Improving herbicide effectiveness on *Hypericum perforatum* L. (St. John's wort) and replacing it with pastures sown on non-arable land

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Summary

Experiments at Orange and Gallymont, New South Wales, examined the effects on *Hypericum perforatum* (St. John's wort) of: rate and type of herbicide; time of spraying; overspraying at annual intervals; rate of water carrier; and spraying and oversowing of improved pasture species. The only herbicide treatment that completely killed *H. perforatum* was two applications of fluoroxypyr at annual intervals; 0.4 kg a.i. ha^{-1} in summer 1993 followed by 0.6 kg a.i. ha^{-1} in summer 1994. Other herbicides that substantially reduced the ground cover of *H. perforatum* were triclopyr + picloram, glyphosate, and glyphosate + metsulfuron. Fluoroxypyr had no effect on the regeneration of annual legumes and did not damage grasses, whereas triclopyr + picloram killed legumes and glyphosate killed grasses. Monthly application of three herbicides between October and February yielded different results at two different locations and the effect of rate of water carrier had little effect on herbicide efficiency. Spraying *H. perforatum* and sowing improved species appeared to be the best treatment for long-term control of the weed because improved pasture species established and replaced the weed.

Introduction

Experiments in 1976 of Campbell *et al.* (1979) showed that picloram + 2,4-D (Tordon 50-D®) was the most effective herbicide combination for spot spraying of *Hypericum perforatum* (St. John's wort). In 1988 at Orange, New South Wales, triclopyr + picloram proved even more effective (Campbell *et al.* 1991). The latter finding was verified by Watson and Love (1993) at Cassilis, New South Wales, although their optimum rate was 4.5 + 1.5 kg a.i. ha^{-1} compared to the 0.6 + 0.2 kg a.i. ha^{-1} suggested by Campbell *et al.* (1991). The difference between the two results is attributed to the rocky shallow soil at Cassilis causing *H. perforatum* to sucker (Clark 1953) after spraying and being more difficult to kill than the *H. perforatum* growing on deep soil near Orange.

The best method for controlling large areas of *H. perforatum* on non-arable land has been a single aerial application of glyphosate in autumn followed by sowing of seed of pasture species and fertilizer application (Campbell *et al.* 1979, Arnott and Campbell 1994, Campbell and Watson 1994). Later findings showed that two applications of glyphosate (spring and autumn) may be more effective than a single application in killing *H. perforatum* and facilitating pasture establishment (Watson and Campbell 1994).

Experiments were set down to investigate ways of improving the efficiency of herbicides in killing *H. perforatum* and to test methods of using the spray-sow technique for controlling the weed on non-arable land.

Materials and methods

Herbicides used in these experiments were tricolopyr + picloram 30% + 10% a.i. (Grazon DS®), fluoroxypyr 20% a.i. (Starane®), glyphosate 45% a.i. (Roundup CT®), glyphosate + metsulfuron 83.5% + 1% a.i. (Trounce®) and 2,4-D amine + metsulfuron (2,4-D + Ally®) 50% + 60% a.i. There was no rain recorded for at least 24 hours after spraying of each experiment. Except for the rate of water carrier experiment, herbicides were applied in 625 L ha^{-1} of water with 0.5 L ha^{-1} of a non-ionic surfactant, from a hand-held pneumatic sprayer. Plot size was 4 × 5 m, and each experiment had four or five replications.

The experiments were conducted at Orange (900 m altitude) where *H. perforatum* was growing on deep fertile soil amongst a degraded *Trifolium subterraneum* pasture that had phosphatic fertilizers applied for 10 years. At Gallymont (740 m) the infertile soil was shallow, stony and unfertilized and the pasture was dominated by native perennial grasses, mainly *Themeda triandra*. The *H. perforatum* at both sites was the broad-leafed variety (Campbell *et al.* 1992).

Experiment 1. Type and rate of herbicide

Five herbicides were applied at three rates (see Table 1) to *H. perforatum* at Gallymont on 30 December 1994 and results recorded on 13 December 1995. The *H. perforatum* had two growth forms, one 40 cm high with 95% of flowers out and a second 8 cm high with no flowers and partly protected from the herbicides by grass. Growth was retarded by dry conditions early in December but had responded moderately to 30 mm of rain five days before spraying.

Experiment 2. Time of spraying

Triclopyr + picloram, fluoroxypyr and glyphosate were applied to *H. perforatum* at, respectively, 0.9 + 0.3, 0.6 and 1.4 kg a.i. ha^{-1} at Orange and Gallymont in October, November, December 1994 and January and February 1995 (middle of each month) and results recorded in December 1995. At Orange *H. perforatum* was growing vigorously at each spraying, whilst at Gallymont, it was in competition with native grasses and shaded by trees 50 m north of the site; stage of growth at spraying is given in Table 2. Additional treatments (see Table 4) were applied at Gallymont (only one plot per treatment) to test the effects of very high rates of the herbicides applied in Experiment 2.

Experiment 3. Rate of water carrier

Triclopyr + picloram and fluoroxypyr were each applied at two rates, the former at 0.45 + 0.15 and 0.9 + 0.3 and the latter at 0.3 and 0.6 kg a.i. ha^{-1}, to *H. perforatum* in 100, 300, 1000 and 3000 L ha^{-1} of water. Two replications were sprayed at Orange on 25 January 1995 and three at Gallymont on 26 January 1995. The *H. perforatum* at Orange was growing well after recent rain and flowering had almost finished. The *H. perforatum* at Gallymont was slightly moisture-stressed, had almost finished flowering (85% green capsule stage) and had a secondary growth of tillers 5–15 cm high.

Experiment 4. Overspraying

First spraying Four rates of each of triclopyr + picloram and fluoroxypyr (see Table 6) were applied on 16 December 1993 and 14 January 1994 to *H. perforatum* near Orange that had been slashed in September and on two previous occasions in 1993. At spraying in December *H. perforatum* was 35 cm high, growing actively with 20% in flower. At spraying in January it was 65 cm high and 90% of plants had flowered; 75% had bright yellow flowers and 15% brown mature flowers. Although conditions had been hot and dry before spraying, plants did not appear moisture stressed. *Trifolium subterraneum* was dormant at spraying but regenerated from seed in February 1994. Results were recorded in March 1994 and December 1995.

Overspraying On 22 December 1994, two replications were oversprayed and two replications left unsprayed. Treatments that had been sprayed with triclopyr + picloram were oversprayed with that herbicide mixture at 0.9 + 0.3 kg a.i. ha^{-1} and those sprayed with fluoroxypyr were oversprayed with it at 0.6 kg a.i. ha^{-1}. The *H. perforatum* was 80% in flower, 60 cm high and slightly affected by dry conditions. Results were recorded on 6 December 1995.

Table 1. Effect of type and rate of herbicide applied to *H. perforatum* at Gallymont on 30 December 1994 and results recorded on 13 December 1995.

Herbicide and rate (kg a.i. ha^{-1})	Reduction in ground cover expressed as a percentage of that present at spraying
Triclopyr + picloram	
0.9 + 0.3	77 bcd[A]
1.35 + 0.45	92 ab
1.8 + 0.6	85 ab
Fluoroxypyr	
0.6	82 abc
0.9	80 abc
1.2	80 abc
Glyphosate	
1.35	87 ab
2.02	89 ab
2.70	94 a
Glyphosate + metsulfuron	
1.4 + 17 g	76 bcd
2.0 + 24 g	87 ab
2.7 + 32 g	96 a
2,4-D amine + metsulfuron	
0.1 + 9 g	12 e
0.7 + 9 g	68 cd
1.6 + 9 g	62 d

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

Table 2. Stage of growth of *H. perforatum* at spraying at two sites in New South Wales (Experiment 2).

Time of spraying	Orange			Gallymont		
	Height (cm)	Flowers out (%)	Dry matter (t ha^{-1})	Height (cm)	Flowers out (%)	Dry matter (t ha^{-1})
October 1994	4	0	0.9	10	0	–
November 1994	20	0	2.0	20	0	–
December 1994	55	10	4.1	40	80	–
January 1995	65	80	5.6	45	95	–
February 1995	65	90	6.2	50	99	2.3

Table 3. Effect of time of application of three herbicides on *H. perforatum* (ground cover in December 1995 expressed as a percentage of ground cover at spraying) at two sites in New South Wales.

Herbicide and rate (kg a.i. ha^{-1})	Time of application	Reduction in ground cover in December 1995 (%)	
		Orange	Gallymont
Triclopyr + picloram (0.9 + 0.3)	October 1994	90 abc[A]	88 abcd
	November 1994	84 abc	99 a
	December 1994	73 bcd	92 abcd
	January 1995	72 cd	96 ab
	February 1995	92 ab	57 e
Fluoroxypyr (0.6)	October 1994	72 cd	76 cd
	November 1994	80 abc	96 ab
	December 1994	98 a	92 abcd
	January 1995	83 abc	96 ab
	February 1995	78 bc	36 f
Glyphosate (1.4)	October 1994	83 abc	80 bcd
	November 1994	52 e	94 abc
	December 1994	44 e	74 de
	January 1995	56 de	97 ab
	February 1995	73 bcd	98 ab

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

Experiment 5. Spray-sow

Triclopyr + picloram, fluoroxypyr and glyphosate were applied at different rates, combinations and timings (see Table 7) to assess the effect of controlling *H. perforatum* and other weeds on the establishment of pasture species surface-sown on 2 June 1995. The respective sowing rate of *T. subterraneum*, *Phalaris aquatica* and *Dactylis glomerata* was 4, 4 and 1 kg ha^{-1} and the rate of molybdenised superphosphate applied was 200 kg ha^{-1}. At spraying on 13 December 1994 *H. perforatum* was 50% in flower and growing vigorously. At spraying on 30 May 1995 *H. perforatum* and pasture species were grazed to a height of 5 cm to allow weed seeds to germinate prior to spraying. Ground cover of established pasture species was recorded on 25 October 1995 and ground cover of *H. perforatum* on 4 April 1996.

Results

The initial effect of triclopyr + picloram and fluoroxypyr was to brown foliage, 90% in 30 days and 100% in 40 days; glyphosate was generally slightly slower. Regrowth occurred from crowns or suckers and, in ineffective treatments, started 30 days after spraying but in the more effective treatments six months after spraying. Ineffective glyphosate treatments often had typical 'small leaf' glyphotic regrowth on the flowering stems. All regrowth that occurred was checked to ensure it was not seedling regeneration.

Experiment 1. Type and rate of herbicide

Meaned for the three rates, all herbicides except 2,4-D + metsulfuron, were equally effective. No herbicide completely killed *H. perforatum*, there being a difference (P<0.05) in effect between the highest and lowest rate for only two herbicides (Table 2). The highest rate of glyphosate and glyphosate + metsulfuron reduced ground cover of native perennial grasses to 3% compared to 49, 61 and 48% on the highest rates of triclopyr + picloram, fluoroxypyr and the control respectively.

Experiment 2. Time of spraying

No distinct pattern emerged for the effect of time of application on the effectiveness of the three herbicides (Table 3). Meaned for time of application the effects of triclopyr + picloram and fluoroxypyr were not significantly different (P<0.05) at the two sites but glyphosate was less effective (P<0.05) at Orange than at Gallymont. The poor results from application of triclopyr + picloram and fluoroxypyr in February at Gallymont was attributed to dry conditions (5 mm of rain in February). Under these conditions it is surprising that glyphosate was so effective (Table 3). It is also surprising that glyphospate was less effective at Orange than at Gallymont in November, December and January

Table 4. Effect of high rates of herbicides applied at Gallymont, New South Wales, on *H. perforatum*.

Time of spraying	Herbicide	Rate (kg a.i. ha^{-1})	% ground cover reduction on 4 April 1996
20 December 1994	Triclopyr + picloram	4.5 + 1.5	99
13 January 1995	Triclopyr + picloram	4.5 + 1.5	94
		2.25 + 0.75	97
	Fluoroxypyr	3.0	97
		1.5	96
17 February 1995	Triclopyr + picloram	1.8 + 0.6	89
	Fluoroxypyr	1.2	80
	Glyphosate	2.7	87

Table 5. Effect of rate of water carrier (meaned for the two sites and for high and low rates of triclopyr + picloram and fluoroxypyr) in reducing ground cover (%) of *H. perforatum*.

Rate of herbicides	Rate of water carrier (L ha^{-1})			
	100	300	1000	3000
Low	64 b[A]	81 a	79 a	66 b
High	85 a	81 a	88 a	85 a

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

Table 6. Effect of herbicides on *H. perforatum* and *T. subterraneum* meaned for the December 1993 and January 1994 sprayings (measured on 28 March 1994) and effect of overspraying *H. perforatum* measured on 6 December 1994.

Herbicide and rate (kg a.i. ha^{-1})	Ground cover (%) *H. perforatum* March 1994	*H. perforatum* December 1995 Not oversprayed	*H. perforatum* December 1995 Oversprayed	*T. subterraneum* March 1994
Fluoroxypyr				
0.2	10 bc[A]	38 cd	2 a	29 a
0.4	2 a	18 b	0 a	24 a
0.6	1 a	17 b	0 a	34 a
0.8	1 a	6 a	0 a	32 a
Triclopyr + picloram				
0.3 + 0.1	18 d	55 e	23 c	5 b
0.6 + 0.2	14 cd	46 de	10 b	5 b
0.9 + 0.3	7 b	30 c	7 b	4 b
1.2 + 0.4	1 a	15 ab	2 a	5 b
Control	63 e	55 e	70 d	5 b

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

because conditions for the growth of *H. perforatum* were better at Orange than at Gallymont. Thus, given that herbicides are applied only when *H. perforatum* is growing vigorously in moist soil, triclopyr + picloram could be applied from October to February and fluoroxypyr from November to January. Results from application of glyphosate during that period would be less reliable and may show greater variation between sites than the other two herbicides.

A side effect of glyphosate was to reduce the ground cover of native perennial grasses, there being, respectively, 72, 70 and 30% on triclopyr + picloram, fluoroxypyr and glyphosate treatments (meaned for the five times of spraying) in December 1996.

High rates of the three herbicides failed to completely kill *H. perforatum* (Table 4).

Experiment 3. Rate of water carrier

Rate of water carrier had no effect on herbicides applied at the high rate but, at the low rate, 300 and 1000 L ha^{-1} were more effective than 100 and 3000 L ha^{-1} (Table 5). There was no difference between triclopyr + picloram and fluoroxypyr but the herbicides were more effective (P<0.05) at Orange (a mean 91% reduction) than at Gallymont (a mean of 70% reduction) in terms of ground cover of *H. perforatum*.

Experiment 4. Overspraying

Results of single applications made in December 1993 and January 1994 showed fluoroxypyr to be superior to triclopyr + picloram in killing *H. perforatum* (Table 6). Overspraying with fluoroxypyr in December 1994 resulted in complete kills of *H. perforatum* which did not occur with oversprayed triclopyr + picloram (Table 6).

Fluoroxypyr applied in December 1993 and January 1994, had little or no residual effect on *T. subterraneum* that germinated in February 1994 whereas triclopyr + picloram had severe effects (Table 6). The low ground cover of *T. subterraneum* on

Table 7. Effect of herbicides applied prior to surface-sowing pasture species on 2 June 1995 on establishment of pasture species, regeneration of annual legumes and recovery of *H. perforatum* (per cent ground cover of each).

Herbicide	Rates (kg a.i. ha^{-1}) and combinations of herbicides applied: Dec 94	May 95	Ground cover (%) *T. subterraneum*	Sown grasses	Annual legumes	*H. perforatum*
Glyphosate (G)	G 1.4+	G 0.9	18 ac	15 b	7 cd	3 c
	G 1.4	–	8	0	55	2
	–	G 0.9	18	18	7	10
Triclopyr + picloram (T)	T 0.9+0.3+	G0.9	8	13	3	10
	T 0.9+0.3	–	7	0	12	6
	–	T 0.9+0.3+G 0.9	0	31	0	10
Fluoroxypyr (F)	F 0.6+	G 0.9	19	15	3	2
	F 0.6	–	13	0	48	10
	–	F 0.6+G 0.9	14	16	3	11
Control	–	–	19	0	32	31

the control was due to competition from unsprayed *H. perforatum*.

Experiment 5. Spray-sow

Application of Glyphosate assisted pasture species to establish but the results did not prove whether two applications (December and May) were better than the one (in May) (Table 7). The May application was essential to remove annuals and other plants that could compete with sown species. Two applications gave better control of *H. perforatum* than one application in May which could assist long-term control. Mixtures of fluoroxypyr and glyphosate gave good pasture establishment but the use of triclopyr + picloram with or without glyphosate depressed the contribution of legumes. Triclopyr + picloram-glyphosate mixtures applied in May gave the highest establishment ($P<0.05$) of sown grasses because all legumes were eliminated.

Herbicide treatments that included a May spraying had large regenerations of *H. perforatum* seedlings. Treatments that had no herbicide applied in May (except triclopyr + picloram) were dominated by annual legumes which grew to 30 cm high and provided intense competition for *H. perforatum*.

Discussion

The only treatment that gave a complete kill of *H. perforatum* in these experiments was the one involving two applications of fluoroxypyr, the first in summer 1993/94 at 0.4, 0.6 or 0.8 kg a.i. ha^{-1} and the second in December 1994 at 0.6 kg a.i. ha^{-1}. The next step should be to ascertain whether this treatment can be successful in other years and in other environments. Two applications have practical disadvantages, especially in hill country, but it would reduce the amount of herbicide applied from the recommended 4.5+1.5 kg a.i. ha^{-1} of triclopyr + picloram ($525 per ha) to 0.4 + 0.6 kg a.i. ha^{-1} fluoroxypyr ($130 per ha). Respraying may be necessary even when triclopyr + picloram is applied at 4.5+1.5 kg a.i. ha^{-1} because this rate failed to completely kill *H. perforatum* at Gallymont in summer 1994/95.

Another advantage of fluoroxypyr is that it does not damage grasses, and annual legumes can regenerate unharmed in autumn after a summer spraying. *Trifolium subterraneum* and naturalized annual legumes (*T. glomeratum, T. arvense, T. campestre, T. dubium*) regenerated in these experiments and those of Watson and Campbell (1994) after the use of up to 0.8 kg a.i. ha^{-1} of fluoroxypyr. This means that fluoroxypyr could be applied in summer either in one application (0.4–0.8 kg a.i. ha^{-1}) or in two applications 12 months apart (0.4 + 0.6 kg a.i. ha^{-1}) to a *T. subterraneum*–native grass–*H. perforatum* pasture, and with 'astute grazing management' control could be achieved without damaging the useful species. This is not possible with triclopyr + picloram as legumes are killed, nor with glyphosate as native grasses are killed.

The new product glyphosate + metsulfuron (Trounce®), promoted for the control of *H. perforatum,* proved no more effective than triclopyr + picloram, fluoroxypyr or glyphosate when applied at Gallymont in December 1994.

Low (100 L ha^{-1}) and high (3000 L ha^{-1}) rates of water carrier depressed the effects of herbicides applied at low rates, the former due to insufficient coverage of the weed and the latter due to run-off. A rate of 3000 L ha^{-1} is recommended (Campbell and Watson 1994) for spot spraying but this is to ensure spray coverage of very dense infestations. Where *H. perforatum* is of moderate to light density rates of 300–1000 L ha^{-1} would give optimum coverage.

Applying herbicides at monthly intervals between October and February, the optimum period for spraying (Campbell *et al.* 1979), gave different results at two locations 80 km apart. Variation in results could be due to the environmental conditions influencing growth rather than to the stage of growth of *H. perforatum*. For example, dry conditions (26 mm in February 1994) reduced the effect of triclopyr + picloram and fluoroxypyr at Gallymont but, when applied at Orange at the same time, the herbicides were relatively effective because of 126 mm rain falling there in February 1994. Variation in results between sites could also be due to different strains, the Cassilis narrow-leafed strain requiring higher rates of herbicides to kill it than the Orange or Gallymont broad-leafed strains. Alternatively, the variation could be due to the environment at Cassilis limiting the effect of herbicides more than the Orange or Gallymont environments.

The most permanent control of *H. perforatum* on non-arable land has been obtained by an autumn aerial application of glyphosate followed by aerial sowing of improved pasture species (Arnott and Campbell 1994, Watson and Campbell 1994). Two applications of glyphosate (summer and autumn) will restrict regrowth of *H. perforatum* more than one application (autumn) but the two applications may not be necessary given that pasture establishment was similar from both and that grazing management could eliminate the *H. perforatum* regrowth. The aerial spray-sow technique has not been widely used, possibly due to high cost, non-applicability on infertile soils and the risks involved.

Because of the difficulties in controlling *H. perforatum* with herbicides it is imperative that every effort be made to promote successful biological control and/or effective grazing management procedures (Campbell *et al.* 1979, Arnott and Campbell 1994).

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References

Arnott, R. and Campbell, M.H. (1994). Control of St. John's wort on large paddocks in hill country by the aerial spray-sow technique and by grazing management. Proceedings 9th Conference Grassland Society NSW, Queanbeyan, pp. 98-9.

Campbell, M.H., Dellow, J.J. and Gilmour, A.R. (1979). Effect of time of application of herbicides on long-term control of St. John's wort (*Hypericum perforatum*). *Australian Journal of Experimental Agriculture* 19, 746-8.

Campbell, M.H., May, C.E., Southwell, I.A., Tomlinson, J.D. and Michael, P.W. (1992). Variation and varietal determination in *Hypericum perforatum* (St. John's wort) in NSW. *Plant Protection Quarterly* 7, 43-5.

Campbell, M.H., Milne, B.R., Dellow, J.J. and Nicol, H.I. (1991). Effect of herbicides on St. John's wort. *Australian Journal of Experimental Agriculture* 31, 499-501.

Campbell, M.H. and Watson, R.W. (1994). St. John's wort. NSW Agriculture Agfact P7.6.1 pp. 11.

Clark, N. (1953). The biology of *Hypericum perforatum* in the Ovens Valley, Victoria, with particular reference to entomological control. *Australian Journal of Botany* 1, 95-120.

Watson, R.W. and Campbell, M.H. (1994). New herbicides for the control of St. John's wort. Proceedings 9th Conference Grassland Society NSW, Queanbeyan, pp. 99-101.

Watson, R.W. and Love, C.O. (1993). The evaluation of herbicides and application techniques for the control of St. John's wort in NSW. Proceedings 10th Australian and 14th Asian Pacific Weeds Conference, Brisbane, pp. 186-9.