Increasing foliar herbicide options for controlling *Clidemia hirta* (L.) D.Don

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Summary *Clidemia hirta* (L.) D.Don. (Koster's curse) is a highly invasive, tropical understory shrub that was discovered in north Queensland in 2001. It was an eradication target species at a single location until the discovery of a second infestation in July 2015. The eradication program mostly involved manually uprooting entire plants; however the discovery of the second infestation signalled a need for more control options to accompany changes in managing this weed by a broader range of stakeholders. The second infestation provided sufficient plants to test eight high-volume foliar herbicides at one or two rates. Three of these herbicides were also applied using a low-volume foliar spraying technique, and comparisons were made of the effectiveness, volume and amounts of active ingredients applied using high and low-volume methods. Herbicide damage was assessed one, three and seven months after treatment. High and low-volume rates of treatments containing 600 g L^{-1} of triclopyr, 333 g L^{-1} fluroxypyr, and 300 g L^{-1} triclopyr + 8 g L^{-1} aminopyralid + 100 g L^{-1} picloram were effective. Treatments with 600 g kg^{-1} metsulfuron-methyl, 300 g kg^{-1} metsulfuron-methyl + 375 g kg^{-1} of aminopyralid and 140 g L^{-1} fluroxypyr +10 g L^{-1} aminopyralid was also effective at both high volume rates tested. Treatment with 625 g L^{-1} of 2,4-D amine was less effective, and results for treatments with 360 g L^{-1} of glyphosate were more variable, than the preceding treatments. This trial identified several effective active ingredients to assist in managing a broader *C. hirta* incursion.

Keywords Rainforest, low-volume application.

INTRODUCTION

Clidemia hirta (L.) D.Don (Koster's curse) is a bushy shade tolerant tropical shrub that was the subject of a national cost-shared weed eradication program after it was discovered near Julatten in 2001 (Breaden *et al.* 2012). This was the only known infestation in Australia until a second was discovered in July 2015, in the Wooroonooran National Park, approximately 130 km south of Julatten. As a result of this second infestation the eradication of *C. hirta* was abandoned and alternative management approaches are now being developed.

During the eradication program, most *C. hirta* was controlled by hand removing the entire plants and root system. However, this technique may be less feasible for treating larger or denser infestations. In its invasive range *C. hirta* occurs across a broad range of vegetation, soil, climate types and invades a wide variety of native and agricultural land types (Breaden *et al.* 2012). Beyond the current control activities amongst native forests, there may be future requirements to treat *C. hirta* in areas such as roadsides, riparian zones, steep slopes, grazing areas, walking tracks and plantations. The management of *C. hirta* will also require treatments suitable for a broader range of stakeholders to apply in a variety of situations, including timely responses to new detections.

Multiple overseas studies have tested a range of foliar herbicides for control of *C. hirta*. Herbicides containing the active ingredient triclopyr have proven highly effective over a range of application rates (Faiz (1993), Hafiz *et al.* (2014), Motooka (2003) and Teoh *et al*. (1982)). Fluroxypyr was more than 90% effective on *C. hirta* (Faiz 1993, Kuan *et al.* 1993), as was a metsulfuron-methyl based herbicide (Faiz 1993). Combinations such as metsulfuron-methyl + fluroxypyr (MSIRI 2010), metsulfuron-methyl and paraquat (Hafiz *et al.* (2014) have been found to be effective while other combinations such as aminopyralid + triclopyr, glyphosate + triclopyr (Hafiz *et al*. (2014) and Ismail *et al*. (2014)) and 2,4-D + picloram (Faiz 1993) were less effective. Individually, active ingredients such as glyphosate, dicamba, MCPA and 2,4-D were relatively ineffective in controlling *C. hirta* at the rates tested by Faiz (1993), Ismail *et al*. (2014), Motooka (2003) and Teoh *et al.* (1982).

The discovery of a new infestation in 2015 provided the opportunity to test the most promising foliar chemicals under local conditions, particularly those containing triclopyr, fluroxypyr and metsulfuron-methyl. Glyphosate and 2,4-D were also included to test whether efficacy may be better at different application rates than those tested previously. Based on its success on other weeds, some low-volume, high-concentration (splatter gun) applications were also included as an alternative to physical control and in situations where there is insufficient access for high-volume foliar spraying equipment and to target weeds amongst desirable vegetation (Brooks *et al.* 2014).

MATERIALS AND METHODS

The trial was located on an abandoned forestry track in the Misty Mountains section of the Wooroonooran National Park, near, 17° 42' S, 146° 41' E and 710 m above sea level. There were thousands of *C. hirta* plants spread over several hectares in the surrounding upland complex mesophyll vine forest of very wet rainfall zones (Regional ecosystem 7.8.2a: Queensland Herbarium 2015).

A randomized complete block experiment incorporating 19 herbicide treatments and three replications was established and measured at the site on the 13 October 2015. Plots were 2 × 2 m, 4 × 1 m or 2.5 × 2.5 m in size to create a total area of 12 or 14.5 m^2 per treatment.

Prior to implementation of treatments, the number of *C. hirta* plants and leaders was recorded in each plot, along with the mean and maximum height of plants. The average height of *C. hirta* was 87 cm. A Campbell

Table 1. Herbicide treatment details. Costs are based on local prices of 5 L of liquid herbicide or 200 g of granular herbicide and applied at trial volumes.

Product	Active ingredients	Active rate	Amount active ($g\ L^{-1}$)	Active applied ($g\ ha^{-1}$)	Application rate ($L\ ha^{-1}$)	Cost of herbicide (\$ ha^{-1})
Amicide® Advance 700	2,4-D (salts)	700 $g\ L^{-1}$	2.80	7933	2833	181
Brush-Off®	metsulfuron-methyl	600 $g\ kg^{-1}$	0.06	200	2807	58
Brush-Off®	metsulfuron-methyl	600 $g\ kg^{-1}$	0.12	337	3333	137
Garlon™ 600	triclopyr	600 $g\ L^{-1}$	1.02	2648	2596	150
Garlon™ 600	triclopyr	600 $g\ L^{-1}$	1.98	5610	2833	318
Grazon™ Extra	triclopyr picloram aminopyralid	300 $g\ L^{-1}$ 100 $g\ L^{-1}$ 8 $g\ L^{-1}$	1.05 0.35 0.03	2726 909 73	2596	480
Grazon™ Extra	triclopyr picloram aminopyralid	300 $g\ L^{-1}$ 100 $g\ L^{-1}$ 8 $g\ L^{-1}$	1.98 0.66 0.05	6105 2035 163	3083	1075
Hotshot™	fluroxypyr aminopyralid	140 $g\ L^{-1}$ 10 $g\ L^{-1}$	1.01 0.07	2856 204	2833	690
Hotshot™	fluroxypyr aminopyralid	140 $g\ L^{-1}$ 10 $g\ L^{-1}$	2.02 0.14	5712 408	2833	1379
Starane™ Advanced	fluroxypyr	333 $g\ L^{-1}$	1.00	2914	2917	621
Starane™ Advanced	fluroxypyr	333 $g\ L^{-1}$	2.00	5661	2833	1207
Stinger™	aminopyralid metsulfuron-methyl	375 $g\ kg^{-1}$ 300 $g\ kg^{-1}$	0.08 0.06	213 170	2833	120
Stinger™	aminopyralid metsulfuron-methyl	375 $g\ kg^{-1}$ 300 $g\ kg^{-1}$	0.15 0.12	463 370	3083	262
Weedmaster® DUO®	glyphosate	360 $g\ L^{-1}$	3.60	10200	2833	436
Weedmaster® DUO®	glyphosate	360 $g\ L^{-1}$	7.20	20400	2833	873
Garlon™ 600*	triclopyr	600 $g\ L^{-1}$	16.80	3584	213	203
Starane™ Advanced*	fluroxypyr	333 $g\ L^{-1}$	19.98	4129	207	882
Grazon™ Extra*	triclopyr picloram aminopyralid	300 $g\ L^{-1}$ 100 $g\ L^{-1}$ 8 $g\ L^{-1}$	15.00 5.00 0.40	3300 1100 88	220	581

* Low-volume applications.

Scientific weather station was also placed in a canopy gap on site to record climatic conditions on an hourly basis for the duration of the trial.

Fifteen high-volume and three low-volume applications, plus an untreated control were deployed (Table 1). Five mL L^{-1} of Uptake™ spraying oil was added to the high-volume treatments and 2 mL L^{-1} of Pulse® penetrant was added to the low-volume treatments. Red Spraymate™ Spray Marker Dye (150 g L^{-1} Rhodamine B) was added to all herbicide mixtures at a rate of 1 mL L^{-1} of solution. Fifteen litres of each high-volume treatment (Table 1) was prepared to treat *C. hirta* with a backpack sprayer and hand wand, and the amount of herbicide mixture used was estimated for each treatment.

For the low-volume treatments, one litre of solution was prepared for each treatment and 9 to 12 × 8 mL 'shots' were applied per plot (Table 1) with a manually operated 'Forestmaster' applicator.

Treatments were applied between 9:30 am and 3:30 pm on the 27 October 2015, a sunny day with hourly temperatures between 19.3 and 28.2°C and humidity between 51.3 and 84.5%. The wind was from the south south-east averaging 0.8 km h^{-1} with gusts below 5.8 km h^{-1} during application.

Post treatment assessments were undertaken 30 (26 November 2015), 94 (29 January 2016) and 218 (1 June 2016) DAT (days after treatment) using a herbicide damage rating score of 1 (undamaged) to 9 (rotten) for each stem (Brooks *et al.* 2012) and recording any plant regrowth. Stem damage scores were averaged per plot. Total *C. hirta* seedlings per plot were counted 218 DAT. Plots were photographed at each assessment. Regular visits were undertaken in 2016 to remove flower buds from the control plots and some herbicide treated plots with lower mortality as noted in Table 2. Live plants were removed when

Table 2. Assessments ranked by 218 DAT mean leader damage score, where 1 is unaffected and 8 appears dead. Means followed by the same letters are not significantly different from each other (P >0.05).

Active ingredients and (amounts) in (g L^{-1})	Initial plants m^{-2}	Initial stems m^{-2}	% Plant mortality 218 DAT	Mean stem damage score 218 DAT
aminopyralid (0.15) metsulfuron-methyl (0.12)	6.83	9.50	100.0[a]	8.00[a]
fluroxypyr (1)	5.17	6.50	100.0[a]	8.00[a]
fluroxypyr (2)	5.42	8.50	100.0[a]	8.00[a]
fluroxypyr (19.98)*	4.42	8.08	100.0[a]	8.00[a]
fluroxypyr (2.02) aminopyralid (0.14)	6.00	8.58	100.0[a]	8.00[a]
metsulfuron-methyl (0.06)	6.58	7.50	100.0[a]	8.00[a]
triclopyr (15) picloram (5) aminopyralid (0.4)*	5.58	6.33	100.0[a]	8.00[a]
triclopyr (1.02)	4.30	5.29	100.0[a]	8.00[a]
triclopyr (1.98)	7.67	11.08	100.0[a]	8.00[a]
triclopyr (16.8)*	7.75	10.42	100.0[a]	8.00[a]
triclopyr (1.98) picloram (0.66) aminopyralid (0.05)	7.42	9.50	100.0[a]	8.00[a]
fluroxypyr (1.01) aminopyralid (0.07)	6.05	7.42	100.0a	8.00[a]
metsulfuron-methyl (0.12)	8.17	10.36	99.58[a]	7.98[a]
triclopyr (1.05) picloram (0.35) aminopyralid (0.03)	6.00	7.33	98.72[ab]	7.96[a]
aminopyralid (0.08) metsulfuron-methyl (0.06)	5.08	7.25	96.31[ab]	7.70[ab]
glyphosate (7.2)**	5.25	6.83	90.08[ab]	7.61[ab]
glyphosate (3.6)**	4.42	5.83	87.11[b]	7.17[b]
2,4-D (2.8)**	6.00	7.75	17.20[c]	2.17[c]
Control**	3.58	6.83	0.00[d]	1.00[d]
s.e.m	2.96	3.19	4.18	0.20
l.s.d statistic			12.00	0.57

* Low-volume applications. ** Flowers removed from these treatments between 94 and 218 DAT.

the trial concluded (218 DAT). Genstat 16th Edition (VSN International) was used to undertake analysis of variance and Fisher's protected least significant difference (l.s.d) test identified which treatments differed from each other.

RESULTS AND DISCUSSION

Pre-treatment and final post-treatment assessments are shown in Table 2. As plants were still standing 218 DAT no leaders were scored as category 9, but the category 8 leaders were considered dead with no regrowth recorded under warm (daily min = 19°C and daily max temps = 27.5°C), wet (1620 mm rain) and humid conditions for the duration of the trial.

Twelve of the high and low-volume treatments showed a high degree of *C. hirta* control (Table 2).

There were no flowers, regrowth or live plants in the low-volume treated plots. The cost and amount of active ingredients applied via low-volume sprays fall between the two high-volume rates of the same herbicides (Table 1) and provide an effective alternative for sites where high-volume applications are difficult (Table 2).

Triclopyr was one of the cheapest and consistently effective active ingredients, which parallels the effectiveness reported in the overseas trials mentioned above. The lower rates tested provide the same efficacy for a lower cost than the more concentrated and expensive high-volume applications.

Granular products containing metsulfuron-methyl were the cheapest treatments applied in this trial and plot photos suggest they were among the treatments with more native seedlings. However, the presence of *C. hirta* biotypes resistant to metsulfuron-methyl in Malay plantations (Ramadzan *et al*. 2012) indicates that metsulfuron-methyl should not be repeatedly applied as a sole active ingredient.

Lower mean plot mortality, stem regrowth, flowers and live leaders were recorded in the 2,4-D and some glyphosate treated plots (Table 2). With high seed production from a single fruit (Breaden *et al.* 2012) the failure of these treatments to prevent flowering renders them unsuitable. This trial and the overseas studies suggest that glyphosate-based herbicides may not provide complete *C. hirta* control particularly on roadsides and in riparian areas.

Clidemia hirta seedlings recorded in most plots and were no significant differences between treatments ($P > 0.05$) in the seedling counts 218 DAT. The treatment of *C. hirta* foliage prevented any conclusions being drawn on pre-emergent effects of picloram, aminopyralid or metsulfuron-methyl active ingredients. Particular care would be needed if applying these herbicides near desirable vegetation; in these situations herbicides containing only triclopyr or fluroxypyr may be preferred.

This trial identified alternative active ingredients applied using high and low-volume techniques to control *C. hirta*. These herbicides can be considered by land managers in conjunction with resources, preferences, land use, access and permits.

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