Safety and efficacy of pre-emergent herbicides in container-grown Australian plants

Manfred Jusaitis, Black Hill Flora Centre, Botanic Gardens of Adelaide, Maryvale Road, Athelstone, South Australia 5076, Australia.

Summary

The safety and efficacy of eight pre-emergent herbicides were evaluated for 18 species (representing nine families) of Australian native plants grown in containers. The herbicides included oxadiazon, chlorthal dimethyl, oxyfluorfen, oryzalin, oryzalin + trifluralin, isoxaben + oryzalin, isoxaben + trifluralin and benfluralin + oryzalin. Oxyfluorfen produced early phytotoxic symptoms on most of the species tested, although the majority outgrew these symptoms before day 85. Species from the families Gramineae and Proteaceae were particularly susceptible to herbicide injury and especially to treatments containing oryzalin at 3 kg ha^{-1} or greater. For the 18 species tested, the optimal combination of safety and efficacy was obtained following oxadiazon (4 kg ha^{-1}) or isoxaben + trifluralin (2 kg ha^{-1}) treatments. Isoxaben + oryzalin (4 kg ha^{-1}) and oryzalin (3.4 kg ha^{-1}) also produced effective weed control and were safe on all species except those belonging to the Gramineae and Proteaceae.

Introduction

While methods of chemical weed control in ornamentals are largely well documented in the literature, reports specifically dealing with container-grown plants are few and mostly restricted to species exotic to Australia (Schubert *et al.* 1986). With growing interest in nursery production of Australian plants for garden, landscaping, cut-flower or foliage use comes the requirement for safe and efficacious weed control during the containerized stages of production. Furthermore, the next decade will see large numbers of endangered plants raised for reintroduction into native habitats. To ensure that weeds are not introduced in association with these plants, absolute weed control in containers will become imperative.

Since earlier studies on weed control in Australian plants (Lamont *et al.* 1985, Watkins 1986), several popular herbicides have been removed from the market, while new ones have appeared. The susceptible weed spectrum is generally well established by the time newly developed herbicides are released, but information on crop safety is invariably restricted to economically important species which warrant immediate label inclusion. This paper sets out to examine the safety and to compare the efficacy of several well established (e.g., oxadiazon, oryzalin) and some newly developed (e.g., isoxaben, benfluralin) pre-emergent ornamental herbicides in a range of containerized Australian species. Eighteen genera covering nine families were chosen to include species important as cut flowers (*Ixodia achillaeoides* ssp. *alata*), ornamental grasses (*Dichantheum sericeum*, *Enneapogon nigricans*), garden (*Correa pulchella*, *Grevillea biternata*, *Thryptomene saxicola*, *Westringia* 'Wynyabbie Gem') or landscape (*Eucalyptus caesia*, *Hakea victoriae*, *Acacia calamifolia*) plants and endangered species (*Prostanthera eurybioides*).

Materials and methods

Between January and June 1989, eight pre-emergent herbicides (Table 1) were evaluated for phytotoxicity and weed control on 18 container-grown Australian native species. Uniform plants (approximately 150 mm high) raised from seed or from cuttings (Table 2) were planted into a mixture of Mount Compass scrub sand, peat moss and vermiculite (3:1:1) supplemented with 250 g m^{-3} of Micromax and 1 kg m^{-3} Osmocote (8–9 month, 17N-1.6P-8.7K) in 1.1 litre plastic pots. Herbicide treatments were applied to plants at the rates shown in Table 1 immediately after potting. Pre-weighed quantities of granular herbicides were applied manually to the surface of pots, while WP, EC and DF formulations were applied over the top of plants using a calibrated LP gas-pressurized backpack sprayer delivering 150 litre ha^{-1}. Pots were placed outdoors on frames and were watered for 20 minutes by overhead sprinklers immediately following herbicide treatment. This watering regime was repeated every two days during summer.

Five days after herbicide treatment, seeds of the most ubiquitous weeds in adjacent nursery pots were collected, mixed with sand and sown evenly over the pots to provide an initially uniform weed population to test herbicidal activity. Weed species included the willow herb (*Epilobium ciliatum*), spike centaury (*Centaurium spicatum*), jersey cudweed (*Pseudognaphalium luteo-album*), prickly lettuce (*Lactuca serriola*) and sow thistle (*Sonchus oleraceus*). As *D. sericeum* and *E. nigricans* plants flowered and set seed during the course of the experiment, self-sown seedlings of these species provided an additional weed inoculum to all pots, so that weed counts included broadleaf and grass weed species.

The experimental design was a split-plot consisting of four blocks with species as whole units and herbicides as sub-units. The experimental unit was a single pot of each species. Visual injury was assessed 5, 20 and 85 days after spraying, using a rating scale from 0 to 10 (0 = no injury, 10 = death of plant). Data (minus controls) were subjected to analysis of variance and means for individual species were separated using least significant differences at P=0.05. The number of weeds in each pot was recorded 50 and 85 days after treatment and results pooled for each herbicide. Weed counts were transformed using the square root transformation prior to analysis of variance.

Results

The results of phytotoxicity assessments 5 or 20 days after herbicide treatment are presented in Table 2. For both assessments there were highly significant effects of, and interactions between, species and herbicide (P<0.001). Of the herbicides tested, oxyfluorfen produced the greatest degree of phytotoxicity, with all species except *Calytrix tetragona* being affected to a greater or lesser extent by day 5. Typical symptoms included leaf spotting and/or degeneration of apical tissue. Plants

Table 1. Herbicide formulations and application rates.

Herbicide	Active ingredient	Formulation[1] (%)	Application rate (kg a.i. ha^{-1})
A Ronstar	oxadiazon	2 G	4.0
B Dacthal	chlorthal dimethyl	75 WP	12.5
C Goal CT	oxyfluorfen	24 EC	1.0
D Yield	trifluralin + oryzalin	12.5 + 12.5 EC	1.0
E Surflan	oryzalin	85 DF	3.4
F Snapshot DF	isoxaben + oryzalin	20 + 60 DF	4.0
G Snapshot G	isoxaben + trifluralin	0.4 + 2 G	2.0
H Balan + Surflan	Benfluralin + oryzalin	20 EC + 85 DF (tank-mix)	1.2 + 1.2

[1]DF = dry flowable, EC = emulsifiable concentrate, G = granules, WP = wettable powder.

Table 2. Phytotoxicity of container-grown ornamentals to pre-emergent herbicides 5 and 20 days after treatment. Phytotoxicity was visually assessed using a rating scale from 0–10, where 0 = no injury and 10 = death of plant. Letters for herbicide treatments correspond to those in Table 1.

		Herbicide								LSD
Family	Species	A	B	C	D	E	F	G	H	(P=0.05)
		Day 5								
Compositae	*Helichrysum apiculatum*	0.0	0.0	4.8	0.0	0.0	0.0	0.3	0.0	1.1
	Ixodia achillaeoides[1]	0.3	0.0	3.5	0.3	0.3	1.0	0.0	0.8	1.2
Goodeniaceae	*Goodenia varia*	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.3
Gramineae	*Dichantheum sericeum*[1]	0.0	0.0	7.0	2.5	2.8	1.5	0.3	2.3	1.3
	Enneapogon nigricans[1]	0.5	0.0	6.3	1.5	1.3	1.8	0.0	1.0	1.1
Labiatae	*Prostanthera eurybioides*	0.0	0.5	2.8	0.0	0.5	1.0	0.0	0.8	1.0
	Westringia 'Wynyabbie gem'[2]	0.0	0.0	2.8	0.0	0.0	0.0	0.0	0.0	0.5
Leguminosae	*Acacia calamifolia*[1]	0.0	0.0	4.0	0.0	0.0	0.0	0.3	0.5	0.8
Myoporaceae	*Eremophila polyclada*	0.0	0.0	3.8	1.3	1.0	0.3	0.3	0.8	1.2
Myrtaceae	*Callistemon rugulosus*[1]	0.0	0.3	1.3	0.0	0.0	0.0	0.0	0.3	0.6
	Calytrix tetragona	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–
	Eucalyptus caesia[1]	0.0	0.0	4.5	1.5	0.0	0.0	0.0	0.5	0.7
	Kunzea pomifera	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.7
	Melaleuca decussata[1]	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.3
	Thryptomene saxicola	0.0	0.3	2.5	0.0	0.0	0.0	0.0	0.0	0.4
Proteaceae	*Grevillea biternata*	0.0	0.0	4.3	0.1	1.3	1.5	0.0	0.9	0.9
	Hakea victoriae[1]	0.0	0.0	3.5	1.4	0.5	1.6	0.0	0.6	1.2
Rutaceae	*Correa pulchella*	0.0	0.0	4.0	1.3	0.8	0.0	0.0	0.0	1.0
		Day 20								
Compositae	*Helichrysum apiculatum*	0.0	0.0	2.5	0.0	1.0	4.3	0.5	0.0	1.3
	Ixodia achillaeoides	0.0	0.0	2.0	0.0	0.3	0.0	0.0	0.0	1.2
Goodeniaceae	*Goodenia varia*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–
Gramineae	*Dichantheum sericeum*	0.5	1.0	3.8	2.3	2.5	1.5	0.5	1.5	1.4
	Enneapogon nigricans	1.5	0.4	3.0	1.3	1.3	1.3	0.0	0.3	1.1
Labiatae	*Prostanthera eurybioides*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–
	Westringia 'Wynyabbie gem'	0.0	0.0	1.8	0.0	0.0	0.0	0.3	0.0	0.7
Leguminosae	*Acacia calamifolia*	0.0	0.0	4.5	0.0	0.0	0.0	0.0	0.0	0.3
Myoporaceae	*Eremophila polyclada*	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.8
Myrtaceae	*Callistemon rugulosus*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–
	Calytrix tetragona	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.4
	Eucalyptus caesia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–
	Kunzea pomifera	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.5
	Melaleuca decussata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–
	Thryptomene saxicola	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–
Proteaceae	*Grevillea biternata*	0.0	0.0	4.8	0.5	1.3	1.3	0.0	0.3	0.7
	Hakea victoriae	0.0	0.0	4.0	0.1	0.5	4.5	0.0	0.5	0.9
Rutaceae	*Correa pulchella*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–

[1] These species were raised from seed. The remainder were struck from cuttings.
[2] *Westringia* 'Wynyabbie Gem' is a hybrid of *W. fruticosa* x *W. eremicola.*

worst affected were members of the Gramineae, with severe necrosis of leaf and sheath tissue, particularly on *D. sericeum*. *Goodenia varia* and *C. tetragona* were relatively tolerant to oxyfluorfen, although by day 20 the latter developed delayed injury symptoms in the form of some stem-tip necrosis.

Herbicides displaying least phytotoxicity included oxadiazon, chlorthal dimethyl and isoxaben + trifluralin. Each of these herbicides, however, produced some delayed phytotoxicity on ornamental grasses (the former two) or on *Helichrysum apiculatum*, *D. sericeum* and *Westringia* 'Wynyabbie Gem' (the latter) by day 20. Typical phytotoxic symptoms of sprayed formulations were leaf spotting and occasionally leaf-tip burn, while granular formulations produced tip burn of younger leaves. Where phytotoxicity was observed on day 5, it had generally decreased by day 20 for the majority of species as they outgrew their injury symptoms. However the Proteaceae exhibited increased oxyfluorfen-induced damage after 20 days, as did *A. calamifolia* and *C. tetragona*. As a group, the Gramineae were least tolerant of the herbicides tested, followed closely by the Proteaceae (Table 2). Species displaying no phytotoxicity by day 20 included *G. varia*, *P. eurybioides*, *Callistemon rugulosus*, *E. caesia*, *Melaleuca decussata*, *T. saxicola* and *C. pulchella.*

By 85 days after treatment, most species had completely outgrown any herbicidal damage evident in the earlier two assessments. Exceptions were members of the Proteaceae and Gramineae, which sustained long-term damage when treated with oryzalin (3.4 kg ha^{-1}) or isoxaben +

Table 3. Phytotoxicity of Proteaceae and Gramineae to pre-emergent herbicides 85 days after treatment. Phytotoxicity was visually assessed using a rating scale from 0–10, where 0 = no injury and 10 = death of plant. Letters for herbicide treatments correspond to those in Table 1.

	Herbicide								
Species	A	B	C	D	E	F	G	H	LSD (P=0.05)
Grevillea biternata	0.0	0.0	2.0	0.0	6.4	8.8	0.0	0.0	2.6
Hakea victoriae	0.0	2.5	1.5	2.5	10.0	10.0	4.5	0.5	4.6
Dichanthium sericeum	0.0	0.3	0.5	1.3	4.8	4.8	1.0	1.0	1.9
Enneapogon nigricans	0.5	1.0	1.0	0.5	4.5	2.5	2.5	1.3	2.4

oryzalin (4 kg ha^{-1}). These treatments resulted in death of *H. victoriae* and produced severe injury and growth retardation in *G. biternata* and in the two grasses studied (Table 3). Less damage was sustained following isoxaben + trifluralin (2 kg ha^{-1}) treatment, possibly due to the lower rate of active ingredient applied and the absence of oryzalin in this treatment.

Optimal weed control after 50 days was recorded following oxadiazon (98%) and isoxaben + oryzalin (95%) treatments (Table 4). Both treatments sustained acceptable weed control over 85 days. Oxyfluorfen, oryzalin, isoxaben + oryzalin, isoxaben + trifluralin and benfluralin + oryzalin also produced significant levels of weed control at day 50, but the latter two herbicides were beginning to fail by day 85 and higher application rates would be required to extend their weed control over this period. Chlorthal dimethyl and trifluralin + oryzalin produced unacceptable weed control at the rates tested and by day 85 they, together with benfluralin + oryzalin, were indistinguishable from controls.

Discussion

Phytotoxicity was found to vary markedly with the plant species treated and the herbicide applied (Table 2). Oxyfluorfen almost universally produced early phytotoxic symptoms on the plants tested. Similar effects of oxyfluorfen have been reported on field-grown cut flowers (Lamont and O'Connell 1986) and on a range of container-grown ornamentals (Watkins 1986). While rates as low as 0.5 kg ha^{-1} have given effective weed control in containerized plants (Watkins 1986), further reduction in rates to 0.24 kg ha^{-1} or less was required before phytotoxicity reached acceptably low levels (Webb 1991). Weller *et al.* (1984) showed that the formulation of oxyfluorfen was also important in determining safety, with the WP formulation producing least injury and EC and G formulations causing greater injury. For the majority of species tested in the present trial, full plant vigour was re-established by day 20 following oxyfluorfen spray.

The herbicides producing least phytotoxicity were oxadiazon and isoxaben + trifluralin (Tables 2 and 3). Coincidentally, these herbicides were both applied as granular formulations, and their safety may be at least partially due to the absence of direct foliar contact by the herbicides during application. The slower root uptake of granular formulations compared with the relatively rapid foliar uptake of sprayed formulations may also explain the delayed but transient phytotoxicity observed in ornamental grasses treated with oxadiazon. Oxadiazon has proven non-phytotoxic on a range of Australian native species (Webb 1991, Lamont *et al.* 1985, Lamont and Spohr 1988) and field-grown cut flowers (Gilreath 1989, Lamont and O'Connell 1986), although the EC formulation produced damage when applied to recently potted up ornamentals, due to direct contact of the herbicide with young foliage (Watkins 1986).

The majority of species showing early symptoms of phytotoxicity (Table 3) had recovered by day 85. Two groups in particular (Proteaceae and Gramineae) were notable for their sustained display of phytotoxic symptoms. These plants were particularly susceptible to oryzalin (3.4 kg ha^{-1}) and isoxaben + oryzalin (4 kg ha^{-1}) treatments which produced severe injury or death of the proteaceous species tested and severely retarded growth and development of the ornamental grasses (Table 3). Similar findings on grasses were reported by Neal and Senesac (1991) who noted severe injury in a range of ornamental grasses sprayed with oryzalin at 2.2 or 4.5 kg ha^{-1} or isoxaben + oryzalin at 3.4 or 4.5 kg ha^{-1} . Isoxaben alone or in combination with trifluralin caused no injury and so this phytotoxicity was attributed to oryzalin (Neal and Senesac 1991). Indeed, treatments receiving low rates of oryzalin (1.2 kg ha^{-1} or less) were not as prone to injury as those receiving 3 kg ha^{-1} or more (Table 3). While isoxaben + trifluralin was safe for use on *D. sericeum*, some slight injury was sustained by *E. nigricans* after 85 days (Table 3). Lamont and Spohr (1988) described severe leaf burn and stunting of four species of Grevillea treated with oxadiazon + simazine at several rates. They suggested that the specialized proteoid roots present in the proteaceae may be more efficient at absorbing herbicides, making this group generally more susceptible to herbicide injury than other non-proteoid rooted plants.

Weeds and ornamental plants vary greatly in their competitiveness; not all weeds significantly reduce plant growth (Berchielli-Robertson *et al.* 1990). Nevertheless it is generally believed that weed free pots are essential for optimal marketability, if not always for the reduced plant competition they may enjoy. Herbicidal efficacy and safety are therefore equally important when selecting cost-effective treatments. For the majority of species tested, both criteria were met by the following herbicides: oxadiazon, oxyfluorfen, oryzalin, isoxaben + oryzalin and isoxaben + trifluralin. Restrictions on this list need to be made for ornamental grasses and for Proteaceae; oxadiazon was the only herbicide to adequately fulfil both criteria for these plant groups.

Isoxaben, a member of the benzamide group of compounds, appears to have excellent potential as an ornamental herbicide, either alone or in combination with dinitroanilines to extend its effective

Table 4. Effects of pre-emergent herbicides on weed control 50 and 85 days after treatment.

	Day 50		Day 85	
Herbicide	Weeds/pot[1]	%[2]	Weeds/pot	%
Oxadiazon	1.07	98.1	1.52	88.7
Chlorthal dimethyl	2.43	39.9	3.06	36.0
Oxyfluorfen	1.46	85.0	2.07	72.7
Trifluralin + oryzalin	2.05	55.3	2.88	41.6
Oryzalin	1.57	78.3	2.43	60.5
Isoxaben + oryzalin	1.17	95.2	1.99	75.3
Isoxaben + trifluralin	1.56	80.5	2.58	53.0
Benfluralin + oryzalin	1.93	61.0	2.91	41.6
Control	3.06	–	3.78	–
LSD (P=0.05)	0.97		0.96	

[1] Weed counts are presented as SQRT (number of weeds+1).
[2] Percentage of control.

weed-control spectrum. Only low rates of isoxaben (1 and 0.3 kg ha^{-1}) were tested in this trial in combination with oryzalin and trifluralin respectively. However, newly planted ornamentals have tolerated up to 2.24 kg ha^{-1} isoxaben (Colbert and Ford 1987). Although control of annual grasses was found to be generally poor at rates less than 0.84 kg ha^{-1} (Neal and Senesac 1990), combinations of isoxaben with trifluralin or oryzalin provided good control of annual grasses and broadleaf weeds (Table 4, Derr 1989, Neal and Senesac 1990).

Chlorthal dimethyl, trifluralin + oryzalin and benfluralin + oryzalin, while safe on the majority of species at the rates tested, were inferior in their weed control. Fretz (1976) reported unacceptable weed control with chlorthal dimethyl and Gilreath (1989) found oxadiazon and oxyfluorfen to be superior to chlorthal dimethyl, in agreement with this study. Some evidence suggests that efficacy of chlorthal dimethyl can be seasonal, with improved weed control occurring during summer as compared to winter (Lamont and O'Connell 1986).

The results presented here suggest that safe and efficacious weed control can be achieved in container-grown, native Australian plants using a range of pre-emergent herbicides. Early symptoms of phytotoxicity produced by some herbicides usually disappeared with time, resulting in little or no setback in plant growth and appearance. Caution, however, should be exercised in herbicide selection for some plant families, notably the Proteaceae and Gramineae.

Acknowledgments

I wish to thank Kelvin Holliday for technical assistance, Dr. Barry Lowe (Elanco) for supply of Snapshot formulations, Surflan and Yield, John Hall (Monsanto) for Goal CT, Peter Philp (AgChem) for Dacthal and Bill McHenry (Schering) for Balan. Special thanks to John Hall for assistance with herbicide application.

References

Berchielli-Robertson, D.L., Gilliam, C.H. and Fare, D.C. (1990). Competitive effects of weeds on the growth of container-grown plants. *HortScience* 25, 77-9.

Colbert, F.O. and Ford, D.H. (1987). Isoxaben for broadleaf weed control in ornamentals, turf and non-bearing trees and vines. Proceedings Western Society of Weed Science 40, 155-63.

Derr, J.F. (1989). Herbicide update for container weed control. Proceedings of the International Plant Propagators Society 38, 584-6.

Fretz, T.A. (1976). Herbicide performance on transplanted annual bedding plants. *HortScience* 11, 110-11.

Gilreath, J.P. (1989). Pre-emergence weed control in statice. *HortScience* 24, 794-6.

Lamont, G.P. and O'Connell, M.A. (1986). An evaluation of pre-emergent herbicides in field-grown cut flowers. *Plant Protection Quarterly* 1(3), 95-100.

Lamont, G.P. and Spohr, L.J. (1988). Evaluation of oxadiazon and simazine for weed control and phytotoxicity in container-grown ornamental plants. *Scientia Horticulturae* 34, 93-9.

Lamont, G.P., O'Connell, M.A. and Nicholls, P.J. (1985). An evaluation of pre-emergent herbicides for container-grown ornamental plants. *Scientia Horticulturae* 26, 241-51.

Neal, J.C. and Senesac, A.F. (1990). Summer annual and winter annual weed control in field soil and soil-less media with Gallery (isoxaben). *Journal of Environmental Horticulture* 8, 124-7.

Neal, J.C. and Senesac, A.F. (1991). Pre-emergent herbicide safety in container-grown ornamental grasses. *HortScience* 26, 157-9.

Schubert, O.E., Creager, R.A., Frank, J.R., Schubert, P.R., Schubert, G.E. and Eisenbeiss, G.K. (1986). A compendium of chemical weed control research in ornamentals in the United States (1944-1985). *HortScience* 21(2), 1-137 (Suppl.).

Watkins, P. (1986). Weed control in ornamental plants. *Australian Horticulture* 84(7), 92-102.

Webb, M.G. (1991). Weed control in Australian native plants and South African proteas. Proceedings of the International Plant Propagators Society 40, 41-4.

Weller, S.C., Masiunas, J.B. and Carpenter, P.L. (1984). Evaluation of oxyfluorfen formulations in container nursery crops. *HortScience* 19, 222-4.