SEASON OF APPLICATION AFFECTS HERBICIDE EFFICACY IN *PINUS RADIATA* PLANTATIONS IN SOUTH AFRICA

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ABSTRACT

Three herbicides (glyphosate, hexazinone, and metsulfuron methyl) at three rates were tested on indigenous herbaceous shrubs (macchia) in a 1-year-old virgin *Pinus radiata* D.Don stand. Mechanical ring weeding of 1 m radius was included as a control treatment. Herbicides were applied over-the-top to uncovered *P. radiata*. These treatments were tested for each of four seasonal applications. Tree height and diameter growth were measured to determine efficacy of the treatments. Two floristic surveys indicated satisfactory weed suppression.

Summer was the best season to apply herbicides. Glyphosate and hexazinone were significantly better than metsulfuron methyl. Hexazinone had no detrimental effect on *P. radiata* and improved height growth, whereas glyphosate scorched the trees but improved their diameter growth. The rates at which metsulfuron methyl was applied were too low for the control of macchia vegetation.

Optimum application rates were 2000 g and 1500 g active ingredient (a.i.) hexazinone/ha and 1500 g a.i. glyphosate/ha. Metsulfuron methyl at 27 g a.i./ha successfully controlled *Rubus* spp.

Keywords: seasonal herbicide application; macchia vegetation.

INTRODUCTION

Weeds can reduce crop growth and survival, increase rotation length, decrease product quality, hinder tending, and impede stand access (Nelson *et al.* 1985; Busby 1988; Richardson 1991). Weed control is the single most important factor in improving tree growth (Richardson 1993). The effect of treatments on growth is related to the amount of weed suppression (Radosevich & Knowe 1992), with maximum crop production invariably occurring in absence of competing weeds (Cousens *et al.* 1987). Generally, weeding is not required after canopy closure (Nambiar 1989), and so weed management should be designed to accelerate early tree growth.

In trials with various herbicides, it became apparent that season of application plays a vital role in herbicide efficacy. Schumann (1990) spraying 1500 g a.i./ha in spring and summer, and Harrington (1993) spraying 900 g a.i./ha in spring, found that hexazinone caused burning of *Pinus patula* Schdl. et Cham. and *P. radiata* respectively. Donald (1986) and

Gous *et al.* (1992), spraying in summer, found that 2000 g a.i. hexazinone/ha caused no damage to *P. radiata*. Thompson (1993) used 4320 g a.i. glyphosate/ha to control herbaceous weeds. Donald (1986) found that an application of 2160 g a.i. glyphosate/ha in summer had minimal effect on macchia vegetation (schlerophyllous scrubs including herbaceous bush). However, Gous *et al.* (1992) found that 1500 g a.i. glyphosate/ha applied in summer (Mediterranean climate, quartsitic soils) successfully controlled macchia vegetation. These contradictory results led to the establishment of a trial in the southern Cape.

Hoeing, slashing, and hand pulling of natural regeneration were the "standard" methods of weed control in the south-western Cape (Donald 1986). Mechanical ring weeding combined with slashing of large weeds between rows, is the most cost-effective mechanical weeding method (Lowery *et al.* 1993), and Schumann (1992) also found mechanical ring weeding to be effective.

In the late 1980s, Thompson (1993) observed that, in New Zealand, there was a trend away from soil disturbing operations towards effective chemical treatment options. In South Africa, soil preparation, especially for re-afforestation, has recently become less intensive, with the result that weed control may become more important. Donald (1986) reported that wages in the southern and western Cape increased from R1.00/unit in 1970 to R15.00/unit in 1986. Today (1995) that same unit cost is R40.00 (C. Bekker pers. comm.) for wages and R40.00 for direct overheads, totalling R80.00 per unit per day. This tremendous increase in labour costs necessitates the search for alternative weed control methods (Lyle 1981; Gous *et al.* 1992).

MATERIALS AND METHODS

The trial was conducted in the southern Cape near Plettenberg Bay on the timber farm, Wynanskraal. The trial area has a Sterkspruit (Typic udalf) and a Kroonstad (Aquic pale udalf) Alfisols (Soil Survey Staff 1975; Soil Classification Working Group 1991), a 5–10° slope, and a mean annual rainfall of 650 mm. According to the Köppen (Koeppe & De Long 1958) formula, the site has hot summers and mild winters, and all months are moist. The site has a predicted mean annual increment (m.a.i.) of 8 m^3/ha (L. Viljoen pers. comm.).

Plot size was 180 m^2 (15 × 12 m) with 24 trees per plot, of which the centre eight were measured. Espacement was 4 × 3 m, with 833 stems/ha at time of planting. Blanking was carried out 3 months after initial planting. Three herbicides (glyphosate, hexazinone, and metsulfuron methyl), each at three rates, were applied to the whole plot, over-the-top, to uncovered 1-year-old *P. radiata* established in a macchia community. This is the most economical and practical way of applying herbicides (Nelson *et al.* 1985). Mechanical ring weeding of 1 m radius was included as a control treatment. Herbicides used, the quantity of active ingredient, the price and the treatment cost per hectare are given in Table 1. Herbicides were diluted with clean water and applied by knapsack sprayers with a standard "TK2"-brass nozzle, at 300 ℓ solution/ha. Herbicides were applied at the end of March, June, September, and December 1992.

Two floristic surveys were carried out—the first immediately prior to the first treatment, and the second 2 years later (i.e., 1 year after the last herbicide application). Six sub-plots of 1 m^2 each were randomly selected in each plot. Herbicide effects on weeds were monitored visually at 3-month intervals, and the percentage cover by species was recorded.

TABLE 1–Herbicides, trade names, amount applied, prices, and herbicide costs per hectare

Herbicide and Trade name	Product quantity applied/ha	a.i. (g/ha)	Unit price in June '95 (R)	Cost (R/ha)
Hexazinone	1.11 kg	1000	128.00	142.08
[Velpar®]	1.66 kg	1500		212.48
	2.22 kg	2000		284.16
Glyphosate	2.77 ℓ	1000	18.50	51.25
[Roundup®]	4.16 ℓ	1500		76.96
	5.55 ℓ	2000		102.68
Metsulfuron methyl	15.00 g	9	1636.00	24.54
[Escort®]	30.00 g	18		49.08
	45.00 g	27		73.62

Crop tree heights were measured to the nearest centimetre, and diameters were measuired 10 cm above ground level (D_{10}), with an electronic calliper, to the nearest 0.1 mm. The first measurements were taken immediately before the initial treatments were applied. Seven subsequent measurements of the entire trial were carried out at 3-month intervals over a 2-year period. Herbicide effects on trees were monitored visually at 3-month intervals.

The experiment was established as a randomised complete block with three replicates. Each replicate was subdivided into four main plots to which four seasonal times of application were assigned at random. Each main plot was subdivided into 10 sub-plots to which 10 weed control treatments were randomly allocated. In consequence, seasonal time of application was tested against the mean square for error (a) which represents the interaction between blocks and treatments and has 6 degrees of freedom. Weed control treatment and interaction with time of application were tested against the mean square for error (b) with 72 degrees of freedom and therefore the data were analysed as a split-plot trial. One-year height and diameter increments were introduced as response variables.

Dunnett's two-tailed t-tests (Miliken & Johnson 1984) were performed on height and diameter increment response variables to test if any treatment differed significantly from the mechanical ring weeded control. The same test was conducted with 2000 g a.i. hexazinone and 1500 g a.i. glyphosate as control.

A cost/benefit analysis was conducted. These figures were based on a mean annual increment of 8 m^3/ha at age 20, a labour cost of R80.00 per man day, and a weighted average timber price of R86.85/m^3. A real discount rate of 3% ($r = 3\%$) and a total timber volume of 215 m^3/ha at clearfelling (30 years) were used. The costs above R240.00/ha, i.e., the cost of mechanical weeding, were calculated with compound interest between treatment age and clearfelling.

RESULTS

The first floristic survey identified *Cynodon dactylon*, *Ehrharta capensis*, *Metalasia muricata*, and *Stoebe incana* as the main weed species. The second survey 21 months later indicated that the area not covered by weeds in the entire trial increased from 9.2% to 45.9%. The percentage cover of the main weeds (Table 2) decreased considerably: *Cynodon*

TABLE 2–Percentage weed cover before herbicide application (March 1992) and 21 months later (December 1993)

Weed species and uncovered area	March 1992 Mean	s.d.	December 1993 Mean	s.d.
Uncovered area	9.2%	7.0	45.9%	17.4
Cynodon dactylon	32.6%	13.3	20.4%	9.5
Ehrharta capensis	12.2%	6.7	3.7%	4.2
Metalasia muricata	12.0%	8.4	5.6%	8.4
Stoebe incana	7.1%	9.1	2.1%	2.2

dactylon from 32.6% to 20.4%, *Ehrharta capensis* from 12.2 to 3.3%, and *Metalasia muricata* from 12.0% to 5.6%, 1 year after herbicide application.

Glyphosate and hexazinone controlled the weeds more effectively than metsulfuron methyl, expressed as the difference between uncovered areas (Table 3). The total percentage cover of the annuals such as the Poaceae increased from 6.5% to 15.7%.

For both height and diameter, the hypothesis of a zero difference between season means and between weed control means was rejected at a 0.05 level of significance, indicating that at least one of the treatment means differed significantly from others. In Table 4 the percentage height and diameter increments 1 year after application are given for the different

TABLE 3–Mean herbicide effects on vegetation cover, 12 months after treatment

Weed species and uncovered area	Glyphosate Mean (%)	s.d.	Hexazinone Mean (%)	s.d.	Metsulfuron Mean (%)	s.d.
Uncovered area	77.8	16.4	46.8	16.3	13.2	5.8
Cynodon dactylon	5.9	4.2	26.3	8.2	29.1	7.2
Struthiola stricta	3.6	2.3	5.5	4.1	33.4	10.5
Stoebe incana	1.1	0.5	2.4	2.0	2.7	1.6
Aspalathus galioides	0.3	0.3	29.1	7.2	1.6	1.2
Antospermum spp.	0.7	0.8	1.4	2.0	3.5	1.6

TABLE 4–Effects of weed control treatments on *P. radiata* height and diameter increments during first year after application

Weed control treatments (g a.i./ha)	Height increment (%)	Diameter increment (%)
Hexazinone 2000	140.6 a	140.4 a
Hexazinone 1500	136.2 ab	127.4 ab
Glyphosate 1500	116.0 b	113.7 abcd
Hexazinone 1000	113.8 bc	97.3 bcd
Glyphosate 1000	110.6 c	111.6 abcd
Glyphosate 2000	105.1 c	118.5 abc
Mechanical ring weeding	100.0 c	100.0 bcd
Metsulfuron methyl 9	100.0 c	82.2 d
Metsulfuron methyl 27	98.8 c	116.4 abc
Metsulfuron methyl 18	95.1 c	91.8 cd

Based on Duncan's Multiple Range Test, means within a column not sharing a common letter differ significantly ($p = 0.05$).
Mechanical ring weeding: height = 56.7 cm; diameter = 14.6 mm

treatments. Hexazinone at 2000 g a.i. produced a statistically significant improvement of more than 40% over the mechanical ring weeding control, in both height and diameter growth responses. The second best treatment was hexazinone at 1500 g a.i./ha producing 36% and 27% improvement in height and diameter growth respectively.

Significant differences also occurred between the treatment means for the season in which herbicides were applied. Application of herbicides in summer produced significantly better results (e.g., 38% in height growth) than when applied in other seasons (Table 5).

No significant interactions occurred between herbicide treatments and season of application. Hexazinone had a significantly greater effect than glyphosate or metsulfuron methyl on height increment, as was disclosed by testing relevant contrasts. A linear response was found within hexazinone.

Dunnett's two-tailed t-test (Miliken & Johnson 1984) revealed that hexazinone at 2000 g a.i./ha performed significantly better than all treatments except hexazinone at 1500 g a.i./ha and glyphosate at 1500 g a.i./ha.

To justify the use of herbicides applied at age 2 years, an increase in yield is needed at clearfelling to obtain break-even volume compared to mechanical ring weeding (Table 6).

TABLE 5–Effect of season of application (combined herbicides and rates) on height increment

Season of application	Mean height increment (cm)	
Summer	83.41	a
Spring	59.97	b
Winter	55.69	b
Autumn	54.11	b

Based on Duncan's Multiple Range Test, means not sharing a common letter differ significantly (P = 0.05).

TABLE 6–Treatment costs (including R120.00/ha application costs) and estimated volume increase required for financial break-even

Treatment	Active ingredient (g/ha)	Cost (R/ha)	Break-even volume increase (m^3/ha)
Ring weeding	–	240.00	Control
Hexazinone	1000	262.08	0.58
Hexazinone	1500	332.48	2.44
Hexazinone	2000	404.16	4.32
Glyphosate	1000	171.25	–1.81
Glyphosate	1500	196.96	–1.13
Glyphosate	2000	222.68	–0.46
Metsulfuron methyl	9	144.54	–2.51
Metsulfuron methyl	18	169.08	–1.87
Metsulfuron methyl	27	193.62	–1.22

Formula used for calculations in Table 6:

$$\text{Break-even volume} = \frac{\text{Compounded value at clearfelling}}{\text{Weighted average timber price per cubic metre}}$$

where $R \times 1.03^n$ = compounded value at clearfelling

R = cost above R240.00

n = clearfelling age – treatment age

(H.J.E.Uys pers. comm.)

DISCUSSION

Floristic surveys suggested that hexazinone and glyphosate controlled weeds adequately. Nelson *et al.* (1985), using 1980 g a.i./ha, in south-western Georgia found a similar response to glyphosate treatment on herbaceous weeds. Application of 1500 g a.i. glyphosate required 1.13 m^3/ha less timber at rotation age for financial break-even, compared with the ring weeded control (Table 6). However, glyphosate rates at 2000 g a.i. and 1500 g a.i. were too high for over-the-top application, as it caused die-back of *P. radiata* growing tips in all seasons. Therefore, glyphosate at the above rates is not recommended for aerial application. Knapsack application costs (R120.00/ha) are relatively high compared to aerial application (R30.00/ha) (J.Ackermann pers. comm.). At 1500 g a.i. glyphosate, weeds were controlled adequately, making it a viable option provided trees are protected or avoided during spraying.

Hexazinone controlled weeds adequately and, based on periodic visual assessments, the effects were longer lasting than those of the other herbicides. Hexazinone, at all rates, inflicted no damage to *P. radiata* when applied over-the-top. Therefore, aerial application of hexazinone is advisable, because of relatively low application costs. Summer applications showed no significant differences between the weed management treatments—hexazinone at 2000 g a.i./ha was the best treatment but not significantly better than hexazinone at 1500 g a.i./ha. Hexazinone at 2000 g a.i./ha applied in other seasons proved to be significantly better than all other treatments. For financial break-even, the hexazinone treatment at 2000 g a.i./ha requires 4.32 m^3 additional timber/ha (Table 6) above the mechanical ring weeding control, at rotation age. However, with aerial application (R30.00/ha) the above-mentioned treatment requires 1.95 m^3 timber/ha more than the control for financial break-even, which makes the treatment financially more attractive. A linear growth response was found within the applied hexazinone rates. Higher rates should be investigated.

Metsulfuron methyl, applied at rates recommended by the producer, had very little effect on the weeds except for *Rubus* spp. Growing tips of *P. radiata* sprayed with 18 g a.i. and 27 g a.i. metsulfuron methyl/ha developed chlorosis and die-back. Therefore, it would be advisable to avoid over-the-top application. Michael (1985), using 28 g a.i. metsulfuron methyl/ha, similarly found no growth responses in *P. taeda* L. and observed damage to the trees.

Early results indicate up to 40% improvement in height and diameter increments due to chemical weed control, compared to mechanical weeding. No interactions occurred between herbicides and season. The phenology of *P. radiata* in the southern Cape is unknown. Spring and autumn growth peaks of macchia in the southern Cape are given in Fig. 1. The arrow heads indicate the time of herbicide application. Summer herbicide application was significantly better than in other seasons of application (Table 5) and the reduced response to herbicide treatment in autumn and winter could be explained by the fact that herbicides were applied during a semi-dormant growth period (Fig. 1). Therefore, herbicides should preferably be applied just before active growth commences in spring and summer.

The spring application of herbicides occurred towards the end of a growth peak. Herbicide translocation and the subsequent suppression of weeds take some time, and it seems that by the time the weeds were suppressed, the weed growth peak had already ended so that there was minimal beneficial effect to the trees.

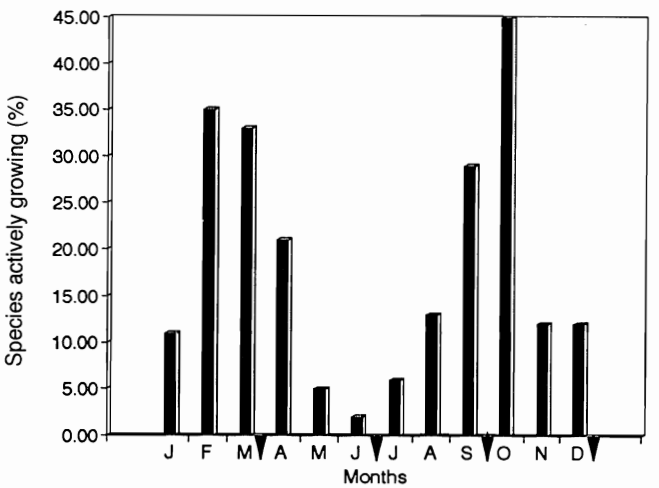

FIG. 1–Phenogram for south coast Renosterveld (from Pierce 1984). Arrows indicate time of herbicide application.

The summer application occurred 1 month before the autumn growth peak started. Therefore, herbicides could suppress weeds before their autumn growth peak, and thereby cause maximum damage to them, with optimum benefit to the trees.

Macchia vegetation has strong vegetative growth potential, provided roots are not damaged. The herbicides used in this investigation are systemic and therefore probably killed macchia root systems. Chemical weed management gave significantly better results than mechanical weeding, which left the roots virtually unharmed.

CONCLUSIONS

Summer was the most effective season to apply herbicides. However, weed control treatments applied during this season showed no significant differences. In the other seasons hexazinone at 2000 g a.i./ha was the most effective treatment except for hexazinone at 1500 g a.i./ha. Hexazinone at 2000 g a.i./ha caused no damage in *P. radiata* plantations when applied over-the-top and can be recommended for aerial application. A linear response was found within the applied hexazinone rates; therefore higher rates should be investigated. Hexazinone gave a longer relief from weeds than the other applied herbicides, as it possesses residual activity.

Glyphosate at the applied rates caused die-back of *P. radiata* growing tips; therefore over-the-top application is not recommended. Application of glyphosate at 1500 g a.i./ha is recommended, if trees are protected or avoided.

Applied rates of metsulfuron methyl, as recommended by the producer, were too low. Higher rates should therefore be examined, but the trees will have to be protected.

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