Selective herbicide strategies for use in Australian desmanthus seed crops

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Abstract

Grass and broad-leaved weeds can reduce both yields and product marketability of desmanthus (*Desmanthus virgatus*) seed crops, even when cultural control strategies are used. Selective herbicides might economically control these weeds, but, prior to this study, the few herbicides tolerated by desmanthus did not control key weed contaminants of desmanthus seed crops. In this study, the tolerance of desmanthus cv. Marc to 55 herbicides used for selective weed control in other leguminous crops was assessed in 1 pot trial and 3 Queensland field trials. One field trial assessed the tolerance of desmanthus seedlings to combinations of the most promising pre-emergent and post-emergent herbicides. The pre-emergent herbicides, imazaquin, imazethapyr, pendimethalin, oryzalin and trifluralin, gave useful weed control with very little crop damage. The post-emergent herbicides, haloxyfop, clethodim, propyzamide, carbetamide and dalapon, were safe for controlling grass weeds in desmanthus. Selective post-emergence control of broad-leaved weeds was achieved using bentazone, bromoxynil and imazethapyr. One trial investigated salvaging second-year desmanthus crops from mature perennial weeds, and atrazine, terbacil and hexazinone showed some potential in this role. Overall, our results show that desmanthus tolerates herbicides which collectively control a wide range of weeds encountered in Queensland. These, in combination with cultural weed control strategies, should control most weeds in desmanthus seed crops.

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Introduction

Representatives of the genus *Desmanthus*, collectively known as desmanthus, have shown potential as persistent and productive perennial legume species for pastures on Queensland clay soils (Clem and Hall 1994; Jones and Rees 1997). Three cultivars, originally classed as *D. virgatus*, were released in 1991 and are now recognised as distinct species (Luckow 1993): *D. virgatus* cv. Marc, *D. leptophyllus* cv. Bayamo and *D. pubescens* cv. Uman. Since then, additional accessions of *D. virgatus* have been evaluated as forages in Queensland and were grown commercially for seed for the first time during 2004–05. If these cultivars are to be adopted widely, seed production systems need to be established, which ensure a ready supply of reasonably priced, good quality seed to end-users.

If not controlled adequately, weeds can significantly reduce seed yields by competing for light, nutrients and water. Some weed seeds are also difficult to remove from harvested desmanthus seed, reducing the quality of harvested seed. Apart from cultural techniques, such as crop rotation and cultivation, weed control in desmanthus seed crops until now has relied mainly on the use of trifluralin and bentazone, both of which are commonly used in legume crops. Nevertheless, several weed species, particularly broad-leaved weeds, remain troublesome in desmanthus crops grown on the Atherton Tableland, north Queensland.

Research to date on other herbicides suitable for use in desmanthus seed crops has been limited to 2 seedling pot trials, 1 each in Brazil (Mastrocola *et al.* 1983) and Queensland (Loch and Harvey 1990). Apart from trifluralin and bentazone, promising herbicides identified by these preliminary trials included fluazifop-P, sethoxydim, diclofop-methyl, MSMA, dinoseb and oryzalin. However, apart from dinoseb, most of these give poor control of broad-leaved species, and dinoseb is no longer used in Australia.

As part of a larger study of desmanthus seed production (Cox 1998), we sought to identify additional selective herbicides tolerated by 'Marc' desmanthus, by conducting a pot trial to screen a wide range of pre-emergent and post-emergent herbicides, followed by 3 field studies with a selected group of chemicals.

Materials and methods

The initial pot trial was conducted at Massey University (New Zealand) and 3 subsequent field trials were carried out on a dairy farm at Kilkivan (26°03′S, 152°15′E), south-east Queensland. Lucerne (*Medicago sativa*) had been grown at the Kilkivan site for the previous 5 years. The soil was a heavy, black cracking clay (Vertosol) (pH = 7.2) and soil tests showed that it was not deficient in any major elements (Cox 1998). The 'Marc' cultivar of desmanthus was used in all trials because it is early flowering (Graham *et al*. 1991), and therefore less prone to frost damage when grown in south-east Queensland. A randomised complete block design was used in all trials, with 5 replicates for the pot trial and 4 replicates in all field trials. In most cases, herbicides were applied at rates recommended for use in other legume crops. Where a range of rates was recommended, lower doses were chosen in the pot trial to identify as many potentially useful herbicides as possible, and higher rates were selected in subsequent field trials to identify any potential damage to desmanthus.

Trial 1 — Pot trial

A Kiwitea loam soil (4.5% organic carbon) was adjusted to pH = 7.0 by adding lime equivalent to 2.0 t/ha and placed in 1.8 L planter bags. Desmanthus seeds were scalpel-excised to provide 98% germination and sown (10 per pot) at 5 mm depth on June 30, 1994. Two treatments (EPTC and trifluralin) were incorporated into the top 10 cm of soil before sowing. The pots were placed on benches fitted with sub-irrigated felt mats in a glasshouse with a mean temperature of 21.9°C (17–33°C) and relative humidity of 71% (48–90%).

Twenty-three pre-emergent herbicides (Table 1) were applied at sowing and 36 post-emergent herbicides (Table 2) on 14 July, 1994, when plants had 3–4 true leaves and had been thinned to 8 plants per pot. The herbicides were applied using a laboratory pendulum sprayer described by Wiese (1977). Plants were placed below the pivotal centre of a swinging boom and the herbicide was forced through 2 flat fan nozzles (35 cm apart) by compressed air (200 kPa). The boom was released from the same height for each application and allowed to pass twice over the pots, applying herbicide solution equivalent to 250 L/ha to give the application rates of active ingredients shown in Tables 1 and 2.

Table 1. Effect of pre-emergent herbicides on seedling growth of desmanthus at 53 days after application at commercially recommended rates (pot trial, Trial 1).

Active ingredient	Trade name	Level of active ingredient applied	Fresh weight
		(kg /ha)	(mg/pot)
untreated			1298
oryzalin	Surflan Flo	3.00	1042
chlorpropham	Chloro IPC	2.40	1020
chlorthal dimethyl	Dacthal 75W	4.50	798
diflufenican+ isoproturon	Cougar	0.10 0.50	767
pendimethalin	Stomp 330E	0.99	535
trifluralin[1]	Treflan	0.80	446
aziprotryne	Brasoran 50WP	2.00	353
terbutryne	Topogard 500FW	0.26	289
alachlor	Lasso	1.40	272
chloridazon	Pyramin DF	0.86	229
diuron	Karmex	0.80	210
methazole	Probe 75WD	1.10	191
norflurazon	Solicam DF	2.00	190
ethofumesate	Nortron 500SC	1.50	156
hexazinone	Velpar L	0.80	116
cyanazine	Bladex 50WP	1.00	98
EPTC[1]	Eradicane Super	4.30	39
methabenzthiazuron	Tribunil	1.10	36
metribuzin	Sencor DF	0.38	23
simazine	Gesatop 500FW	1.00	22
acetochlor	Roustabout	2.10	19
oxadiazon	Foresite 380	1.50	19
linuron	Linuron 50	1.00	4
oxyfluorfen	Goal	0.72	2
LSD (<0.05)			310

[1] Herbicide incorporated into soil.

Plants in the pots were scored weekly for height, form and colour to give a vigour score, using a scale of 1 (totally necrotic) to 10 (very vigorous). Plants with any green material were counted after the first week and at harvest. Harvesting on August 26 and September 1, 1994, for the pre- and post-emergent treatments, respectively, consisted of cutting growing plants at ground level and immediately measuring the fresh weight.

Table 2. Effect of post-emergent herbicides, applied at the 3–4 leaf stage, at commercially recommended rates on growth of desmanthus seedlings at 35 days after application (pot trial, Trial 1).

Active ingredient	Trade name	Level of active ingredient applied	Fresh weight
		(kg/ha)	(mg/pot)
untreated			1675
propyzamide	Kerb Flo	0.52	2536
carbetamide	Carbetamex 70	2.80	1945
chlorthal dimethyl	Dacthal 75W	4.50	1783
asulam	Asulox	0.80	1514
chlorpropham	Chloro IPC	2.40	1513
clethodim[1]	Centurian 240EC	0.12	1309
bromoxynil	Bromoxynil 40	0.90	1281
bromoxynil+ ioxynil	Combine	0.20 0.20	1279
benazolin	Cornox CWK	0.15	1107
dalapon	Chemagro Dalapon	2.20	1074
haloxyfop	Gallant	0.20	924
bromofenoxim	Faneron 50WP	0.30	780
chlorimuron	Classic	0.03	779
flumetsulam	Preside	0.04	639
chlorsulfuron	Glean	0.02	634
ioxynil	Totril	0.45	581
glyphosate	Roundup	0.36	451
bentazone	Basagran	1.40	448
ethofumesate	Nortron 500SC	1.50	425
pendimethalin	Stomp 330E	0.99	411
chloridazon	Pyramin DF	1.20	263
aziprotryne	Brasoran 50WP	2.00	154
cyanazine	Bladex 50WP	1.00	93
diquat	Reglone	0.60	83
MCPB	DowElanco MCPB	1.20	75
2,4–DB	DowElanco 2,4–DB	2.40	67
diflufenican + isoproturon	Cougar	0.10 0.50	62
terbutryn	Igran 500FW	0.26	55
MCPA	DowElanco MCPA	0.56	53
linuron	Linuron 50	1.00	39
methabenzthiazuron	Tribunil	0.60	39
paraquat	Gramoxone	0.20	38
metribuzin	Sencor DF	0.38	35
2,4-D amine	DowElanco 2,4-D Amine	0.80	33
LSD (P < 0.05)			499

[1] Applied with equivalent of 2 L/ha DC-Trate.

Trial 2 — Field study

Eighty-four plots (each 2.0 × 2.5 m with 0.5 m borders) were pegged out at the Kilkivan site within 4 blocks positioned down an eastern-facing slope (approximately 5°), and glyphosate was applied to kill existing vegetation. The plots were rotary-hoed on November 11, 1994, immediately prior to sowing Marc desmanthus seed, which had been acid-scarified and inoculated (CB3126 *Bradyrhizobium*). The seed was sown in rows 25 cm apart at 7.7 kg/ha. Rainfall was supplemented by an average of 5.2 mm/d irrigation throughout the trial (irrigation supplied 83% of total water).

Herbicides identified in the pot trial as potentially useful in desmanthus seed crops and available in Queensland were applied to individual plots using a propane-pressurised, chest-mounted boom sprayer at constant spray pressure of 200 kPa. Eight taper fan nozzles off-set at 10° applied a total volume of 1 L in a spray swath 2.65 m wide, providing a total spray volume to each plot equivalent to 250 L/ha. A constant rate of travel was achieved by using a calibrated metronome to regulate walking speed for a comfortable stride length. A non-ionic wetting agent was used when specified as normal practice for application to legume crops. Treatments and application rates are listed in Tables 3 and 4. The pre-plant herbicides (trifluralin and pendimethalin) were incorporated into the top 10 cm of soil with a rotary hoe immediately after spraying and before planting. Pre-emergent herbicides were applied immediately after planting and post-emergent herbicides on December 22, 1994, when desmanthus seedlings were at the 4–6 leaf stage. Pendimethalin was treated as both a pre-plant and a post-emergent herbicide. Two control treatments (hand-weeded and unweeded) were included.

Johnson grass (*Sorghum halepense*) was present on the trial area and was treated with a wick-applied 36% glyphosate solution as most of the chemicals used are effective only against broad-leaved weeds. This provided effective control without any obvious effect on other species in the plots.

All measurements were conducted on plants within the internal two-thirds of each plot. Population counts were conducted on desmanthus plants several times during the trial using three 0.1 m^2 randomly placed quadrats per plot. Vigour of desmanthus plants was scored as for the pot trial, with the final scoring conducted 108 days after planting. All weed species which appeared were recorded. The major ones were monitored during the course of the study when observations were made on desmanthus.

Weed populations were scored by visually estimating the proportion of the plot area covered by each weed species. Hence, layering of different

Table 3. Effect of pre-emergent herbicides applied at commercial rates on the population density of desmanthus (21 days after application) and vigour of desmanthus and weeds (56 days after application) (field study, Trial 2).

Herbicide			Density	Vigour score[2]				
Active ingredient	Trade name	Level of active ingredient applied	Desmanthus	Desmanthus	Noogoora burr	Bellvine	Common sida	Bladder ketmia
		(kg/ha)	(plants/m^2)					
hand-weeded	–	–	127	9.2	–	–	–	–
unweeded	–	–	87	5.7	3.7	4.0	3.5	4.2
imazethapyr	Spinnaker	0.07	127	8.7	1.0	4.2	1.7	3.7
trifluralin[1]	Treflan	0.84	102	10.0	3.7	2.2	3.5	6.7
chlorthal dimethyl	Dacthal 750WP	8.25	85	6.7	1.0	6.0	3.0	4.7
diflufenican	Brodal	0.10	75	6.5	1.5	6.2	4.0	5.0
pendimethalin[1]	Stomp 330E	0.99	70	9.5	3.2	3.2	1.0	7.0
pendimethalin	Stomp 330E	0.99	67	8.2	3.7	5.2	1.0	3.0
oryzalin	Surflan 500 Flo	3.40	52	8.5	1.0	4.7	3.2	4.7
metolachlor	Dual	1.44	32	8.0	1.7	5.2	2.2	5.2
LSD ($P < 0.05$)			54	1.2	2.2	1.2	1.4	1.6

[1] Herbicide incorporated into soil. [2] Scale: 1 = totally necrotic to 10 = very vigorous.

Table 4. Effect of post–emergent herbicides, applied at commercial rates, on vigour of desmanthus and weeds (34 days after application) (field study, Trial 2).

Herbicide			Vigour score[1]				
Active ingredient	Trade name	Level of active ingredient applied	Desmanthus	Noogoora burr	Bellvine	Common sida	Bladder ketmia
		(kg/ha)					
hand-weeded	–	–	9.5	–	–	–	–
unweeded	–	–	6.5	2.5	5.0	2.8	5.3
haloxyfop	Verdict	0.16	7.5	3.0	6.3	4.3	6.3
bentazone	Basagran	0.96	7.0	1.3	1.0	1.5	1.0
imazethapyr[2]	Spinnaker	0.10	7.0	1.0	2.8	3.8	4.8
propyzamide	Kerb WP	1.00	6.7	3.8	5.5	2.8	3.8
bromoxynil	Buctril 200	0.40	6.5	1.3	2.3	1.5	1.8
asulam	Asulox	1.20	5.7	1.3	3.8	2.8	3.8
chlorthal dimethyl	Dacthal 750WP	8.25	5.5	2.3	3.0	4.3	5.0
flumetsulam[2]	Broadstrike	0.02	5.2	1.3	2.8	1.0	1.8
bromoxynil + diflufenican	Jaguar	0.25 + 0.03	3.7	1.0	1.8	1.0	1.0
LSD ($P < 0.05$)			1.3	1.2	1.1	1.0	1.4

[1] Scale: 1 = totally necrotic to 10 = very vigorous. [2] BS-1000 (a non-ionic wetter) applied at 100 mL/100 L.

weeds in the canopy often resulted in total weed cover for all species exceeding 100%. Plant vigour of the monitored weed species was assessed using the same method as for desmanthus.

Stage of plant development was recorded for all species whenever data were collected. Plants were classified as seedlings (emergence until development of the first branch), immature (branching but no reproductive buds), mature (evidence of reproductive buds), flowering or seeding (carrying mature seed).

Trial 3 — Field study

While Trials 1 and 2 examined the effectiveness of single herbicides, this study examined combinations of herbicides (*e.g.* pre- and post-emergent) as might be used in a commercial situation. All vegetation was removed from part of the trial site used for Trial 2 and new plots of desmanthus were planted on November 29, 1995, using the same techniques as for Trial 2, but with a slightly lower sowing rate (6.8 kg/ha). Irrigation was used to supplement rainfall over the trial period with an average application of 6.25 mm/d (irrigation was 48% of total water received).

Weed control treatments applied (Table 5) involved combinations of herbicides evaluated in Trial 2, plus 3 herbicides that had not been previously assessed, namely imazapic, imazaquin and pyridate. For most treatments, the first herbicide was applied immediately after planting on November 29, the exception was imazethapyr, which was applied on December 1. The first post-emergent applications occurred on January 15, 1996, when desmanthus was at the early flowering stage, and the second post-emergent application of bentazone was on February 21. Techniques used to apply the herbicides were the same as those used in Trial 2. On March 13, 1996, dimethoate (30 g ai/ha) was applied to the entire trial area to control a minor psyllid (*Acizzia* sp.) infestation. The effect of treatments on desmanthus and weeds was assessed as for Trial 2. The final observation occurred on March 27, 1996 (119 days after planting). Unweeded and hand-weeded plots were included as controls.

Trial 4 — Field study

The objective of the fourth trial was to determine which herbicides could be used to selectively control weeds in 1-year-old desmanthus crops. Part of the area planted with desmanthus during November 1994 for Trial 2 was sprayed with bentazone in late January 1995 to control broad-leaved weeds and several times during February–April with haloxyfop to control Johnson grass. The area was then mown to 15 cm during May and trash was removed. From mid-November 1995 onwards, weeds were removed from the control plots by hand every 2 weeks. The remaining treatments were applied on December 15, 1995 (Table 6), when desmanthus was at the early flowering stage, with application procedures as in Trial 2. When treatments were applied, the desmanthus was at an early flowering stage, whereas the monitored weeds were at varying growth stages. Assessments of vigour of desmanthus and weed species were conducted as in Trial 2 until 39 days after treatments were applied. Unweeded and hand-weeded plots were included as controls.

Statistical analysis

Simple one-way analysis of variance was used to compare means of selected variates. Those with a significant F-value were compared using Fischers' least significance difference (P = 0.05) procedure.

Results

Crop growth

Desmanthus plants grew rapidly in all trials and branched within 3 weeks of sowing. Plants did not flower in Trial 1 (53 days total duration after sowing), probably because cool conditions slowed development. Flowering began 42 days after sowing at Kilkivan, peaked during early February (10 weeks after sowing) and declined until mid-April. In Trial 4, plants showed low vigour during winter and new branches were not produced until November, although flowering on these branches began during early December.

Weeds present in the field trials

Eighteen weed species occurred in the plots over the 2 seasons (Cox 1998). Species monitored in both years were bladder ketmia (*Hibiscus trionum*, Malvaceae), common sida (*Sida rhombifolia*, Malvaceae), bellvine (*Ipomoea plebeia*, Convolvulaceae), rhyncosia (*Rhyncosia minima*, Fabaceae) and Noogoora burr (*Xanthium pungens*, Asteraceae). Phyllanthus (*Phyllanthus tenellus*, Euphorbiaceae) and euphorbia (*Euphorbia prostrata*, Euphorbiaceae) were also monitored in the second season for Trials 3 and 4. Verbena (*Verbena bonariensis*, Verbenaceae) was also present in Trial 4, but not in all plots.

Trial 1

All pre-emergent herbicides tested in the pot study reduced the growth of desmanthus seedlings, although the depression was not significant (P > 0.05) for oryzalin and chlorpropham. Chlorthal dimethyl and diflufenican + isoproturon suppressed seedling growth by about 40%

Table 5. Effect of combinations of pre- and post-emergent herbicides, applied at commercial rates, on vigour of desmanthus and ground cover by weeds (field study, Trial 3).

Treatment[1]			Desmanthus vigour score[2]			% weed ground cover (Feb 28)[3]				
Herbicide 1 (Nov 29–Dec 1)	Herbicide 2 (Jan 15)	Herbicide 3 (Feb 21)	22 Jan	28 Feb	27 Mar	Bladder ketmia	Noogoora burr	Bellvine	Common sida	Phyllanthus
hand-weeded			8.5	8.0	8.8	–	–	–	–	–
unweeded			9.3	6.8	6.0	48	38	73	15	0
imazaquin (0.20)	bentazone (0.96)	bentazone (0.96)	9.3	9.8	9.0	0	0	0	0	3
imazethapyr (0.10)	bentazone (0.96)	bentazone (0.96)	9.3	8.8	8.3	0	30	30	0	0
trifluralin (0.84)	imazethapyr (0.10)[4]	bentazone (0.96)	9.0	7.0	7.5	48	20	18	8	0
trifluralin (0.84)	bromoxynil (0.40)	bentazone (0.96)	8.8	7.5	7.8	15	30	38	0	3
trifluralin (0.84)	bentazone (0.96)	bentazone (0.96)	8.8	7.8	7.0	10	33	25	5	0
trifluralin (0.84)	bentazone (0.96)	none	8.5	8.8	7.3	0	40	43	5	0
pendimethalin (0.99)	bentazone (0.96)	bentazone (0.96)	8.5	8.3	7.0	0	25	15	0	18
trifluralin (0.84)	imazapic (0.07)[4]	bentazone (0.96)	8.0	6.8	7.8	75	10	0	0	10
trifluralin (0.84)	pyridate (0.90)[4]	bentazone (0.96)	6.3	8.0	8.3	70	38	48	10	0
LSD ($P < 0.05$)			1.3	1.0	1.5	25[5]	21[5]	33[5]	13[5]	17[5]

[1] Application rates of active ingredient in brackets (kg/ha).
[2] Scale: 1 = totally necrotic to 10 = very vigorous.
[3] Since plants overlap, totals may exceed 100%.
[4] BS-1000 (a non-ionic wetter) applied at 100 mL/100 L.
[5] The initial random distribution of weed plants between plots contributed to high levels of variation during monitoring.

Table 6. Effect of post-emergent herbicides, applied at commercial rates to 1-year-old desmanthus, on vigour and population density of desmanthus and vigour of key weed species (field study, Trial 4).

Herbicide			Desmanthus			Weed vigour scores[1]			
Active ingredient	Trade name	Level of active ingredient applied	Vigour score[1]		Density	Common sida[3]		Bellvine[4]	
			7 DAT[2]	39 DAT	39 DAT	7 DAT	39 DAT	7 DAT	39 DAT
		(kg/ha)			(plant/m^2)				
hand-weeded	–	–	10.0	10.0	80	–	–	–	–
unweeded	–	–	9.8	9.3	55	10.0	10.0	10.0	8.8
ethofumesate	Tramat	2.00	8.0	8.5	45	9.3	9.5	8.8	7.8
acifluorfen	Blazer	0.45	7.3	8.8	38	9.5	8.8	5.0	7.5
atrazine	Atradex 900WG	0.99	6.3	9.0	55	8.8	9.8	3.3	1.0
paraquat	Gramoxone	0.40	5.5	8.8	63	4.5	8.5	2.8	7.3
terbacil	Sinbar	2.40	2.5	7.8	55	2.0	1.0	1.0	1.0
metribuzin	Lexone DF	0.56	2.3	7.8	48	4.8	8.0	3.3	2.5
glyphosate	Roundup	1.80	2.0	6.0	8	4.5	1.0	4.0	1.8
hexazinone	Velpar L	1.00	1.5	6.5	48	2.0	1.3	1.3	1.0
LSD (P < 0.05)			1.3	1.2	26	2.1	1.7	2.2	2.0

[1] Scale: 1 = totally necrotic to 10 = very vigorous.
[2] Days after treatment.
[3] Vegetative at time of spraying.
[4] Flowering at time of spraying.

(P < 0.05), while all other pre-emergent herbicides suppressed growth by more than 60% (Table 1).

A number of post-emergent herbicides (carbetamide, chlorthal dimethyl, asulam, chlorpropham, clethodim, bromoxynil and bromoxynil + ioxynil) produced no significant change in growth of desmanthus seedlings (P > 0.05), while propyzamide stimulated growth (P < 0.05) (Table 2). All of the remaining post-emergent herbicides caused significant (P < 0.05) reductions in growth of desmanthus seedlings at 35 days after application.

Trial 2

The pre-emergent herbicides imazethapyr and trifluralin had no effect on seedling emergence of desmanthus (Table 3). Chlorthal dimethyl suppressed emergence, but not significantly (P > 0.05) so, while seedling density in plots treated with metolachlor and oryzalin was only 25% and 41%, respectively, of that in hand-weeded plots 21 days after application (P < 0.05).

There appeared to be little adverse effect from most of these treatments on vigour of desmanthus plants, especially after the first few weeks. None of these herbicides gave good weed control. Weed competition became severe in some plots one month after planting, especially the twining growth of bellvine.

Scoring of desmanthus 5 days after spraying with post-emergent herbicides showed that immediate damage was caused by bentazone, imazethapyr, flumetsulam and the bromoxynil + diflufenican mixture (data not shown). However, desmanthus had recovered well from the effects of bentazone and imazethapyr 34 days after spraying. At that time, vigour of desmanthus was worse (P < 0.05) on all treated plots than in the hand-weeded control but most were not different from the unweeded control (Table 4).

Bentazone gave good control of the main weed species present, especially bellvine and bladder ketmia. Bromoxynil also gave useful broad-spectrum control, whereas control of weeds by other herbicides was variable.

Trial 3

None of the herbicide combinations tested produced any lasting reduction in vigour of desmanthus. Pyridate and imazapic caused some temporary decrease in vigour but the plants recovered later (Table 5).

Imazaquin followed by 2 applications of bentazone gave excellent weed control. Application of imazethapyr gave much better weed control in combination with other chemicals, as a pre-emergent rather than a post-emergent treatment. Most of the treatments, apart from the one involving pyridate, gave some control of weeds, although the post-emergent herbicides were applied when weeds were slightly older than is recommended for best control. In plots that had been mostly cleared of weeds by these herbicide combinations, an increase in leguminous weed species such as *Indigofera hirsuta, Macroptilium atropurpureum* and *Chamaecrista rotundifolia* was noted 71 days after sowing, particularly in imazethapyr plots.

Trial 4

All herbicides applied to the 1-year-old desmanthus plants suppressed vigour of desmanthus at 7 days after treatment relative to that on control plots (both hand-weeded and unweeded) ($P < 0.05$) (Table 6). However, desmanthus had recovered on most treatments by 39 days after treatment. Only glyphosate reduced plant density ($P < 0.05$) at this time relative to the unweeded control.

Control of weeds was quite variable. Glyphosate, hexazinone and terbacil gave excellent control of both sida and bellvine, while atrazine and metribuzin gave good control of bellvine but had no lasting effect on sida.

Discussion

This study has identified promising herbicides, in addition to trifluralin and bentazone, for selective weed control in desmanthus seed crops. While trifluralin and bentazone were confirmed as being safe for use on desmanthus, these herbicides are not sufficient by themselves to solve all weed problems in Australian desmanthus seed crops. Trifluralin, a pre-emergent dinitroalinine herbicide, gives poor control of most species from the Asteraceae, Fabaceae, Malvaceae, Brassicaeae and Solanaceae families (Matthews 1975), which covers many important weeds. It must also be incorporated into the soil because of its volatile nature, potentially increasing the amount of cultivation required at establishment. Bentazone, a contact post-emergent herbicide, is also tolerated by many weeds, especially if not treated while young.

The field experiments clearly demonstrated that poor control of weeds can inhibit growth of desmanthus. Desmanthus vigour scores were consistently lower in unweeded plots than in weeded plots, although sometimes this effect did not occur until late in the growing season. In Trial 2, treatments which caused poor vigour of desmanthus plants (Table 3) probably did so through poor weed control by the herbicides rather than any direct effect of chemicals on the desmanthus. Plots that had best control of bellvine and Johnson grass, especially the incorporated dinitroalinines, also had the best desmanthus growth.

Although an assessment was made on the effect of the herbicide treatments on the growth of desmanthus, it was difficult to measure this effect on seed yield. In the pot trial, the environmental conditions were not conducive to proper flowering. In the subsequent field trials, the severe weed invasions after the use of only single herbicide applications in Trials 2 and 4 meant that treatment effects were masked by the time seeds were harvested. Sequential applications of herbicides as used in Trial 3 gives the best weed-free environment for seed production, but yields were not measured in this trial because of problems with seed shattering.

To estimate the effects of herbicide damage or weed competition (field trials) on 'Marc' seed yield, we assumed that desmanthus plants of relatively low vigour at advanced growth stages (45–90% of normal crop duration) were more likely to produce lower seed yields than plants with higher plant vigour. We reasoned that a first-year desmanthus seed crop, being of short duration (~ 130 days), would not recover from such growth checks before initiating reproductive growth. However, if grown as a 2-year seed crop, there may be opportunity for plant recovery sufficient to annul any herbicide effects on seed yield.

Herbicide options during establishment

Imazethapyr and imazaquin, both imidazolinone herbicides, seemed particularly useful for controlling weeds during the establishment of desmanthus seed crops. Imazethapyr seemed reasonably safe at both pre- and post-emergence, though it gave the best weed control if applied before weeds became established. A third imidazolinone herbicide, imazapic, also gave useful weed control but did not appear to be as safe as imazethapyr or imazaquin. All of these herbicides are used selectively in legume crops around the world, especially in soyabeans (Ayene 1997; Tecle *et al.* 1997; Johnson *et al.* 1998). Imazethapyr and imazapic have also been found to be very useful for successfully establishing a range of grassland legume species in USA (Beran *et al.* 1999). Between them, these herbicides control many of the weed species that tolerate trifluralin and bentazone.

In addition to imazethapyr and imazaquin, safe and potentially useful alternatives to trifluralin include the dinitroalinine herbicides pendimethalin and oryzalin, which, unlike trifluralin, do not require incorporation into the soil. There was some evidence in Trial 2 that both oryzalin and pendimethalin reduced the emergence of desmanthus seedlings (Table 3). However, once emerged, the desmanthus grew well, especially with the reduced weed densities resulting from the effects of the herbicides. Pendimethalin had a similar effect, regardless of whether it was incorporated, on desmanthus growth and on many of the weeds. However, incorporating pendimethalin gave substantially better control of Johnson grass. Presumably, this was due to better distribution of the herbicide through the root zone of re-establishing rhizome fragments.

Should pre-emergent herbicides be ineffective, there are plenty of options available to control grasses. Before our trials, the suite of selective post-emergent herbicides that had already been identified as being safe for grass control in desmanthus were fluazifop-P, sethoxydim and diclofop-methyl (Mastrocola *et al.* 1983; Loch and Harvey 1990). Our work has shown that the following herbicides can be added to the list: haloxyfop, clethodim, propyzamide, carbetamide and dalapon. However, the anilide herbicides used (alachlor, acetochlor and metolachlor) were shown to damage desmanthus, even though some (alachlor and metolachlor) are used to control grasses in tropical legume crops.

Broad-leaved weeds are usually more difficult to control in tropical legume seed crops than grasses. During crop establishment, some broad-leaved weeds are controlled by the dinitroalinines, but the imidazolenones showed the most promise for controlling weeds in desmanthus seed crops. Although having a similar mode of action (inhibiter of acetolactate synthase) (Tomlin 1997) to the imidazolenones and being registered in Queensland for use in another tropical legume crop (peanuts), flumetsulam was comparatively damaging to desmanthus and is not recommended for use in desmanthus seed crops.

Bentazone is a commercially proven option for controlling many broad-leaved weeds, and proved useful in our trials as well. Several other contact herbicides were compared with bentazone to see if they would cause less initial scorch while controlling other weed species. Bromoxynil showed the most potential from this group of chemicals as it appeared to have little effect on desmanthus in Trial 1. However, in Trials 2 and 3, the damage to desmanthus caused by bromxynil was similar to that caused by bentazone. Pyridate was assessed only in Trial 3 and caused more initial damage to desmanthus than either bentazone or bromoxynil. Weed control by bromoxynil and pyridate was also superior to that achieved with bentazone.

Acifluorfen could be a very useful herbicide to control broad-leaved weeds because it is registered for use in legume seed crops (*Macroptilium atropurpureum* and *Stylosanthes* spp.) to control problem weeds encountered in the main seed-growing district of Queensland (Atherton Tablelands, north Queensland). We evaluated acifluorfen only on well established plants 1 year after planting (Trial 4). While it caused some loss of leaf in desmanthus plants 1 week after application, the crop recovered well from this initial damage, although the plant density 39 days after treatment was reduced (Table 6). As it is a contact herbicide, it is normally recommended for use only on young weeds, which may explain why it did not give satisfactory control of the well established common sida and bellvine. More work is required with this herbicide in younger crops to determine whether it is superior to bentazone or bromoxynil.

In addition to the above, the pot trials indicated that some herbicides (*e.g.* chlorpropham, clethodim and carbetamide) have potential for use in desmanthus seed crops. As they were not registered for use in Queensland at the time of the study, they were not evaluated in field trials. Clethodim has since been registered for use in legume crops in Queensland. The diflufenican + isoproturon combination appeared to damage desmanthus plants only when applied post-, rather than pre-emergence.

Controlling weeds in mature crops

Of the other herbicides applied to mature weeds in the 1-year-old stand of desmanthus, most were selected because they were tolerated by established lucerne or white clover and had potential to control well established weed species. All produced some damage on desmanthus plants, although the crops generally recovered well. Other work with seed production in second-year legume crops with similar canopy structure to desmanthus, such as lucerne, has shown that damage to the plants by herbicides prior to flowering will not necessarily reduce seed yields (Askarian *et al.* 1993). Often the increase in yield from reducing weed competition may be much greater than the check in crop growth caused by the herbicide.

A limitation of our study was that we used only a single rate of herbicide. There may be potential to reduce the damage to desmanthus by these herbicides by reducing the application rate of herbicide. However, reduced rates may decrease weed control as well. Examples are as follows:

- Atrazine provided very good control of bellvine and desmanthus recovered rapidly from this treatment, but it gave poor control of common sida; higher rates could be tested.
- Terbacil controlled both the weed species monitored without causing excessive crop damage, which suggests that a reduced rate of terbacil would be worth investigating.
- Hexazinone gave good weed control, and, although it was initially very damaging to the desmanthus, there was reasonable recovery. Lower rates could be examined.
- The other treatment worth further investigation was metribuzin, although a reduction in application rate to reduce crop damage may not be useful as the control of weeds is likely to be unsatisfactory at lower application rates.

The other herbicides assessed on mature desmanthus are probably of limited use. While glyphosate effectively controlled the weeds, desmanthus showed limited tolerance. Although desmanthus behaved like many established legume species and recovered well from the paraquat application, most established weed species also recovered, as did common sida and bellvine. Ethofumesate caused only minimal damage to desmanthus but was also ineffective on the weeds. Although it can be useful on some grass species, haloxyfop would probably be more useful in this role than ethofumesate.

Integrated weed control strategies

In most instances, an integrated herbicide strategy is needed to control weeds in desmanthus seed crops grown in Australia. Timely use of glyphosate prior to seed-bed preparation is important to properly control perennial weeds such as Johnson grass, as these regrowing perennial weeds can be difficult to kill once the crop is present. A pre-emergent herbicide should be used to allow the crop to establish well. Trifluralin has been used in this role in the past for desmanthus seed crops. Other treatments that have been identified from this work as being suitable pre-emergence alternatives are imazaquin, imazethapyr, pendimethalin and oryzalin. All have the advantage over trifluralin of not needing to be incorporated into the soil prior to planting.

The choice of pre-emergent herbicide will have some influence on the weeds that manage to establish within the young desmanthus crop, and thus will determine which herbicide is the best option to use post-emergence. If grasses are present, then haloxyfop, clethodim or other closely related herbicides can be applied. For broad-leaved weeds, the main options are probably imazethapyr, bentazone and bromoxynil, with the most appropriate one being selected for the specific weed flora present. In the absence of data on seed yield, caution should be exercised if applying herbicides once flowering has begun, as even small phytotoxic effects at this time may have severe effects on seed production. The main determinant of desmanthus seed yield is inflorescence number (Cox 1998), and this could be easily reduced by poorly timed herbicide application.

Desmanthus seed yields can be low in second-year crops due to poor plant recovery from mechanical harvesting (Cox 1998). Thus, devising weed control recommendations for second-year crops may not be necessary. However, these systems are likely to be used for desmanthus seed production in Queensland because they are already used to harvest legume seed crops with similar canopy structure and seed production characteristics (*e.g. Stylosanthes* spp.). For crops of this nature, several options exist, though more research is required: the translocating properties of herbicides such as haloxyfop and clethodim would be sufficient to control any perennial grasses that existed at the start of the growing season; the post-emergent herbicides suitable for use on broad-leaved weeds in first-year desmanthus crops are all quite weak on well established weeds, so assistance would be required from chemicals such as atrazine, terbacil or hexazinone.

Overall, herbicide options are available to control most weeds likely to be encountered in Queensland desmanthus seed crops. However, even the best herbicide combinations used in this study provided poor control of leguminous weeds. It will be important, therefore, to consider site history, contamination of plant-seed with legume seed and crop rotation (say, with a graminaceous crop where legumes can easily be controlled with herbicides), when planning a desmanthus seed crop.

Acknowledgements

We thank Dr Donald Loch and Dr John Hopkinson for advice relating to trial design and commercial application of results and Greg Harvey for technical assistance. We also gratefully acknowledge Wrightson Seeds Pty Ltd for financial support.

References

Ayene, A.O. (1997) Use and optimisation of imidazolinone herbicides in legume production in Nigeria. *Proceedings of the Crop Protection Weeds Conference, Brighton, 1997.* **2**, 693–698.

Askarian, M., Hampton, J.G. and Harrington, K.C. (1993) Control of weeds, and particularly white clover (*Trifolium repens* L.), in lucerne (*Medicago sativa* L.) grown for seed production. *Journal of Applied Seed Production*, **11**, 51–55.

Beran, D.D., Masters, R.A. and Gaussoin, R.E. (1999) Grassland legume establishment with imazethapyr and imazapic. *Agronomy Journal*, **91**, 592–596.

Clem, R.L. and Hall, T.J. (1994) Persistence and productivity of tropical pasture legumes on three cracking clay soils (Vertisols) in north-eastern Queensland. *Australian Journal of Experimental Agriculture*, **34**, 161–171.

Cox, K.G. (1998) *A study of seed production in desmanthus* (Desmanthus virgatus *L.*). Ph.D. Thesis. Massey University.

Graham, T.W.G., Hall, T.J. and Clem, R.L. (1991) Release of three cultivars of *Desmanthus virgatus*. *Internal Report, Queensland Department of Primary Industries, Brisbane.*

Johnson, W.G., Dilbeck, J.S., Defelice, M.S. and Kendig, J.A. (1998) Weed control with reduced rates of imazaquin and imazethapyr in no-till narrow-row soybean (*Glycine max*). *Weed Science*, **46,** 105–110.

Jones, R.M. and Rees, M.C. (1997) Evaluation of tropical legumes on clay soils at four sites in southern inland Queensland. *Tropical Grasslands*, **31**, 95–106.

Loch, D.S. and Harvey, G.L. (1990) Weed control in pasture seed crops in southern Queensland. In: Hawton, D. (ed.) *Weeds Research Workshop.* pp. 34–42. (Department of Primary Industries: Brisbane).

Luckow, M. (1993) Monograph of *Desmanthus* (Leguminosae — Mimosoideae). *Systematic Botany Monographs*, **38**, 1–166.

Mastrocola, M.A., Paulino, V.T., Almeida, J.E., Cruz, L.S.P. and De Santos, C.A.L. (1983) Sensitivity of forage legumes to post-emergence herbicides. *Boletim De Indústria Animal*, **40**, 159–168.

Matthews, L.J. (1975) *Weed Control by Chemical Methods.* (A.R. Shearer: Wellington).

Tecle, B., Shaner, D.L., Cunha, A. D., Devine, P. J. and Ellis, M. R. van (1997) Comparative metabolism of imidazolinone herbicides. *Proceedings of the Crop Protection Weeds Conference, Brighton, 1997.* **2**, 605–610.

Tomlin, C.D.S. (1997) *The Pesticide Manual.* 11th Edn. (British Crop Protection Council: Farnham, United Kingdom).

Wiese, A.F. (1977) Herbicide application. In: Truelove, B. (ed.) *Research Methods in Weed Science.* pp. 1–13. (Southern Weed Science Society: Alabama).

(Received for publication August 27, 2003; accepted December 12, 2004)