Spot-spraying of hexazinone and amitrole/atrazine in the establishment of first and second rotations of *Pinus radiata* in south-western Victoria

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Summary

This paper describes a field trial that evaluated the herbicide hexazinone (at 1, 3 and 6 kg ha^{-1}) and a mixture of amitrole (1 kg ha^{-1}) + atrazine (4 kg ha^{-1}) applied using a 'spot-gun' to control herbaceous weeds competing with recently planted *Pinus radiata* (radiata pine) in south-western Victoria. The trial also examined the effect of timing of herbicide application on pine growth response and weed control on both first-rotation (1R) and second-rotation (2R) sites.

The results 3 years after treatment showed that, on both sites, spot-spraying in September after a July planting gave greater growth response (volume index) than when spraying was delayed to December. On the 1R site, all herbicide treatments resulted in a significant growth response when sprayed in September, whereas December spraying produced no such response. On the 2R site, hexazinone at all rates significantly improved growth in September, and at 6 kg ha^{-1} improved growth in December. The difference from 1R was probably due to differences in site preparation and weed spectra. The cheapest, most effective treatments were amitrole + atrazine ($13 ha^{-1} chemical cost) on the 1R site, and hexazinone at 1 kg ha^{-1} ($21 ha^{-1}) on the 2R site, both applied in the September after planting.

Chemical cost of spot spraying is only 17% and 42% of the costs of broadcast and strip spraying respectively, and has particular application on 2R sites where slash is retained.

Introduction

Control of herbaceous weeds competing with newly planted *Pinus radiata* D. Don (radiata pine) for soil moisture, light and nutrients is important, since up to two years' growth can be irretrievably lost through competition (Jack 1970; Balneaves 1982). This is particularly important for pine plantations on sandy soils in low rainfall zones such as the Heywood, Rennick and Casterton areas of south-western Victoria, and in the Mount Gambier area of south-eastern South Australia, where soils dry out rapidly in the spring and early summer months (Nambiar and Zed 1980). It is also important in plantations established on ex-pasture sites in the Strzelecki Ranges (Flinn 1978*a*).

In many situations, it is necessary to supplement chemical or mechanical pre-planting weed-control treatments with post-planting chemical treatments, using selective herbicides such as amitrole, atrazine, simazine, hexazinone, or mixtures thereof (McKinnell 1975; Van Schie 1978; Eilert 1979; Minko 1980). These treatments can be applied from the air or the ground to the entire planted area or by tractor-drawn boom sprayers or hand-held controlled droplet applicators to 1–1.5 m wide strips along planting lines (Flinn and Fagg 1984). Strip treatments reduce chemical costs compared with broadcast methods while still effectively controlling herbaceous weeds, because weeds in the untreated areas between the rows do not seriously compete with the young pine trees during the first spring and summer after planting (Woods 1977).

To save even further on chemical costs a logical modification to the treated strip method is the spot-spraying technique, in which a circle of radius 0.5–0.6 m, centred on each young tree, is treated. The use of this technique has been facilitated by the development of a herbicide applicator known as a 'spot-gun' (Porter 1979; Stokes 1980). Glass (1985) undertook cost–benefit analyses over a full rotation for spot and aerial spraying of 2 kg ha^{-1} hexazinone for grass control in *P. radiata* in the Canterbury area of New Zealand. These analyses showed that spot-spraying was economically justifiable compared with no spraying at all, whereas aerial spraying was not.

This report describes a trial designed to evaluate different rates of hexazinone and amitrole + atrazine, applied using the spot-spraying technique, to control herbaceous weeds competing with recently planted *P. radiata* on sandy soils in south-western Victoria. The trial also examined the effect of a season of herbicide application on pine growth response and weed control for both first-rotation (1R) and second-rotation (2R) sites.

Study area

Description of sites

The trial was located in the Rennick Plantation in far south-western Victoria. Both sites were on the Caroline Sand soil type. This soil type, described in detail by Stephens *et al.* (1941), is widespread in south-western Victoria and in lower south-eastern South Australia. At the 1R site, the soil is a greyish-yellow, loamy sand of pH 6–6.5, gradually becoming paler with depth to 1 m. At the 2R site the soil is a yellowish-grey, loamy sand, with the surface horizon containing relatively large amounts of organic material due to the retention of logging residue from the previous pine crop.

Before clearing (in early 1980) the 1R site carried forest dominated by *Eucalyptus baxteri* (Benth.) Maid. & Blakeley (brown stringybark), with the common understorey species being *Pteridium esculentum* (Forst. f.) Nakai (Austral bracken), *Xanthorrhoea minor* R. Br. (small grass-tree), and *Acacia melanoxylon* R. Br. (blackwood). The main weed species present on unsprayed areas in December 1980, in order of decreasing frequency, were *Holcus lanatus* L. (Yorkshire fog), Austral bracken, *Hyphochaeris radicata* L. (cat's ear), *Aira caryophyllea* L. (silvery hair-grass), blackwood, *Scirpus marginatus* Thunb. (club rush).

On the 2R site, the main weed species in early 1980 were Yorkshire fog, *Senecio glomeratus* Desf. ex Poir (fireweed), *Senecio lautus* Forst. f. ex Willd. (variable groundsel), *Conyza bonariensis* (L.) Cronquist (tall fleabane), and *H. radicata*. In addition, some naturally regenerated *P. radiata* seedlings occurred, and stumps, old eucalypt logs, and radiata pine residue covered 10–50% of the site.

These weed spectra are typical of ex-native forest 1R and 2R sites in the region.

Site preparation and planting

The 1R site was cleared and ploughed in early 1980, and was machine-planted at a spacing of 2.4 m × 2.4 m in June that year with *P. radiata* seedlings raised from genetically improved seed. Each seedling was fertilized in August 1980 with 180 g superphosphate and ammonium sulphate (3:1) plus 2% w/w zinc sulphate heptahydrate, placed in a slot 10–15 cm from the base of the seedling. A further 10.2 kg ha^{-1} of zinc sulphate heptahydrate was aerially applied in January 1982 to correct incipient zinc deficiency in the trees.

On the 2R site, the previous *P. radiata* plantation was clearfelled at 27 years of age in 1978–79, and the logging residue was spread, rolled and chopped in 1979–80 with a 'roller-chopper' (Leitch and Farrell 1980) and left unburnt. The site was then hand-planted in July 1980 at a spacing of 2.4 m × 2.4 m, with similar stock as used on the 1R site. No fertilizer was applied to the trial area.

Methods

Experimental design and treatment application

Both trial sites were divided into two areas, one for September spraying and the other for December spraying, and these areas were further subdivided into three blocks. Four spot-spraying treatments and a control (Table 1) were randomly allocated within each block to five adjacent plots, each consisting of a row of 20 *P. radiata* trees. As the spot-spraying covered a circle

Table 1 Details of treatments used in the spot-spraying trials

Treatment	Rate (kg ha^{-1})	% a.i. in product (trade name)	Product:water ratio for 10 ml doses	Product cost (retail) for 1670 trees ha^{-1} ($ Feb. 1988)
Hexazinone	1	25 (Velpar L)	1:24	20.80
Hexazinone	3	25 (Velpar L)	1:7.3	62.40
Hexazinone	6	25 (Velpar L)	1:3.2	124.80
Amitrole + atrazine[A]	1+4	25 (Weedazol TL PLUS) +50 (Gesaprim 500 FW)	1:3:22	13.30
Control	nil			

[A] The component chemicals were mixed before application.

of only 0.5–0.6 m radius around each tree, there was no need to separate treated rows or blocks with buffer rows.

The chemicals were applied using a Dupont Velpar Forestry Spotgun fitted with a Spraying Systems 4.3W solid-cone nozzle. The nozzle was held 45–50 cm above ground level and 10 ml of spray mixture was applied on/around each (unshielded) tree. The mixing ratios and costs (Table 1) were calculated assuming a sprayed area of 1.0 m^2.

Weather conditions during the December 1980 sprayings varied according to the site. For the 1R site, temperature was 42°C, relative humidity 20%, and wind 3–10 km h^{-1}, whereas for the 2R site these parameters were 19°C, 68% and 0–3 km h^{-1}. Weather conditions for the September 1980 sprayings were not recorded. Rainfall at Rennick for the period September 1980–April 1981 inclusive was 346 mm (14% less than the long-term average of 402 mm). The weeds sprayed in September, though relatively small, were green and growing vigorously, in contrast to the partly dried-off condition of the weeds sprayed in December.

Measurement and analysis

The trial was measured three times: initially in December 1980 (tree height and mortality), in July 1981 (height, mortality and weed control, the latter being visually estimated as the difference in percentage bare ground between treated and untreated plots), and finally in November 1983 (height, diameter over bark at 5 cm above ground level, mortality, average depth of mulch (2R site only), and browsing damage to main leader). Depth of mulch (logging residue) was rated as low (0–5 cm), medium (5–10 cm), or high (>10 cm).

For each site, analyses of variance (ANOVAs) were performed on the 1983 data to examine the effect of treatments on height, diameter, volume and mortality of trees. Plot (row) means were used as input data for the analyses. These were based on an average of 17 trees per plot, two trees (on average) dying from various causes and one tree excluded because of browsing damage by kangaroos. A volume index, 0.01 (diameter^2 × height) was calculated for each tree, and a logarithmic transformation was applied to the mean index in each plot in order to stabilize the variance. Mortality was analysed after an arcsine transformation had been applied to the proportion of live trees in a row. ANOVAs were also performed on the plot mean heights measured in July 1981.

Where there was significant interaction between treatments and spraying months, a separate ANOVA was performed for each month. In cases where the treatment effect was significant, comparisons were made between individual treatments, using the test of least significant difference.

Results

Weed control

By December 1980, all four herbicide treatments applied in September 1980 had controlled most weeds in the sprayed spots. By July 1981 however, weed control, particularly for the amitrole + atrazine treatment, was more marked on the 1R than on the 2R site. By November 1983, on the 1R site, only the spots of the 3 and 6 kg ha^{-1} hexazinone treatments were visible, whereas on the 2R site, weed control was still relatively distinct for all three rates of hexazinone.

For each site and month of spraying there was a clear trend for weed control to decrease, in the order: hexazinone (6 kg ha^{-1}), hexazinone (3), hexazinone (1), amitrole + atrazine, control (Table 2). For the same spraying month, there was no marked difference in percent weed control between the two sites. However, weed control appeared to be substantially better for the September sprayings compared with those in December for the two lower rates of hexazinone. The average rating of mulch depth was between moderate and heavy in the September spraying and between light and moderate in the December spraying, and this mulch was a weed control measure in itself.

Response of P. radiata

Mortality Analysis showed that the only treatment with a significantly greater *P. radiata* mortality than control ($P<0.05$) was 6 kg ha^{-1} hexazinone on the 2R site, the trees on the wetter microsites being most affected. Data for mean mortality as at December 1980, July 1981 and November 1983 (Table 3) show that the majority of deaths occurred within the first 7–10 months after treatment, although high mortality (23%) occurred within 3 months for the September spraying of 6 kg ha^{-1} hexazinone on the 2R site. This early, high mortality probably also occurred for the December spraying of this treatment, but was not detected until the trial was first assessed in July 1981, i.e. 7 months after the spraying.

Height, diameter and volume In the initial analysis for the 1R site, there was a significant ($P<0.05$) treatment by month of spraying interaction, so a separate ANOVA was performed for each month. The results in Table 4 show, for the September spraying, that all four herbicide treatments produced significantly better growth ($P<0.05$) than the control, and none was significantly different from the others. For the December spraying, the treatments were not significantly different (except for their effect on height, but no treatment was significantly better than the control).

For the 2R site (Table 5), the analysis suggested that 1 kg ha^{-1} hexazinone would be the most appropriate treatment in the period September–December because it produced significantly better growth ($P<0.01$) than either the control or the amitrole + atrazine treatment (Figure 1 illustrates the latter treatment), and as the higher rates of hexazinone (3 and 6 kg ha^{-1}) did not produce significantly better growth.

Analysis of the July 1981 height measurements showed treatments to be not significant on the 1R site, although a similar pattern to that found for the final measurements was emerging. For the 2R site, the results which were later established were already evident at this early stage, with 1 kg ha^{-1} hexazinone producing significantly

Table 2 Mean weed control (expressed as the difference in percentage bare ground between treated and untreated spots) in July 1981, after spot-spraying herbaceous weeds in September and December 1980, for each treatment, site, and spraying month

Treatment (kg ha^{-1})	Site and spraying month: First rotation		Second rotation	
	September	December	September	December
Hexazinone (1)	52	22	42	32
Hexazinone (3)	78	57	77	65
Hexazinone (6)	83	85	90	88
Amitrole (1) + atrazine (4)	20	22	17	8

Table 3 Mean mortality (%) of *P. radiata* trees as at December 1980 (Sept. 1980 spraying only), July 1981 and November 1983, for each treatment, site, and spraying month

Treatment (kg ha^{-1})	Spraying month: September 1980 Dec. 1980	July 1981	Nov. 1983	December 1980 July 1981	Nov. 1983
First rotation					
Hexazinone (1)	1[A]	10	12	12	12
Hexazinone (3)	5	12	13	15	17
Hexazinone (6)	7	23	23	26	28
Amitrole (1) + atrazine (4)	0	21	21	8	8
Control	0	20	20	12	12
Second rotation					
Hexazinone (1)	0	2	2	20	20
Hexazinone (3)	3	13	13	23	23
Hexazinone (6)	23	60	60	62	62
Amitrole (1) + atrazine (4)	0	3	3	7	7
Control	0	3	3	7	7

[A] Mean percentages rounded to nearest whole number.

Table 4 Mean height, diameter, and volume index of *P. radiata* trees, 38 and 35 months after spot-spraying in September and December 1980 respectively – first rotation site

Treatment (kg ha^{-1})	September Height (cm)	September Diam.[A] (cm)	September Volume index	December Height (cm)	December Diam.[A] (cm)	December Volume index
Hexazinone (1)	265	7.4	165	239	6.0	99
Hexazinone (3)	273	7.6	183	216	5.5	75
Hexazinone (6)	264	7.2	183	231	6.0	101
Amitrole (1) + atrazine (4)	274	7.3	165	228	6.0	93
Control	230	5.8	93	226	5.6	82
l.s.d. (P=0.05)	18	0.9	45[B]	14	n.s[C]	n.s.

[A] At 5 cm above ground level over bark.
[B] This is an approximate figure, as the analysis of variance was performed on the (logarithmically) transformed data.
[C] Not significant.

Table 5 Mean height, diameter, and volume index of *P. radiata* trees, 38 and 35 months after spot-spraying in September and December 1980 respectively – second rotation site

Treatment (kg ha^{-1})	September Height (cm)	September Diam.[A] (cm)	September Volume index	December Height (cm)	December Diam.[A] (cm)	December Volume index
Hexazinone (1)	269	6.3	126	201	4.8	59
Hexazinone (3)	254	5.8	105	182	4.5	45
Hexazinone (6)	242	5.6	88	230	5.8	96
Amitrole (1) + atrazine (4)	208	4.3	53	140	3.1	28
Control	203	4.4	48	153	3.5	29
l.s.d.[B] (P=0.05)	36	1.0	39[C]	36	1.0	39[C]

[A] At 5 cm above ground level over bark.
[B] Least significant differences apply to the mean of the September and December spraying months, and not to the individual months.
[C] This is an approximate figure, as the analysis of variance was performed on the (logarithmically) transformed data.

greater height growth ($P<0.05$) than either the control or the amitrole + atrazine treatment.

Discussion

Spraying in September controlled weeds more effectively than did spraying in December (Table 2). This may have been due partly to higher rainfall in the September–December period (226 mm) compared with that in December–March (122 mm), since reasonable soil moisture is required to promote hexazinone absorption by the weed species (Anon. 1982).

The amitrole + atrazine treatment was successful on the 1R site when applied in September, but not on the 2R site for either of the spraying months. This was probably due to differences in the weed spectra: the biennial species on the 2R site such as *S. glomeratus* and *C. bonariensis* are harder to kill than the grasses such as *H. lanatus* and *A. caryophyllea* that were more common on the 1R site. Although the 1 kg ha^{-1} hexazinone treatment was as effective as amitrole + atrazine in promoting growth for the 1R September spraying (Table 4), its higher cost ($21 ha^{-1}) (Table 1) leads to the choice of amitrole + atrazine as the better treatment for the 1R site. The deeper mulch on the plots for the September spraying on the 2R site probably contributed to the better height and diameter growth compared with the December spraying (Table 5), as Farrell (1984) showed that mulch retention had a beneficial effect on pine growth on 2R sites in the Rennick area.

The growth response of pine to the treatments (Tables 4 and 5) was clearly not correlated with the degree of weed control recorded 7–10 months after spraying (Table 2).

The lack of response to any of the treatments applied in December on the 1R site (Table 4) was probably due to the fact that the common weeds were mostly dead or dying at the time of application. This contrasts with the significant response of the *P. radiata* on the 2R site to the December spraying of hexazinone, indicating that, here, weeds were still actively competing in early summer. This extended weed competition is mainly attributed to conservation of soil moisture and release of nutrients by the mulch, and the greater numbers of biennial weed species on the 2R site. The lack of response to amitrole + atrazine is similar to that recorded by Flinn (1978*b*) who applied amitrole (0.7 kg ha^{-1}) + atrazine (2.7 kg ha^{-1}) in two consecutive years to scalped and mulched 2R sites on sandy soil near Rennick, but differs from the results of Cellier and Stephens (1980) who found significant responses to amitrole (1.7 kg ha^{-1}) + atrazine (4.1 kg ha^{-1}) up to at least 4 years after treatment on a 2R site in the same region. The application of amitrole caused chlorosis in the leading shoots of some trees, particularly on the 2R site, and this may have been a factor in the lack of a growth response to the amitrole + atrazine treatment on this site.

Substantial differences in pine growth

Figure 1 *P. radiata* on the 2R site, 3 years after treatment. LHS, hexazinone (3 kg ha^{-1}) (2.5 m ht, 5.8 cm diam.); RHS, amitrole (1) + atrazine (4) (2.1 m, 4.3 cm diam.).

occurred between sites and between the two spraying months at each site up to 3 years after treatment (Tables 4 and 5). The pines treated in December were invariably smaller than those treated in September, clearly indicating the lasting impact of weed competition in the first spring.

The far better pine growth (based on mean volume index) on the 1R compared with the 2R site probably is explained by the application of fertilizer at the time of planting of the 1R site.

Though it was found that spraying was not worthwhile on the 1R site in December, spraying in October or November may have yielded a significant response in tree growth. Nevertheless, the forest manager should endeavour to complete spraying by the end of September in order to obtain the best value for money, though it is recommended that hexazinone should not be applied within 4 weeks of planting (Anon. 1982).

Reduction of *P. radiata* mortality, in addition to stimulation of growth, is one of the objectives of herbaceous weed control. While our treatments did not significantly reduce mortality compared with the untreated controls, the recommended treatment for the 2R site (1 kg ha^{-1} hexazinone) should result in a *P. radiata* mortality of less than 13%. The 21% mortality rate for the amitrole + atrazine September spraying on the 1R site was higher than expected, though it was comparable with the control mortality (20%). Perhaps waterlogging of the site caused this relatively high mortality level.

Though strip and broadcast spraying methods were not compared with spot-spraying in the present experiment, the spot-spraying technique has a substantial chemical cost advantage over both these methods. Calculated on a tree espacement of 3 × 2 m (1670 trees ha^{-1}) the cost of a given herbicide used in spot-spraying (1 m^2 spots centred on each tree) is only 16.7% of a broadcast spraying and 42% of a strip-spraying (1.2 m wide strips centred on rows 3 m apart). On 2R sites where logging slash is retained, making it difficult to use tractor-drawn boom sprayers, the manual spot-spraying technique has particular application.

Conclusions

1. The cheapest and most effective treatment tested was amitrole (1 kg ha^{-1}) + atrazine (4) on the 1R site and hexazinone (1) on the 2R site, both applied in the September after planting. However, where soil type and the weed spectrum differ substantially from that encountered in this study, these treatments may not be appropriate.
2. Spraying in the September after planting resulted in a much better growth response than when spraying was delayed until December. No treatment on the 1R site for the December spraying was successful due to the mainly annual weed species having died by then.
3. Spot-spraying is a significantly cheaper technique (in terms of chemical cost) than either strip or broadcast spraying methods and has particular application on 2R sites where slash is retained.

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