Herbicide control of exotic annual plant species in *Acacia acuminata–Eucalyptus loxephleba* woodland in south-western Australia and effects on native ground flora

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Summary

The exotic annuals *Avena fatua, Vulpia myuros, Erodium botrys, Hypochaeris glabra* and *Pentaschistis airoides* are major invaders of *Acacia acuminata–Eucalyptus loxephleba* woodland. Two small plot experiments tested herbicides at two sites in 1990 for their control of exotic species without destroying the native species and were assessed at the end of the 1990 and 1991 growing seasons. The herbicides used were Assure®, Fusilade®, Fusilade plus Simatox®, Oust®, Roundup®, Sertin® and Surflan®. Only Oust gave good control of exotic dicots and monocots at both sites. There were some carryover effects in 1991 at site 1 where *A. fatua* was significantly lower on all herbicide treatments than on controls. Oust at 300 g ha^{-1} gave the best second year control of this species and of *V. myuros* but also eliminated native *Crassula* species. Nevertheless, in 1991 plots sprayed with both rates of Surflan, Oust and Roundup in 1990 had twice the cover of native species in control plots.

A further selection of herbicides were compared at another site in 1991. The herbicides were Assure, Atrazine®, Fusilade, Goal®, Oust, Sertin, Simatox and Sprayseed®. In the year of spraying, Goal came closest to the desired outcome of reducing exotic species without detriment to native species but it would have to be combined with a pre-emergence application of Simatox to eliminate the grass *P. airoides* and the dicot *H. glabra*. In 1992, there were no differences between any treatments and control plots in the proportions of exotic and native species. There were some differences in the composition of the native species.

It is concluded that herbicides can be used to eliminated certain exotic annual species with little damage to native herbaceous species. However, because of soil seed banks, application in just one year may not provide much carryover effect and so not allow native species to increase.

Introduction

There is growing interest in trying to restore plant species diversity in remnant woodlands in Australia. The central problem is the control or elimination of invasive plants so that native species can be re-established either from soil seed stores or by replanting. The causes of invasions and the approaches to their control have been discussed in detail by Hobbs and Humphries (1995) who point out that invasibilty of ecosytems is usually linked to the level of disturbance, both physically and from changes in nutrient status, to a system. In the Western Australian wheatbelt, plant communities vary with soil type and Hobbs and Atkins (1988) demonstrated how the major communities responded to these two forms of disturbance. The soils are inherently low in both major and minor elements. The development of agriculture requires inputs of phosphorus in particular. Weed cover in native plant communities increases with increasing phosphorus in the soil which comes from wind drift from farmland and by direct transfer when livestock are able to access remnants (Cale and Hobbs 1991, Hobbs and Atkins 1988).

The *Acacia acuminata–Eucalyptus loxephleba* woodlands in the south-west of Western Australia were favoured grazing areas from the early pastoral days of agricultural development because of the relatively abundant ground flora. The Danberrin landform on which the woodland occurs has rock outcrops which make much of it unsuitable for agriculture. In the wheatbelt of Western Australia it is by far the most abundant remnant woodland and is of high conservation value, more especially for the species rich ground flora. However, many of the areas of this woodland are heavily invaded by aggressive exotic annual species that crowd out the native species. Of 20 invaders recorded by Hobbs *et al.* (1993) in three remnants of this type of woodland, the dominants were the grasses *A. fatua, V. myuros, Briza maxima* and *P. airoides*, and the forbs *E. botrys* and *H. glabra*.

In the short and medium term, herbicides remain the only potential control mechanism in systems such as this where widespread control is needed, large areas are affected, and human population densities are low (Hobbs and Humphries 1995). In this study we examined the effects on both exotic and native species of a broad range of agricultural herbicides. The objective was to find out whether any of them could be used to control the exotic species whilst allowing the native species to survive and increase. To be successful, a herbicide would have to have some carryover effect into the year following application, allowing space for the redevelopment of the native ground flora.

Materials and methods

Sites and treatments

In the spring of 1989, a number of woodland remnants were surveyed for composition of the ground flora, and two sites that differed in herbaceous composition were selected (Table 1) that covered the range of exotic species found and the levels of weed invasion. Site 1 had a comparatively low level of weed invasion and site 2 was heavily invaded by annual weed species. The exotic annual grasses were dominated by *A. fatua* at both sites, with small amounts of *V. myuros* and other species. *E. botrys* and *H. glabra* were the major exotic forbs in site 2.

At each site 28 plots of 2.5 × 4.0 metres were marked out within which a section 2.0 × 3.5 m was sprayed. Details of all herbicides used in the two experiments are given in Table 2. In 1990 seven herbicides treatments (Table 3) were chosen partly on the basis of their known effects on the main target species but also to allow the effects on native species of control of only exotic grasses or both grasses and forbs to be assessed. Each herbicide was applied at two rates and at two different dates that coincided with stages 13 (three leaf stage) and 21 (main shoot and one tiller stage) of the Zadock's scale in the development of *A. fatua*. Two replicates of each treatment were randomized throughout each site

Herbicides were mixed with water and a wetting agent added. They were applied with a knapsack spray at a rate of 200 L ha^{-1} on 15 May and 26 June 1990.

In 1991, a third site was used which was similar in initial composition to site 1. The plot size and methods of application were the same as in 1990. There were three replicates of treatments (8 herbicides each at two rates plus a control) randomized within the site. The treatments included both pre- and post-emergence herbicides and chemicals that controlled just grasses

Table 1. Summary of the botanical composition in sites 1 and 2 in the spring of 1989, the year before treatments were applied. Values are the percentage cover .

Component	Site 1	Site 2
Exotic annual grasses	47.3	34.1
Exotic annual forbs	9.1	61.3
Native perennial grasses	26.9	4.0
Native herbaceous forbs	25.7	0.6

Table 2. Details of chemicals used and the rates of application.

Trade name of chemical	Active compound	Rates of application of chemical	Target group of exotics
Assure	quizalofop-P (88.6 g L^{-1} ethyl ester)	0.5 and 0.75 L ha^{-1} post-emergence	grasses
Atrazine	atrazine (800 g L^{-1})	1.5 and 3.0 kg ha^{-1} pre-emergence	forbs and grasses
Fusilade	fuazifop (212 g L^{-1})	0.5 and 1.0 L ha^{-1} post-emergence	grasses
Simatox + Fusilade	simazine + fuazifop	both 0.5 and 1.0 L ha^{-1} pre- and post-emergence	forbs and grasses
Goal	oxyfluorfen (240 g L^{-1})	2.0 and 4.0 L ha^{-1} post-emergence	forbs and grasses
Oust	sulfometuron (750 g kg^{-1} methyl ester)	200 and 300 g ha^{-1} post-emergence	forbs and grasses
Roundup	glyphosphate (360 g L^{-1})	0.8 and 1.2 L ha^{-1} post-emergence	forbs and grasses
Simatox	simazine (900 g kg^{-1})	0.5 and 1.0 L ha^{-1} pre emergence	forbs and grasses
Sertin	sethoxydim (189 g L^{-1})	0.5 and 1.0 L ha^{-1} post-emergence	grasses
Sprayseed	paraquat (135 g L^{-1} dichloride) + diquat (115 g L^{-1} dibromide monohydrate)	1.0 and 2.0 L ha^{-1} post emergence	forbs and grasses
Surflan	oryzalin (500 g L^{-1})	4.0 and 6.8 L ha^{-1} post-emergence	forbs and grasses

Table 3. Summary of results for site 1 in year of spraying (1990) and in 1991. Values are percentage of ground cover at the end of the growing season.

Treatment		*Hypochaeris glabra*		Total exotic forbs		Total exotic grasses		Native forbs		Native grasses	
		1990	1991	1990	1991	1990	1991	1990	1991	1990	1991
Assure	R1	4.6 bc	3.7	9.8 b	5.8	18.4 b	18.4 b	6.9 b	12.7	10.5 bc	2.1
	R2	6.8 c	4.6	8.9 b	7.5	8.9 ab	12.8 ab	9.6 bc	16.6	15.9 c	2.2
Fusilade	R1	5.4 bc	6.6	6.2 ab	10.7	3.1 a	11.2 ab	10.1 bc	17.6	10.4 bc	3.7
	R2	4.8 bc	4.8	7.8 b	7.5	7.4 ab	10.2 ab	5.0 b	14.6	12.2 c	1.8
Fusilade +	R1	3.1 b	6.9	5.0 ab	13.6	5.8 ab	14.7 b	3.4 ab	18.6	1.3 ab	2.0
Simazine	R2	6.9 bc	5.6	7.7 b	7.1	11.3 b	15.8 b	11.6 b	17.1	16.3 cd	1.5
Oust	R1	0.6 a	3.1	2.1 ab	9.3	7.9 ab	15.5 b	0.2 a	20.3	17.3 d	4.1
	R2	0.0 a	6.0	0.0 a	11.1	5.0 ab	9.7 b	0.1 a	21.5	8.0 b	3.8
Roundup	R1	0.2 a	3.8	0.2 a	8.1	3.3 a	16.1 bc	0.2 a	24.1	0.1 a	1.7
	R2	0.3 a	3.3	1.0 a	4.7	4.6 ab	14.9 b	0.3 a	25.3	0.4 a	2.0
Sertin	R1	2.7 ab	4.3	8.0 b	12.1	9.8 ab	20.3 c	9.5 c	18.3	14.5 c	5.0
	R2	3.9 b	4.1	4.4 ab	9.0	10.0 ab	13.6 ab	7.8 b	20.2	7.2 ab	1.6
Surflan	R1	4.0 b	9.0	6.2 ab	11.6	8.8 ab	9.5 a	6.4 b	23.5	30.6 e	1.0
	R2	1.4 ab	7.4	4.6 ab	17.2	8.6 ab	9.6 a	5.1 b	25.7	11.0 bc	5.0
Control		4.1 b	2.6	5.8 ab	4.8	31.9 c	14.8 b	7.6 bc	10.4	7.9 b	0.9
F values											
Chemical		2.97**	1.50	6.95***	1.71	4.41***	2.15*	6.77***	1.62	4.21***	1.38
Application time		3.60	5.96*	1.55	9.03**	4.25*	0.00	8.19**	1.27*	4.25*	0.11
Interaction		1.55	2.77**	1.06	1.51*	1.07	1.03	1.93*	1.28	1.07	1.40

Values in a column with no letter in common differ significantly at P<0.05 or more. * P<0.05, ** P<0.01, *** P<0.001.

or both grasses and forbs. The post-emergence treatments were applied at two different times that coincided with the same Zadock's scale stages for *A. fatua* as in 1990. Pre-emergence applications were done on 7 May and post emergence applications on 13 and 25 June.

Estimation of botanical composition

Two quadrats of 0.25 m^2 were chosen at random within each plot and visual estimates made of the percentage of bare ground. Then the composition of the vegetation was estimated species by species with a minimum value of 5% being used. Because of the range of species many did not contribute 5% and functional groups based on life forms were then used viz. exotic annual grasses, exotic forbs, native grasses, native herbaceous forbs. Estimates were made in the late spring of the year of application and the subsequent year.

Data analysis

Analysis of variance was done on the angular transformed values of the percentages. The analyses compared time of application and chemical treatments as factors (rates of each chemical were considered as different treatments).

Results

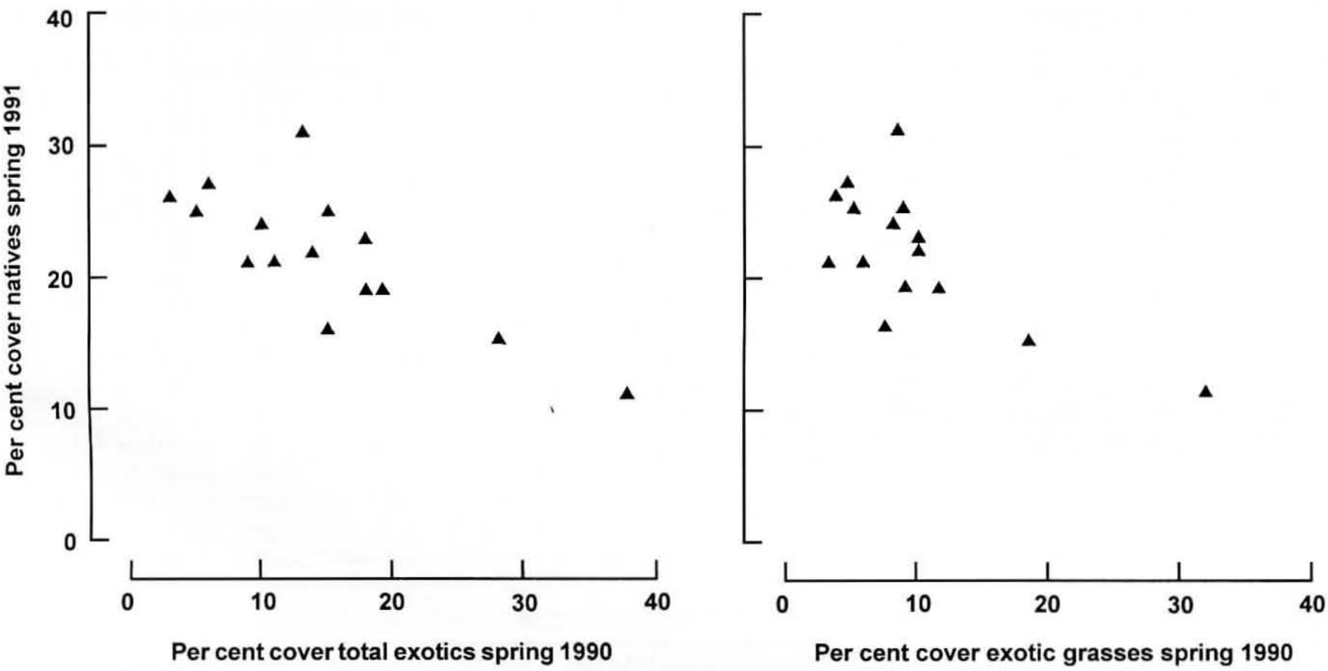
There were very few statistically significant time of application effects or treatment × time of application effects. Thus the data are presented as 14 herbicide treatments and a control in 1990, and 16 herbicide treatments and a control in 1991. Where time of application or the interaction term was significant this is mentioned in the text.

1990 treatments

Site 1. The major exotic dicot at this site, *H. glabra*, was significantly reduced or eliminated by Oust and Roundup in 1990 (Table 3). Total exotic forbs were significantly lower on plots sprayed with the higher rate of Oust and both rates of Roundup than on control plots and plots sprayed with other herbicides. Total exotic grasses were lower on all sprayed plots than on control plots, with little difference between the herbicides in level of control achieved. The control plots averaged 32% exotic grasses and treated plots from 3–18%. There were no differences in control of exotics with time of application. However, for *E. botrys* the lower rate of Oust was more effective when sprayed at the earlier date.

Native herbaceous forbs were almost totally eliminated by Oust and Roundup.

Figure 1. Relationship between cover of exotics at site 1 in 1990 and cover of natives in 1991. Values are means of each treatment.



This group was unaffected by the other herbicides. The native grasses were most affected by Roundup. On most other treatments the cover of native grasses was either similar to that on control plots or was significantly higher.

More detailed separation of species was done in 1991 than in 1990. There were small but statistically significant differences (P<0.01) in the cover of the following species due to treatment in 1990: the exotics *A. fatua* and *V. myuros* and the native species *Stipa trichophylla*, *Podolepis* spp., *Helipterum hyalospermum*, *Waitzia acuminata* and *Waitzia aureum*. The most significant differences were that Surflan treated plots had significantly less exotic grasses than control plots (9.5% cf. 14.8%). Plots sprayed early in 1990 had less *V. myuros* in 1991. The differences in individual native species varied with the herbicide treatments. However, the main effect was that total native species cover was significantly higher on some treated plots than on controls (P<0.01). Not all herbicides produced a significant increase in native species. The control plots had 11.3% cover of natives in 1991. Those sprayed in 1990 with Surflan had 27.6%, those sprayed with Roundup 26.5% and those sprayed with Oust 24.8%. Overall, the higher the cover of exotics in 1990, the lower the cover of natives in 1991 (Figure 1).

Site 2. The exotic forbs *E. botrys* and *H. glabra* were only reduced or eliminated by Oust at both rates of application and by Roundup at the higher rate (Table 4). Surflan gave no control of either exotic forbs or exotic grasses. The interactions that were significant were due to some herbicides giving some control with early application and others with late application. Total exotic grasses were significantly lower on plots sprayed with the higher rate of Assure, and both rates of Fusilade, the Simatox-Fusilade mixture, Oust, Roundup and Sertin than on control plots. Exotic grasses were significantly lower with the later applications (4.8% vs. 11.9%). There was too little cover of native species to show any effects of treatments.

In 1991, there were some carryover effects. Plots sprayed early in 1990 had less *H. glabra* in 1991 (5.8 vs. 9.1%). The significant interactions were due to some herbicide treatments showing lower contents of exotics with early spraying, whilst others did not. No clear pattern was apparent. The cover of native species in 1991 remained a mere 1%.

1991 treatments

The results for site 3 are given in Table 5. In the year of application all herbicide treatments significantly reduced the cover of *A. fatua* from 28.8% on control plots to 0–10.3% on treated plots. Atrazine and Oust gave the greatest control of this species and overall of all exotic grasses. *P. airoides* was controlled by most herbicides but not by Sprayseed. The lower rates of Sprayseed and Fusilade gave more effective control of exotic grasses when applied at the later date, but this was not the case for other herbicide treatments.

The exotic forbs were unaffected by the herbicides Fusilade, Assure and Sertin. Of the rest, Atrazine, Goal and Oust gave similar levels of control and were equally effective at low and high rates. Simatox was only effective at the high rate of application. Sprayseed was more effective in controlling *H. glabra* when applied late whereas Goal gave better control of exotic grasses when applied early.

Native grasses were not significantly reduced by any herbicide treatment. However, native herbaceous forbs were eliminated by Atrazine and Oust and reduced by Simatox, Goal and Sprayseed. Some species were more affected than others. For example *Crassula* spp. were eliminated by Atrazine, Simatox, Goal and Oust but *Podolepis* spp. were unaffected by Goal. When total cover of natives is considered, the cover was significantly higher than on control plots, on all plots sprayed with Sertin and Assure, and significantly lower on plots sprayed with Atrazine, Simatox, Goal, Oust and Sprayseed (P<0.001).

There were some carryover effects of treatments applied in 1991 on the composition in spring 1992. There was less *V. myuros* in plots sprayed early with any herbicide than in plots sprayed late All plots had a similar cover of exotic forbs. The native grass *Stipa trichophylla* was affected in different ways by different herbicides. It was absent from plots sprayed early with Oust and those sprayed late with Sertin. The species averaged 17% in plots sprayed early with Fusilade but only 3% in plots sprayed late. The native annual forb *Crassula* spp. were absent in 1992 only from plots sprayed in 1991 with Goal but overall content of native and exotic species were very similar on all plots.

Discussion

Responses in the year of application

Two aspects need to be considered. The first is the effectiveness of the herbicides

Table 4. Summary of results for site 2 in the year of treatment (1990) and in 1991. Values are percentage of ground cover at the end of the growing season.

		Erodium botrys		*Hypochaeris glabra*		Total exotic forbs		Total exotic grasses		Total native species	
Treatment		1990	1991	1990	1991	1990	1991	1990	1991	1990	1991
Assure	R1	16.8 bc	14.9 ab	12.8 c	4.1 a	31.1 d	29.0 ab	10.1 bc	14.0 b	1.3	0.8
	R2	17.3 bc	11.1 a	12.7 c	8.2 b	30.1 cd	23.0 a	6.6 ab	14.0 b	2.1	0.7
Fusilade	R1	21.4 c	25.4 bc	10.5 bc	8.8 b	32.6 d	30.7 b	6.5 ab	11.4 ab	2.1	0.0
	R2	10.0 b	19.4 b	6.9 b	14.8 c	16.8 bc	36.0 b	9.3 bc	17.0 b	0.8	0.3
Fusilade+	R1	17.6 bc	18.4 b	7.8 bc	5.3 ab	25.3 c	25.2 ab	1.3 a	11.4 ab	1.5	0.3
Simazine	R2	23.9 c	21.5 bc	4.4 ab	8.0 b	28.9 c	24.7 ab	3.1 ab	7.3 ab	1.1	0.7
Oust	R1	5.0 ab	11.1 a	0.0 a	6.4 ab	5.1 ab	24.9 ab	2.1 a	14.5 b	0.9	0.2
	R2	0.3 a	23.3 bc	0.0 a	4.4 a	0.3 a	29.0 ab	0.3 a	8.5 ab	0.3	0.0
Roundup	R1	20.8 c	13.9 ab	0.9 a	7.6 ab	21.7 c	23.0 a	6.0 ab	10.8 ab	1.6	0.9
	R2	6.3 ab	19.4 b	3.6 ab	8.8 b	9.9 ab	30.7 b	5.3 ab	13.5 b	0.9	0.6
Sertin	R1	20.6 c	26.5 c	13.0 c	6.1 ab	37.4 d	36.0 b	5.1 ab	6.5 a	1.5	0.0
	R2	40.8 d	17.0 bc	8.9 bc	6.6 ab	49.8 e	25.1 ab	6.6 ab	5.8 a	0.5	0.2
Surflan	R1	7.4 ab	19.1 b	5.0 ab	5.6 ab	12.6 b	24.7 ab	25.3 d	5.3 a	1.6	0.1
	R2	13.3 b	14.7 ab	6.6 b	8.5 b	22.3 c	24.9 ab	15.6 c	13.8 b	2.1	1.3
Control		17.6 ab	14.8 ab	9.4 bc	8.1 b	27.7 c	24.0 ab	15.4 c	11.7 ab	0.9	1.1
F values											
Chemical		5.25***	1.91*	4.43***	2.11*	8.29***	1.96*	4.77***	2.36*	0.43	0.31
Application time		0.14	2.31	0.29	18.35***	0.53	7.70**	20.98***	0.82	0.11	0.21
Interaction		2.20	2.89**	2.79**	1.22	2.19*	2.24*	1.64	2.14*	0.09	0.15

Values with no letter in common differ significantly at P<0.05 or more. * P<0.05, ** P<0.10, *** P<0.001.

in controlling the target group of exotic species and the second is the effects on the native species. Site 2 was dominated by exotic forbs which were only effectively controlled by Oust at both rates of application and by Roundup at the higher rate. Surflan gave no control. In 1991 the exotic forbs at site 3 were controlled by Goal, Oust and Sprayseed at both rates of application and by Simatox at the higher rate. There were virtually no native herbaceous forbs at site 2. At site 1 in 1990, control of exotic forbs was accompanied by elimination of native forbs. At site 3 in 1991, the result was the same. However, reduction in exotic grasses led to an increase in native and exotic forbs at site 3.

In general, both dual target herbicides and those that only control grasses were equally effective in controlling exotic grasses in sites 1 and 2 in 1990. The exception was Surflan. In 1991 at site 3, there were two exceptions viz. the lower rates of Simazine and of Sprayseed. Roundup was the only herbicide to kill the native grasses in the year of application at site 1; other herbicides resulted in levels of native grasses similar to, or higher than, those in control plots. In 1991 at site 3, native grasses made up only a small percentage of the ground cover so that effects of herbicides could not be assessed.

The conclusion must be that grass killing herbicides can give sufficient control of exotic grasses in these woodlands to allow an overall increase in cover of native species. The advantage from this is that seed production of the natives is also increased which may benefit their competitive situation in the following year. However, this is offset by an increase in exotic forbs. Control of the exotic forbs is at the expense of the native forbs as well.

Responses in the year after herbicide application

Loss of a year's seed production by annual species as a consequence of herbicide treatment will have different effects in different species on their future contribution to the annual ground cover. Species in which seed dormancy is short lived, such as many of the grasses, should be reduced in abundance in the subsequent year (Barrett *et al.* 1973). Species in which some seed remains dormant for several years may not change in abundance. Little is known about seed dormancy characteristics in the native species in these woodlands. Of the major exotic species, *E. botrys* has a high seed dormancy (Arnold and Anderson 1987) whilst *H. glabra* and *V. myuros* have low dormancy as was demonstrated by Arnold *et al.* (1970) and by Barrett *et al.* (1973).

Exotic species

A potential problem with examining botanical composition on small plots is the possibility of wind borne seed moving between plots. This will be a particular problem with species like *H. glabra* which is dispersed entirely by wind. It showed up in both sites 1 and 2 where despite some herbicides giving control in 1990, all plots had similar levels in 1991. However, it was not the case for other exotic forb species for which there were carryover effects. At both sites 1 and 2, early application in 1990 resulted in lower total exotic forb content in 1991 across those herbicide treatments that affected forbs. This resulted in the large interaction term in the analyses of variance seen in Tables 2 and 3. However, this interaction was not found at site 3. As is discussed later, this is one of several differences in response between sites 1 and 3 which were of similar initial composition.

There were some small carryover effects on exotic grass cover of the vegetation. Surflan treated plots at site 1 and Sertin treated plots at site 2 had less grass than other plots. With Surflan this result does not reflect a lower grass (and thus seed production) content in 1990 but probably some residual herbicide in the soil affecting germination in 1990 (Surflan is a germination inhibiting herbicide when used pre-emergence). With Atrazine, Oust and the high rate of Sertin at site 3 the carryover effect was most likely a consequence of suppression of seed production in the year of application.

Native species

There were no carryover effects on native herbaceous forbs or grasses at site 3. At site 1, native herbaceous forbs and total native species did vary with the treatment the previous year. These difference were examined. As figure 1 shows, the higher the total exotic cover in 1990, the lower the native cover in 1991. Why this relationship existed at one site but not the other is hard to explain. It may relate to seasons and/or sites. At site 1, control plots decreased in cover of exotics from 37.7% in 1990 to 19.6% in 1991 whereas at site 3 there was 59.5% in 1991 falling marginally to 48.6% in 1992. However, native cover on control plots decreased from 15.5% to 11.3% at site 1 but increased markedly at site 3 from

Table 5. Summary of results for site 3 in 1991and 1992. Values are percentage ground cover at the end of the growing season.

Treatment		*Avena fatua*		*Pentaschistis airoides*		*Hypochaeris glabra*		*Podolepis* spp.		*Crassula* spp.		Exotic forbs		Exotic grasses		Native forbs		Native grasses	
		1991	1992	1991	1992	1991	1992	1991	1992	1991	1992	1991	1992	1991	1992	1991	1992	1991	1992
Atrazine	R1	0.4a	2.5a	0.0a	7.0	1.7ab	7.9	1.3a	11.8	0.0a	4.8ab	2.8a	16.9	0.4a	14.6a	1.3a	31.6	0.0a	7.4
	R2	0.1a	2.5a	0.0a	8.0	0.0a	5.8	0.0a	3.6	0.0a	2.6ab	0.2a	14.2	0.0a	19.3a	0.4a	19.6	0.4a	18.4
Simazine	R1	20.5c	2.1a	0.0a	6.8	7.3b	3.5	13.1b	9.3	0.0a	3.5ab	22.7bc	15.3	21.3b	16.1a	16.5b	31.7	2.6ab	11.5
	R2	2.1ab	7.0b	0.0a	3.1	0.0a	2.0	3.7ab	11.2	0.0a	5.1ab	3.8a	11.9	2.1a	16.8a	6.4ab	24.6	2.7ab	22.1
Goal	R1	0.3a	3.7ab	3.7b	13.3	3.9ab	2.0	8.9ab	16.7	0.0a	0.0a	4.3a	10.3	5.0a	21.3ab	9.0ab	23.4	0.2a	10.1
	R2	0.3a	3.7ab	7.7b	7.7	2.6ab	9.6	5.3ab	5.9	0.0a	0.0a	4.5a	15.8	8.8a	17.3a	7.6ab	25.5	1.8ab	11.0
Oust	R1	1.9ab	2.5a	0.0a	11.0	0.4a	2.2	0.0a	5.2	0.0a	4.5ab	5.5a	15.3	1.9a	20.9ab	2.0a	23.8	2.0ab	17.2
	R2	0.6ab	2.1a	0.0a	10.5	0.0a	3.3	0.0a	8.6	0.0a	4.1ab	0.3a	10.2	0.8a	18.3a	1.3a	24.1	1.3ab	11.2
Sprayseed	R1	10.3b	6.2b	5.4b	10.9	1.7ab	8.4	1.0a	9.1	1.5ab	4.8ab	9.7a	20.8	20.5b	30.7b	8.8ab	33.0	0.4a	8.8
	R2	2.5ab	3.9ab	6.7b	5.9	2.0ab	4.9	0.6a	8.9	1.7ab	3.7ab	4.4a	14.5	10.7ab	24.2ab	4.5a	28.7	1.9ab	16.4
Fusilade	R1	3.7ab	3.9ab	2.6ab	7.0	14.1c	2.0	17.8bc	11.5	1.1ab	7.9b	24.4bc	13.3	9.0a	24.6ab	21.1bc	29.3	1.1ab	15.3
	R2	0.0a	3.3ab	0.4a	5.2	17.1c	2.0	13.9b	11.4	1.6ab	4.6ab	31.3c	9.1	7.0a	24.2ab	22.5bc	28.4	5.3b	11.1
Sertin	R1	1.4ab	5.2ab	0.0a	4.6	12.9bc	5.3	21.1bc	11.1	0.2ab	3.1ab	48.8 d	18.4	6.4a	21.4ab	25.3bc	34.4	2.3ab	13.2
	R2	1.0ab	2.3a	0.0a	6.8	16.5c	2.9	17.6bc	12.8	0.5ab	4.8ab	34.6c	16.3	2.3a	19.4ab	27.7bc	42.6	5.4b	9.6
Assure	R1	3.2ab	3.2ab	0.4a	7.6	13.9c	0.6	21.4bc	9.0	2.1b	4.6ab	26.2bc	12.8	6.0a	18.4a	27.0bc	31.9	1.3ab	13.1
	R2	1.4ab	2.8ab	0.4a	5.3	11.9bc	5.8	26.9c	7.2	2.5b	5.5ab	29.3bc	19.1	5.5a	17.9a	35.2c	36.4	1.1ab	17.3
Control		28.8c	7.7b	5.2b	5.0	10.0bc	0.0	7.1ab	7.9	2.1b	4.0ab	21.8bc	25.3	37.7c	23.1ab	16.0b	25.3	2.0ab	10.2
F values																			
Chemical		9.43***	3.27**	7.53***	1.87	28.89***	1.57	15.22***	1.39	3.15***	3.15***	28.95***	0.85	9.76***	1.91*	14.26***	1.19	2.46***	0.94
Application time		12.57***	0.66	1.93	1.19	5.83*	0.62	1.51	0.41	2.68	0.13	4.24*	0.07	2.71	1.02	1.21	0.61	0.01	0.00
Interaction		2.21*	1.51	3.29***	1.38	3.00***	1.16	0.77	1.03	0.53	0.69	3.31***	1.00	2.75**	1.41	1.02	0.81	0.98	1.31

Values in a column that have no letter in common differ significantlyat P<0.05 or more. * P<0.05, ** P<0.01, *** P<0.001.

18.0% to 35.5%. Thus it could be that at site 1 the control of exotics for a year was needed to create space for an increase in cover of natives in the second year because of a site characteristic that supports only a low cover of herbaceous vegetation. By contrast, site 3 appears to sustain a much higher herbaceous cover and, given good seasonal conditions in 1992 for native annuals, it was possible to have an increase in native cover without the creation of space in the previous season; soil seed stores must have been adequate to allow this. They were obviously not adequate at site 2 where there was no improvement in the very low level of native cover. Such sites require re-seeding to enhance their conservation value.

Substantiation of the overall findings of these small plot studies was obtained from the results of Hobbs *et al.* (1993) on 5 ha plots. At sites 1 and 2, and at a third site, these plots were used in 1991 to compare plant and animal responses to removal of the herbaceous vegetation for a year by applying Sprayseed. At all three sites removing most of the exotics in 1991 produced no higher levels of native cover in 1992. It is clear that weed control programs need to be followed by immediate reseeding or replanting of native species.

The overall conclusion is that whilst herbicides can be used to control exotic annuals in the ground flora in these woodlands, there is little flow-on effect in the next year. The exotics have sufficient soil seed stores to sustain the loss of a year's seed supply and/or receive wind-borne supplements. For herbicides to be of value in conservation of the ground flora of these woodlands they would require two or more years of herbicide treatment but even then a favourable outcome would depend on the longevity of soil seed stores of native species being greater than that of the exotic species. The coupling of herbicide treatment followed by reseeding needs to be researched. This requires harvesting of seed of native species from undisturbed areas and the surface spreading of this seed. The disturbance caused by cultivation is likely to favour the alien weed species.

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References

Arnold, G.W., Barrett, D.W., Lapins, P. and Whitehead, J. (1970). Some effects of paraquat on yield of dry matter and nutrients, and on sheep production from annual pastures. Proceedings Eleventh International Grasslands Congress, Surfers Paradise, p. 86.

Arnold, G.W. and Anderson, G.W. (1987). The influence of nitrogen levels, rainfall, seed pools, and pasture biomass on the botanical composition of annual pastures. *Australian Journal of Agricultural Research* 38, 339-54.

Barrett, D.W., Arnold, G.W. and Campbell, N.A. (1973). Effects of time and rate of paraquat application on yield and botanical composition of annual pastures containing subterranean clover in a Mediterranean climate. *Australian Journal of Experimental Agriculture and Animal Husbandry* 13, 556-62 .

Cale, P. and Hobbs, R.J. (1991). Condition of roadside vegetation in relation to nutrient status. *In* 'Nature Conservation 2: The role of Corridors', eds. D.A. Saunders and R.J. Hobbs., pp. 353-62. (Surrey Beatty & Sons, Chipping Norton).

Hobbs, R.J. and Atkins, L. (1988). Effect of disturbance and nutrient addition on native and introduced annuals in plant communities in the Western Australian wheatbelt. *Australian Journal of Ecology* 13, 171-9.

Hobbs, R.J. and Humphries, S.E. (1995). An integrated approach to the ecology and management of plant invasions. *Conservation Biology* 9, 761-72.

Hobbs, R.J., Arnold, G.W. and Leone, J. (1993) Weed control and rehabilitation of woodlands in the western Australian wheatbelt. Final Report to World Wide Fund for Nature for Project P146. (CSIRO Division of Wildlife and Ecology, Midland, Western Australia).