Efficacy of some grass specific herbicides in controlling exotic grass seedlings in native grassy vegetation

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Summary

In a series of experiments the efficacy of grass specific herbicides (ethofumesate, sethoxydim and fluazifop) were evaluated for their ability to remove exotic grass seedlings amongst native grasses. In glasshouse seedling trials the three herbicides applied at varying rates to native and exotic species had no marked selectivity. When the same herbicides were applied at varying rates to vigorously growing mature tussocks of native species outright mortality was low in most instances. Canopy dieback, however, ranged from slight to severe indicating that tolerance was not absolute. In the final experiment, fluazifop was trialled in a grassy woodland community north of Melbourne. Under semi-natural conditions canopy dieback occurred amongst all native grasses tested but mortality was low. Regrowth was evident 36 weeks after treatment for all species other than *Poa morrissii* Vick. Grass weed seedling cohorts were completely controlled with the exception of *Vulpia bromoides* (L.) Gray*. This study indicates that the herbicide fluazifop may be useful in the management of remnant grassy vegetation.

Introduction

Throughout much of south eastern Australia, grassy vegetation, be it grassland per se, or the grass dominated understorey associated with various woodland communities, is seriously threatened by introduced grass weeds. These weeds vary considerably in their ecological and morphological characteristics and the degree of threat they pose to indigenous plant communities. Relatively small growing, seasonal gap colonisers such as *Aira cupaniana* Guss.*, compete for resources previously utilized by native forbs and may reduce recruitment success in some species, but do not appear to directly threaten established plants of indigenous dominants such as *Themeda triandra* Forssk. or *Chrysocephalum apiculatum* (Labill.) Steetz. At the other pole of the grass weed spectrum are highly productive, large growing perennial grasses such as *Phalaris* species* and *Nassella neesiana* (Trin. and Rupr.) Pohl* that advance along an invasion front, eventually eliminating most native grasses and forbs. Most introduced grass weeds associated with semi-natural vegetation lie somewhere between these two extremes.

The need to control grass weeds should primarily be based on an objective assessment of the capacity of the introduced species to significantly diminish the biological values of a plant community. Large perennial species such as *Phalaris**, whose presence leads to the obliteration of native species, command the highest priority for control. In some cases consideration should also be given to the degree to which the characteristic appearance of the vegetation has been affected. This latter aspect will become more important as mixed communities of native and exotic species (the synthetic vegetation of Bridgewater 1990) become recognized as a virtual inevitability in many situations.

Within the literature associated with the management of natural and semi-natural grassy vegetation, fire has often been seen as the most appropriate means by which to manage grass weeds (for example, Stuwe and Parsons 1977). Grass weeds whose seed does not exhibit long term dormancy or has poor capacity to be incorporated into the soil and subjected to enforced dormancy, for example *Bromus* spp.*, are likely to be better controlled by fire than species that develop persistent seed banks. McDougall (1989) and Lunt (1990) recorded abundant germination of *Vulpia bromoides* (L.) Gray* following a grassland fire suggesting this species forms a persistent seed bank.

As a weed management tool in this context, fire suffers from a number of disadvantages:

i. It is often difficult to employ in urban and urban fringe landscapes due to community concerns of damage to property and persons.

ii. It does not effectively control established perennial grass weeds and may even increase their dominance. The latter may happen where perennial grass weeds recruit from seed in the soil seed bank, or where they resprout more rapidly after fire than do native species.

iii. At the intensities typically permissible in vegetation management fires, only a percentage of the soil seed bank of introduced grass weeds is likely to be eliminated. In Western Australia, the use of fire as a means of controlling grass weeds such as *Ehrharta calycina* Smith* has proved to be counterproductive and has been largely abandoned as a weed management technique in conservation reserves (Kings Park Board 1989).

iv. Annual burning for three to seven years is likely to be necessary to eliminate grass weeds with persistent seed banks. This presents several difficulties in practice: the politics of fire as previously mentioned; the availability of sufficient fuel to achieve a fire of adequate intensity each year; and the impact that annual burning may have on the recruitment potential of indigenous plants, both woody and herbaceous.

Despite these problems the low frequency of many annual grass weeds from the annually burnt native grassland communities of western Victorian roadsides suggests that this can be a highly effective weed control technique for this group of grasses.

Some of the alternative weed management techniques that have been suggested are various forms of cutting and the use of herbicides. The use of a “whipper snipper” to remove the inflorescence of annual grasses after anthesis, but prior to the formation of viable seed, has been suggested as a means of exhausting the seed bank of the annual grass *Briza maxima* L.* (McMahon 1991).

Herbicides have become increasingly used in the management of native vegetation during the past decade, despite the reservations of some conservation managers. The paradox of the increasing use of herbicides in conservation management at a time of growing pressure from the popular ecological lobby to restrict or ban their use elsewhere has been discussed by Hitchmough (1991). As with fire and all other weed control techniques, in conservation management, herbicides are a mixture of positives and negatives. The real value of herbicides as management tools can only be realised in most cases when integrated with fire and other weed control strategies.

To date, most chemical control of grass weeds in semi-natural vegetation has involved the use of non-selective herbicides such as glyphosate, applied selectively to weed foliage by spot spraying, hand or boom mounted wick wipers. With established plants of large tussock forming

Footnote:
* introduced taxa. Research conducted between 1988 and 1992 in association with Victorian College of Agriculture and Horticulture, Burnley.

species this can be very effective, although by the time the weed grasses are large enough to be effectively targeted, much of the adjacent indigenous vegetation may have been eliminated. It would be better to control both annual and perennial grass weeds whilst at the seedling stage and at their most sensitive to applied herbicides, allowing low herbicide concentrations to be used. This may be achieved by overspraying with selective herbicides that kill or damage the grass weeds, but cause only minimal damage to the native grasses.

The management of grass weed invasion in native grassy vegetation therefore requires that herbicides be identified that are capable of functioning as genuine selectives at the following levels:

i. control of grass seedlings (3–5 leaf stage) growing amongst native grasses at the same developmental stage;
ii. control of 3–5 leaf stage seedlings of grass weeds growing amongst established tussocks of native grass species;
iii. control of established weed grasses growing amongst established tussocks of native grass species.

This paper describes a series of experiments that review the first two of these levels of herbicide selectivity.

Experiment 1. Tolerance of native and exotic grass seedlings (3–5 leaf stage) to three grass specific herbicides

Materials and methods

The study was conducted over a three month period in 1988 to assess the phytotoxic effects of three grass specific herbicides ethofumesate (Tramat), sethoxydim (Sertin 186EC) and fluazifop (Fusilade 212) at three application rates (0.5, 1 and 2 times recommended rates for seedling grass control) on a range of native and exotic seedling grass species of significance in native grassland management.

Grass seed was sown in 100 mm pots and placed in a greenhouse with a daily watering regime. The growing medium was a pine bark potting mixture containing a slow release fertilizer. Emerging seedlings were culled to promote even-aged replicates of 25 seedlings per pot, with four pots per treatment and a control. The grasses were sprayed at the 3–5 leaf stage with pots remaining unwatered for 24 hours after spraying. Post spraying germinants were removed.

The effects of the herbicides were assessed visually and by statistical analyses of dry weights eight weeks after spraying. Visual assessments of chlorosis, necrosis and turgidity were made each six days after spraying, according to the criteria set out in Table 1. The visual rating, although subjective and not statistically analysed, allows an assessment of plant responses.

Table 1. Visual rating of damage to foliage.

Rating	Criteria	
4	Plant Appears healthy	No Damage
3	Plant exhibiting damage to approx. 50% of tissue	Moderate damage
2	Plant exhibiting damage to approx. 75% of tissue	Severe damage
1	Plant exhibiting damage to 100% of tissue	Death

Replicates not killed by treatments were decapitated at soil level at the termination of the experiment (eight weeks after spraying) and placed into separate bags for dry weighting and statistical analysis.

The effects of different rates of application and the control were assessed with an Analysis of Variance with a post hoc comparison LSD test. Where raw data existed for only a single treatment and a control, a t-test was used.

Results

For the visual assessment (Table 2) most species showed a tolerance to ethofumesate at all rates of application with the exceptions of *Briza maxima** and *Microlaena stipoides* (L.) R.Br. at the 1.50 kg ha^{-1} a.i. With *B. maxima** death resulted at the 18 day stage at 0.75 kg ha^{-1} a.i., severe damage at 1.50 kg ha^{-1} a.i. and moderate damage at 3.0 kg ha^{-1} a.i. *Briza maxima** was not only controlled more effectively at lower rates of herbicide concentration, but damage was displayed as suppression of flowering. *Microlaena stipoides* showed severe damage at 1.50 kg ha^{-1} a.i. after 36 days. Both *Danthonia racemosa* R.Br. and *Dicanthium sericium* (R.Br.) A. Camus showed moderate damage at 1.50 and 3.00 kg ha^{-1} a.i., with no damage to *D. racemosa* and moderate damage to *D. sericium* at the 0.75 kg ha^{-1} a.i. application rate. *Phalaris aquatica* L.* showed moderate chlorotic and necrotic damage at 1.50 and 3.00 kg ha^{-1} a.i. with no damage at 0.75 kg ha^{-1} a.i., there was however a loss of turgidity observed at all rates, moderate at 0.75 kg ha^{-1} a.i. and severe at 1.50 and 3.00 kg ha^{-1} a.i. *Poa labillardieri* Steudel showed minimal phytotoxic effects at any rate of application of ethofumesate.

Fluazifop was toxic to the majority of species at all rates of application. The exception was *Vulpia bromoides**, which showed no phytotoxic effects at the 0.10 kg ha^{-1} a.i. rate of application and indeed appeared stimulated by the herbicide application. Phytotoxicity of moderate severity was induced in all other species at an early stage at all rates of application followed by death of most species by six weeks. The exceptions were *M. stipoides* which exhibited severe damage at all rates of application by four weeks and *Phalaris aquatica** and *D. racemosa* at 0.05 kg ha^{-1} a.i.

Sethoxydim, as with fluazifop, had a more toxic effect on the range of species than did ethofumesate and caused similar effects to fluazifop. All species showed moderate damage one to two weeks after sethoxydim was applied. Death of plants occurred in most species with the following exceptions: *P. aquatica** at 0.095 kg ha^{-1} a.i., *Ehrharta longiflora** Smith and *M. stipoides* at 0.19 kg ha^{-1} a.i., with all suffering severe damage.

The statistical analysis of mean dry weights as set out in Table 3 clearly show the toxic effects of both sethoxydim and fluazifop on all species trialled except *V. bromoides**. All treatments show a significant decrease in dry weight at the 0.01 level of significance with the exception of *V. bromoides** which showed a marginal increase in weight over the control.

These results concur with those of the visual assessment for sethoxydim and fluazifop. This is not the case with ethofumesate where plants had significantly lower dry weights but otherwise did not appear significantly damaged visually.

Table 2. Summary of visual analysis for treated seedlings showing the level of damage sustained in a number of taxa.

	kg ha^{-1} a.i.								
	Ethofumesate			Sethoxydim			Fluazifop		
Species	0.75	1.50	3.00	0.095	0.19	0.38	0.05	0.10	0.20
*Briza maxima**	D	SD	MD	D	D	D	D	D	D
Danthonia racemosa	ND	MD	MD	D	D	D	SD	D	D
Dicanthium sericium	MD	MD	MD	D	D	D	D	D	D
*Ehrharta longiflora**	–	–	–	–	SD	–	–	D	–
Microlaena stipoides	–	SD	–	–	SD	–	SD	SD	SD
*Phalaris aquatica**	ND	MD	MD	SD	D	D	SD	D	D
Poa labillardieri	ND	ND	ND	D	D	D	D	D	D
*Vulpia bromoides**	–	–	–	–	–	–	–	ND	–

ND = no damage, MD = moderate damage, SD = severe damage, D = death, – = not trialled

Poa labillardieri showed a tolerance for ethofumesate at all rates of application with the 0.75 kg ha^{-1} a.i. being significantly greater in weight than the control.

The loss of turgidity displayed by *P. aquatica** at all rates of application of ethofumesate shows up with significantly decreased dry weights. Even where no visual display of necrosis or chlorosis occurred at the 0.75 kg ha^{-1} a.i. rate significant decreases occurred at the 0.05 level.

The response of *B. maxima** to ethofumesate in terms of dry weight was shown to have been significant at the 0.01 level across all rates albeit with greater effect at the lower rates.

The combination of visual assessment and statistical analysis shows the potential for use of herbicides at low rates of application to decrease the vigour, and to confer competitive advantage to preferred species.

Table 3. A comparison of the mean dry weights of taxa which were not killed by the treatments.

	kg ha^{-1} a.i.									
	Control	Ethofumesate			Sethoxydim			Fluazifop		
Species	0	0.75	1.50	3.00	0.09	0.19	0.38	0.05	0.10	0.20
*Briza maxima**	1.67	–	0.08^{+}	0.19^{+}	–	–	–	–	–	–
Danthonia racemosa	0.64	0.22^{+}	0.10^{+}	0.14^{+}	–	–	–	–	–	–
Dicanthium sericium	0.68	0.35^{+}	$0.38^{\ddagger}$	0.63	–	–	–	–	–	–
*Ehrharta longiflora**	na	na	na	na	na	na	na	na	na	na
Microlaena stipoides	0.62	na	0.10^{+}	na	na	0.08^{+}	na	0.07^{+}	0.11^{+}	0.04^{+}
*Phalaris aquatica**	0.86	$0.63^{\ddagger}$	0.10^{+}	0.14^{+}	0.08^{+}	–	–	0.10^{+}	–	–
Poa labillardieri	0.30	0.82^{+}	0.44	0.32	–	–	–	–	–	–
*Vulpia bromoides**	0.95	na	na	na	na	na	na	na	1.22	na

Statistical significance: ‡ = P<0.05, $^{+}$ = P<0.01, – = taxa killed by the treatment, na = data not assessed

Table 4. Visual assessment criteria used to rate the affect of herbicide damage to trialled species.

Rating	Criteria
8	No visible sign of damage
7	Slight chlorosis: 0–25% of the plant's foliage affected
6	Moderate chlorosis: 25–75% of the plants foliage affected
5	Severe chlorosis and / or slight necrosis: 75–100% of the plant's foliage exhibits chlorosis and / or 1–25% of the plant's foliage exhibits necrosis
4	Moderate necrosis: 25–50% of the plant's foliage affected
3	Significant necrosis: 50–75% of the plant's foliage affected
2	Severe necrosis: 75–99% of the plant's foliage affected
1	100% necrosis

Experiment 2. Tolerance of established native grass tussocks to grass specific herbicides

Materials and methods

The study was conducted at the field station of the Victorian College of Agriculture and Horticulture, Burnley campus on a sandy neutral clay loam that had a history of nutrient addition and cultivation. The trial commenced in September 1988.

Whole tussocks of the trial species (*Danthonia* spp., *Poa labillardieri*, *Stipa* spp. and *Themeda triandra*) were removed with large root balls from grasslands under imminent threat of destruction close to Melbourne and soaked in water prior to separation into smaller fragments. The four species were chosen because they included the most common native genera of lowland grasslands in western Victoria. Transplanting occurred between September and November 1988. Each tussock had its canopy reduced by half to reduce water loss. Tussocks were divided by hand into plantlets consisting of several tillers and planted into weedmat at 200 mm spacings. *Danthonia* tussocks were small enough to be planted as a whole in most cases. Nine plantlets were planted in a 3 × 3 block to form a replicate. There were six replicates for each treatment.

Dead transplants were replaced two weeks after the final plantlets had been planted. The transplants were irrigated infrequently over the summer period and invading weeds removed. In the first week of March 1989, tussocks were sprayed with ethofumesate (Tramat), sethoxydim (Sertin 186EC) and fluazifop (Fusilade 212) at two application rates (one and two times recommended rates for seedling grass control).

At seven day intervals after spraying, a visual assessment of damage to the foliage of each transplant in each replicate was recorded according to the criteria in Table 4. The visual assessment was conducted for 16 weeks. Further observations on foliar damage and re-growth were made at 32 weeks from spraying. At 16 and 42 weeks from spraying, per cent survival of transplants was also recorded. At 42 weeks, the percentage of surviving transplants flowering was recorded. Data on survival at 16 weeks and flowering were analysed using a 1-way ANOVA. Where significant differences were found, multiple comparisons between pairs of means were analysed using the T method (Sokal and Rohlf 1981).

Results

Outright mortality of vigorously growing transplants of the study species was low after 16 weeks and few statistically significant differences were found (Table 5). By 42 weeks, the effect of competition due to crowding of tussocks at 200 mm intervals was possibly responsible for the increased incidence of mortality but the percentage of surviving tussocks flowering (Table 6) is a measure of the success of regeneration after spraying. Only *T. triandra* sprayed with fluazifop or ethofumesate (both at the lower rate of application) had statistically different per cent flowering when compared to unsprayed controls.

The visual assessment data, however, reveal canopy dieback in the short-term

Table 5. Percentage survival of sprayed tussocks at 16 and 42 weeks (in parentheses) from treatment.

		Species			
Herbicide	kg ha^{-1} a.i.	*Themeda*	*Poa*	*Stipa*	*Danthonia*
Control	0	94 (83)	100 (100)	98 (85)	90 (71)
Ethofumesate	1.50	93 (78)	98 (98)	89 (74)	92 (68)
	3.00	98 (56)	100 (100)	80 (72)	96 (50)
Sethoxydim	0.19	91 (43)	100 (98)	83 (82)	86 (60)
	0.38	76 (39)	100 (82)	$76^{\ddagger}$ (48)	71 (60)
Fluazifop	0.10	87 (50)	96 (83)	96 (93)	62 (36)
	0.20	85 (22)	98 (91)	$87^{\ddagger}$ (80)	44^{+} (20)

Statistical differences at 16 weeks are given for treated plants versus control (‡P<0.05, $^{+}$P<0.01).

that ranged from slight, to moderate to severe, the response observed being determined by species, herbicide and rate of application.

Ethofumesate caused little or no damage to *Poa* at both spray rates. *T. triandra* suffered minor outer foliage scorch but regrew vigorously in the longer-term. Moderate to severe foliage necrosis was induced in *Stipa* and *Danthonia*, along with a significant suppression in growth at both 1.50 and 3.00 kg ha^{-1} a.i. This suppression of growth did not last longer than 32 weeks for *Stipa* at both rates. *Danthonia* never recovered from the spraying.

Sethoxydim caused rapid and very severe necrosis to all species, particularly at 0.38 kg ha^{-1} a.i. However, by 16 weeks from spraying, poor to very good regeneration was observed for *Danthonia* and *Poa* respectively. Little regrowth of *Stipa* or *Themeda* was observed until 32 weeks from spraying, when good to excellent regeneration was observed for *Stipa* and, to a lesser extent, *Themeda* when sprayed at the lower rate (0.19 kg a.i. ha^{-1} a.i.).

Fluazifop caused rapid and severe necrosis to *Danthonia* at both 0.1 and 0.2 kg ha^{-1} a.i. Regrowth was not evident in the period over which the trial was monitored. Both *Stipa* and *Themeda* suffered moderate to severe necrosis at both spray rates. However, unsprayed control plants also suffered moderate necrosis due to frost at 84 days (for *T. triandra*) and a rust (*Puccinia* sp.) infestation on *Stipa*, making longer-term interpretation of the effect of spraying difficult. Good after-spray regrowth, however, was evident at 32 weeks for *Stipa*, particularly when sprayed at the lower rate (0.1 kg ha^{-1} a.i.). *Themeda* never recovered from the spraying. Fluazifop appears to be poorly translocated in *P. labillardieri* and damage was restricted to severe outer foliage necrosis. Growth was initially suppressed but, by 32 weeks, vigorous regeneration was evident for tussocks sprayed at both application rates.

Table 6. Percentage flowering of surviving propagules at 42 weeks.

Herbicide	kg ha^{-1} a.i.	Species: *Themeda*	*Poa*	*Stipa*	*Danthonia*
Control	0	93	98	22	90
Ethofumesate	1.50	71‡	100	18	83
	3.00	87	100	31	85
Sethoxydim	0.19	87	87	36	87
	0.38	62	93	46	79
Fluazifop	0.10	56‡	82	14	60
	0.20	70	90	26	80

‡ Treatments statistically different from unsprayed controls ($P<0.05$).

Experiment 3. Selective removal of grass weed seedlings from semi-natural grassy woodlands with fluazifop

Materials and methods

The experiment was conducted over 36 weeks (30 July 1991 to 31 March 1992) at Plenty Gorge Park, 20 km north of Melbourne. Soils at the site are derived from Upper Silurian siltstone. The top soil is clay to clay-loam of variable thickness, and its pH is neutral. Following heavy rain, soils become water-logged due to the shallowness and higher permeability of the top soil compared to the heavy clay subsoils.

Average annual rainfall at the closest meteorological station (Preston, 12 km south west) is 672 mm. October is the wettest month (69 mm) while January is the driest (46 mm). The warmest month is January and the coolest is July.

Vegetation occurring on site is an open forest-woodland with a grassy under-storey. Dominant tree species are *Eucalyptus melliodora* Cunn. ex Schauer and *E. goniocalyx* F. Muell. ex Miq. The ground flora is a mosaic of *Themeda triandra* Forssk., *Poa morrisii* Vick., *Danthonia spp.* and *Microlaena stipoides* (Labill.) R.Br., with introduced species including *Phalaris aquatica* L.*, *Holcus lanatus* L.*, *Anthoxanthum odoratum* L.*, *Agrostis capillaris* L.*, *Dactylis glomerata* L.* and a range of forbs and annual grass weeds.

Fluazifop was chosen as the herbicide to be tested as it was felt that it would be less damaging as a winter application to essentially dormant native grasses, than might be sethoxydim. Given its apparently greater contact action, the protection conferred to native grasses by low physiological vigour or partial dormancy, might be less pronounced with sethoxydim.

i. Treatment of established native grass tussocks

Thirteen 1 m^2 plots were laid out to encompass a range of the native grasses occurring at the site. Established indigenous tussocks were of comparable size for each trialled species. Species included in the experiment are shown in Table 7.

A visual analysis of chlorosis and necrosis of treated and untreated mature native tussocks was recorded for 36 weeks. Individual plants were ranked according to the degree of chlorosis and / or the amount of dead leaves using scoring criteria similar to those in Table 4.

ii.Treatment of grass weed seedlings

This study, which was conducted simultaneously and on the same plots as the experiment on mature native tussocks, was to assess the phytotoxicity of the herbicide on grass weed seedlings occurring between established perennial tussocks. Taxa found in inter-tussock spaces varied in density from less than 100 to more than 1000 per m^2. The species observed were *Aira cupaniana* Guss.*, *Briza maxima* L.*, *Briza minor* L.*, *Bromus hordeaceus* L.*, *Bromus madritensis* L.*, *Holcus setosus* Trin.* and *Vulpia bromoides* (L.) Gray*. Observations were also made of phytotoxic effects on forbs growing on treated plots.

A constant pressure mini-plot sprayer was used to apply the herbicide. The sprayer was calibrated to produce a fluazifop application rate of 0.10 kg ha^{-1} a.i., a water volume output of 150 L ha^{-1}, and a fine spray (150–300 micron range). The treatment was applied to five of the plots on 30 July 1991. At this time, the *Briza minor** cohort had reached the four to five leaf stage. Seedlings of other grass weeds were generally less advanced with one to four leaves.

The phytotoxicity exhibited by grass weed seedlings was quantitatively assessed using the following criteria:

i. species killed by herbicide application
ii. species which survived herbicide application and
iii. species which germinated after herbicide application.

Table 7. Number of mature indigenous tussocks of each species monitored during the experiment.

Species	Untreated (control)	Treated
Danthonia geniculata J. Black	24	24
Danthonia setacea R. Br.	13	10
Poa morrisii Vick.	15	15
Stipa rudis Sprengel	8	9
Stipa semibarbata R. Br.	10	13
Themeda triandra Forssk.	14	14

Results

i. Mature native tussocks

Application of fluazifop at 0.l0 kg ha^{-1} a.i. caused a decline in green leaf mass of all treated tussocks. After approximately 18 weeks, treated plants had increased dead leaf mass by 5–15%. The exception to this was *P. morrisii* which increased dead leaf mass by 70–80%, resulting in the death of two individuals. In contrast, untreated plants increased green leaf mass by 10–20% during the same period.

Herbicide damage was evident within two to five weeks, depending on the species. Once initial damage was sustained individuals tended to stabilize, with recovery of treated species apparent by the end of the experiment (31 March 1992). At this stage all surviving plants (100% for *T. triandra, S. semibarbata, S. rudis, D. setacea, D. geniculata* and 87% for *P. morrisii*) had initiated new healthy tillers. At the end of the observation period there was very little difference between the green leaf mass of treated and untreated species. The exception was *P. morrisii* which remained stable over the summer but did not increase its biomass significantly.

The visual rating scores collected over the duration of the experiment were subjected to statistical analysis using a Wilcoxon Two-sample Test (Sokal and Rohlf 1981). The analysis revealed that after ten weeks from herbicide treatment there was significant difference between all treated species and their controls. However, by the end of the trial the difference between treated and untreated species, with the exception of *P. morrisii*, was not significant (Table 8).

The application of fluazifop delayed culm formation in *S. rudis, S. semibarbata* and *T. triandra* for one, five and four weeks respectively, compared to untreated plants. The number of culms produced per plant was also less on treated specimens, although the majority of individuals produced at least one culm. All untreated plants produced two or more culms. Of the remaining species approximately 50% of untreated plants flowered in the observation period. Only a few individuals of treated *Danthonia* formed culms. No culms formed on treated *P. morrisii*.

ii. Grass weed seedlings

Three weeks after herbicide treatment (20 August) *Aira cupaniana**, *Briza maxima**, *B. minor**, *Bromus hordeaceus**, *B. madritensis** and *Holcus setosus** seedlings all exhibited chlorosis or necrotic patches on the foliage. Only the *V. bromoides** cohort showed no sign of damage. By week five (3 September) it was apparent that affected seedlings would not recover.

*Vulpia bromoides** continued to grow strongly throughout the observation period on treated and untreated plots. Its vigour appeared to be enhanced where forbs or perennial grasses were relatively sparse, or where competition was reduced as a result of the death of other seedlings following herbicide application.

A second germination flush did not occur on treated (or untreated) plots even though there were ample gaps following the death of large numbers of seedlings from the herbicide application.

Table 8. Statistical analysis using a Wilcoxon Two-sample Test for treated and untreated (control) species for visual analysis data collected over the duration of the trial.

Species	at 10 weeks	at 36 weeks
Danthonia geniculata	+	ns
Danthonia setacea	+	ns
Poa morrisii	+	+
Stipa rudis	‡	ns
Stipa semibarbata	‡	ns
Themeda triandra	+	ns

ns = not significant (P>0.05), ‡ = significant (P<0.05), + = highly significant (P<0.01)

Discussion

Experiment 1. Tolerance of native and exotic grass seedlings to three grass specific herbicides

The aim of this study was to see if marked variations in selectivity existed between native and exotic grass seedlings at the 3–5 leaf stage in response to grass-specific herbicides. In practical field management this might allow a herbicide to selectively control seedlings of some exotic grasses growing amongst native grass seedlings

Unfortunately under glasshouse conditions, fluazifop and sethoxydim proved to be highly phytotoxic, resulting in the death of most native and exotic grass species trialled at the 3–5 leaf stage. Amongst the weed species *Ehrharta** and *Phalaris** survived sethoxydim at 0.19 and 0.095 kg ha^{-1} a.i. respectively. *V. bromoides** is resistant to fluazifop.

Ethofumesate tended to result in moderate damage rather than outright death as in the case of the preceding herbicides, with *Briza maxima** and *Microlaena* proving most sensitive.

Given the high vigour of the seedlings in the optimal conditions of the glasshouse, damage to seedlings in the field during autumn to late winter is likely to be less marked. Fluazifop and sethoxydim only appear to have the capacity to selectively remove 3–5 leaf stage exotic grass seedlings from native grass seedlings at the same developmental stage when the latter involve *D. racemosa* or *M. stipoides*. Similarly, ethofumesate appears to have potential to control *Briza** via suppression of flowering, growing amongst the relatively tolerant native grass *D. racemosa*. There is a need for further work to establish whether these variations in selectivity can be of significant value in practical weed management in the field. These results suggest there is potential, at least for the herbicide-species combinations discussed, to control 3–5 leaf stage grass weeds amongst established native grasses with acceptable damage to the latter.

Experiment 2. Tolerance of established native tussocks to grass specific herbicides

Having established a general lack of selectivity between native and exotic grass species at the 3–5 leaf stage in Experiment 1, this second study investigated the tolerance of established tussocks of native grass species. All three herbicides evaluated in this experiment had some adverse effects on established native grasses. The grass that proved most tolerant of these herbicides was *P. labillardieri.* The most adversely affected genera were *Danthonia* and *Themeda,* which recorded poor survival rates at 42 weeks following overspraying with fluazifop, and to a lesser degree sethoxydim. There is a marked difference in the pattern of native grass response to fluazifop and sethoxydim. Both result in necrosis soon after application, but the inhibition of growth is typically of shorter duration in the case of sethoxydim. This is reflected in the generally lower percentage flowering at 42 weeks of fluazifop, as opposed to sethoxydim treated plots of all species (Table 6). Ethofumesate is the least damaging of the three herbicides to established native grasses, but is not as effective as fluazifop and sethoxydim in terms of controlling a wide range of grass weeds. The capacity of ethofumesate, reported earlier in this paper, to inhibit flowering in *B. maxima** at rates of application that are not severely damaging to established native grasses, may prove to be of considerable value.

The severe damage sustained by *Danthonia* and to a lesser degree *Themeda* in response to fluazifop, must be interpreted in an appropriate context. Due to the restricted time available for the experiment, herbicides were applied in summer to irrigated plots to maintain an abundant, photosynthetically active canopy. It is evident from field observation that damage from these herbicides, and especially fluazifop, is typically maximal for vigorously growing plants under conditions of minimum stress. The results obtained in this experiment can be considered to constitute the worst case scenario likely with these grass species and herbicide combinations.

In practical vegetation management, the aim of such herbicide applications would be to control flushes of C3 and C4 grass weed seedlings amongst less vigorously growing, native grass tussocks in autumn-winter, and spring respectively. Consequently the incidence of damage to the latter is likely to be considerably less severe in the field than is demonstrated in this experiment. This has largely been borne out by the results of Experiment 3.

To minimize the risk of severe damage, the use of these herbicides should however be timed, whenever possible, to coincide with the period of maximal dormancy of the native grasses in question. This is particularly so in the case of markedly sensitive genera such as *Danthonia*, and to a lesser degree *Themeda*. Where this is not possible due to the presence of native grasses with contrasting growth physiologies, there would appear to be an opportunity to lower dose rates to reduce damage to sensitive native grasses whilst still maintaining satisfactory control of many grass weeds at the 3–5 leaf stage. Further work is required to assess the capacity of these herbicides to kill, severely stress or inhibit flowering in seedling grass weeds in the field at reduced dose rates.

Experiment 3. Selective removal of grass weed seedlings from semi-natural woodlands with fluazifop

The aim of this experiment was to determine the effect of fluazifop on a range of established native grasses and seedling exotic grasses in a semi-natural community. The experiment was designed to correspond to how fluazifop would be employed to control germinating cohorts of exotic grass weeds in a realistic grassland management situation.

i. Effects on established native grasses

Poa morrisii, and to a slightly lesser degree, *D. geniculata* and *D. setacea* proved to be the species most sensitive to fluazifop. Whilst all three of these species demonstrated a marked decline in green leaf mass following herbicide application, plant deaths were restricted to *P. morrisii* which recorded a 13% mortality rate. By the end of the experiment (36 weeks after herbicide application) the *Danthonia* had recovered and were indistinguishable from the controls, whilst surviving *P. morrisii* were stable but had made little growth. The sensitivity of *P. morrisii* to fluazifop is in marked contrast to the high degree of tolerance exhibited by *P. labillardieri*, and suggests that tolerance may vary considerably between species within a genus, according to leaf morphology, physiology and phenology. On the basis of this, and the preceding experiment, *Danthonia* would appear to be inherently sensitive to fluazifop. Whilst good recovery was observed in this experiment after initial damage, it would be desirable to lower fluazifop concentrations below those used in this study when this genus is present.

The other native grasses in the study were little affected by fluazifop and by the end of the experiment could not be distinguished from the control plants. As anticipated, *T. triandra* proved to be far less sensitive to fluazifop when applied to semi-dormant plants. Established plants of *Stipa* would appear to be fairly tolerant of fluazifop. Site factors prevailing in this study that further restricted vigour, for example, waterlogged soils, are likely to have further contributed to the enhanced tolerance of some native grasses to this herbicide.

In the absence of detailed information on the likely response of native grass species not investigated in this study, the most important factor for land managers to consider when planning the use of herbicides such as fluazifop is probably timing of application in relation to the growth physiology of the native grass species in question. In many cases a range of grass species of contrasting, for example, C3 versus C4, growth physiologies will be present, making application of a herbicide at a time when weeds are present and growing vigorously, and all native grasses fully dormant, difficult or impossible. Under such conditions decisions on whether or not to utilize a herbicide such as fluazifop become a question of weighing the potential benefits of use against the risks associated with non-use, in the context of plant community invasion by exotic grasses.

ii. Control of grass weeds

With the exception of the tolerant species *Vulpia bromoides**, control of exotic grass weeds on the plots was absolute. The efficacy of control was such that it seems likely that applications of fluazifop could be made at reduced dosages and still achieve satisfactory control. Our concern that the coverage of herbicide spray might not reach all of the germinating grass seedlings growing in gaps in the sward, and in some cases overhung by the growth of perennial tussocks, proved unfounded at the herbicide concentration, spraying volume and droplet size range employed.

Of particular significance is the fact that no further recruitment of annual grass weeds occurred following the death of the initial germination flush, despite the fact that there were both ample gaps and adequate soil moisture to do so. It is possible that all of the seed of the grass weeds that was present on the soil and capable of germination, did so in the first germination flush. Presumably some viable seed from the previous season was also present in the litter layer, or in cracks in the soil, but in the absence of mechanical disturbance a state of enforced dormancy prevailed. Relatively little data is available on the seed bank characteristics of Australian semi-natural grassland communities. In the work that is available, e.g., Lunt (1990), little distinction is made between temporary seed banks (i.e., those resulting from the previous years seed fall) and persistent seed banks derived from seed that is two or more years old. This distinction is of fundamental importance when assessing the effects of weed control techniques. McMahon (1991) reports that *Briza maxima** forms a persistent seedbank, although the bulk of viable seed germinates in the first autumn after shedding. It is suggested that *Aira** and *Vulpia** behave similarly although meaningful data to confirm is sparse. Information on the seed bank characteristics of some of these species in Europe is available in Grime *et al.* (1988). In common with most Bromes that have been investigated, *Bromus hordeaceus** does not form a persistent seed bank. Data on *Holcus setosus** appears to be unavailable, some other *Holcus* species* form persistent seed banks, others do not (Grime *et al.* 1988).

In annual grass weeds that do not form persistent seed banks, and in the absence of significant surface disturbance stimulating synchronic recruitment, these herbicides offer a real possibility of eliminating these types of grass weeds from native grassy vegetation. Further work on the seed bank characteristics of these weeds is likely to prove valuable.

The effective control of all grass seedlings other than *V. bromoides** allowed the latter to dominate and fully occupy the gaps in the sward. Whilst *Vulpia** may be less damaging to vegetative indigenous sward components than larger growing grasses such as *Bromus hordeaceus**, the control of these types of species is desirable to maintain gaps to allow the recruitment of indigenous species. This demonstrates the need for managers of semi-natural grassy vegetation to first define what weed species are present both as standing vegetation and as a seed bank. Control strategies can then be devised in relation to the biology of these species to ensure that "resistant" species are not unintentionally encouraged to dominate. This is necessary for all weed control strategies, not just those involving herbicides (*V. bromoides** is effectively controlled by propyzamide).

Whilst this study addressed the control of 3–5 leaf stage seedlings of grass weeds in a relatively undisturbed grassy vegetation, it also has implications for the control of these weeds in more disturbed situations. It has been observed on a number of occasions (McDougall 1988, Lunt 1990) that following the burning of weedy grassy vegetation that the great bulk of post fire recruitment consists of exotic, and often annual grass weeds. Depending upon the nature of the indigenous and exotic grasses in the community, this competition may restrict the recruitment of indigenous species from seed, or even diminish the contribution that vegetative regrowth from established native grasses makes to the total community biomass. As recruitment from surviving exotic grass seed banks is generally extremely rapid after fire, (given adequate soil moisture) and often precedes the emergence of native grass seedlings or foliage regrowth from vegetative plants, the use of fluazifop is potentially an extremely effective grass weed control technique in these circumstances.

In this experiment all of the grass weeds present on the plots were annuals and consequently controlling seedlings at the 3–5 leaf stage is an effective strategy. On sites where perennial grass weeds such as *Phalaris** and *Nassella* spp.* are present, control of seedling establishment by fluazifop or similar herbicides must be accompanied by spot application of non-selective herbicides such as glyphosate, using a wick wiper or shielded spray, to the foliage of established weed grasses. Ideally however, the establishment of perennial weed grasses should be pre-empted by the application of fluazifop to seedlings at the 3–5 leaf stage at the periphery of the invasion front.

iii. Effects on forbs

Observations revealed fluazifop had no discernible effect on forbs and sub-shrubs occurring on plots. Species included *Arctotheca calendula**, *Asperula conferta, Bossiaea prostrata, Cymbotonus preissianus, Drosera peltata, Geranium solandri, Hypochoeris radicata**, *Oxalis exilis, Romulea rosea** and *Sherardia arvensis**. It is unlikely that indigenous forbs and shrubs will be seriously damaged by fluazifop and similar, as they are primarily grass-specific herbicides. Fluazifop has been assessed for phytotoxicity on a wide range of forbs used in horticultural landscapes (Rice *et al.* 1985, Skroch *et al.* 1988), and most species are not adversely affected at the dosage ranges discussed in this paper. The repeated use of grass specific herbicides such as fluazifop in semi-natural grassy vegetation is likely to lead to at least some reduction in grass (native and exotic) dominance, as the establishment and growth of both native and exotic forbs is facilitated by periods of reduced grass competition for resources. These effects have been documented for other compounds with grass-specific properties (Marshall 1988).

These changes may be either highly desirable or undesirable, depending upon the suite of forbs originally present in, or capable of becoming established in, grassy vegetation. Where aggressive exotic forbs are poorly represented, the opportunity for an increase in the percentage cover of native forbs is likely to be regarded as desirable by the lay public, landscape managers and ecologists. It is generally the forbs that are the most endangered taxa in semi-natural grassy vegetation, as well as being the plants with the most attractive flowers.

Where exotic forbs are either present on, or adjacent to the site, the recurrent use of fluazifop may be counterproductive and lead to the substitution of annual or perennial exotic grasses by these forbs. This can be countered to some degree via the use of forb specific herbicides such as MCPA applied to the vegetation within critical phenological windows when the foliage of sensitive native forbs is largely absent. This form of management is realistic in some situations, but little understood at present.

The information generated by these experiments assists in clarifying the potential of herbicides such as fluazifop as weed management agents in semi-natural grassy vegetation, although not without raising almost as many questions as are answered. To use these herbicides effectively it is necessary to collect and utilize phenological and other data at a level of intensity that is currently foreign to most managers responsible for these vegetation types. The toxicity of fluazifop to non target organisms including maintenance staff and the public is another issue of importance. Fluazifop is a medium toxicity, schedule 6 compound, and is more toxic than herbicides such as glyphosate that have become widely used and largely accepted in the management of semi-natural vegetation. The chemical, biological and toxicological characteristics of fluazifop are discussed in Worthing and Hance (1991), and Hayes and Laws (1991). Conservation managers inevitably hold valid concerns about the non-target effects of these and other herbicides, and it is clear that an understanding of the impact of these substances on most organisms present in a semi-natural ecosystem is limited. It is equally obvious however, that when native grassy vegetation is converted by unchecked weed invasion to a sward of exotic grasses, the adverse consequences for many indigenous organisms are rather more clear cut than the non target uncertainties associated with herbicide use.

Acknowledgments

Robyn Watson and Peter May of VCAH Burnley, Keith McDougall and Ross Young (Melbourne Water) gave constructive criticism of the manuscript for which we are most grateful. Mark Tscharke (Plenty Gorge Park) kindly allowed field trials to be undertaken in the park.

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