Efficacy of herbicides on weedy Sporobolus grasses in the glasshouse in Australia

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Summary

Twenty three herbicides including the current registered herbicides were screened for activity on pre-emergent, juvenile and mature plants of the weedy Sporobolus grass species *Sporobolus pyramidalis* P.Beauv. and *Sporobolus fertilis* (Steud.) Clayton. No new herbicides trialled effectively controlled mature plants. Propaquizafop, fluazifop-P-butyl, flupropanate, haloxyfop-R-methyl ester, glyphosate-ipa and clethodim + haloxyfop-R-methyl ester mix showed good activity on juvenile plants while atrazine, flupropanate, dithiopyr and imazapyr where effective as pre-emergent herbicides. Further work needs to be done to define the recommended application rates for juvenile and pre-emergent plant stages and to determine the selectivity of these herbicides on native and exotic pasture grasses.

Key words: Sporobolus, weeds, herbicide efficacy.

Introduction

Weedy Sporobolus grasses (WSGs) (*Sporobolus fertilis* (Steud.) Clayton, *S. africanus* (Poir.) Robins & Tournay, *S. pyramidalis* P.Beauv., *S. natalensis* (Steud.) T.Durand & Schinz. and *S. jacquemontii* Kunth, are serious introduced weeds for the beef and dairy industries of Australia. The economic cost of WSGs is high (Vogler and Bahnisch 2006) because they reduce animal production and are relatively expensive to control. They are also significant environmental weeds that destroy habitat and alter biodiversity particularly where monocultures form. Current registered herbicides for WSG control are restricted to flupropanate and glyphosate, with each having limitations in terms of poor selectivity in grass pastures, high cost and variable efficacy across a range of situations. Herbicide resistance has also become an issue, with resistance being recorded with *S. fertilis* where flupropanate has been used exclusively over long periods (Ramasamy *et al.* 2007).

Previous herbicide experimentation conducted by Loch and Harvey (1999) trialled 15 herbicides on *S. pyramidalis* and *S. fertilis* and several sown pasture species. They identified several herbicides that effectively controlled these species as seedlings or pre-emergence in a glasshouse situation. However, only atrazine provided some useful selectivity to certain grasses when applied in a field situation during pasture establishment. Research conducted by Biosecurity Queensland, Department of Primary Industries and Fisheries and the CRC for Australian Weed Management has been undertaken to identify more herbicides for WSG control using *S. pyramidalis* and *S. fertilis* as the test species. The objective was to determine the efficacy of a range of herbicides on *S. pyramidalis* and *S. fertilis*. Effective new products would broaden the present control options and reduce the risk of resistance development to flupropanate, as has occurred with *Nassella tritochoma* (Nees) Hack. ex Arechav. (Noble 2002) and other grass weeds (Milton 2004).

Materials and methods

Experimental design

Three glasshouse experiments were conducted at the Tropical Weeds Research Centre, Charters Towers, Queensland, Australia from 2003 to 2005. All experiments used a randomized complete block design with three replicates. Each treatment was applied to 20 plants of each species (juvenile and mature plant life stages) and 50 seeds (viability >90%) planted <1cm deep in dry soil prior to herbicide application (pre-emergence study). For the mature plant life stage in the first experiment, 20 plants were evenly spread across two 400 mm pots (10 plants per pot) to allow sufficient space for each plant. In the second experiment 20 mature plants were spread evenly across four 250 mm pots (five plants per pot) to allow sufficient space for each plant and to facilitate easier handling. For the juvenile and pre-emergent plant life stages 20 plants were grown and 50 seeds planted in single 200 mm pots respectively for all experiments. All plants were watered using overhead sprinklers to maintain soil at or near field capacity with limited drainage from the base of each pot.

Soil and fertilizer

A sandy loam soil was used for all treatments. Mature and juvenile plants were fertilized using a soil applied fertilizer at the time of planting at a rate of 4, 5 and 10 g (10.5% N, 3.3% P, 10.0% K, 12.3% S, 3.2% Ca, 1.13% Mg, 0.09% Mn, 0.05% Cu, 0.07% B, 0.07% Zn) per 200, 250 and 400 mm pot, respectively. Pre-emergent treatments were not fertilized.

Herbicide application

Herbicides were applied using two XR Teejet 110 03 VP fan nozzles at a spray volume of 200 L ha^{-1} for all plant growth stages. These nozzles were 50 cm apart and attached to a computer controlled overhead gantry spray unit located in a glasshouse. All plants were placed beneath the gantry in the area between each nozzle to ensure uniform coverage. Watering ceased for one day following foliar herbicide application, but was then resumed using overhead sprinklers at a rate sufficient to maintain pots near field capacity without significant drainage of water from the base of each pot.

Herbicides applied

Twenty-three herbicides were selected for testing based on their registration in Australia as effective grass killers, including flupropanate and glyphosate, the current herbicides registered for control of these species. Most of these herbicides are used in agriculture for in crop grass weed control in either broad leaf crops such as legumes or grass crops such as wheat, sorghum or sugar cane. Some are non selective and used for knockdown and/or residual weed control in situations where total weed control is required, while others are selective and will not damage broad leaf crops or pasture species. Anecdotal evidence also suggested that some desirable native and exotic pasture grass species may have a degree of tolerance to some of the chosen herbicides. Propaquizafop was tested only against mature plants in the first screening due to a limited supply of this herbicide when the testing was done. It was included in subsequent testing for both mature and juvenile plants.

Herbicide application rates

The herbicides and application rate(s) for each experiment are listed in Tables 1–6. The initial study used a high rate of these herbicides to assess pre-emergent and post-emergent (juvenile and mature) efficacy. The application rate chosen as the highest rate listed on the product label. Where useful efficacy was evident the best treatments for one or more growth stages were selected for a second experiment using two rates (high and low). The highest rates for the second experiment were either higher or lower than those of the first study depending on efficacy identified in the first experiment.

A third experiment was then conducted using the most efficacious herbicides

for each plant life stage identified in the second experiment. This experiment used five rates of each herbicide with the highest rate based on results from the second experiment and lower rates determined using a Log scale. The herbicide clethodim + haloxyfop-R-methyl ester mix (Table 5) was included in the third experiment as both component herbicides had shown efficacy in the previous experiments.

The adjuvant Uptake® (582 g L^{-1} paraffinic oil, 240 g L^{-1} alkoxylated alcohol non-ionic surfactants) was used at the rate of 1 L ha^{-1} for all herbicide treatments on mature and juvenile plants except with the soil active herbicide flupropanate. No adjuvant was used for soil applied pre-emergence treatments.

Plant size, efficacy assessment and data analysis

Juvenile plants were 10 to 15 cm high with 5 to 6 developed tillers in the first and second experiment and 15 to 20 cm high with 7 to 8 developed tillers in the third experiment. Mature plants were 120 to 140 cm high with 10 to 12 developed tillers and at least one inflorescence at the time of herbicide application. In all experiments herbicide efficacy was determined by plant mortality based on visual inspection. Where mortality was limited, visual ratings (Table 1) or plant dry weights (Table 3) were also used to determine efficacy and select herbicides for further experimentation. In all cases, apart from the final pre-emergence herbicide experiment and with flupropanate, plant mortality was assessed by visual inspection for any live shoots 84 days after herbicide application. Plant mortality for the final pre-emergent herbicide experiment (Table 6) and treatment by the slow acting herbicide flupropanate were assessed 55 days and six months after herbicide application respectively. Analysis of variance with conducted on data and differences identified using Fisher's Protected LSD.

Results

First experiment

While mature plant mortality was low, most herbicides caused significant plant damage to both species (Table 1). The herbicides retained for further testing on mature plants caused severe damage (damage ratings of at least 4) (Table 1) to one or both test species. Nine of the 23 herbicides were retained for further testing on mature plants (Table 1).

Juvenile plants were more susceptible to a wider range of herbicides than mature plants, with 12 herbicides selected for further testing based on high levels of mortality for one or both species (Table 2). Apart from flupropanate, most of these herbicides caused plant mortalities of 80% or more for one or both of these species. Although flupropanate did not cause high levels of mortality it was included in subsequent testing because it is one of the registered herbicides for control of *Sporobolus* species (Table 2). Tebuthiuron showed high levels of efficacy, particularly on juvenile plants. However, testing on both juvenile and pre-emergent plants was discontinued as severe off target damage to trees may occur where tree feeder roots are present in the treated zone around target weeds.

Of the nine herbicides tested for pre-emergent efficacy four showed sufficient activity to warrant further testing. In particular, imazapyr and dithiopyr caused 100% mortality while atrazine and flupropanate were included for subsequent testing due to high juvenile and known pre-emergent activity and a current registration for *Sporobolus* control respectively (Table 2).

Second experiment

Mortality of mature plants of *S. fertilis* was generally higher than that of *S. pyramidalis* for all herbicides except for glyphosate-ipa where the result was reversed (Table 3). Imazapyr, propaquizafop, fluazifop-P-butyl, flupropanate and haloxyfop-R-methyl ester caused greater than 90% mortality of *S. fertilis* compared to no more than 60% mortality for *S. pyramidalis*, indicating that these herbicides may be useful in the control of at least some *Sporobolus* species (Table 3). All herbicides except the low rates of clethodim and sethoxydim applied to *S. pyramidalis* caused significant reductions in plant biomass compared to control treatments, indicating significant activity even though in most instances this was not reflected in high plant mortality (Table 3). However, the application rates used to achieve these levels of mortality and biomass reduction were very high making the use of these herbicides in a practical sense questionable (Table 3), resulting in the discontinuation of herbicide testing on mature *Sporobolus* plants.

All herbicides except MSMA and dithiopyr produced high mortality of juvenile

Table 1. Experiment 1 – plant mortality (average %) and damage ratings (visual) of mature *S. pyramidalis* and *S. fertilis* plants 84 days after herbicide application.

		S. pyramidalis		*S. fertilis*	
Herbicide	Rate (kg ha^{-1} a.i.)	Mortality	Damage rating[C]	Mortality	Damage rating[C]
Imazapyr[A]	1.0	20.0 e	4	91. 7 a	4
Atrazine	3.0	0.0 h	2	15.0 ef	2
Isoxaflutole	0.15	0.0 h	2	0.0 h	2
Glufosinate-ammonium	0.8	0.0 h	2	0.0 h	3
Metsulfuron-methyl	0.036	0.0 h	2	0.0 h	2
Propaquizafop[A]	0.09	1.7 gh	3	41.7 d	4
Diuron	1.8	0.0 h	2	0.0 h	2
DSMA	0.7	0.0 h	2	0.0 h	1
Imazapic	0.096	0.0 h	2	0.0 h	1
Fluazifop-P-butyl[A]	0.414	0.0 h	3	63.3 c	4
Tebuthiuron	2.0	0.0 h	2	36.7 d	3
Ethoxysulfuron	0.15	0.0 h	2	0.0 h	2
Iodosulfuron-methyl-sodium	0.01	0.0 h	2	0.0 h	2
MSMA[A]	4.8	0.0 h	3	11.7 efg	4
Dithiopyr	0.42	0.0 h	2	0.0 h	1
Sulfometuron-methyl	0.3	0.0 h	2	0.0 h	1
Fenoxaprop-P-ethyl	0.041	0.0 h	2	0.0 h	2
Glyphosate-ipa[A]	0.72	8.3 efg	4	3.3 h	3
Clethodim[A]	0.096	0.0 h	3	8.3 fgh	4
Sethoxydim[A]	0.192	0.0 h	2	6.7 fgh	4
Imazethapyr	0.096	0.0 h	1	0.0 h	1
Flupropanate[A,B]	1.49	0.0 h	2	80.0 b	4
Haloxyfop-R-methyl ester[A]	0.416	8.3 efg	4	81.7 b	4
Untreated control		0.0 h	1	0.0 h	1

[A] Herbicides selected for second experiment.
[B] Mortality assessed six months after application due to slow acting nature of herbicide.
[C] Damage ratings: 1 – No apparent effect; 2 – Mature leaf death with regrowth; 3 – Stem and leaf death with regrowth; 4 – Stem and leaf death with minimal regrowth; 5 – Plant death.
Values within columns followed by the same letter are not significantly different ($P < 0.05$).

Table 2. Experiment 1 – plant mortality (average %) of pre-emergent and juvenile *S. pyramidalis* and *S. fertilis* plants 84 days after herbicide application.

Herbicide	Rate (kg ha^{-1} a.i.)	*S. pyramidalis*		*S. fertilis*	
		Pre-emerge	Juvenile	Pre-emerge	Juvenile
Imazapyr[A,C]	1.0	100.0 a	100.0 a	100.0 a	100.0 a
Atrazine[A,C]	3.0	21.2 bcd	84.1 b	16.4 cde	82.2 bcd
Isoxaflutole	0.15	15.1 cd	32.5 cd	4.1 de	18.8 fgh
Glufosinate-ammonium[A]	0.8	–	100.0 a	–	96.3 ab
Metsulfuron-methyl	0.036	14.5 cd	9.5 fgh	1.8 e	2.4 hij
Diuron	1.8	28.1 bcd	0.0 h	30.5 bcd	10.3 hij
DSMA	0.7	11.1 cd	6.7 gh	9.0 de	37.6 ef
Imazapic	0.096	25.4 bc	21.7 def	12.0 cde	10.0 hij
Fluazifop-P-butyl[A]	0.414	–	100.0 a	–	100.0 a
Tebuthiuron	2.0	53.6 b	100.0 a	39.4 bc	100.0 a
Ethoxysulfuron	0.15	2.0 d	8.3 fgh	7.8 de	16.7 ghi
Iodosulfuron-methyl-sodium	0.01	6.8 cd	9.3 efg	3.2 de	5.0 hij
MSMA[A]	4.8	–	33.1 cd	–	92.6 abc
Dithiopyr[AC]	0.42	100.0 a	41.7 c	100.0 a	30.2 efg
Sulfometuron-methyl	0.3	17.9 bcd	52.2 c	21.2 bcde	10.8 hij
Fenoxaprop-P-ethyl[A]	0.041	–	100.0 a	–	73.3 d
Glyphosate-ipa[A]	0.72	–	84.1 b	–	93.2 abcd
Clethodim[A]	0.096	12.7 cd	100.0 a	9.4 de	100.0 a
Sethoxydim[A]	0.192	–	93.3 ab	–	84.6 cd
Imazethapyr	0.096	13.9 cd	5.6 gh	6.2 de	7.5 hij
Flupropanate[A,B,C]	1.49	27.8 bcd	19.4 de	7.1 de	44.7 e
Haloxyfop-R-methyl ester[A]	0.416	–	100.0 a	–	100.0 a
Untreated control		20.9 bcd	0.0 h	4.4 de	0.0 j

[B] Mortality assessed six months after application due to slow acting nature of herbicide.
[A] Herbicides selected for second experiment on juvenile plants. [C] Herbicides selected for second experiment as pre-emergent herbicide. – Indicates herbicide not applied to plant life stage.
Values within columns followed by the same letter are not significantly different (P <0.05).

Table 3. Experiment 2 – plant mortality (average %) and dry weight (average g) of mature *S. pyramidalis* and *S. fertilis* plants 84 days after herbicide application.

Herbicide	Rate (kg ha^{-1} a.i.)	*S. pyramidalis*		*S. fertilis*	
		Mortality	Weight	Mortality	Weight
Imazapyr	1.0	0.0 e	352.5 cdefg	0.0 g	284.2 bc
	2.0	8.3 bcd	286.8 fgh	96.7 a	148.5 fgh
Propaquizafop	0.2	15.0 bc	387.8 cdefg	93.3 ab	166.6 efgh
	0.4	50.0 a	337.0 defg	96.7 a	142.1 h
Fluazifop-P-butyl	0.424	3.3 cde	277.9 gh	46.7 de	207.6 cdefg
	0.848	61.7 a	389.0 cdefg	93.3 ab	163.4 efgh
MSMA	4.8	0.0 e	405.0 bcdef	0.0 g	345.33 b
	9.6	0.0 e	355.6 cdefg	0.0 g	314.4 bc
Glyphosate-ipa	0.720	0.0 e	335.3 defg	0.0 g	261.0 cd
	1.44	60.0 a	200.0 h	18.3 f	147.4 gh
Clethodim	0.192	0.0 e	515.4 ab	1.7 g	205.9 defg
	0.384	0.0 e	414.2 bcde	63.3 cd	300.4 bc
Sethoxydim	0.24	0.0 e	616.0 a	21.7 ef	214.7 de
	0.48	0.0 e	455.6 bcd	46.7 d	209.6 def
Flupropanate	1.49	3.3 cde	361.0 cdefg	95.0 ab	200.1 defgh
	2.98	5.0 cde	327.1 efg	100.0 a	196.1 efgh
Haloxyfop-R-methyl ester	0.52	6.7 bcd	472.1 bc	81.7 bc	164.3 efgh
	1.04	13.3 bc	359.1 cdefg	90.0 ab	175.9 efgh
Untreated control		1.7 e	624.1 a	1.7 g	555.1 a

Values within columns followed by the same letter are not significantly different (P <0.05).

plants of both *Sporobolus* species (Table 4). This resulted in the discontinuation of testing of MSMA and dithiopyr on juvenile plants (Table 4). Although glufosinate-ammonium, sethoxydim and atrazine produced high mortality, testing of these herbicides on juvenile plants was also discontinued, as the high application rates used to achieve these levels of mortality are likely to severely limit the probable use of these herbicides (Table 4).

The pre-emergent herbicides produced 100% mortality at both application rates on both species. The exception was the lower rate of flupropanate applied to *S. pyramidalis*, where 83% mortality was recorded (Table 4).

Third experiment

The higher rates of flupropanate, haloxyfop, propaquizafop, fluazifop-P-butyl and the clethodim-haloxyfop mix caused high mortalities of juvenile *S. fertilis* plants and warrant further trialling under field conditions (Table 5). The high mortality of juvenile *S. fertilis* plants caused by imazapyr, fenoxaprop-P-ethyl and glyphosate-ipa during the second experiment (Table 4) was not repeated in the third experiment even though the application rates were similar (Table 5). Mortality of juvenile *S. pyramidalis* was not significantly different to the control treatment (Table 5), which was contrary to the high mortality caused by a number of the same herbicides during the second experiment (Table 4). In contrast to plant mortality, plant biomass comparisons showed significant herbicide effects, with almost all herbicides at all application rates significantly reducing plant biomass compared to control treatments.

Plant mortality was high in the pre-emergent treatments, with all herbicides causing 100% mortality for at least one application rate (Table 6), which supported the results from the second experiment. The effects of dithiopyr were not significantly different at all application rates across both species. In many cases there were no significant differences between these herbicides except at some of the lower application rates (Table 6).

Discussion

Overall *S. fertilis* was generally more susceptible to a wider range of herbicides at lower application rates than *S. pyramidalis*, particularly with mature and juvenile plants and to a lesser extent with pre-emergent herbicides (Tables 1–6). This has been observed in the field with applications of flupropanate, where lower rates have been used to successfully control *S. fertilis*. Of concern in this study is the apparent low efficacy of flupropanate on juvenile and mature *S. pyramidalis* plants compared to efficacy on *S. fertilis* plants when applied at registered rates. These differences in efficacy are likely due to genetic factors

Table 4. Experiment 2 – plant mortality (average %) of pre-emergent and juvenile *S. pyramidalis* and *S. fertilis* plants 84 days after herbicide application.

Herbicide	Rate (kg ha^{-1} a.i.)	*S. pyramidalis*		*S. fertilis*	
		Pre–emerge	Juvenile	Pre–emerge	Juvenile
Imazapyr[A,B]	0.5	100.0 a	100.0 a	100.0 a	93.3 a
	1.0	100.0 a	100.0 a	100.0 a	100.0 a
Glufosinate-ammonium	0.6	–	95.2 ab	–	26.7 b
	1.2	–	100.0 a	–	100.0 a
Propaquizafop[A]	0.1	–	100.0 a	–	100.0 a
	0.2	–	100.0 a	–	100.0 a
Dithiopyr[B]	0.24	100.0 a	0.0 e	100.0 a	0.0 d
	0.48	100.0 a	0.0 e	100.0 a	0.0 d
Fluazifop-P-butyl[A]	0.212	–	100.0 a	–	100.0 a
	0.424	–	100.0 a	–	100.0 a
MSMA	4.8	–	0.0 e	–	0.0 d
	9.6	–	9.5 e	–	11.7 c
Atrazine[B]	2.0	100.0 a	85.0 b	100.0 a	94.6 a
	4.0	100.0 a	100.0 a	100.0 a	98.3 a
Fenoxaprop-P-ethyl[A]	0.041	–	100.0 a	–	98.3 a
	0.082	–	100.0 a	–	95.0 a
Glyphosate-ipa[A]	0.720	–	100.0 a	–	100.0 a
	1.44	–	100.0 a	–	100.0 a
Clethodim[A]	0.048	–	61.4 c	–	96.7 a
	0.096	–	93.9 ab	–	95.0 a
Sethoxydim	0.12	–	80.0 b	–	95.0 a
	0.24	–	100.0 a	–	98.3 a
Flupropanate[A,B]	1.49	83.9 ab	40.7 d	100.0 a	100.0 a
	2.98	100.0 a	100.0 a	100.0 a	100.0 a
Haloxyfop-R-methyl ester[A]	0.208	–	100.0 a	–	100.0 a
	0.416	–	100.0 a	–	100.0 a
Untreated control		71.1 b	0.0 e	30.9 b	0.0 d

[A] Herbicides selected for third experiment on juvenile plants.
[B] Herbicides selected for third experiment as pre-emergent herbicide.
– Indicates herbicide not applied to plant life stage.
Values within columns followed by the same letter are not significantly different (P <0.05).

influencing the herbicide tolerance of these *Sporobolus* species to flupropanate and the other herbicides

Flupropanate is registered for the control of *Sporobolus* grasses at all growth stages (Australian Pesticides and Veterinary Medicines Authority 2008) and offers some selectivity to grasses. However, anecdotal evidence suggests that there are several issues to be resolved with its use, such as soil type effects, tolerance of native grasses (particularly in the tropics), withholding periods, residue levels in agricultural products and herbicide resistance. Nevertheless the outcomes of this study indicate further work is needed to refine the application rates of flupropanate for effective control of *S. pyramidalis* and to resolve some of the unresolved issues with the use of this herbicide.

The absence of any potential post emergent grass selective herbicide for mature *S. pyramidalis* control is a critical gap in the management options for these grasses. There does, however, appear to be opportunities for further investigation of the efficacy and grass selectivity of several herbicides including imazapyr, propaquizafop, fluazifop-P-butyl and haloxyfop-R-methyl ester, which caused high mortality when used on mature plants of *S. fertilis* (Table 3). However, it appears the likelihood of advances in this area in the near future is low due to limited funding opportunities and limited development of new active ingredients.

The variability in efficacy of herbicides on juvenile plants of both species (Tables 4 and 5) is likely to be caused by the different plant growth stage/size, with the larger juvenile plants being more tolerant of herbicides. This is common with many plant species (Ahmadi *et al.* 1980, Radosevich *et al*. 1997, Buriuan *et al.* 1999, Mc Daniel *et al*. 2002) and is a known key factor with many of the herbicides tested such as fluazifop-P-butyl, haloxyfop-R-methyl ester and fenoxaprop-P-ethyl. However there appears to be potential to control juvenile *S. fertilis* in legume crops and pastures, given that fluazifop-P-butyl and haloxyfop-R-methyl ester are currently registered for grass control in these situations (Australian Pesticides and Veterinary Medicines Authority 2008). Control of *S. pyramidalis* in these situations is problematic as little activity was shown by these herbicides in the final experiment, even though with the previous experiment they caused high mortality. This indicates that plant growth stage/size at time of herbicide application will be critical if these herbicides are to be used successfully to control these species, given that the efficacy on the slightly larger plants of the third experiment was low (Table 5). Further experimentation will be required to resolve the interaction between growth stage/size and herbicide efficacy for both of these species if fluazifop-P-butyl and haloxyfop-R-methyl ester are to become part of recommended control practices.

From the current experiments and the work of Hawton (1976, 1980) and Loch and Harvey (1999) it appears that atrazine, with its pre-emergence and post emergence activity on seedlings, may offer some opportunities for control of WSGs in established grass pastures. However, residual effects on broad leaved herbaceous plants (legumes and forbs) in lower rainfall native pasture systems, where pasture regeneration and replacement are slower after initial injury; means lower potential utility for this treatment.

Dithiopyr may offer opportunities as a pre-emergence herbicide in established pastures as it appears to have no post emergence activity and is highly efficacious on both *Sporobolus* species (Tables 4 and 6). However further evaluation is needed before any recommendations could be made. The use of dithiopyr on large areas or in low input grazing systems may be cost prohibitive but where eradication of small infestations is the aim dithiopyr may be useful and therefore warrants further investigation.

Future work will need to focus on detailed field studies using the most efficacious rates of herbicides and weed growth stages identified in this study. This will further define application rates, growth stages and selectivity to pastures that will provide information for registration of new treatments for these weeds in pastures.

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Table 5. Experiment 3 – plant mortality (average %) and dry weight (average g) of juvenile *S. pyramidalis* and *S. fertilis* plants 84 days after herbicide application.

Herbicide	Rate (kg ha^{-1} a.i.)	*S. pyramidalis*		*S. fertilis*	
		Mortality	Weight	Mortality	Weight
Imazapyr	1.025	0.0 a	20.4 t	33.3 hi	19.8 nopqr
	0.675	0.0 a	38.1 opqr	13.3 jk	19.9 nopqr
	0.45	0.0 a	41.8 nopq	16.7 ijk	19.5 nopqr
	0.3	0.0 a	43.3 mnopq	0.0 m	23.2 klmno
	0.2	0.0 a	40.0 nopqr	0.0 m	30.1 fghijk
Propaquizafop	0.11	3.3 a	46.5 lmnop	100.0 a	8.8 u
	0.07	0.0 a	43.3 mnopq	88.3 cde	17.0 opqrst
	0.045	0.0 a	50.4 jklmno	23.3 ij	22.3 lmnop
	0.03	0.0 a	57.7 fghijkl	15.0 jk	19.9 nopqr
	0.02	0.0 a	63.3 cdefghi	0.0 m	29.8 fghijk
Fluazifop-P-butyl	0.223	0.0 a	34.5 pqrs	85.0 bcde	11.8 stu
	0.148	0.0 a	40.1 nopqr	35.0 hi	16.6 opqrst
	0.095	0.0 a	51.1 ijklmn	13.3 jkl	20.0 nopqr
	0.064	0.0 a	50.4 jklmno	0.0 m	24.0 jklmno
	0.042	0.0 a	54.7 ghijklm	8.33 klm	22.4 lmnop
Fenoxaprop-P-ethyl	0.131	0.0 a	61.4 defghij	0.0 m	34.3 cdefgh
	0.083	0.0 a	67.3 bcdefg	0.0 m	35.0 bcdefgh
	0.052	0.0 a	71.7 abcde	0.0 m	39.4 bc
	0.035	0.0 a	73.2 abcd	0.0 m	41.7ab
	0.021	0.0 a	46.6 lmnop	0.0 m	41.6 ab
Glyphosate-ipa	0.756	0.0 a	31.6 qrst	3.3 klm	17.2 opqrs
	0.504	8.3 a	29.0 rst	6.7 klm	18.3 opqrs
	0.324	0.0 a	58.0 fghijkl	0.0 m	36.2 bcdef
	0.216	0.0 a	60.7 defghijk	1.7 lm	30.6 fghij
	0.144	0.0 a	43.2 mnopq	0.0 m	35.7 bcdefg
Clethodim	0.264	0.0 a	52.6 hijklmn	63.3 fg	13.0 rstu
	0.168	0.0 a	75.6 abc	11.7 jkl	20.7 mnopq
	0.108	0.0 a	61.2 defghij	3.3 klm	29.8 fghijk
	0.072	0.0 a	64.6 bcdefgh	0.0 m	32.0 cdefghi
	0.048	0.0 a	77.1 a	0.0 m	38.7 bcd
Flupropanate	3.054	3.3 a	50.8 ijklmno	100.0 a	17.9 opqrs
	2.012	1.7 a	56.1 fghijkl	91.7 bcd	26.7 ijklmn
	1.341	0.0 a	76.3 ab	68.3 fg	24.1 jklmno
	0.894	0.0 a	60.4 efghijk	75.0 def	30.8 efghij
	0.596	0.0 a	80.5 a	53.3 gh	27.9 hijklm
Haloxyfop-R-methyl ester	0.208	6.7 a	25.0 st	93.3 abc	14.6 qrstu
	0.135	5.0 a	31.4 qrst	96.7 ab	15.7 pqrstu
	0.083	0.0 a	48.4 klmno	6.7 klm	23.8 jklmno
	0.052	0.0 a	58.8 fghijkl	0.0 m	38.1 bcde
	0.031	0.0 a	60.8 defghijk	3.3 klm	27.7 hijklm
Clethodim + Haloxyfop-R-methyl ester	0.22 + 0.053	16.7 a	31.3 qrst	88.3 cde	9.2 u
	0.154 + 0.034	3.3 a	46.1 lmnop	96.7 ab	9.8 tu
	0.09 + 0.022	0.0 a	50.4 klmno	51.7 gh	18.1 opqrs
	0.06 + 0.014	0.0 a	63.0 cdefghij	10.0 ijk	28.6 ghijkl
	0.04 + 0.01	0.0 a	67.7 bcdef	0.0 m	30.8 efghij
Untreated control		0.0 a	82.1 a	0.0 m	46.9 a

Values within columns followed by the same letter are not significantly different (P <0.05).

Table 6. Experiment 3 – plant mortality (average %) of pre-emergent *S. pyramidalis* and *S. fertilis* plants 55 days after herbicide application.

Herbicide	Rate (kg ha^{-1} a.i.)	*S. pyramidalis*	*S. fertilis*
Imazapyr	0.525	100.0 a	100.0 a
	0.350	100.0 a	100.0 a
	0.225	96.7 ab	100.0 a
	0.15	88.9 bcd	90.8 bc
	0.1	91.7 abc	97.1 ab
Atrazine	2.05	99.1 ab	100.0 a
	1.35	100.0 a	100.0 a
	0.9	100.0 a	100.0 a
	0.6	97.5 ab	100.0 a
	0.4	88.1 bcd	100.0 a
Flupropanate	3.055	100.0 a	100.0 a
	2.011	100.0 a	91.1 bc
	1.341	92.2 abc	93.3 abc
	0.894	79.4 d	100.0 a
	0.596	86.6 cd	90.7 c
Dithiopyr	0.252	100.0 a	100.0 a
	0.168	100.0 a	100.0 a
	0.108	100.0 a	100.0 a
	0.072	100.0 a	97.4 ab
	0.048	100.0 a	100.0 a
Untreated control		6.1 e	25.1 d

Values within columns followed by the same letter are not significantly different ($P < 0.05$).

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