Effect of split applications of herbicides on the control of *Hypericum perforatum* L. (St. John's wort) and regeneration of native grasses and annual clovers on non-arable land

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Summary

The effects of single and split applications of herbicides on the kill of *Hypericum perforatum* L. (St. John's wort) and the regeneration of annual clovers and native perennial grasses were recorded from 1997 to 1999 in an experiment near Wellington, New South Wales. Split applications of fluoroxypyr (0.4 + 0.6, 0.6 + 0.4 and 0.6 + 0.6 kg a.i. ha^{-1}) and triclopyr + picloram ((0.9 + 0.3) + (0.9 + 0.3) kg a.i. ha^{-1}) at flowering in Novembers 1997 and 1998 gave 100% kill of the weed while split applications of glyphosate at 1.35 + 1.35 kg a.i. ha^{-1} were less successful. Split applications of all three herbicides in November 1997 and February 1998 were less effective in killing *H. perforatum* than applications in Novembers 1997 and 1998, probably because the weed had insufficient time to recover from the November 1997 spraying and grow sufficient foliage to absorb the herbicide from the February 1998 application. Single applications of all herbicides resulted in <100% kill of the weed, the small populations remaining after spraying having the potential to increase to large infestations over time. Single and split applications of fluoroxypyr had no deleterious effects on the regeneration of annual clovers with and without superphosphate and promoted the ground cover and quality of native perennial grasses. Triclopyr + picloram reduced the ground cover of clovers and glyphosate reduced the ground cover of native perennial grasses. The results suggest that long term control of *H. perforatum* could be achieved using split applications of fluoroxypyr and aerial distribution of superphosphate and *Trifolium subterraneum* seed, followed by heavy stocking in winter/early spring to graze any *H. perforatum* present, with animal free periods in summer to promote native grass dominance.

Introduction

Research in the 1970s and 1980s showed that picloram + 2,4-D (Tordon 50-D®) and triclopyr + picloram (Grazon®) were effective in killing *Hypericum perforatum* L. (St. John's wort) (Campbell *et al.* 1979, Campbell *et al.* 1991, Watson and Love 1993). However the high rates (from 1.2 to 6.0 kg a.i. ha^{-1}) recommended for killing the weed by spot spraying (Campbell 1986, Campbell and Watson 1994) also killed clovers for a number of years after spraying and were too costly for large scale spraying. Later research at Cassillis, New South Wales (NSW) and Orange, NSW showed that fluoroxypyr (Starane®) could kill *H. perforatum* at a much lower cost than picloram + 2,4-D or triclopyr + picloram, without damaging associated clovers or grasses (Watson and Campbell 1994). Further research showed that split applications of fluoroxypyr (0.2 + 0.6, 0.4 + 0.6, 0.6 + 0.6, 0.8 + 0.6 kg a.i. ha^{-1}) applied at two successive flowerings gave complete kills of *H. perforatum* without damaging introduced clovers and grasses (Campbell and Nicol 1997). The latter experiment did not investigate the lowest combination of rates that might be effective in killing the weed. Thus a new experiment was conducted in another environment (Wellington, NSW) and on another type of pasture (naturalized clovers and native perennial grasses) to examine lower rate combinations of fluoroxypyr for selectively removing *H. perforatum*.

Materials and methods

Site

The experiment was carried out near Wellington, NSW on a non-arable hill heavily infested with the narrow leaved variety (Campbell *et al.* 1992) of *H. perforatum*, which had superphosphate aerially applied at 125 kg ha^{-1} in 1985 and 1993 and subterranean clover (*Trifolium subterraneum* L.) seed aerially sown at 3 kg ha^{-1} in 1993. The pasture was lightly grazed with Aberdeen Angus cattle and Merino wethers at 2 d.s.e. ha^{-1} until 1999 when heavy grazing (20 d.s.e. ha^{-1}) was imposed for two months in the dry winter/early spring to force the animals to graze *H. perforatum* and other species to ground level.

At the first spraying on 13 November 1997, ground cover of species was: native grasses (redleg, *Bothriochloa macra* (Steud.) S.T.Blake; threeawn spear, *Aristida* spp.; crested wheat, *Agropyron cristatum* (L.) Gaertn.; Queensland blue, *Dicanthium sericeum* (R.Br.) A.Camus; wallaby, *Danthonia* spp.; corkscrew, *Stipa* spp. and windmill, *Chloris truncata* R.Br.) 14%; naturalized clovers (hop, *Trifolium campestre* Schreb.; hare's foot, *T. arvense* L.; subterranean; narrowleaf, *T. angustifolium* L.; ball, *T. glomeratum* L. and suckling, *T. dubium* Sibth.) 10%; *H. perforatum* 40%; bare ground 20%; litter 8%; broadleaved weeds 6%; and annual grasses 2%.

Treatments

Fluoroxypyr (20% a.i.) was applied to *H. perforatum* on 13 November 1997 at 0, 0.2, 0.4 and 0.6 kg a.i. ha^{-1}. These treatments were oversprayed with all combinations of these rates on each of 20 February 1998 or 19 November 1998 (Tables 1 and 3). Triclopyr + picloram (30% + 10% a.i.) and glyphosate (45% a.i.) were applied at, respectively, 0.9 + 0.3 and 1.35 kg a.i. ha^{-1} on 13 November 1997 and these plots were oversprayed with the same rates on 20 February 1998 or 19 November 1998. Molybdenised superphosphate was applied to two replications on 20 February 1998 at 100 kg ha^{-1}.

At spraying on 13 November 1997, 95% of the *H. perforatum* stems were in flower and growing under moisture stress (15, 79 and 66 mm of rain in, respectively, the one, two and three months prior to spraying). Each crown had 2–6 flowering stems 55 cm high but no non-flowering stems.

At spraying on 20 February 1998, *H. perforatum* had finished its main flowering but a second population of tillers 2–10 cm high were flowering. It was suffering moisture stress despite 101, 123 and 60 mm of rain in, respectively, the one, two and three months before spraying. The critical factor affecting growth prior to this spraying was a hot, dry period of 26 days with only 32 mm of rain.

At spraying on 19 November 1998, 90% of the *H. perforatum* stems were in flower and growing vigorously after 98, 113 and 119 mm of rain in, respectively, the one, two and three months before spraying. Flowering stems were short, 30 cm high, due to heavy grazing in winter/early spring 1999. Annual clover growth was prolific on plots that had been topdressed with superphosphate.

Herbicides were applied in 500 L ha^{-1} water with 0.5 L ha^{-1} of a non-ionic surfactant, from a hand held pneumatic sprayer. No rain fell on the experiment for at least 12 hours after each spraying. Rainfall during the experiment was 1155 mm for 1998 and 701 mm for 1999.

Effect of treatments was measured by visual estimation of percentage ground cover of the component species by two independent observers at various times in the two years after the initial spraying.

The experiment had 4 × 5 m plots replicated four times in a randomized block design with all treatment combinations randomized within replication. The analysis of variance isolated the main effects of time of second application. The factorial main effects and interaction of rate of fluoroxypyr at first and second application were separated. All interaction terms were significant (P<0.05), therefore individual means are presented.

Results

Kill of H. perforatum

Complete kills of *H. perforatum* were obtained from split applications of fluoroxypyr at 0.6 + 0.4, 0.4 + 0.6 and 0.6 + 0.6 kg a.i. ha^{-1} and triclopyr + picloram at (0.9 + 0.3) + (0.9 + 0.3) kg a.i. ha^{-1} in successive Novembers of 1997 and 1998 (Table 1). Of nine split applications in November 1997 + February 1998 eight were unsuccessful (Table 1), probably because the *H. perforatum* had insufficient time to recover from the November 1997 spraying to grow sufficient foliage to absorb the herbicide from the February 1998 application. Single applications of fluoroxypyr did not result in 100% kills of *H. perforatum* (Table 1). They were more effective (P<0.05) from the November 1998 spraying than from the November 1997 or the February 1998 sprayings (Table 1), possibly because of the more favourable growing conditions before it than before the other sprayings. Glyphosate gave inferior results (P<0.05) to both fluoroxypyr and triclopyr + picloram (Table 1).

Promotion of annual clovers and native grasses

When measured in November 1998, fluoroxypyr and glyphosate treatments applied in November 1997 + February 1998 had no effect (P<0.05) on legume content with or without superphosphate, while triclopyr + picloram reduced legume content with and without superphosphate (Table 2). The most abundant clover on the + superphosphate treatments was *T. campestre* with *T. arvense, T. subterraneum* and *T. angustifolium* also prevalent. On the – superphosphate treatments *T. arvense* was the dominant clover.

When measured in November 1999, fluoroxypyr and glyphosate treatments applied in November 1997 + February 1998 and November 1997 + November 1998 had more (P<0.05) annual legumes than the nil and triclopyr + picloram treatments for both + and - superphosphate (Table 2). In 1999 clover content was much reduced due to heavy grazing in winter and early spring; the low clover content on the nil treatment was attributed to competition from *H. perforatum*.

Superphosphate markedly promoted legume content in 1998 under light grazing but in 1999 the promotion was restricted due to heavy grazing (Table 2).

Treating *H. perforatum* with either single or split applications of fluoroxypyr or triclopyr + picloram increased (P<0.05) the ground cover of native perennial grasses above that on the control when measured in November 1999 whereas glyphosate either reduced ground cover or had no effect (Table 3).

As a result of all herbicides wholly or partially killing *H. perforatum*, ground cover of the low quality threeawn spear grass was reduced and ground cover of the higher quality redleg grass association was promoted when measured on 5 March 1998 (Table 4). Fluoroxpyr and triclopyr + picloram were more effective (P<0.05) in promoting the redleg grass association than glyphosate (Table 4). Ground cover of the perennial grasses at this time (42% on the nil treatment to 59% on the fluoroxypyr treatments) was higher than in Novembers 1998 / 1999 (17% on the nil treatment to 44% on the triclopyr + picloram treatment) because, by March, they had more time to recover from winter frosting than by November.

Table 1. Effect of single (13 November 1997, 20 February 1998, 19 November 1998) and split applications (November 1997 + February 1998, November 1997 + November 1998) of herbicides on ground cover (%) of *H. perforatum* measured on 25 November 1999.

Herbicide (kg a.i. ha^{-1}) applied on 13/11/97	Rate (kg a.i. ha^{-1}) applied on 20 February 1998				Rate (kg a.i. ha^{-1}) applied on 19 November 1998			
	(0)	(0.2)	(0.4)	(0.6)	(0)	(0.2)	(0.4)	(0.6)
Fluoroxypyr								
(0)	34 a[A]	14 cdef	18 bc	23 b	38 a	8 fghi	3 hij	4 ghij
(0.2)	38 a	24 b	10 ef	8 fghi	35 a	6 ghij	2 ij	2 ij
(0.4)	17 bc	15 cde	4 ghij	9 efg	15 cde	6 ghij	2 ij	0 j
(0.6)	16 cd	18 bc	9 fgh	10 defg	19 bc	2 ij	0 j	0 j
Triclopyr + picloram (0.9 + 0.3)	(0.9 + 0.3) 8 fghi				(0.9 + 0.3) 0 j			
Glyphosate (1.35)	(1.35) 16 cde				(1.35) 8 efgh			

[A] Values not followed by a common letter differ significantly (P<0.05).

Table 2. Effect of herbicides and superphosphate on ground cover (%) of annual clovers measured on 19 November 1998 and on 25 November 1999.

Herbicide	Superphosphate	19 November 1998	25 November 1999
Nil	+	35 a[A]	5 ef
	–	22 bc	3 f
Fluoroxypyr	+	43 a[B]	14 b[C]
	–	18 c[B]	6 de[C]
Triclopyr + picloram	+	16 cd	8 cd
	–	6 d	3 f
Glyphosate	+	33 ab	19 a
	–	20 c	9 c

[A] Values in columns not followed by a common letter differ significantly (P<0.05).
[B] Mean of 15 treatments sprayed in November 1997 + February 1998.
[C] Mean of 30 treatments sprayed in November 1997 + February 1998 and November 1997 + November 1998.

Discussion

In this experiment split applications of low rates of fluoroxypyr (0.4 + 0.6, 0.6 + 0.4, 0.6 + 0.6 kg a.i. ha^{-1}) and triclopyr + picloram ((0.9 + 0.3) + (0.9 + 0.3) kg a.i. ha^{-1}) at full flower in successive Novembers 1997 and 1998 gave 100% kill of *H. perforatum* (Table 1). The results for fluoroxypyr agree with those achieved by spraying *H. perforatum* in full flower in Decembers 1993 and 1994 at Orange NSW where 100% kill was achieved with split applications of 0.4 + 0.6, 0.6 + 0.6 and 0.8 + 0.6 kg a.i. ha^{-1} (Campbell and Nicol 1997). At Orange the weed flowers one month later than at Wellington. These results are remarkable because it has been difficult to completely kill *H. perforatum* with single applications of low rates of any herbicide (Campbell *et al.* 1991; Watson and Love 1993; Campbell *et al.* 1995). The lowest rate of fluoroxypyr that gave 100% kill in both experiments was 1.0 kg a.i. ha^{-1} applied as 0.4 + 0.6 or 0.6 + 0.4 kg a.i. ha^{-1}. In practice it may be most effective to apply the high

Table 3. Effect of single (13 November 1997, 20 February 1998, 19 November 1998) and split applications (13 November 1997 + 20 February 1998, 13 November 1997 + 19 November 1998) of herbicides on ground cover (%) of native perennial grasses recorded on 25 November 1999.

Herbicide (kg a.i. ha^{-1}) applied on 13 November 1997	Rate (kg a.i. ha^{-1}) applied on 20 February 1998				Rate (kg a.i. ha^{-1}) applied on 19 November 1998			
	(0)	(0.2)	(0.4)	(0.6)	(0)	(0.2)	(0.4)	(0.6)
Fluoroxypyr								
(0)	22 ij[A]	26 hi	30 fgh	22 ij	17 jk	37 bcde	41 abc	40 abc
(0.2)	30 fgh	35 bcdef	33 efg	28 ghi	33 efg	34 def	38 bcde	41 ab
(0.4)	35 def	36 bcde	28 ghi	34 ef	39 abcd	35 cdef	40 abcd	37 bcde
(0.6)	26 hi	37 bcde	33 efg	34 def	35 cdef	38 bcde	38 bcde	40 abcd
Triclopyr + picloram (0.9 + 0.3)	(0.9 + 0.3) 36 bcde				(0.9 + 0.3) 44 a			
Glyphosate (1.35)	(1.35) 12 k				(1.35) 17 jk			

[A] Values not followed by a common letter differ significantly ($P<0.05$).

Table 4. Effect of herbicides on ground cover (%) of native perennial grasses measured on 5 March 1998.

Herbicide	Redleg grass association	Threeawn spear grass
Nil	15 d[A]	27 b
Fluoroxypyr[B]	38 a	21 c
Triclopyr + picloram	35 a	21 c
Glyphosate	28 b	18 cd

[A] Values not followed by a common letter differ significantly ($P<0.05$).
[B] Mean of 15 treatments sprayed in November 1997 + February 1998.

rate 0.6 kg a.i. ha^{-1} in the first application because of the greater biomass of the weed present then or to apply equal rates of 0.5 kg a.i. ha in each split application.

Although split applications of triclopyr + picloram did not give a complete kill in the Orange experiment, a 98% reduction was achieved with (1.2 + 0.4) + (0.9 + 0.3) kg a.i. ha^{-1}. In the Wellington experiment, glyphosate was less effective than fluoroxypry or triclopyr + picloram in killing *H. perforatum* which agrees with results at Casillis and Orange (Watson and Love 1993; Campbell and Nicol 1997).

The advantage of fluoroxypyr over triclopyr + picloram and glyphosate is that, when applied at full flower in late spring or early summer, it does not affect the regeneration of annual clovers or native grasses or introduced perennial grasses (Campbell and Nicol 1997) in the following year whereas triclopyr + picloram reduces clover content and glyphosate reduces grass content (Campbell and Nicol 1997). In this experiment the annual clover content was unaffected by fluoroxypyr, reduced by triclopyr + picloram and promoted by a low rate of superphosphate. An added benefit from the reduction of *H. perforatum* from the November 1997 + February 1998 applications of fluoroxypyr and triclopyr + picloram was the increased content and quality of native perennial grasses. Quality was improved by the reduction in content of the *Aristida* spp., a native grass weed which supports low animal production, pollutes wool and injures carcasses by seed penetration (Lodge and Hamilton 1981). Glyphosate reduced the content of the grasses due its phytotoxic effects.

The implications of these results are that *H. perforatum* can be 100% killed with split applications of fluoroxypyr in consecutive years when the weed is in full flower and is preferably growing well after good rain. For long-term control on non-arable land subterranean clover seed and superphosphate should be aerially applied in the late autumn following the first spraying, allowed to establish and then grazed lightly in late spring or, preferably, not at all in the year of sowing to allow the clover maximum seed set.

After the second split application, the area should be set stocked to force animals to graze any *H. perforatum* plants that establish from seed. If small amounts of *H. perforatum* return, the area should be grazed heavily in winter and early spring until *H. perforatum* begins to flower, to force animals, preferably fine wool Merino sheep with at least four months wool growth for sun protection, to graze the weed (Bourke 1999). Grazing in winter has the advantage that the level of hypericin (the sunlight activated poison) in the weed is lowest (Southwell and Campbell 1991; Bourke 1999) and heavier grazing pressure can be exerted then, than in other seasons. This grazing treatment should be repeated annually with biennial superphosphate additions and spelling in favourable summer periods to allow the native grasses to seed and increase ground cover, as occurred in this experiment. If large amounts of *H. perforatum* return, the area can be re-sprayed with fluoroxypyr and the whole management process started again. However re-spraying is costly, \$125 ha^{-1} for the 5 L (1.0 kg a.i. ha^{-1}) of fluoroxypyr (recommended retail price in Orange in 1999), and thus control by pasture competition and grazing is preferable and also more environmentally acceptable.

Crofts (1989) devised a grazing system for developing non-arable hill country using low rates of superphosphate and subterranean clover seed to improve native pastures, keeping increased production in line with increased stock numbers and grazing pressure. This management system would be suitable, after the application of fluoroxypyr, to foster the long-term survival of native grass pastures with the additional aim of controlling *H. perforatum*.

It is possible that a single application of fluoroxypyr at 0.6 kg a.i. ha^{-1} at flowering when the weed is growing well, followed by application of subterranean clover seed and superphosphate and annual heavy winter/early spring grazing could achieve control. However the success of such management would depend on the initial kill achieved by fluoroxypyr and the efficiency of the grazing management afterwards. Campbell and Dellow (1984) showed that light infestations of *H. perforatum* in native pastures can be controlled by heavy grazing with Merino sheep. However if this is not possible small populations remaining after a single spraying of fluoroxypyr can increase to large infestations over time (Campbell and Watson 1994). Increasing the rate of a single application above 0.6 kg a.i. ha^{-1}

may result in a complete kill in some situations but 0.8 kg a.i. ha^{-1} applied at flowering and 3.0 kg a.i. ha^{-1} applied in summer was insufficient to kill the weed completely in experiments near Orange (Campbell and Nicol 1997).

Fluoroxypyr is only registered for use on *H. perforatum* from ground application but as the greatest areas of *H. perforatum* in Australia are on non-arable land, experiments should be conducted to establish the effectiveness of the herbicide from aerial application. As the herbicide is reported to have only minor effects on trees (personal communication Dow-Elanco Pty. Ltd.) it is probable that it could be registered for aerial application.

In this experiment, glyphosate proved less effective in killing *H. perforatum* and promoting native perennial grasses than fluoroxypyr and triclopyr + picloram. However glyphosate has application, with or without prior aerial spraying with fluoroxypyr, for providing high percentage kills of *H. perforatum* and all associated species before aerially sowing introduced species in late autumn (Arnott and Campbell 1994, Campbell and Watson 1994, Campbell and Nicol 1997).

Control of heavy infestations of *H. perforatum* in large paddocks in hill country without herbicides to provide the initial kill has been attempted using a number of grazing techniques (Campbell *et al.* 1995) but the only successful method, the combination of goats and cattle (Arnott and Campbell 1994), requires good fences, aerially applied superphosphate and subterranean clover seed and astute management.

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