Herbicides for Container-grown Rain Forest Species

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Additional index words. *Dysoxylum rufum*, *Syzygium fibrosum*, *Alphitonia excelsa*, *Macaranga tanarius*, *Acmena hemilampra*, *Metrosideros queenslandica*, *Arytera lautereriana*, *Polyscias elegans*, *Ficus racemosa*, *Cardwellia sublimis*, oxadiazon, simazine, oxyfluorfen, oryzalin, dichlobenil, Proteaceae

Abstract. Four granular formulations of preemergence herbicides-oxadiazon, oxadiazon in combination with simazine, dichlobenil, and oxyfluorfen + oryzalin-were evaluated for weed control and phytotoxic effects on 10 species of container-grown Australian rain forest plants. Herbicides were applied at half and at one and two times the manufacturer's recommended rate. Oxyfluorfen + oryzalin, oxadiazon, and oxadiazon + simazine controlled all weed species at half the recommended rates (1.0 + 0.5, 2.0, and 2.0 + 0.5 kg·ha⁻¹, respectively) with no phytotoxic effects after 10 weeks to nine of the 10 rain forest species tested: broad-leaved lilly-pilly [*Acmena hemilampra* (F. Muell. ex Bailey) Merr. and Perry], red ash [*Alphitonia excelsa* (Cunn. ex Fenzl) Reisseck ex Benth.], rusty bean [*Dysoxylum rufum* (A. Rich.) Benth.], macaranga [*Macaranga tanarius* (L.) Muell. Arg.], fibrous satinash [*Syzygium fibrosum* (Bailey) T. Hartley and Perry], Queensland golden myrtle [*Metrosideros queenslandica* L.S. Smith], cluster fig [*Ficus racemosa* L.], corduroy tamarind [*Arytera lautereriana* (Bailey) Radlk.], and celerywood [*Polyscias elegans* (F. Muell. and C. Moore) Harms]. Dichlobenil depressed plant growth of red ash and failed to control bittercress (*Cardamine hirsuta* L.) and green amaranth (*Amaranthus viridis* L.), even at twice the recommended rate (4.0 kg·ha⁻¹). All herbicides applied at half the recommended rates produced minor to moderate plant injury within 5 weeks of the first application to corduroy tamarind and northern silky oak [*Cardwellia sublimis* F. Muell.]. A second application 10 weeks after the first caused no significant plant injury to corduroy tamarind but resulted in severe plant injury to northern silky oak. This finding validates the previously reported sensitivity of Proteaceous spp. to preemergence herbicides. Chemical names used: 2-tert-butyl-4-(2,4-dichloro-5-isopropoxyphenyl)-Δ²-1,3,4-oxadiazoline-5-one (oxadiazon); (2-chloro-4,6-bisethylamino-1,3,5-triazine) (simazine); 2,6-dichlorobenzonitrile (dichlobenil); 2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl)benzene (oxyfluorfen); and 3,5-dinitro-N,N'-dipropylsulfanilamide (oryzalin).

Weed control is a major problem in the production of container-grown plants because no phytotoxic postemergence herbicides are available for general use on such crops (Weller et al., 1984) and hand weeding is time consuming and expensive (Currey et al., 1977). Long-term container crops (trees and shrubs) that are grown outdoors are particularly problematic. Some common problem weeds such as creeping oxalis (*Oxalis corniculata* L.) and bittercress have short life cycles and can flower and reseed in 8 weeks (Lamont, 1984). If not controlled, these weeds can completely occupy containers, particularly in subtropical

areas where climatic conditions are conducive to rapid growth during the year. Long-term production may also allow other larger broad-leaf weeds, such as green amaranth and sow thistle (*Sonchus oleraceus* L.), to establish.

Granular preemergence herbicides are effective against many weeds in containers; however, they cannot be used safely on all container nursery crops (Weller et al., 1984). Oryzalin or oxyfluorfen granules applied at 9 kg·ha⁻¹ inhibited growth and reduced marketability of *Ilex* spp. (Singh et al., 1984). Plant injury was less at 2.2 kg·ha⁻¹ of either herbicide, but Pennsylvania bittercress (*Cardamine pensylvanica* Muhl.) and yellow wood sorrel (*Oxalis dellenii* Jacq.) were not controlled. *Rhododendron obtusum* (Lindl.) Planch. 'Coral Bells' was susceptible to injury when oxyfluorfen granules were applied at the label rate of 2.2 kg·ha⁻¹, whereas *R. obtusum* Planch. 'Hino Crimson' was tolerant to 9.0 kg·ha⁻¹ (Singh et al., 1981). *Rhododendron* and *Azalea* cultivars differed in their sensitivity to dichlobenil granules (Ahrens, 1966). In another study, oxyfluorfen granules combined with oryzalin damaged newly emerging leaves of several container-grown palm species when applied at recommended rates (4.0 + 1.0

kg·ha⁻¹) (Donselman and Broschat, 1986). Oxadiazon granules are considered safe for use on a range of ornamental species (Lamont et al., 1985; Neel, 1977). Lamont et al. (1985) and Lamont and Spohr (1988) reported that 36 of the 37 Australian native and exotic species evaluated exhibited no phytotoxic effects or reduced shoot dry weight when oxadiazon was applied at 8 kg·ha⁻¹ (four times the recommended rate). Unacceptable plant injury has been recorded on *Ilex* spp. from oxadiazon applications at 4.5 kg·ha⁻¹ (Singh et al., 1984).

Some Australian rain forest species are becoming popular in the nursery trade where their growth habit, attractive foliage, and colorful flowers and fruit make them salable items (Jones, 1986). In subtropical Australia, these ornamental trees and shrubs are produced outdoors as long-term container crops destined for the landscaping market or reforestation programs. Phytotoxic effects of preemergence herbicides on these species are unknown.

This study evaluated the phytotoxicity of granular preemergence herbicides to rain forest species grown in containers, and assessed their efficacy on weeds prevalent in subtropical nurseries. Granular formulations of oxadiazon, oxadiazon + simazine, dichlobenil, and oxyfluorfen + oryzalin were applied at half and at one and two times the manufacturer's recommended rate: oxadiazon, 2.0, 4.0, and 8.0 kg·ha⁻¹; oxadiazon + simazine, 2.0 + 0.5, 4.0 + 1.0, and 8.0 + 2.0 kg·ha⁻¹; dichlobenil, 1.0, 2.0, and 4.0 kg·ha⁻¹; and oxyfluorfen + oryzalin, 1.1 + 0.5, 2.2 + 1.0, and 4.4 + 2.0 kg·ha⁻¹. Controls, which received no herbicide, were included for comparison.

The experimental work was conducted at the Redlands Research Station, Cleveland, Australia, a subtropical location (lat. 27°35'S, long. 153°16'E). Plants were grown in a medium consisting of 50% composted hardwood sawdust, 25% composted softwood shavings, 15% pinebark fines, and 10% medium (1-mm-diameter grains) washed sand at pH 5.8. Micronutrients (Micromax; Sierra Chemical, Milpitas, Calif.), ferrous sulfate, and isobutylidene diurea were each added at a rate of 0.5 kg·m⁻³. Nutricote Black slow-release fertilizer (16N-4.4P-8.3K, 8- to 9-month formulation) (Chisso Asohi Fertilizer Co., Tokyo) was incorporated at 7.5 kg·m⁻³ before potting all species except *C. sublimis* (Proteaceae), which received Nutricote Purple (20N-0P-10.8K, 3- to 6-month formulation) because P toxicity has been reported for some Proteaceae spp. grown in soilless media (Nichols and Beardsell, 1981). Uniform tube-stock of 10 rain forest species (Table 1) were planted in 2-liter containers on 11 Aug. 1990. Herbicide treatments were applied 4 weeks after planting and again 10 weeks later. Herbicides at treatment rates were weighed individually for each container; mixed with 20 ml dry, coarse sand; and sprinkled evenly over the soil surface. Containers were placed in full sun and irrigated daily with 500 ml water, except during wet weather. The containers were kept weed free, and plants were observed for symptoms of phytotoxicity 5 weeks after each herbicide application. Phytotoxicity was recorded

Received for publication 10 Oct. 1991. Accepted for publication 31 July 1992. I thank J. Giles for statistical analyses, K. Bodman for advice during the project, L. Mochan for technical support, Rhône-Poulenc Pty. and Nufarm for providing chemicals and plants, and J. Gage for comments during the preparation of this manuscript. Reference to trade products is for purposes of publication and does not imply approval or recommendation of the product to the exclusion of others that may be suitable. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

Table 1. Rain forest species evaluated for tolerance to preemergence herbicides.

Species	Family	Common name
<i>Acmena hemilampra</i>	Myrtaceae	Broad-leaved lilly-pilly
<i>Alphitonia excelsa</i>	Rhamnaceae	Red ash
<i>Arytera lautereriana</i>	Sapindaceae	Corduroy tamarind
<i>Cardwellia sublimis</i>	Proteaceae	Northern silky oak
<i>Dysoxylum rufum</i>	Meliaceae	Rusty bean
<i>Ficus racemosa</i>	Moraceae	Cluster fig
<i>Macaranga tanarius</i>	Euphorbiaceae	Macaranga
<i>Metrosideros queenslandica</i>	Myrtaceae	Queensland golden myrtle
<i>Polyscias elegans</i>	Araliaceae	Celerywood
<i>Syzygium fibrosum</i>	Myrtaceae	Fibrous satinash

on a scale of 1 = no plant injury (as in control), 2 = minor injury, 3 = moderate injury, 4 = severe injury, and 5 = plant died due to herbicide injury. Plant height (in millimeters) was recorded before each treatment (weeks 0 and 10) and 15 weeks later, when shoot dry weight (in grams) was also recorded. Each species represented a separate experiment—a randomized block with three replications using single-plant plots. Analysis of variance of plant height, shoot dry weight, and phytotoxicity data was performed for each experiment.

Treatment efficacy was evaluated for seven weed species in one of two trials: green amaranth, thickhead, bunchy sedge, caustic weed, asthma plant, creeping oxalis, and phyllanthus were used in trial 1; bittercress, scarlet pimpernel (*Anagallis arvensis* L.), Mexican poppy, cobbler's pegs, smooth cat's ear (*Hypochaeris glabra* L.), sago weed, and sowthistle were used in trial 2. Herbicides were applied to containers, as described above, on 25 Sept. (trial 1) and 30 Oct. (trial 2) 1990. Forty seeds of each weed species were combined with 20 ml of dry, coarse sand and sprinkled evenly over each container's surface. Containers were placed in full sun and irrigated with 250 ml water twice daily to maintain a moist surface for germination. Each trial was arranged in a randomized complete-block design with three replications of each herbicide treatment plus three nontreated controls. The number of plants of each weed species in each container was recorded 5 weeks after sowing. Weed counts were transformed by adding 0.5 and taking the square root. Analysis of variance was conducted for each weed species except scarlet pimpernel and smooth cat's ear, which failed to germinate in control pots. Weed control was considered effective if the retransformed mean number of weeds for an herbicide at a given rate was $\leq 25\%$ of the corresponding retransformed mean of the control. An effective herbicide was one that controlled $\geq 75\%$ of total weeds (Creager, 1982).

The type of herbicide used significantly influenced weed control. Oxyfluorfen + oryzalin, oxadiazon, and oxadiazon + simazine effectively controlled all weed species at 1.1 + 0.5, 2.0, and 2.0 + 0.5 kg·ha⁻¹, respectively (half the recommended rates) (data not shown); dichlobenil controlled weeds poorly (Table 2). Dichlobenil at 1.0 kg·ha⁻¹ (half the recommended rate) did not reduce populations of green amaranth, thickhead, asthma plant, and creeping oxalis. There were fewer bunchy sedge, caustic weed, phyllanthus, bittercress, and sowthistle plants at 1.0 kg·ha⁻¹,

but control was not acceptable. Twice the recommended rate of dichlobenil (4.0 kg·ha⁻¹) was required to control green amaranth and bittercress effectively.

The effect of preemergence herbicides on plant growth and phytotoxicity was species dependent. Broad-leaved lilly-pilly, rusty bean, macaranga, Queensland golden myrtle, and fibrous satinash were not affected by herbicide treatment (data not shown), while plant height and shoot dry weight of red ash decreased with increasing rates of dichlobenil (Table 3).

Phytotoxic symptoms were observed on corduroy tamarind, northern silky oak, cluster fig, and celerywood 5 weeks after herbicide treatment (Table 4). Herbicide-affected plants of susceptible species exhibited lower leaf necrosis. Curling of the new leaves also accompanied lower leaf necrosis in affected plants of celerywood, whereas all leaves on herbicide-affected plants of northern silky oak were necrotic, including the shoot tips. One application of any herbicide at the recommended rate caused minor plant injury to corduroy tamarind, cluster fig, and celerywood, except the application of oxyfluorfen + oryzalin

and dichlobenil to cluster fig, which remained uninjured (Table 4). No further phytotoxic effects were observed on treated plants of these species after herbicides were applied a second time (10 weeks later). Mean plant height of corduroy tamarind, cluster fig, and celerywood at that time was 58% $\pm$ 5%, 80% $\pm$ 7%, and 41% $\pm$ 3% greater, respectively, than at the first application. Therefore, the phytotoxic effect may have been less after the second application because plants were larger; hence, the dose of herbicide per shoot or root weight was reduced.

Northern silky oak was highly susceptible to preemergence herbicides, with moderate injury recorded after the first application and severe injury after the second, even at half the recommended rates. The Proteaceae may be particularly susceptible to preemergence herbicides, since other members of this family—*Grevillea*, *Protea*, *Leucospermum*, and *Banksia*—are also reported to be sensitive. Lamont and Spohr (1988) reported that container-grown *Grevillea hookeriana* Meisner and *G. juniperina* R.Br. $\times$ *G. rosmarinifolia* Cunn. 'Pink Lady' exhibited marginal leaf necrosis and had reduced dry weight when oxadiazon + simazine was applied at 4.0 + 1.0 kg·ha⁻¹, while *G. laurifolia* Sieber ex Sprengel $\times$ *G. willisii* R.V. Smith and McGillivray 'Royal Mantle' was more sensitive, with plant injury occurring at 2.0 + 0.5 kg·ha⁻¹. In another study, plant growth of *Protea neriifolia* R. Br. 'Pink Mink' was reduced in field plantings after application of oryzalin, alone and with simazine, at 4.5 and 3.5 + 1.1 kg·ha⁻¹, respectively (Besemer and Elmore, 1987). Field-grown *Banksia* and *Leucospermum* spp. were also damaged by simazine (Nishimoto, 1975).

Table 2. Effect of dichlobenil preemergence herbicide applied at half and one and two times the manufacturer's recommended rate of 2.0 kg·ha⁻¹ on the number of weeds per pot.²

Species	$\sqrt{\text{No. weeds} + 0.5 \text{ per pot}}$			
	Amount applied (kg·ha ⁻¹)			
	1.0	2.0	4.0	0
Trial 1				
<i>Amaranthus viridis</i> L. (green amaranth)	2.15 b	2.38 b	1.17 a	2.29 b
<i>Crassocephalum crepidioides</i> Benth. (thickhead)	2.32 b	1.00 a	1.00 a	2.39 b
<i>Cyperus polystachyos</i> L. (bunchy sedge)	1.72 a	1.25 a	0.88 a	2.10 b
<i>Euphorbia drummondii</i> Boiss (caustic weed)	1.68 a	1.10 a	1.29 a	2.81 b
<i>Euphorbia hirta</i> L. (asthma plant)	1.17 b	0.70 a	0.70 a	1.76 b
<i>Oxalis corniculata</i> L. (creeping oxalis)	1.10 b	0.70 a	0.70 a	1.10 b
<i>Phyllanthus tenellus</i> Roxb. (phyllanthus)	1.56 b	0.70 a	0.70 a	2.04 c
Trial 2				
<i>Cardamine hirsuta</i> L. (bittercress)	1.34 b	1.48 b	0.88 a	1.77 c
<i>Argemone mexicana</i> L. (Mexican poppy)	0.70 a	0.70 a	0.87 b	1.90 b
<i>Bidens pilosa</i> L. (cobbler's pegs)	1.93 b	1.17 a	1.27 ab	6.05 c
<i>Plantago varia</i> R. Br. (sago weed)	0.88 a	0.88 a	0.88 a	1.95 b
<i>Sonchus oleraceus</i> L. (sowthistle)	1.34 b	1.17 b	0.70 a	2.10 c

²Mean separation within rows by LSD at $P \leq 0.05$.

Table 3. Effect of preemergence herbicides on red ash shoot dry weight and plant height.^z

Herbicide	Amount applied (kg·ha ⁻¹)	Shoot dry wt (g)	Plant ht (mm)
Oxadiazon	2.0	54.8 c	875 bc
	4.0	46.8 bc	790 ab
	8.0	46.8 bc	843 a-c
Oxadiazon + simazine	2.0 + 0.5	48.5 bc	850 a-c
	4.0 + 1.0	55.0 c	817 a-c
	8.0 + 2.0	42.0 ab	865 bc
Oxyfluorfen + oryzalin	1.1 + 0.5	42.0 ab	740 a
	2.2 + 1.0	48.0 bc	823 a-c
	4.4 + 2.0	48.7 bc	892 bc
Dichlobenil	1.0	54.7 b	878 bc
	2.0	43.8 b	827 a-c
	4.0	33.0 a	737 a
Nontreated control		54.5 c	911 c

^zMean separation within columns by LSD at $P \leq 0.05$.

As with other members of the Proteaceae, northern silky oak has specialized proteoid roots that form in dense clusters near the soil surface and are believed to play a role in selective nutrient uptake (Jeffrey, 1967; Vorster and Jooste, 1986). Proteoid roots may also be more metabolically active than ordinary roots (Smith and Jooste, 1986). To account for the high incidence of plant injury after application of oxadiazon in combination with simazine, Lamont and Spohr (1988) proposed that proteoid roots in *Grevillea* may be more efficient in absorbing simazine than oxadiazon. Simazine is readily translocated from roots to plant shoots, where it inhibits photosynthesis (Black, 1985; de Prado et al., 1990), while oxadiazon and other herbicides such as oryzalin, oxyfluorfen, and dichlobenil translocate to a limited extent and are known to increase cell membrane permeability at absorption sites (Balke, 1985). The proteoid root system of northern silky oak (which was observed to be present on the test plants) may be particularly efficient at absorbing a range of herbicides, and/or this species may be particularly sensitive to the herbicides tested. Both factors could have contributed to the overall severity of symptoms observed in this species.

Oxyfluorfen + oryzalin, oxadiazon, and oxadiazon + simazine provided excellent weed control at half the recommended rates (applied

at 1.1 + 0.5, 2.0, and 2.0 + 0.5 kg·ha⁻¹, respectively), with no plant injury or retardation of plant growth, during 10 weeks on all of the rain forest species tested, except northern silky oak. Further research is required to determine the mechanism of herbicide sensitivity in the Proteaceae to find safe herbicide practices for northern silky oak and other family members.

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Table 4. Phytotoxicity rating^z on four rain forest species from four granular herbicides evaluated 5 weeks after two 1990 application dates.^{y,x}

Treatment	Amount applied (kg·ha ⁻¹)	Corduroy tamarind		Northern silky oak		Cluster fig		Celerywood	
		Sept.	Dec.	Sept.	Dec.	Sept.	Dec.	Sept.	Dec.
Oxadiazon	2.0	3.3 b	1.0 a	3.3 b	4.7 b	1.7 ab	1.0 a	3.0 b	1.7 ab
	4.0	2.7 ab	1.0 a	3.3 b	4.3 b	2.7 b	1.0 a	3.0 b	1.7 ab
	8.0	3.3 b	2.3 a	3.3 b	5.0 b	1.7 ab	1.0 a	2.0 ab	2.0 a-c
Oxadiazon + simazine	2.0 + 0.5	2.0 ab	2.7 a	3.0 b	4.7 b	1.3 ab	1.0 a	1.7 ab	1.0 a
	4.0 + 1.0	3.3 b	1.7 a	2.7 ab	4.7 b	2.7 b	1.0 a	2.7 ab	1.0 a
	8.0 + 2.0	3.0 b	1.7 a	3.7 b	5.0 a	1.0 a	1.0 a	3.7 b	3.0 c
Oxadiazon + oryzalin	1.1 + 0.5	3.7 b	1.0 a	3.3 b	5.0 b	1.0 a	1.0 a	1.0 a	1.0 a
	2.2 + 1.0	3.7 b	2.0 a	2.3 ab	4.7 b	1.0 a	1.0 a	3.0 b	2.3 bc
	4.4 + 2.0	2.3 ab	1.0 a	3.0 b	4.7 b	1.0 a	1.0 a	2.0 ab	1.0 a
Dichlobenil	1.0	2.3 ab	1.7 a	3.3 b	5.0 b	1.0 a	1.0 a	1.0 a	1.0 a
	2.0	3.0 b	1.7 a	3.0 b	5.0 b	1.7 ab	1.0 a	3.3 b	1.7 ab
	4.0	3.7 b	1.0 a	3.7 a	4.7 b	1.0 a	1.0 a	2.7 ab	1.7 ab
Nontreated control		1.0 a	1.0 a	1.0 a	1.0 a	1.0 a	1.0 a	1.0 a	1.0 a

^zPhytotoxicity rating: 1 = no plant injury (control), 2 = minor injury, 3 = moderate injury, 4 = severe injury, and 5 = plant death due to herbicide.^yMean separation within columns by LSD at $P \leq 0.05$.^xSpecies not mentioned rated 1.0 (no plant injury) for all herbicides and both evaluation dates.