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Research Paper

Herbicide sensitivity of desmanthus (*Desmanthus virgatus*) at different stages of development

*Sensibilidad a herbicidas del frijolillo (*Desmanthus virgatus*) en diferentes etapas de desarrollo*

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Abstract

Desmanthus (*Desmanthus* spp.) is a native, naturalised or sown legume in many tropical and subtropical areas, including Australia where its potential use as a companion legume is extending to more southern latitudes. Desmanthus pastures are commonly sown into former cropping paddocks which have a significant weed burden. In these situations, weeds can be an issue during the establishment phase as well as in established desmanthus pastures. Three field experiments were conducted in northern New South Wales to assess the sensitivity of *D. virgatus* 'Marc' to herbicides at different stages of pasture development. At sowing, imazethapyr [0.41 kg active ingredient (a.i./ha)] and trifluralin (0.85 kg a.i./ha) were suitable for pre-emergent use. In a 9-week-old seedling pasture, bromoxynil (0.14–0.56 kg a.i./ha) and flumetsulam (0.02–0.08 kg a.i./ha) caused little plant damage and are suitable for use, while 2,4-D amine (0.54–2.16 kg a.i./ha) and MCPA (0.49–1.95 kg a.i./ha) caused extensive damage, reducing herbage production and delaying flowering. In a 10-month-old established pasture, bromoxynil (0.14–0.56 kg a.i./ha), imazethapyr (0.04–0.14 kg a.i./ha) and terbuthylazine (0.44–1.75 kg a.i./ha) caused minor short-term plant damage. Isoxaflutole (0.04–0.15 kg a.i./ha) resulted in temporary plant foliage bleaching and reduced production, without on-going effects following cutting. Established plants of desmanthus were defoliated by paraquat (0.2–0.8 kg a.i./ha) but regrew without phytotoxic effects. All these herbicides could be used on desmanthus plants. In established desmanthus pastures 2,4-DB (0.35–1.4 kg a.i./ha) caused significant damage but not plant death. There were no ongoing effects of the herbicide on plant productivity following cutting.

Keywords: Fluroxypyr, phytotoxicity, pyroxasulfone, S-metolachlor, yield.

Resumen

El Frijolillo (*Desmanthus* spp.) es una leguminosa nativa, naturalizada o sembrada en muchas áreas tropicales y subtropicales, incluida Australia, donde su uso potencial como leguminosa acompañante se está extendiendo a latitudes más meridionales. El frijolillo se siembra comúnmente en antiguos terrenos de cultivo que tienen una carga significativa de malezas. En estas situaciones, las malezas pueden ser un problema durante la fase de establecimiento, así como en en praderas de frijolillo establecidas. Se llevaron a cabo tres experimentos de campo en el norte de Nueva Gales del Sur para evaluar la sensibilidad de *D. virgatus* 'Marc' a los herbicidas en diferentes etapas de desarrollo de la pastura. En la siembra, el imazetapir [0.41 kg de ingrediente activo (i.a./ha)] y la trifluralina (0.85 kg i.a./ha) fueron adecuados para uso como preemergente. A las 9 semanas, el bromoxinil (0.14–0.56 kg i.a./ha) y el flumetsulam (0.02–0.08 kg i.a./ha) causaron poco daño a las plantas y son adecuados para su uso, mientras que la 2,4-D amina (0.54–2.16 kg i.a./ha) y el MCPA (0.49–1.95 kg i.a./ha) causaron daños fuertes, reduciendo la producción de

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forraje y retrasando la floración. En una pastura de 10 meses de edad, el bromoxinil (0.14–0.56 kg i.a./ha), el imazetapir (0.04–0.14 kg i.a./ha) y la terbutilazina (0.44–1.75 kg i.a./ha) causaron daños menores a corto plazo. El isoxaflutol (0.04–0.15 kg i.a./ha) provocó un blanqueamiento temporal del follaje y una reducción de la producción, sin efectos persistentes tras el corte. Las plantas establecidas de frijolillo fueron defoliadas por paraquat (0.2–0.8 kg i.a./ha), pero rebrotaron sin efectos fitotóxicos. Todos estos herbicidas pueden utilizarse en plantas de frijolillo. En pasturas establecidas de frijolillo, el 2,4-DB (0.35–1.4 kg i.a./ha) causó daños significativos, pero no la muerte de las plantas. No se observaron efectos persistentes del herbicida en la productividad de las plantas en cortes posteriores.

Palabras clave: Fluroxypyr, fitotoxicidad, pyroxasulfone, S-metolachlor, rendimiento.

Introduction

Desmanthus (*Desmanthus* spp.) is a tropical forage legume with multiple species native to the Americas and/or Caribbean which has naturalised in many tropical and subtropical environments (Burt 1993; Lazier and Ahmad 2016; Cook et al. 2020). In Australia, *D. leptophyllus* Kunth is naturalised in the northern parts of the country (Cook et al. 2020), with cultivars of several species available and suitable as a companion legume in grass pastures and rangelands (Gardiner 2016). Desmanthus is predominantly found on soils with neutral to alkaline pH with textures ranging from loams and heavy clays to gravel and sands (Cook et al. 2020). In Australia, desmanthus is sown at latitudes north of approximately -28.5° (Cook et al. 2020). Additionally, over the last decade, this legume demonstrated potential in mixtures with sown tropical perennial grasses in field experiments in northern inland New South Wales (NSW), at latitudes of -30.7°, south of those previously tested in Australia (Boschma et al. 2021a, 2021b).

Desmanthus has been commercially available in Australia for several decades, initially with the release of 'Jaribu' in the 1990s. It was a blend of 3 cultivars consisting of *D. virgatus* (L.) Willd. 'Marc', *D. leptophyllus* Kunth 'Bayamo' and *D. pubescens* B.L. Turner 'Uman'. 'Marc' was the only persistent cultivar in the mix (Pengelly and Conway 2000) and is still available today, along with several other cultivars. Information on establishment and management is required for successful adoption of new species into grazing systems. This information includes preferred soil types, suitable companion species and herbicide options to control weeds.

When sowing new pastures, it is recommended to conduct weed control for several years prior to sowing (Harris et al. 2014). However, the commercial reality is that this preparation time is often circumvented, and herbicide options are sought to control weeds during the establishment phase. Weeds can provide significant competition with desmanthus, especially in establishing stands, reducing vigour and productivity (Cox 1998; Cox and Harrington 2005). Weeds can also reduce productivity of established pastures. The range of weeds varies greatly with location and soil type, including annual summer-growing grasses and broadleaf species.

Several studies have been conducted in Australia to test the tolerance of desmanthus to a range of herbicides (Cox 1998; Cox and Harrington 2005), however none of the herbicides tested are registered for use with desmanthus. Our paper reports 3 field experiments conducted with the objective to quantify the sensitivity of *D. virgatus* to a range of herbicides not previously tested for use with desmanthus, applied at 3 developmental stages: pre-emergent, seedling (9-week-old) and established pasture (10-month-old). Sensitivity was assessed using measures of plant density, herbage production and phytotoxicity to increase knowledge of the sensitivity of desmanthus to a broader range of herbicides and provide data to increase confidence for their use. In Australia, the findings and previously published reports will be used as evidence for an Australian Pesticides and Veterinary Medicines Authority (APVMA) permit application for commercial use of suitable herbicides in desmanthus pastures/seed crops.

Materials and Methods

Three experiments were conducted at the Tamworth Agricultural Institute (-30.1445° 150.9677°, 400 masl, 649 mm annual average rainfall) on a brown Chromosol soil (pH $CaCl_2$ (0–10 cm) 6.7; Isbell 2021). *Desmanthus virgatus* 'Marc' was used in the experiments conducted at 3 different stages of pasture development: Pre-pasture emergence, seedling pasture (<3 months old) and established pasture (>9 months old).

In each experiment, mechanically scarified seeds of desmanthus were sown at 4 kg/ha (germinable) at 1 cm depth with a narrow tyned cone seeder in 6 rows, each row 0.25 m apart. The plots were 2 m wide and at least 3 m long and each experiment was arranged in a randomised complete block design with 4 replicates. Four rates of each herbicide, nil (0), half (0.5x), standard (1x) and twice (2x) the standard rate for legume pastures, were applied using a battery operated backpack sprayer (Selecta 15 L model KN14-2, silvan.com.au) with a 1 m hand-held boom. The half and standard rates, and sometimes the double rate were within the registered label application rate for other pasture legumes or related species. The nil treatments were sprayed with water. Most herbicides tested were registered for use on other pasture legumes (trifluralin, imazethapyr, bromoxynil, 2,4-DB) or local evidence suggested they may be suitable (2,4-D amine, MCPA, paraquat), however, several were purely for experimental testing (fluroxypyr, S-metolachlor, pyroxasulfone). Rainfall (mm) figures from the Bureau of Meteorology (Station 55325, 1993–2023) were collected (Figure 1).

Experiment 1 – Pre-pasture emergence

Desmanthus was sown on 23 February 2016. Four herbicides were tested at 4 application rates (Table 1). Trifluralin was applied 5 days prior to sowing and incorporated to approximately 5 cm; the other 3 herbicides were applied 4 days after desmanthus was sown. The experiment was irrigated with 74 mm over a 7-day period after the herbicide treatments had been applied to assist legume establishment. Seedling density (plants/m^2) was assessed 3 weeks after sowing by counting the number of plants in 9 lengths of 0.3 m row (total 2.7 m of row) and converting to plants/m^2.

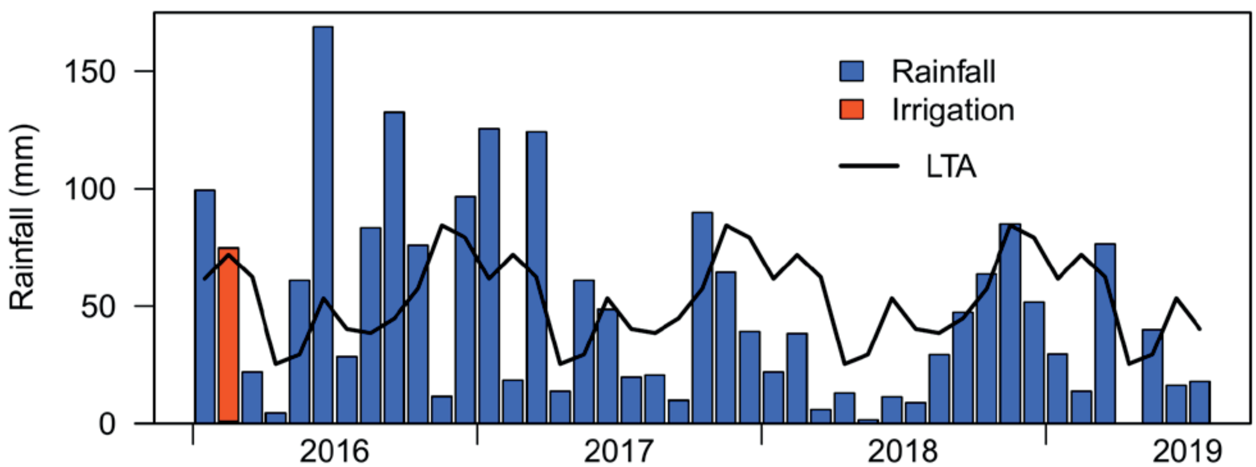

Figure 1. Actual and long-term average rainfall (mm) recorded from Bureau of Meteorology (Station 55325, 1993–2023). Irrigation applied is shown in red. LTA=Long-term average rainfall. The experiments were conducted February–November 2016 (experiment 1), November 2017–March 2018 (experiment 3) and February–June 2019 (experiment 2).

Table 1. Herbicides, rates, details of application and chemical group in the pre-pasture emergent experiment (experiment 1).

Herbicide	Rate of active ingredient in application rates (kg a.i./ha)			Water volume applied (L/ha)	Application details	Chemical group[1]
	0.5x	1x	2x			
Trifluralin	0.41	0.82	1.63	135	Applied pre-sowing and incorporated (18.2.16)	3
Imazethapyr	0.04	0.07	0.14	148	Applied post-sowing (29.2.16)	2
S-metolachlor	0.72	1.44	2.88	148	Applied post-sowing (29.2.16)	15
Pyroxasulfone	0.05	0.10	0.20	148	Applied post-sowing (29.2.16)[2]	15

[1]Chemical group is based on the herbicide mode of action (www.croplife.org.au)
[2]Recommended practice is application pre-sowing with incorporation by sowing using knife points with press wheels or narrow points and harrows (Anon. undated)

Seedling herbage production (kg DM/ha) was assessed on 29 March 2016, 5 weeks after sowing to estimate seedling vigour. On 10 May 2016, prior to the first frost when the pasture was 11 weeks old, desmanthus herbage production was assessed a second time. The experiment was mown to 10 cm during winter when the plants were defoliated by frost. Spring regrowth was assessed on 17 November 2016.

All herbage production assessments were conducted using a calibrated visual estimate similar to that reported in Boschma et al. (2011). Each plot was divided into 3 equal strata, and total herbage production scored on a continuous scale 0–5 (where 0=nil, 5=highest) and proportion (%) of desmanthus assessed in each strata by a single operator. Fifteen quadrats (0.4 × 0.4 m) were selected representing the range in total production and proportion of desmanthus present in the experiment. The calibration quadrats were cut to 1 cm above the soil surface and herbage sorted into desmanthus and other plants. The material was dried in a dehydrator at 80 °C for 48 hr. Total production scores were converted to dry matter (kg DM/ha) and actual percentage using linear and quadratic regressions ($R^2 \geq 0.83$) to determine the herbage production of desmanthus.

Experiment 2 – Seedling pasture

Desmanthus was sown in December 2018. Five herbicides at 4 rates (162 L water/ha) were applied to the 9-week-old pasture on 7 February 2019 (Table 2). Phytotoxicity was assessed weekly for 4 weeks following treatment application using a plant damage score of 0–10 (Table 3). Herbage production was assessed on 1 April 2019, 8 weeks after application (WAA) and prior to first frost using the method described for experiment 1. Phenological development of desmanthus plants was assessed every 6–11 days (total 8 times) over the period 7 March–29 April 2019 using the scoring system where 0=vegetative, 1=reproductive (buds present), 2=flowering, and 3=seed set (pods present). In June 2019 once frosts had commenced and plant growth ceased, the percentages of pods that had matured (either contained brown seed or pod had dehisced) were recorded.

Table 2. Herbicides, the chemical group and application rates greater than zero applied to seedling desmanthus (experiment 2).

Herbicide	Rate of active ingredient in application rates (kg a.i./ha)			Chemical group[1]
	0.5x	1x	2x	
2,4-D amine	0.54	1.08	2.16	4
MCPA	0.49	0.98	1.95	4
Flumetsulam[2]	0.02	0.04	0.08	2
Fluroxypyr	0.01	0.02	0.40	4
Bromoxynil	0.14	0.28	0.56	6

[1]Chemical group is based on the herbicide mode of action (www.croplife.org.au)

[2]Applied with paraffinic oil (0.29 L a.i./100 L water) and alkoxylated alcohol non-ionic surfactant (0.12 L a.i./100 L water)

Table 3. Phytotoxicity scores to rate sown plant (crop) damage up to 4 weeks after herbicide application (modified from Vanhala et al. 2004). Damage symptoms included plant injury, necrosis and reduced growth.

Score	Criteria
0	No crop reduction or injury
1	Slight discolouration or stunting
2	Some discolouration or stunting
3	Slight crop damage
4	More pronounced crop damage
5	Moderate crop damage
6	Moderately high crop damage
7	More pronounced crop damage
8	Heavy crop damage
9	Heavy crop damage with potential plant losses
10	Potential total crop death

Experiment 3 – Established pasture

Six herbicides were applied to 10-month-old desmanthus 'Marc' on 16 November 2017 (Table 4). Plant damage was assessed 1, 2 and 4 weeks after treatment application using the phytotoxicity score described in Table 3. The extent of brown out (percentage of plant leaf that was desiccated) was assessed on the plots applied with paraquat. Herbage production was assessed on 3 occasions: 15 December 2017, 1 February and 8 March 2018 (4, 11 and 16 WAA, respectively). The plots were mown after each assessment to 10 cm with a flail mower and the herbage removed from the experimental area. Production was assessed using the visual assessment method described in experiment 1.

Data analyses

Seedling counts, phytotoxicity scores, pod maturity and herbage production data were analysed by analysis of variance (AOV) with herbicide, rate of herbicide (0, 0.5x, 1x, and 2x recommended rate) and their interaction were explanatory factors and replicate a blocking factor. All analyses were conducted using R (R Core Team 2023). Herbage production data assessed in experiment 1 on 10 May and 17 November 2016 were square root transformed to meet the assumption of homogeneity of variance. For all variables, differences between means were determined using the least significant difference (LSD) at P=0.05.

Plants in all plots had pods present by the final phenological development assessment which was quantitatively summarised by calculating the area under a curve (AUC) (Simko and Piepho 2012) where plants with earlier flowering and pod development had a higher AUC. The AUCs were calculated, analysed and LSD determined as above.

Table 4. Herbicides, the chemical group and application rates greater than zero, applied to established desmanthus (experiment 3).

Herbicide	Rate of active ingredient in application rates (kg a.i./ha)			Chemical group[1]
	0.5x	1x	2x	
Paraquat	0.20	0.40	0.80	22
Isoxaflutole	0.04	0.08	0.15	27
2,4-DB	0.35	0.70	1.40	4
Terbuthylazine	0.44	0.88	1.75	6
Imazethapyr	0.04	0.07	0.14	2
Bromoxynil	0.14	0.28	0.56	6

[1]Chemical group is based on the herbicide mode of action (www.croplife.org.au)

Results

Experiment 1 – Pre-pasture emergence

There was no effect of imazethapyr applied pre-emergent on desmanthus seedling plant densities assessed 3 weeks after sowing (Figure 2). Trifluralin had no effect on seedling density at the half rate, however density declined at the standard and double rates, with plant densities at the double rate 45% of the control ($P<0.05$). Plant density was significantly reduced at all rates of both S-metolachlor and pyroxasulfone compared to the control. At the double rate of pyroxasulfone, plant density was 5% of the control ($P<0.05$).

Seedling herbage production assessed 6 weeks after sowing reflected significant damage ($P<0.05$) by all herbicides (Table 5a). Imazethapyr and trifluralin resulted in the least effect on seedling growth while pyroxasulfone had the greatest effect. S-metolachlor damage was intermediate. There was no interaction with herbicide rate, with seedling herbage production declining with increasing herbicide rate for all herbicides ($P<0.05$).

The effect of the herbicides was still evident on plant production assessed at the end of the growing season with significant main effects and herbicide-rate interaction (Table 5b). Herbicides ranked from least to greatest effect on desmanthus plants were trifluralin<imazethapyr <S-metolachlor and pyroxasulfone ($P<0.05$). Damage increased with increasing rate of active ingredient (main effect, $P<0.05$), but there was no effect of 0.5 rates of trifluralin and imazethapyr ($P<0.05$).

The effects of the pre-emergent herbicides were still evident the following growing season (November 2016, 8 months after application), especially those sprayed with S-metolachlor and pyroxasulfone (Table 5c). At standard rates of these 2 herbicides, desmanthus production was about 25% of the control, although at half application rates production was approximately 80% and similar to the majority of the controls. In contrast, the productivity of desmanthus sprayed with imazethapyr and trifluralin at standard rates was 70–75% of the control ($P<0.05$).

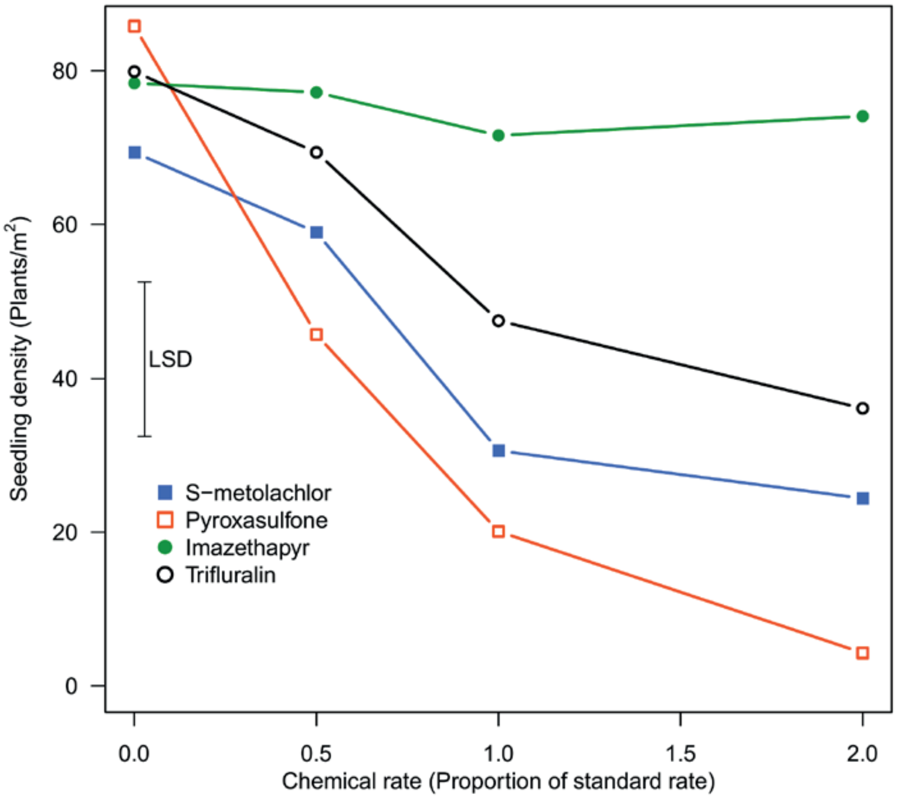

Figure 2. Seedling density (plants/m^2) of desmanthus 3 weeks after sowing and treatment with pre-emergent herbicide. LSD ($P=0.05$) is shown.

Table 5. Herbage production (kg DM/ha) of desmanthus on (a) 29 March 2016, (b) 10 May 2016 and (c) 17 November 2016 sprayed pre-emergent with herbicides at 4 rates (0, 0.5x, 1x and 2x).

Herbicide	Rate of active ingredient in application rates (kg a.i./ha)				Average
	0	0.5x	1x	2x	
(a) 29 March 2016					
S-metolachlor	53.6	30.4	18.0	14.3	29.1B
Pyroxasulfone	56.5	25.5	17.5	4.4	26.0C
Imazethapyr	50.7	46.2	33.8	18.3	37.3A
Trifluralin	59.4	45.0	38.1	25.5	42.0A
Average	55.1A	36.8B	26.9C	15.6D	
(b) 10 May 2016[1]					
S-metolachlor	1,957a	916cd	280e	47fg	602C
Pyroxasulfone	2,049a	1,227bc	231e	2g	589C
Imazethapyr	1,616ab	1,499ab	978cd	197ef	965B
Trifluralin	1,848a	1,684ab	978cd	613d	1,211A
Average	1,864A	1,315B	548C	139D	
(c) 17 November 2016[1]					
S-metolachlor	2,144abc	1,788bcd	571f	32g	872B
Pyroxasulfone	2,374a	1,750cd	549f	10g	858B
Imazethapyr	2,146abc	2,067abcd	1,615d	678f	1,560A
Trifluralin	2,209ab	2,137abc	1,609d	1,123e	1,740A
Average	2,217A	1,932A	1,018B	292B	

[1]Herbage production values were back transformed. Values with the same lowercase letter within an assessment date are not significantly different (herbicide × rate interaction, P=0.05). Within each assessment, average herbicide and rate values with the same uppercase letter are not significantly different (main effect, P=0.05).

Experiment 2 – Seedling pasture

Significant damage (P<0.05) to desmanthus seedlings resulted following application of MCPA, 2,4-D amine and fluroxypyr (Figure 3). The damage caused by fluroxypyr was severe (phytotoxicity score >8) and most seedlings died. Seedlings sprayed with 2,4-D amine and MCPA showed moderately high to heavy damage at all rates 1 WAA (phytotoxicity score>5) with phytotoxicity scores still >6 at the standard and double rates 4 WAA (P<0.05). Seedlings sprayed with the half rate of both herbicides recovered over the 4 weeks following application, but damage (phytotoxicity score ~3) was significantly greater than the control 4 WAA (P<0.05).

Bromoxynil and flumetsulam caused only slight distortion to the plant growing points (phytotoxicity scores ≤3) of desmanthus seedlings. Damage caused by the double rate of bromoxynil was initially greater than the control (P<0.05) but receded to be minor (phytotoxicity scores=2) 4 WAA and not significantly different to the control. At the initial assessment (1 WAA), flumetsulam at all rates caused some damage to the seedling desmanthus (average phytotoxicity scores=2.7, P<0.05), however the plants recovered with damage assessed to be minor compared to the control by 4 WAA at all applied rates, except the standard rate.

Herbage production in April (8 WAA) showed the contrasting effect of the herbicides on desmanthus seedling growth. MCPA and 2,4-D amine had the greatest effect (P<0.05), especially at the standard and double rates (productivity 25–50% of the control). In contrast, flumetsulam had no effect and bromoxynil a moderate effect (66% of the control) on herbage production (Figure 4).

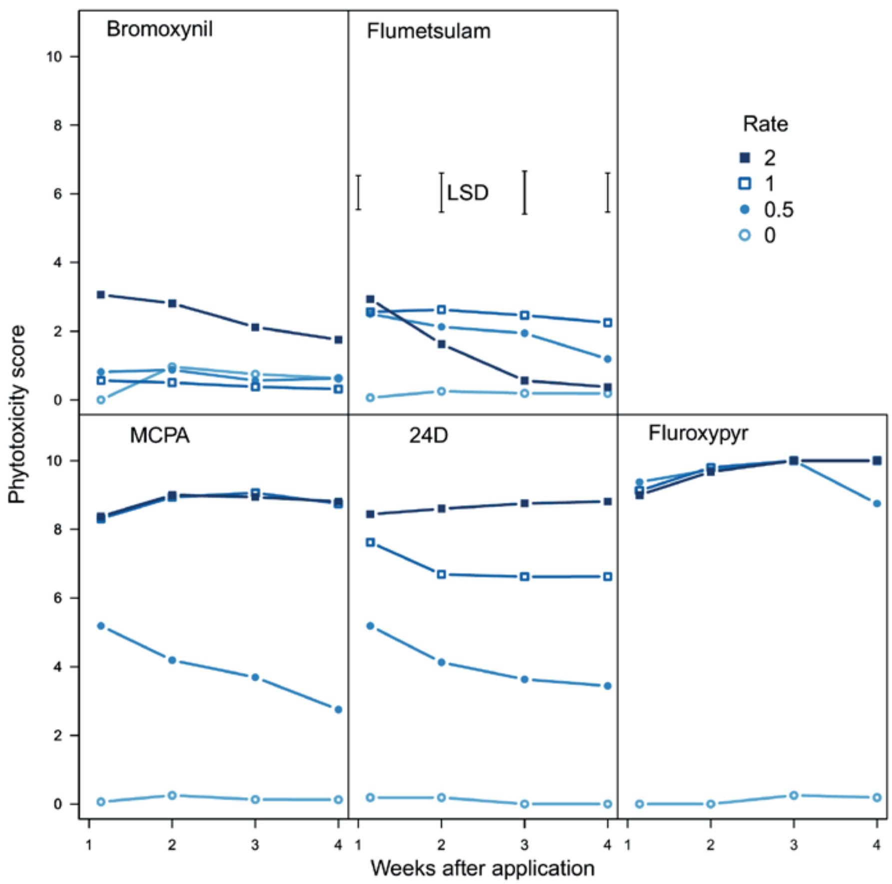

Figure 3. Phytotoxicity score to assess desmanthus plant damage over 4-week period following treatment with (a) bromoxynil, (b) flumetsulam, (c) MCPA, (d) 2,4-D amine, (e) fluroxypyr, at 4 rates (details in Table 2). Score 0=nil damage and score 10=plant death. LSD for comparison within an assessment date of each herbicide are shown (P=0.05).

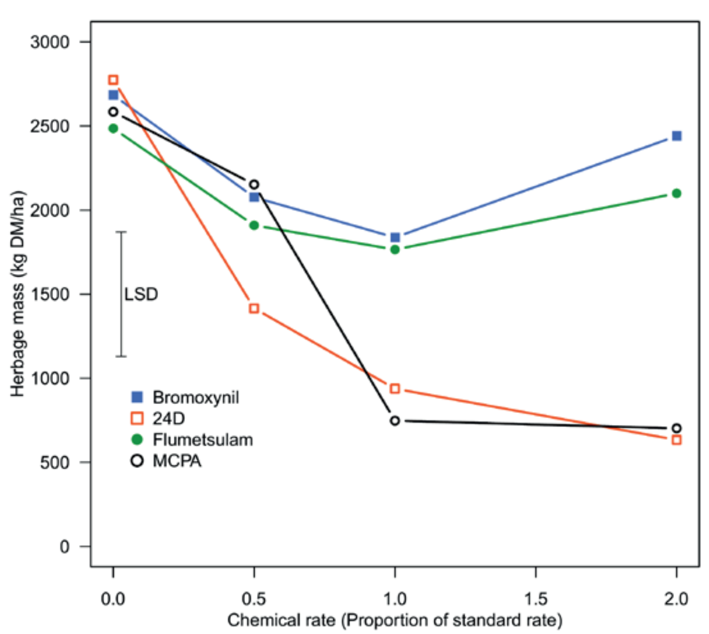

Figure 4. Herbage production (kg DM/ha) of establishing desmanthus, 8 weeks after application of 4 herbicides. Fluroxypyr was not included in the analysis because all plants had died. LSD is shown (P=0.05).

Both MCPA and 2,4-D amine delayed flowering (smaller area under a curve) of the establishing desmanthus plants (Table 6). This was particularly evident at the standard and double rates (P<0.05). Bromoxynil had nil to slight effect on flowering at all rates tested while flumetsulam was intermediate (P<0.05).

The proportion of seed pods that had matured at the end of the growing season was highly variable. Plants sprayed with flumetsulam had the highest proportion of mature pods (66%), similar to bromoxynil and MCPA (51–56%), while plants sprayed with 2,4-D amine had the lowest proportion (35%) (P<0.05). There was no effect of any herbicide rate, except for the double rate of 2,4-D amine where plants had a lower proportion of mature pods than the control and half rate (P<0.05).

Experiment 3 – Established pasture

The greatest plant damage to mature desmanthus plants during the 4 weeks following herbicide application was inflicted by 2,4-DB, isoxaflutole and paraquat (Figure 5).

2,4-DB resulted in significant damage (P<0.05) to mature plants of desmanthus with plant stems twisting and growing points distorted. Damage was significant at all rates applied compared to the control 1 WAA (phytotoxicity scores average 7 compared to 0.5 for control), and damage generally increased over the 4 weeks phototoxicity was assessed (P<0.05). At the final phytotoxicity assessment (4 WAA), plants sprayed with all rates of 2,4-DB still showed significant damage (P<0.05) with a phytotoxicity score >7 (Figure 5).

Plant damage resulting from all rates of isoxaflutole 1 WAA was moderate (phytotoxicity score 5–6) compared to the control (P<0.05). Over the following weeks as plants continued to grow, the extent of foliage bleaching due to the herbicide declined, except for the double rate which resulted in maximum damage 2 WAA (phytotoxicity score 6.6) (Figure 4). By 4 WAA, plants sprayed with the half rate of isoxaflutole had fully recovered and those sprayed with the standard rate showed only slight damage.

No physical damage to desmanthus plants was incurred due to imazethapyr, bromoxynil or terbuthylazine at the half and standard rates (phytotoxicity scores <1). There was slight growth retardation at the double rate 1–2 WAA (P<0.05) and the plants had recovered within 4 WAA (Figure 5).

Paraquat had the fastest and most significant effect of the herbicides tested on desmanthus plants with phytotoxicity scores of 8–9.5 at all rates compared to the control 1 WAA. By 2 WAA, plants were recovering and phytotoxicity scores fell as the plants produced new leaf. Peak brownout caused by paraquat application ranged from 91–98% and occurred 1 WAA at the standard and double rates. Brownout was slower for the 0.5 rate, peaking 2 WAA. Plants regrew quickly with no phytotoxic effects of the herbicide evident 4 WAA (Figure 5).

Herbage production assessed 4 weeks after treatments were applied reflected the phytotoxicity assessment (Figure 6) with all rates of 2,4-DB and paraquat reducing herbage production compared to the control by an average 38 and 26%, respectively (P<0.05). There was no effect of bromoxynil, imazethapyr and terbuthylazine on desmanthus production. Isoxaflutole reduced herbage production at the standard and double rates by 9 and 21% respectively (P<0.05).

There was no effect of any of the herbicides on desmanthus regrowth after cutting, indicating no long-lasting effects of the herbicides applied. Herbage production assessed 11 and 16 weeks after treatment application averaged 5,560±126 kg DM/ha (standard error) and 1,854±42 kg DM/ha, respectively.

Table 6. Time to flowering reported as an area under the curve for 4 herbicides applied at 4 rates (0, 0.5x, 1x and 2x). Fluroxypyr was not included in the analysis because all plants had died.

Herbicide	Rate of active ingredient in application rates (kg a.i./ha)				Average
	0	0.5x	1x	2x	
Bromoxynil	2.8a	2.7a	2.3bc	2.8a	2.7A
2,4-D	2.9a	2.1cd	1.9de	1.6e	2.1C
Flumetsulam	2.8a	2.3bcd	2.1cd	2.3bcd	2.4B
MCPA	2.8a	2.5ab	2.1cd	2.0d	2.3B
Average	2.8A	2.4B	2.1C	1.4C	

Values with the same lowercase letter are not significantly different (herbicide × rate interaction, P=0.05). Average herbicide and rate values with the same uppercase letter are not significantly different (main effect, P=0.05).

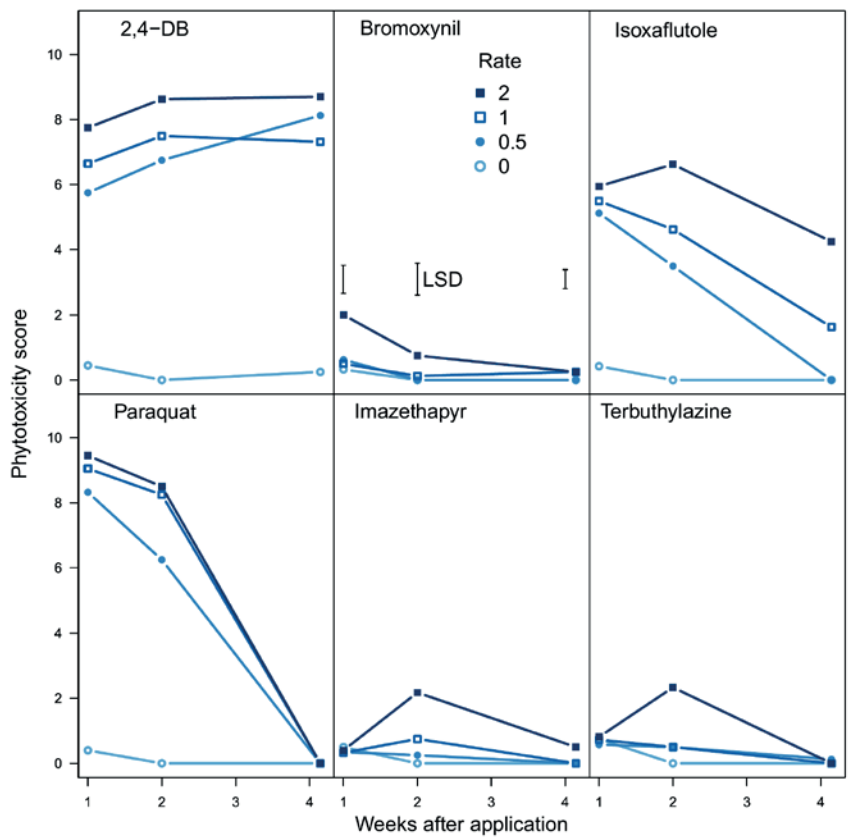

Figure 5. Phytotoxicity score to assess desmanthus plant damage following treatment with (a) 2,4-DB, (b) bromoxynil, (c) isoxaflutole, (d) paraquat, (e) imazethapyr and (f) terbuthylazine at 4 rates (details in Table 3). Score 0=nil damage and score 10=plant death. LSDs for comparison within an assessment date of each herbicide are shown (P=0.05).

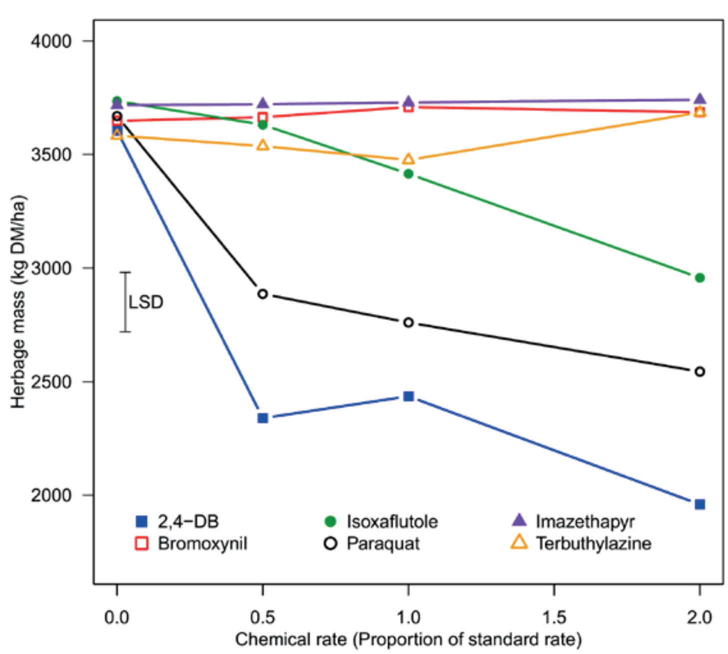

Figure 6. Desmanthus herbage production (kg DM/ha) in December 2017, 4 weeks after application of 6 herbicides at 4 rates.

Discussion

These experiments have identified a range of herbicides that can be used to control weeds in desmanthus pastures without damage to the forage. The objective of the study was not to quantify the extent that weeds can be controlled but determine the sensitivity of desmanthus to the herbicides. Currently, each of the herbicides tested is registered for control of a range of weeds in Australia.

Pre-emergent desmanthus

The negative effect of both trifluralin and imazethapyr at the standard rate is in contrast to findings of Cox and Harrington (2005), who reported no effect of either pre-emergent herbicide on desmanthus 'Marc' emergence and/or productivity. This difference could be associated with the drier environmental conditions experienced during this experiment. In the 2 months following emergence, about 27 mm rainfall was received (about 60 mm less than the long-term average) while the Cox and Harrington (2005) studies were conducted in pots or in the field with irrigation. Greater plant damage caused by herbicides was reported in lower rainfall situations in other crops, including *D. bicornutus* (Grichar and Ocumpaugh 2007). Grichar and Ocumpaugh (2007) associated the greater damage they recorded with longer persistence of herbicides in the soil due to reduced microbial activity following suboptimal soil temperature and moisture conditions (Goetz et al. 1990; Ahmad et al. 2003; Reedich et al. 2017).

Collectively, these results and those of Cox and Harrington (2005) suggest that trifluralin and imazethapyr can be applied pre-emergence to desmanthus pastures. Trifluralin can be applied at rates of 0.4 and up to 0.8 kg a.i./ha and imazethapyr at 0.04 and up to 0.07 kg a.i./ha. During conditions that are unfavourable for pasture establishment, herbicides applied at the maximum rates may inhibit establishment and subsequent productivity.

In Australia, trifluralin is currently registered for control of weeds during establishment of several temperate pasture legumes at 0.58–0.82 kg a.i./ha and imazethapyr at 0.05–0.10 kg a.i./ha. Additionally, imazethapyr is registered as a pre-emergent crop herbicide for the tropical legume centrosema (*Centrosema pascuorum*) 'Cavalcade' in the Northern Territory at 0.05–0.10 kg a.i./ha (Moore and Moore 2024).

Pyroxasulfone is recommended to be applied then incorporated by sowing within 3 days of application using either knife points and press wheels or narrow points and harrows (Anon. undated). Sowing using these techniques moves herbicide treated soil from the sown seed. We did not apply the herbicide using this method which would explain the poor establishment of desmanthus observed.

S-metolachlor is registered as a pre-emergent herbicide for control of toad rush (*Juncus bufonius* L.) in several temperate pasture legumes and grasses in Australia. The registered rates are low with 0.19–0.24 kg a.i./ha (Moore and Moore 2024) and insufficient to control the majority of weeds common in establishing pastures. Development of seed safeners such as oxabetrinil and metcamifen which protect sorghum [*Sorghum bicolor* (L.) Moench] from the phytotoxic effects of metolachlor allow higher rates of S-metolachlor to be applied (Rosinger 2014). Extension of this technology to pasture and other crop species would provide significant advantages for agricultural systems.

Seedling desmanthus

Flumetsulam and bromoxynil caused little effect on seedling desmanthus plants when they were applied at rates of 0.02–0.08 and 0.14–0.28 kg a.i./ha respectively. On desmanthus seedlings younger than in this research, Cox and Harrington (2005) reported greater damage caused by flumetsulam, but less damage by bromoxynil. We concur that these herbicides can be used in seedling stands of desmanthus. Application of these herbicides also resulted in increased herbage production post-application at the rates below and above the standard. This stimulatory response when associated with subtoxic concentrations of herbicide is called hormesis and is considered an adaptive response of stressed plants (Belz and Duke 2014; Vargas-Hernandez et al. 2017). Hormesis has been reported in oats (*Avena sativa* L.) in response to bromoxynil application (Wiedman and Appleby 1972).

Flumetsulam is registered in Australia for the control of broadleaf weeds in a range of temperate legumes at 0.02–0.04 kg a.i./ha with similar results to findings for desmanthus (Moore and Moore 2024). Also, only minor damage was observed when seedlings were sprayed with 0.08 kg a.i./ha (double rate) with only a slight delay in flowering, but no effect on seed pod maturity. Bromoxynil is registered for control of broadleaf weeds in pastures or cereals undersown with several temperate legumes at 0.14–0.56 kg a.i./ha (Moore and Moore 2024).

MCPA and 2,4-D amine, and especially fluroxypyr caused significant damage to seedling desmanthus at all rates applied, with application of fluroxypyr resulting in significant plant death. Fluroxypyr is registered for control of broadleaf weeds in lucerne (*Medicago sativa* L.) pastures although clovers (*Trifolium* sp.) are susceptible (Moore and Moore 2024). Similarly, Cox and Harrington (2005) reported extensive damage to 2-week-old desmanthus seedlings by MCPA and 2,4-D amine. We recommend that these herbicides should not be used on seedling desmanthus pastures.

Established desmanthus

Bromoxynil, imazethapyr and terbuthylazine caused minor damage and isoxaflutole moderately high damage to established plants at all rates applied, with plants recovering within 4 weeks of application with no productivity losses. Bromoxynil is registered for control of broadleaf weeds in a range of temperate legume pastures at 0.14–0.56 kg a.i./ha; rates similar to those used in this study (Moore and Moore 2024). Also, imazethapyr is registered for use in established lucerne (*Medicago sativa* L.) and serradella (*Ornithopus* sp.) pastures at 0.05–0.10 kg/ha; a slightly narrower and lower range than found suitable for desmanthus (Moore and Moore 2024). Terbuthylazine is registered to control grass and some broadleaf weeds in established lucerne at rates lower than found suitable for desmanthus in this study (0.75–1.05 compared with 0.44–1.75 kg a.i./ha) (Moore and Moore 2024).

Paraquat caused rapid and significant brown out of desmanthus plants although subsequent regrowth was healthy and there was no ongoing effect of the herbicide. Paraquat is registered for control of grass and broadleaf weeds in lucerne at 0.3–0.6 kg a.i./ha (Moore and Moore 2024); a narrower and lower range than found suitable for desmanthus in the study.

2,4-DB caused significant distortion of stems and the growing points of desmanthus plants at all the rates applied. Herbage production 4 WAA reflected this damage, however, once the damaged material was removed, the plants regrew normally with no further effects on plant development or productivity. This study indicates that 2,4-DB could be an option in established desmanthus pastures at application rates up to 1.4 kg a.i./ha. However, further testing is recommended to understand the effect of stress, including moisture stress and competition in mixtures, on plant response and recovery. Label recommendations of 2,4-DB for control of broadleaf weeds in temperate legume pastures are 0.5–1.6 kg a.i./ha, although the critical comments highlight that crop sensitivity can vary with species, variety and season of application (Moore and Moore 2024).

Herbicide sensitivity of other Desmanthus species

These studies used 'Marc' because it was a commercial and readily available cultivar at the time experiment 1 was conducted. Currently, more cultivars are available in Australia from several other species. The greatest number of cultivars are of *D. virgatus* ('Marc', 'Ray', 'JCU 2', 'JCU 3', 'JCU 5', 'JCU 8') with cultivars available of *D. bicornutus* ('JCU 4', 'JCU 6'), D. leptophyllus ('JCU 1', 'JCU 7') and *D. pernambucanus* ('JCU 9') as well. Further testing of these species, and potentially cultivars, is required to ensure their tolerance to the herbicides identified in this study is similar to 'Marc'. This will be particularly important where multiple desmanthus species are sown as a mixture, such as cultivar 'Progardes' which is a blend of multiple species and cultivars (Gardiner 2016).

Conclusions

This research identified herbicides suitable for use with desmanthus to control broadleaf weeds in desmanthus pastures at different stages of development. Imazethapyr (0.41 kg a.i./ha) and trifluralin (0.85 kg a.i./ha) supported good establishment when used as pre-emergent. In seedling pastures, bromoxynil (0.14–0.56 kg a.i./ha) and flumetsulam (0.02–0.08 kg a.i./ha) caused little damage. In established pastures, bromoxynil (0.14–0.56 kg a.i./ha), imazethapyr (0.04–0.14 kg a.i./ha), terbuthylazine (0.44–1.75 kg a.i./ha) and isoxaflutole (0.04–0.15 kg a.i./ha) caused minor and temporary damage only. Additionally, established plants of desmanthus regrew well after application of paraquat (0.2–0.8 kg a.i./ha). There may be an opportunity to use 2,4-DB (0.35–1.4 kg a.i./ha) in established pastures in some situations, for example, to salvage a desmanthus pasture.

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