generally promoted with paclobutrazol, while phytotoxicity symptoms were observed on 4 species.

Index words: Growth retardant, Bonzi, Clipper, growth inhibition
Growth regulators used in this study: Bonzi (paclobutrazol) (2*RS*, 3*RS*)-1-(4-chlorophenyl)-4,4-dimethyl-2-(1*H*-1,2,4-triazole-1-yl)pentan-3-ol
Species used in this study: Japanese euonymus (*Euonymus japonica* 'Microphylla' H. Jaeg.); dwarf Burford holly (*Ilex cornuta* Lindl. & Paxt. 'Burfordii Nana'); compacta Japanese holly (*Ilex crenata* Thunb. 'Compacta'); shore juniper (*Juniperus conferta* Parl. 'Blue Pacific'); Hino Crimson azalea (*Rhododendron obtusum* Planch 'Hino Crimson'); Formosa azalea (*Rhododendron indicum* L. 'Formosa'); photinia (*Photinia* × *fraseri* Dress); privet (*Ligustrum japonicum* Thunb. 'Aureo-marginatum')

Significance to the Nursery Industry

Paclobutrazol is an effective growth retardant on a wide range of woody landscape plants when applied as either a drench or spray. This may offer growers an additional management tool; for example, it's use offers the ability to retard growth during a depressed market or avoid transplanting. Due to the magnitude and persistence of growth suppression, drench applications during production are probably not practical and spray rates should be carefully chosen. Drench and spray application methods have potential for the landscape industry, however established plants may respond differently than container-grown plants to paclobutrazol rate and application method due to differences in growth medium or other factors. Sensitivity to paclobutrazol varied greatly among species, and appropriate rates are likely to be highly species-dependent; hence, paclobutrazol should first be tested on a small group of plants before committing to large scale application.

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