CAN WE MANAGE ALLIGATOR WEED BETTER IN AUSTRALIA? LESSONS FROM HERBICIDE TRIALS

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ABSTRACT

Alligator Weed [*Alternanthera philoxeroides* (Mart.) Griesb] is acknowledged as the aquatic invader that poses the largest threat to Australian waterways and moist, terrestrial habitats. Despite control efforts over several decades, alligator weed is now widespread across NSW, and occurs as sporadic infestations in Queensland, ACT and Victoria, as well. It has the potential to cause losses of millions of dollars from agricultural, tourism and extractive industries across major waterways and catchments in Australia.

Control methods for alligator weed include mechanical control, classical bio-control and herbicides, and combinations of these. Of these, mechanical control may provide immediate control, but also results in fragmentation and increased risks of further spread, and bio-control agents have not been particularly successful on aquatic or terrestrial infestations. Chemical control has been successful, but only short term, and several repeat applications have been required per season to contain or eradicate local infestations.

Recent glasshouse trials evaluated the efficacy of a range of herbicides (glyphosate, metsulfuron, 2, 4-D, triclopyr, a mixture of mecoprop and dicamba, and imazamox) on Alligator Weed, with and without adjuvants. Field trials conducted in Fairfield and Liverpool Local Government Areas in NSW, demonstrated that effective reduction of alligator weed infestations in urban creeks requires multi-year, multiple herbicide treatments. This research provides new insights into alligator weed control using herbicides, and should offer more effective options for managing both aquatic and terrestrial infestations.

Keywords: Aquatic weeds, Alligator Weed, Aquatic Herbicides

INTRODUCTION

Most weed managers agree that alligator weed [*Alternanthera philoxeroides* (Mart.) Griesb] is the No. 1 aquatic invader in Australia, which poses the largest threat to Australian waterways and moist, terrestrial habitats. It is widespread across two major regions in the State of New South Wales (NSW) - the Sydney basin and Hunter region, with deeply entrenched infestations (referred to as 'core' infestation areas). In NSW, it is declared as a Class 2 or Class 3 Noxious Weed. Relatively small, sporadic infestations (referred to as 'non-core' infestation areas) are also present in Queensland, Victoria, and the Australian Capital Territories (ACT).

Over the past two decades, significant research has been conducted in Australia on alligator weed, improving the 'knowledge base' for integrated management (Sainty *et al*., 1998; Schooler *et al*. 2008). Other management experiences (Chandrasena *et al*. 2004;

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Chandrasena and Pinto, 2007) also provide significant insights in to factors that affect alligator weed management. Since 2000, a national plan and several state-wide alligator weed management plans have been developed for implementation (CRC, 2003 and NSW DPI, 2007 and references therein).

In 2002, a research program, sponsored by the *CRC for Australian Weed Management* commenced and research continued until 2008. The main strategies of alligator weed management in Australia, advocated by the above plans, have been to prevent its spread into new areas by: (a) maintaining quarantine, (b) managing current infestations, and (c) educating people to recognise and respond quickly to outbreaks. Despite these considerable efforts, alligator weed has continued to invade more territory in NSW and elsewhere, as highlighted in a recent review (Chandrasena, 2009). This view was confirmed by Burgin *et al*. (2010), who stated: "…*we are no closer to control of alligator weed in local government areas of NSW in 2007 than in 2001, despite substantially more monetary resources contributed in 2007 compared with 2001...*"

Whilst the herbicides effective against alligator weed have been known for some time, there is need to make them more effective by understanding how to improve treatment regimes (Chandrasena *et al*. 2004). The objective of the current research was to evaluate a selection of herbicides, rates, adjuvants and treatment regimes that could provide some answers and improve the overall alligator weed management in Australia.

MATERIALS AND METHODS

Glasshouse Studies

Glasshouse trials were conducted at the University of Western Sydney, Richmond, over two years. Trial 1 (September 2008 to April 2009) and Trial 2 (September 2009 to April, 2010) both used uniform batches of alligator weed plants, raised from stem cuttings (about 25-30 pieces, 3-4 cm long) planted in nursery trays (0.5 x 0.3 m) in top soil and potting mix. At the time of treatments (i.e. 4-5 months from planting), the cuttings had produced a dense growth of plants in each tray. Four trays constituted a single replicate (laid out as ~1 m^2). There were three replicates per treatment, which were completely randomised.

Trial 1

In Trial 1, six herbicides were evaluated: glyphosate (Roundup® Biactive™, 360 g/L), an aquatic glyphosate formulation (Country Glyphosate®, 360 g a.i./L), metsulfuron-methyl (Brush-Off® 600 g a.i./kg), 2,4-D amine (500 g a.i./L), triclopyr (Garlon®, 600 g a.i./L) and a commercial turf weed control mixture of mecoprop (336 g a.i./L) and dicamba (40 g a.i./L). Only glyphosate and metsulfuron-methyl currently have label recommended rates for alligator weed control, which were used in the trials (Table 1). The other broad-leaf herbicides: 2,4-D, triclopyr, mecoprop and dicamba, which do not have a label recommendation for alligator weed control, were included in the study for comparison, as they were likely to significantly affect alligator weed at the right concentrations. These herbicides were tested at label recommended rates to control hard-to-kill weeds. Some treatments had additional adjuvants: either an alkyl ethoxylate surfactant (BS1000®), or Canola Oil (Synetrol®). A total of nine treatments were evaluated (Table 1).

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Trial 2

In Trial 2, four herbicides were tested: Biactive™ glyphosate, metsulfuron-methyl, triclopyr and imazamox (Raptor®, 120 g ai.l/L), with 12 treatments (Table 2). The adjuvant guar gum (Hydrogel®) was incorporated in to spray treatments as a thickener and sticker.

In both glasshouse Trials, herbicide treatments were applied with a 2 L hand-held, pressurised sprayer, using a high carrier volume equivalent to 1000 L/ha. At this volume, the spray treatments wetted all the plants in the trays with some runoff.

Alligator Weed control was visually evaluated at weekly intervals, by following plant death (% death and necrosis) until the end of trial. Control ratings were a percentage scale with 0 = no injury and 100 = complete killing. Alligator Weed regrowth data were recorded 16 weeks after treatment (16 WAT) and expressed as regrowth percentage (i.e. (Number of shoots, which emerged at 60 DAT/Number of shoots, originally planted) x 100).

Field Studies – Multiple Treatments

Field Trials were conducted over two summers (2008 and 2009) at Fairfield and Liverpool Local Government Areas (LGAs) in the Sydney basin. Within the Fairfield LGA, field sites were located at downstream Cabramatta Creek, Prospect Creek and Orphan School Creek. Within the Liverpool LGA, the sites were at upstream Cabramatta Creek and Brickmakers Creek. At all locations, the aquatic infestations were on water, extending from shoreline edges, and also spreading on to upper riparian zones. Average size of a treatment replicate was 25-30 m^2. Treatments were replicated (minimum three replicates) at different locations in the different creeks.

Herbicide treatments in the field studies were limited to glyphosate (Roundup® Biactive™) and metsulfuron-methyl (Brush-Off®) with either BS1000® or Hydrogel® adjuvants. Herbicides were applied to mature and dense alligator weed infestations, which showed lush growth, with a 15 L back-pack, to achieve maximum foliar coverage. Treatments were applied three times with a gap of four weeks during November and December 2009 and January 2010. Effectiveness on both alligator weed, and on riparian zone vegetation was assessed over the following two to six months, and subsequently, 12 months after treatment, by visual rating of phytotoxicity and photographic recordings.

A one way Analysis of Variance (ANOVA) with repeated measures was performed with each set of visual rating and regrowth control results. Mean comparisons were conducted by a Tukey's Multiple Comparison Test. All analyses were conducted at a $p = 0.05$ level of significance using GraphPad Prism 5.0 Statistical software (GraphPad Prism™ 2010).

RESULTS

Glasshouse Trials

The phytotoxicity ratings and regrowth after eight weeks (Table 1) indicated that the aquatic glyphosate formulation, Biactive™ glyphosate and metsulfuron-methyl were highly effective at the label recommended rates in controlling alligator weed. The aquatic glyphosate formulation was particularly effective, as it killed the treated plants almost totally, with very little regrowth occurring at 16 WAT. Based on visual phytotoxicity and percent regrowth results, the effects of adjuvants were not significant on Biactive™

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glyphosate, although, at the time of treatment, the foliar sprays with adjuvants achieved better coverage than the spray without an adjuvant.

Triclopyr achieved the next best initial control, and also suppressed regrowth to a level achieved by the glyphosate and metsulfuron-methyl. Overall, initial control was relatively low with 2, 4-D and the dicamba-mecoprop mixture, although both treatments achieved partial control of alligator weed, evident through leaf and shoot death and necrosis, and stunting of shoot growth. However, inadequate control was reflected in significant regrowth, which was produced by the surviving shoots, by 16 WAT.

Table 1. Effect of selected herbicides and adjuvants on Alligator Weed – Trial 1

Herbicide and Rate of products	Adjuvant (% v/v)	% Control		% Regrowth
		4 WAT	8 WAT	16 WAT
Biactive™ glyphosate (100 mL/10L)	None	88 a	94 a	13.3 c
Biactive™ glyphosate (100 mL/10L)	BS1000 (0.05%)	92 a	95 a	6.7 c
Biactive™ glyphosate (100 mL/10L)	Synetrol (0.1%)	92 a	96 a	10.0 c
glyphosate (Aquatic) (100 mL/10 L)	None	95 a	100 a	1.7 d
metsulfuron-methyl (1 g/10 L)	BS1000 (0.05%)	91 a	95 a	6.7 c
metsulfuron-methyl (1 g/10 L)	Synetrol (0.1%)	89 a	91 a	10 c
2,4-D amine (50 mL/10 L)	BS1000 (0.05%)	63 b	77 b	60 b
triclopyr (17 mL/10 L)	BS1000 (0.05%)	73 b	75 b	16.7 c
dicamba-mecoprop (80 mL/10 L)	BS1000 (0.05%)	68 b	63 c	45 b
Untreated control	-	0 d	0 d	100 a

Means in each column, followed by the same letter are not significantly different at 0.05 level of significance, according to Tukey's Multiple Comparison Test

In Trial 2, the effects of incorporating Hydrogel® as a sticker to improve spray retention on alligator weed foliage were not significant (Table 2). As in Trial 1, Biactive™ glyphosate and metsulfuron-methyl at the full rates were highly effective in controlling alligator weed. Even their half rates provided a high degree of regrowth control.

The control achieved by triclopyr and imazamox, at the tested rates, was somewhat less, which was reflected in regrowth at 16 WAT from the treatments (Table 2). However,

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slightly higher rates of triclopyr and imazamox may achieve a more comprehensive initial kill and more effective control of regrowth.

Field Trials

When a single treatment of a given herbicide does not provide a high level of season-long control of a target weed, it is necessary to consider multiple treatments. Climatic conditions often interfere with the timing of herbicide applications, and difficulties in access to infestations also make herbicide treatments less effective.

Figure 1 and 2 present the results of alligator weed control achieved by single field treatments of specific sites in the urban creeks with glyphosate and metsulfuron-methyl. Control, rated by visual phytotoxicity, indicated that the effects of both herbicides were slow to develop, but by 4 WAT, significant effects were visible and infestations were breaking up. However, significant regrowth occurred at nearly all treated locations at 12 WAT, indicating that the treatments were only partially effective.

Overall, the single treatments led to only 50-60% control with glyphosate (Figure 1) and slightly higher control with metsulfuron-methyl (Figure 2). As in the glasshouse trials, the effects of adjuvants were not significant. However, adjuvant incorporated sprays visibly achieved better coverage.

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Table 2. Effects of selected herbicides and adjuvants on Alligator Weed – Trial 2

Herbicide and Rate of Product	Adjuvant (% v/v)	% Control 4 WAT	% Control 8 WAT	% Regrowth 16 WAT
Biactive™ glyphosate half rate (50 mL/10L)	None	66 cd	61.7 c	18 b
Biactive™ glyphosate half rate (50 mL/10 L)	Hydrogel (0.05%)	62.7 cd	66.7 c	16 b
Biactive™ glyphosate full rate (100 mL/10 L)	None	90 a	95 a	6.7 d
Biactive™ glyphosate full rate (100 mL/10 L)	Hydrogel (0.05%)	90 a	91.7 a	6.7 d
metsulfuron-methyl half rate (0.5 g/10 L)	None	56.7 d	70 c	18 b
metsulfuron-methyl half rate (0.5 g/10 L)	Hydrogel (0.05%)	60 cde	75 bc	16.7 bc
metsulfuron-methyl full rate (1 g/10 L)	None	86.7 a	95 a	6.7 d
metsulfuron-methyl full rate (1 g/10 L)	Hydrogel (0.05%)	87.7 a	95 a	5.7 d
triclopyr half rate (8.5 mL/10 L)	Hydrogel (0.05%)	56.7 de	64.3 c	25 b
triclopyr full rate (17 mL/10 L)	Hydrogel (0.05%)	67.7 bc	71.7 bc	20 b
imazamox half rate (75 g/10 L)	Hydrogel (0.05%)	54.3 e	65 c	17.3 bc
imazamox full rate (150 g/10 L)	Hydrogel (0.05%)	76.7 b	83.3 ab	13.3 cd
Untreated control	-	0 d	0 d	100 a

Means in each column, followed by the same letter are not significantly different at 0.05 level of significance, according to Tukey's Multiple Comparison Test

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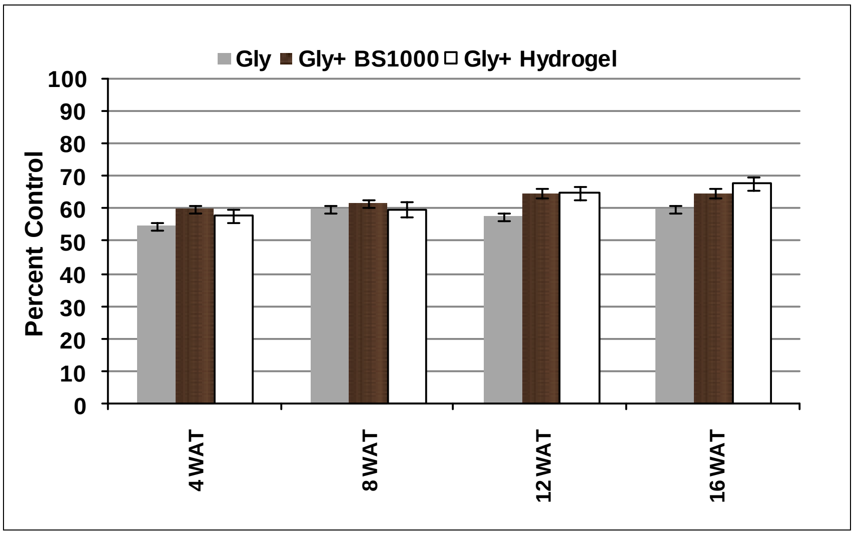

Figure 1. Effect of single treatments of Glyphosate and adjuvants on Alligator Weed field infestations

Figure 3 presents the combined results of multiple treatments on alligator weed infestations, conducted at several locations in the urban creeks. These infestations were robust and dense over water at the outset (e.g. approximately, 10-11 kg wet weight of shoot and root systems per m^2).

The first treatment caused a spectacular collapse of infestations, and phytotoxicity and percent control obtained at each of the treated sites increased with time. With each subsequent treatment, there was significant suppression and increasing collapse of the initial dense infestations at most sites. The second and third treatments were actually given to collapsed infestations at most sites, which still showed significant numbers of live shoots, which would have regrown. Very little alligator weed was found regrowing at the treated sites one year after treatment, indicating the success of the multiple treatments. At some locations, the multiple treatments led to complete eradication of the original patches.

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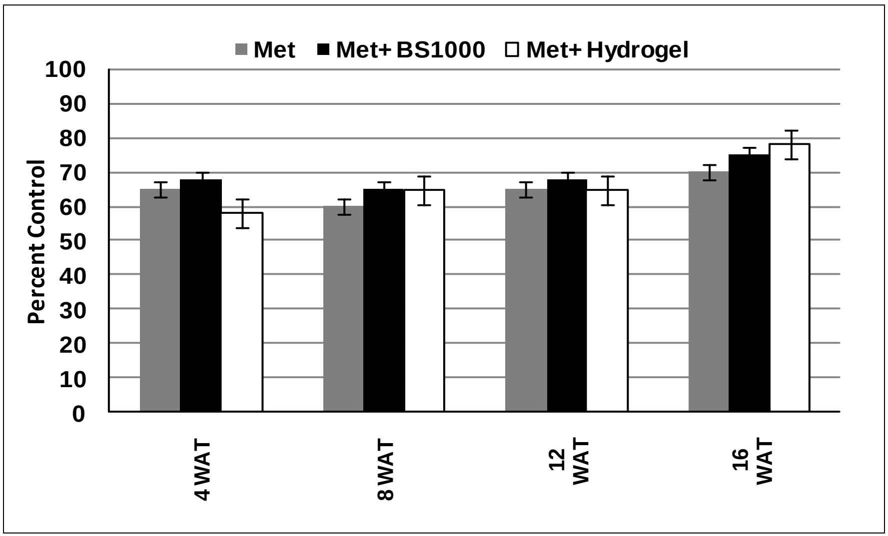

Figure 2. Effect of single treatments of Metsulfuron-Methyl and adjuvants on Alligator Weed field infestations

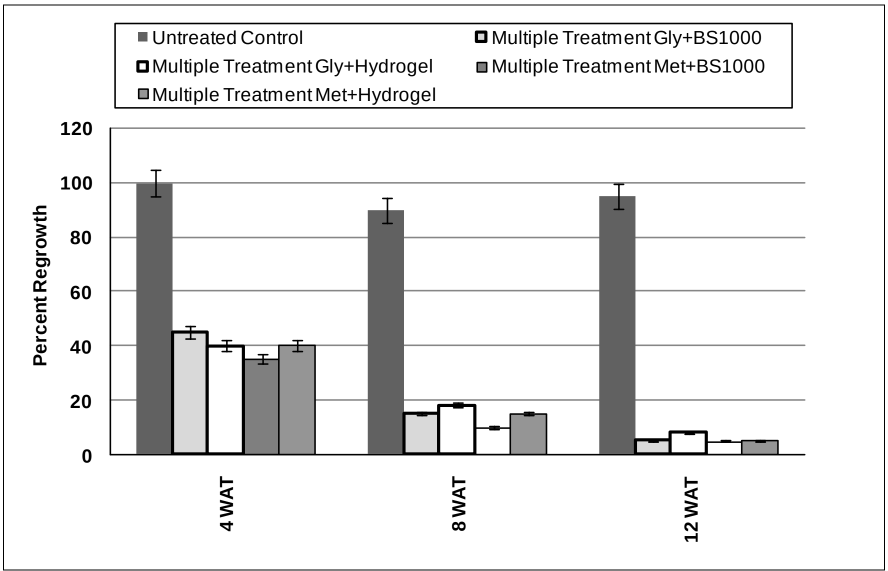

Figure 3. Effect of multiple treatments at select locations of urban creeks in NSW

Nearly two years after the multiple treatments, the levels of infestation were very low at the treated locations and in the creeks, in general. However, there was evidence of re-infestation of the creeks by alligator weed, and these were evidently from upstream untreated areas, particularly from riparian areas. There were no noticeable adverse effects on the upper and lower riparian vegetation except for a decline in some bull rushes (*Eleocharis* sp.) at one location.

DISCUSSION AND CONCLUSIONS

Alligator Weed is regarded in Australia as a remarkably hard-to-control weed, which is often recalcitrant to herbicide treatments. This view has led to a widely expressed sentiment that alligator weed management over large areas is rarely successful or even possible. However, our experiences indicate a more optimistic view. As shown in this research, glyphosate and metsulfuron-methyl are exceptionally effective herbicides against alligator weed. In addition, other selective herbicides are also effective to varying degrees.

The use of metsulfuron-methyl near water or over water is under a special, off-label permit in Australia. However, this herbicide is not registered in USA and other developed countries for applications in water, primarily due to its adsorption and persistence in some soils, and resistance development that has occurred in some weeds. Therefore, increased use of metsulfuron-methyl may not be desirable in the long run. The selectivity of metsulfuron-methyl allows riparian treatments to be conducted without killing all types of reeds and rushes. This is clearly an advantage in many situations. Glyphosate, on the other hand, may kill or reduce most native macrophytes, opening up an infested area, which allows effective targeting of the infestations for re-treatment.

Adequate spray coverage and foliar wetting are important issues when dealing with alligator weed, which can often form multiple layers of thick vegetation, lying over each other. Therefore, treatments must be made at a high enough water volume to carry the herbicides down into all layers of the alligator weed canopy. Often the failures in field control are attributable to access difficulties into infested creeks to achieve good spray coverage. We believe that the biodegradable surfactants, vegetable oils or a natural product like Hydrogel® will overcome this issue. Incorporating an adjuvant is a must to achieve better foliar coverage, and make the alligator weed treatments more reliable.

A contentious issue in managing alligator weed in the field has been the timing of multiple treatments of herbicides. The long-standing practice in LGAs has been to implement three rounds of herbicide applications per year, usually applied early-season (i.e. September-October), mid-season (i.e. February-March) and late-season (April-May). The basis for this practice is actually not scientific, but operational reasons (i.e. limited funding and availability of contractors to adequately cover the treatment areas in a single growing season). However, alligator weed regrowth in between these treatments is typically substantial and often could be such that that season after season, there appears no actual reduction in the infestations. When a treatment does not adequately cover the infested area, alligator weed will re-infest such areas, and the progress is lost.

An integrated strategy for LGAs with large infestations of alligator weed must include several years of sequential herbicide treatments to achieve a successful eradication or a drastic reductionin a given area. In almost all cases, shortening the gap between treatments will reduce the opportunity for treated infestations to ‘escape’ and regrow. With the currently registered herbicides, four to five consecutive years of multiple treatments of glyphosate or metsulfuron-methyl would be typically required, with monitoring of treated areas and follow-up treatments (if required) for up to about 10 years.

However, there will be a need to increase selectivity, if multiple treatments with relatively short gaps are to be implemented. Applying herbicides at the correct time will reduce the rates of herbicide use or the need for multiple treatments in a season. Proper timing may also lessen impacts on non-target vegetation, because the differences in life-cycles between alligator weed and non-target plants. We believe that other selective herbicides,

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such as triclopyr and imazamox, and possibly others, should be part of the overall effort to manage alligator weed. Other ways of improving treatment regimes include manipulating half-dose treatments of the effective herbicides, as sequential treatments and combinations of herbicides. A judious integration of methods, effective application and possibly, a rotation of herbicides, as best practice, will prevent any possibility of alligator weed developing resistance to herbicides.

We believe that alligator weed managers in Australia should not wait until more effective biological control agents are discovered and developed. The march of alligator weed across many landscapes has been steady and increasing in the last 5-10 years. In some creeks, such as South Creek in Sydney, the situation is dire. Effective treatment regimes with herbicides are essential to contain alligator weed. In our view, more dedicated effort and leadership is needed to garner commitment from all stakeholders and to better access funding, expertise and public involvement - to effectively implement the existing alligator weed control plans.

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