EVALUATION OF GLYPHOSATE TO CONTROL REGROWTH OF *EUCALYPTUS* SPP. IN PINE PLANTATIONS IN WESTERN AUSTRALIA

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Summary. This paper describes field experiments to evaluate glyphosate[2] for the control of *Eucalyptus* spp. regrowth in West Australian pine plantations. Applications by the stem injection, foliar spray and cut-stump methods were used.

Foliar spraying with a concentration of 2.3 per cent glyphosate proved to be the most efficient method of regrowth control. All newly established plantations will have eucalypt regrowth controlled by this method.

Effective control of regrowth was also achieved using an 18 per cent concentration of glyphosate applied by stem injection or by cut-stump application of a 1.7 per cent concentration of glyphosate. These methods will have application in pine plantings where regrowth is advanced and when thinning hardwood forests.

INTRODUCTION

From 1966 to 1983, eucalypt regrowth in Western Australia's pine plantations was controlled using chemicals containing 2,4,5-trichlorophenoxyacetic acid (2,4,5-T). Initially the practice was to allow the regrowth to develop before applying a basal bark spray of 2,4,5,-T in diesel. Though effective, this method was costly and slow, and was not favoured from the viewpoint of operator safety and comfort. In addition, regrowth was competing with pines for up to four years before being controlled.

A low volume spray technique using misters was developed (McKinnell and Butcher, 1973). It had the potential for suppressing regrowth before pines were established, but this technique was discontinued after unsatisfactory field trials.

Stem injection and cut-stump methods using mixtures of 2,4,5-T and picloram[1] were subsequently employed to control eucalypt regrowth. However, like the earlier basal bark spraying method, these were costly and slow, and could not be implemented early enough to eradicate competition without delaying pine planting.

The debate surrounding the safe use of 2,4,5-T and the decision by manufacturers to cease production prompted the Western Australian Forests Department's examination of alternative chemicals and methods.

Foot Note: 1 Tordon 105. - Trademark of Dow (Australia) Ltd.
2 Roundup - Trademark of Monsanto (Australia) Ltd.

This paper describes three field experiments used to evaluate glyphosate for control of eucalypt regrowth in pine plantations. The first experiment was to determine the optimum concentration of glyphosate (in water) needed to control regrowth by the stem injection method. This trial was necessary because there is a backlog of plantations where regrowth control has not been carried out. The second experiment was to determine the optimum concentration of glyphosate (in water) required to kill eucalypt regrowth by foliar spraying soon after the planting of pines. The third experiment was to determine the optimum concentration of glyphosate (in water) needed to kill eucalypt regrowth by the cut-stump method.

MATERIALS AND METHODS

STEM INJECTION. This study was undertaken in Jarrahwood plantation in the Donnybrook Sunkland, about 30 km south east of Busselton. Planted with radiata pine (*Pinus radiata* D. Don) in 1978, the site carried a dense population (700 - 1500 stools ha^{-1}) of jarrah (*Eucalyptus marginata* R. Br.) and marri (*E. calophylla* Sm.) regrowth with a height range of 1.5 to 3.5 m. Stem diameters ranged from 20 mm to 100 mm. Marri accounted for about 91 per cent of all regrowth.

In January 1982 five treatments were applied to twenty 24 m by 9 m plots arranged in a randomized block.Four seperate treatments used concentrations of 18.0,13.1,8.0,and 3.3 per cent of glyphosate in water.The fifth treatment,using 10.0 per cent 2,4,5-T + picloram (in water),was the routine prescription for the control of eucalypt regrowth(by the stem injection method)used in Western Australian pine plantations from 1976 to 1983. Plots were ranked according to the number of regrowth stools (ranged from 15 to 33),and the ranked list was then devided into four blocks. Treatments were randomly allocated within the blocks.

In these trials, the season in which treatments were applied was based on earlier pilot studies and on conclusions reached by McKinnell and Butcher (1973).

Injection of the stems was carried out using a vaccinator and small axe with a blade width of 25 mm. The vaccinator was calibrated to deliver 2 ml of mixture per dose, and axe notches were placed on the stems at a convenient height for the operator (between 0.4 m and 0.8 m from ground level). The dose frequency was determined by cutting a notch for every 25 mm of stem diameter, spacing the notches evenly round the stem.

The trial was assessed at 4, 26 and 48 weeks after treatment. The results were recorded for each of six efficacy categories:

0 - above ground material initially killed, recoppicing at ground level occurring

1 - no effect of herbicide

2 - slight effect, complete recovery likely (<25% defoliation)

3 - moderate effect, recovery probable (26 - 75% defoliation)

4 - severe effect, recovery unlikely (>75% defoliation)

5 - dead

FOLIAR SPRAY. This experiment was located in Baudin plantation in the Donnybrook Sunkland, about 20 km south of Busselton. The native eucalypt forest was cleared and windrowed in summer 1981, burned, ploughed and mounded in autumn 1982, and planted with loblolly pine (*P. taeda* L). in winter of 1982.

In December 1982, when treatments were applied, the height of the eucalypt regrowth ranged from 0.1 m to 1.0 m. The main species were marri and jarrah, while bullich (*E. megacarpa* F.v.M.) was present to a lesser extent and was not represented in every plot. The site selected for the trial represented an average regrowth population (200 to 500 stools).

Plots were established with a minimum of 20 regrowth stools in each plot. Plots were completely randomized and each treatment replicated four times. Treatments were 6.0, 3.3, 1.7, 0.9, 0.4, 0.2 and 0 (control) per cent of glyphosate in water. Solutions were applied using a vaccinator fitted with a "Rega NZ 6" variable nozzle. The vaccinator was calibrated to deliver 5 ml of mixture and doses were repeated to each stool until complete coverage of the foliage was achieved. No surfactant was added to the mixtures. In instances where regrowth was greater than 0.8 m in height the stem was cut off and a dose administered to the stump. The volume of mixture applied to each stool ranged from 2 ml to 56 ml, at an average of 7 ml.

Efficacy of treatment was assessed 6, 32 and 50 weeks after spraying, and was expressed as a percentage, using the same categories as those in the stem injection trial.

CUT-STUMP. This trial was located in an area of Baudin plantation cleared of native eucalypt forest in summer 1980. Burning and ploughing were completed in autumn 1980 and the site was planted with maritime pine (*P. pinaster* Ait.) in the winter of the same year. In February 1983, at the time of glyphosate treatment, the site carried a dense population (>500 stools ha^{-1}) of marri and jarrah with a height range of 1.0 m to 4.5 m. Stem diameters ranged from 10 mm to 450 mm. Marri comprised 71 per cent of the eucalypt regrowth on the site.

Twenty-eight plots were established with a minimum of 20 regrowth stools in each. Plots were ranked according to the number of regrowth stools they contained, and the ranked list was divided into four equal sections. Seven treatments were randomly allocated in each section. Treatments were 14.4, 7.2, 2.8, 1.4, 0.7, 0.4 and 0 (Control) per cent concentration of glyphosate in water.

Regrowth was felled at a height of 50 mm to 100 mm from the ground, using a "Stihl 020" chainsaw. The herbicide treatments were applied to the surface of the stumps within one minute of felling. All treatments were applied with a vaccinator, fitted with a "Rega NZ 6" variable nozzle calibrated to deliver 2 ml per dose. One dose was applied for every 25 mm of stump diameter. Ciba Geigy red herbicide dye was added to each mixture to avoid the risk of stumps being treated twice or being missed. The species of eucalypt and the volume of solution applied to each stool was recorded. The volume of mixtures applied to each stool ranged from 2 ml to 92 ml, at an average volume of 12 ml. The control plots were felled but no herbicide was applied to the stumps.

The percentages of regrowth stools falling into six efficacy categories were recorded 5, 26 and 41 weeks after treatment. These categories were:

0 - recoppicing, healthy

1 - recoppicing, slight residual effect, complete recovery likely

2 - recoppicing, moderate residual effect, recovery possible

3 - recoppicing, severe residual effect, recovery unlikely

4 - recoppicing, dead

5 - dead, no recoppicing

STATISTICAL ANALYSIS. For each trial the plot percentages in each efficacy category were transformed using the formula $y = \text{arcsine}\sqrt{\%}$ before an analysis of variance. Differences between means were tested for significance by Duncan's multiple range test procedure. Jarrah was excluded from the analysis in the stem injection trial because it was not represented on all plots. Similarly, species in the cut-stump trial were not analysed separately because jarrah was not present on all plots and numbers were low on others. Regression analysis of glyphosate data was done, relating efficacy to concentration for each trial.

RESULTS

STEM INJECTION. Acceptable control of eucalypt regrowth was apparent 26 weeks after treatment with glyphosate, at concentrations of 8.0 per cent and above. The 2,4,5-T plus picloram treatment was also satisfactory. However, after 48 weeks recoppicing had occurred with a greater incidence at low concentrations of glyphosate (Table 1). The highest concentration of glyphosate (18.0 per cent) and 2,4,5-T plus picloram were responsible for significantly ($p<.05$) higher mortality (77 per cent and 88 per cent respectively) than other treatments. When efficacy classes 4 and 5 were combined and analysed, the lowest concentrations of glyphosate (3.3 per cent) was significantly ($p<.01$) less effective than other treatments.

Regression analysis showed that there was a significant ($p<.01$) positive relationship between the concentration of glyphosate and its efficacy (Figure 1). Also there was a significant ($p<.01$) negative correlation between the percentage of stools that recoppiced and the concentration of glyphosate.

FOLIAR SPRAY. After six weeks, there was little change in the percentage of dead stools that were treated with concentrations of glyphosate above 1.7 per cent. After 32 weeks there was an apparent increase in mortality for treatments sprayed with concentrations below 1.7 per cent. However, the majority of recoppicing occurred between 32 and 50 weeks post treatment, resulting in a decrease in the percentage of stools recorded as dead 50 weeks after treatment. The 50 week data are given in Table 2. A t - test of the mortality at the 50 week assessment revealed no significant differences between jarrah and marri.

Table 1. Effect of different concentrations of glyphosate and 2,4,5-T + picloram, using stem injection, on eucalypt regrowth (48 weeks after treatment).

Herbicide	Concentration of Herbicide in water (%)	Proportion of regrowth stools in each category (%)					
		recopp-iced	defoliation				dead
		0	Nil 1	25% 2	26-75% 3	75% 4	5
Glyphosate	18.0	6	0	4	0	13	77
Glyphosate	13.1	12	0	4	9	15	60
Glyphosate	8.0	15	0	8	10	15	52
Glyphosate	3.3	32	0	14	22	14	19
2,4,5-T + picloram	10.0	6	0	4	2	0	88

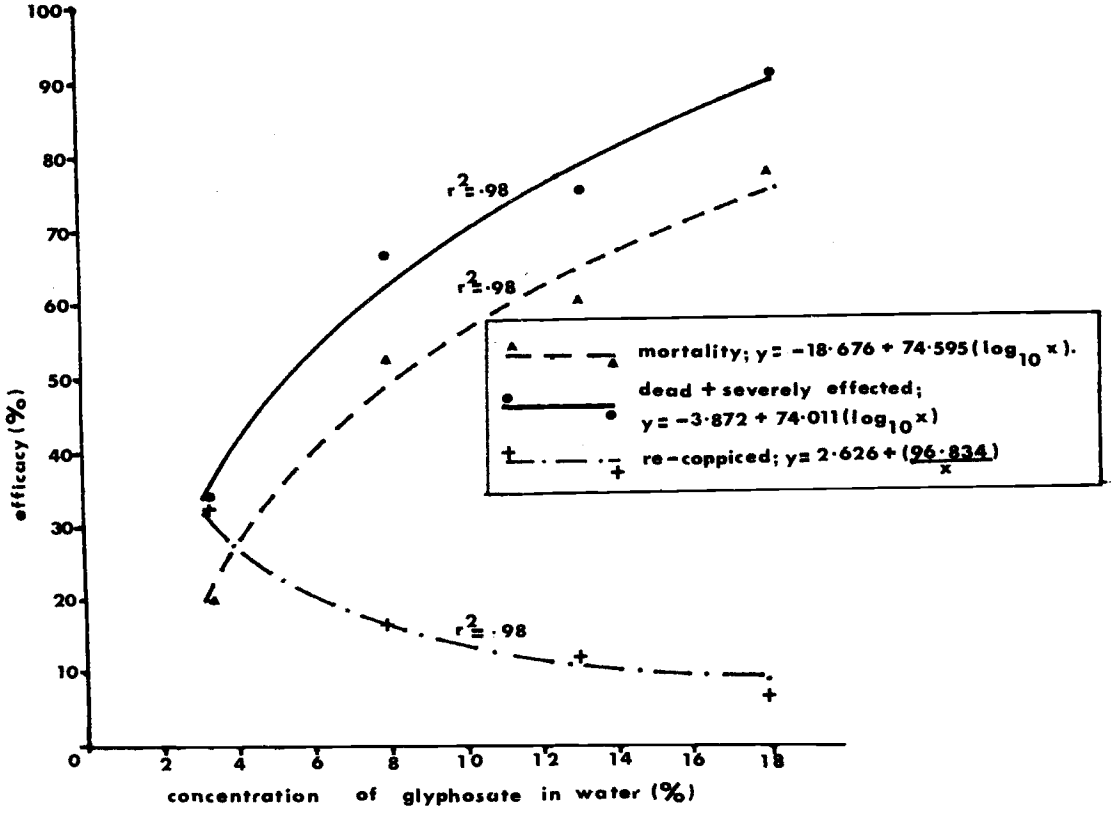

Figure 1.

Regression analysis of the efficacy, 48 weeks after different concentrations of glyphosate were applied by stem injection to eucalypt regrowth.

Table 2. Effect of different concentrations of glyphosate, using foliar spraying on jarrah (J)+, marri (M), and bullich (B) regrowth (50 weeks after treatment). Nil* category includes regrowth missed being sprayed and subsequent emergents.

Concentration of glyphosate in water (%)	Proportion of regrowth stools in each category (%)																	
	re-coppicing						defoliation									dead		
		0			Nil* 1			<25% 2			25-75% 3			>75% 4			5	
	J+	M	B	J	M	B	J	M	B	J	M	B	J	M	B	J	M	B
6.0	0	0	0	8	9	20	2	0	0	0	0	0	0	0	0	98	100	100
3.3	0	3	0	12	15	15	2	0	0	0	0	0	0	0	0	98	97	100
1.7	0	2	0	9	12	25	3	1	0	0	1	0	0	0	0	93	96	100
0.9	6	2	0	8	7	0	7	13	0	7	4	0	4	0	0	76	81	100
0.4	7	17	0	7	7	11	11	18	50	13	10	0	3	1	0	66	54	50
0.2	25	16	0	14	8	50	26	30	0	17	17	0	2	1	0	30	36	100
0 (Control)	0	0	0	59	67	100	41	33	0	0	0	0	0	0	0	0	0	0

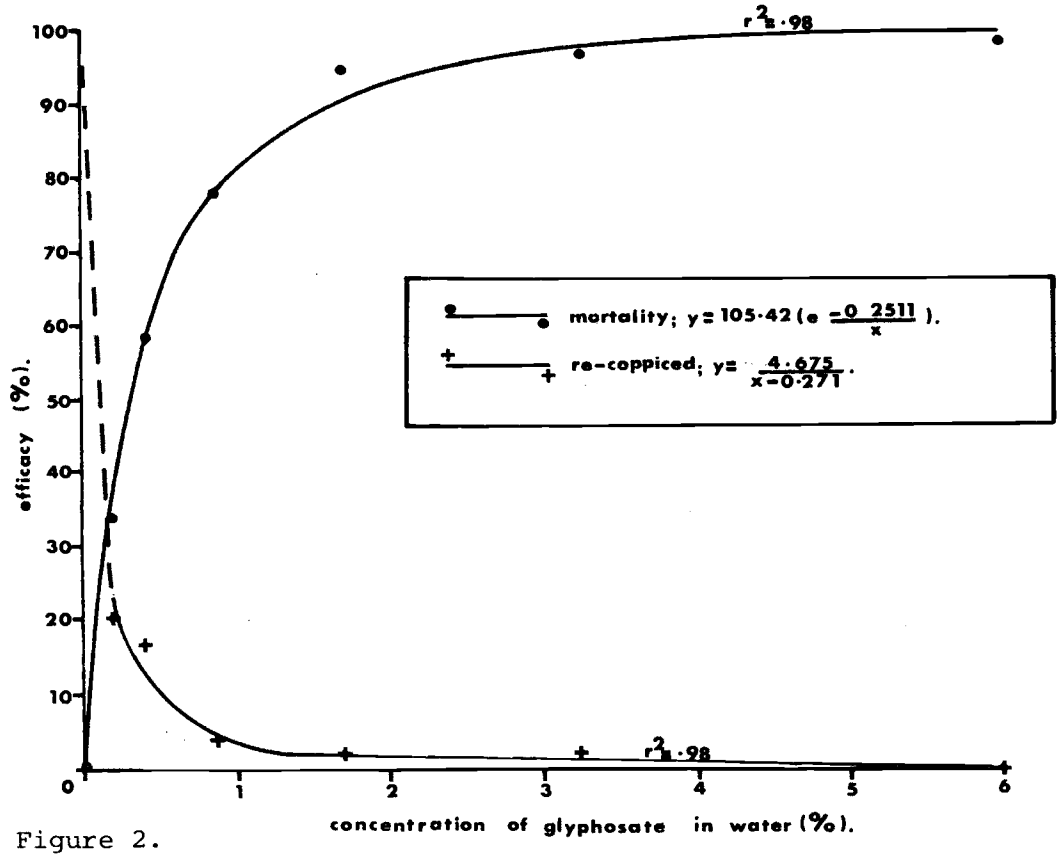

Figure 2.

Regression analysis of efficacy, 50 weeks after different concentrations of glyphosate were applied as a foliar spray to small regrowth of jarrah, marri and bullich.

Table 3. Effect of different concentrations of glyphosate, using the cut-stump method of application on eucalypt regrowth (41 weeks after treatment).

Concentration of glyphosate in water (%)	Proportion of regrowth stool in each category (%)					
	recoppiced following treatment					No recoppicing following treatment
	coppice healthy	coppice likely to recover	coppice may/maynot recover	coppice unlikely to recover	coppice dead	
	0	1	2	3	4	5
14.4	0	0	0	0	5	95
7.2	0	0	0	1	1	98
2.8	0	0	0	0	6	94
1.4	0	0	0	0	7	93
0.7	2	0	3	0	10	85
0.4	5	3	1	0	3	88
0 (Control)	31	10	3	1	17	38

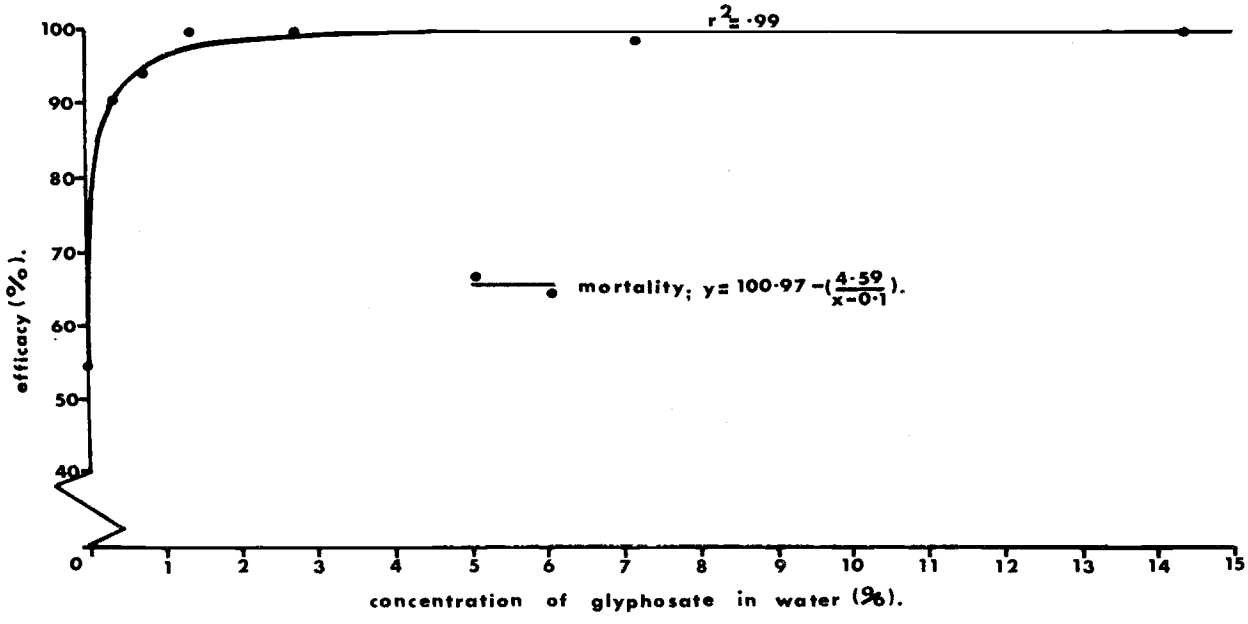

Figure 3.

Regression analysis of efficacy, 41 weeks after treatment with concentrations of glyphosate applied by the cut-stump method to eucalypt regrowth.

When efficacy categories of each species were combined and analysed by regression there was a significant ($p<.01$) positive correlation between the number of stools killed and the concentration of glyphosate (Figure 2). Also, there was a significant ($p<.01$) negative correlation between the concentration of glyphosate and the percentage of stools that recoppiced.

CUT-STUMP. No recovery was recorded for any treatment five weeks after treatment. After 26 weeks mortality of regrowth stools in herbicide treated plots ranged between 95 and 100 per cent, and was not significantly different between treatments. There was significantly ($p<.001$) less mortality on control plots, where 60 per cent of stools had recoppiced.

After 41 weeks mortality was 100 per cent for concentrations of 1.4 per cent and above (Table 3). This was significantly ($p<.05$) higher than the mortality at the lower concentrations.

Regression analysis showed a significant ($p<.01$) positive correlation between mortality of regrowth and concentration of glyphosate (Figure 3).

There was little difference between the susceptibility of jarrah and marri to glyphosate. For treatments where recovery was recorded (concentrations of 0.7 per cent and less) the proportion of jarrah (31 per cent) at the end of the trial remained similar to that at commencement (29 per cent).

DISCUSSION

Each method of controlling eucalypt regrowth described in this paper has a place in plantation management. The choice will depend on the circumstances because the intention of any control method is to eliminate regrowth in pine plantations before competition reduces pine growth. Stem injection is recommended only when the stem diameter of regrowth is over 100 mm. To ensure an acceptable level of control (>90 per cent when administering the dose at a height convenient for the operator, an 18 per cent (1 part Roundup to 1 part water) concentration is adequate. However, if 100 per cent mortality is required a higher concentration may be necessary. Notches should penetrate the cambium and be spaced evenly around the stem, once for every 25 mm of stem diameter. Injector bars are preferred to notching axes and vaccinators because they allow the operator to stand in an upright position when administering the dose to the base of the stem. Nonetheless, in pine plantations where multi-stemmed stools comprise a high proportion of the regrowth, both injector bars and notching axes are awkward and the likelihood of stems being missed is high. It is considered, based on observations from this trial, that the closer to the ground the treatment is administered the more effective it is.

Foliar spraying proved to be the most efficient technique tested. The greater number of jarrah stools that appeared to be slightly affected at higher concentrations is presumably a reflection of the number of large live stumps that remained after clearing. Similarly, the slightly higher level of recoppicing of marri, sprayed at high concentrations of glyphosate, was associated with large, comparatively undisturbed root systems.

Foliar spraying with a 2.3 per cent (1 part Roundup to 15 parts water) concentration will give acceptable mortality in all plantation situations, including those where coppice originating from jarrah stumps forms a high

proportion of the regrowth. Earlier pilot studies (Fremlin, unpublished) showed that complete coverage of foliage, especially that of coppice, was necessary if mortality was expected. This also applied to high concentrations (>6 per cent) of glyphosate. After the implementation of the technique in 1983, the 2.3 per cent spray cost between \$20 and \$100 ha^{-1}. Operators have shown a preference for pneumatic sprayers because of the fatigue associated with the pumping action of vaccinators. The average dose per stool is likely to increase using pneumatic sprayers, with a subsequently higher unit cost for the chemical, but this cost would be offset by improved coverage and reduced maintenance.

Radiata pine is the only pine species tested for tolerance to oversprays of glyphosate in Western Australia. Studies by Fremlin (unpublished) showed that late summer or autumn sprays should cause little damage at concentrations below 0.5 per cent. Spraying in spring is likely to cause more damage, so precautions should be taken to avoid any contact of spray with pines.

The cut-stump technique is suitable for controlling eucalypt regrowth taller than one metre, with a stem diameter less than 100 mm. A concentration of 1.7 per cent (1 part Roundup to 20 parts water) applied at the rate of 2 ml for every 25 mm of stem diameter will ensure certainty of control in all situations that are likely to occur. The high level of mortality (55 per cent) in the control treatment is unprecedented. Severe frosts in late winter/early spring were responsible for killing new coppice on some stools. In many cases there was no recovery. Even in a season without frost, however, it is unlikely that the efficacy of the recommended concentration of glyphosate will alter significantly from that recorded in this trial. It is probable that without frost the recovery of regrowth in the control treatment would have been greater.

The cut-stump technique using glyphosate was actually introduced into operations in 1983, before final results of this trial were available. A concentration of 3.3 per cent (1 part Roundup to 10 parts water) was used in all situations where the technique was applied, including the thinning of hardwood forests. The cost in pine plantations ranged between \$60 and \$200 ha^{-1}. Using a concentration of 1.7 per cent will reduce the cost by between \$5 and \$40 ha^{-1}.

All newly established plantations will have eucalypt regrowth controlled by the foliar spray method. The stem injection and cut-stump methods will have greater application for thinning in hardwood forests, although refinement of the technique to suit that purpose will be necessary.

ACKNOWLEDGEMENTS

We wish to thank that staff of the Busselton Research Station, of the Forests Department of Western Australia, for assistance in all aspects of this work. Monsanto (Australia) donated some of the Roundup used in the experiments. The constructive comments of Messrs. G. Siemon, T. Butcher and F. McKinnell were appreciated.

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