Chemical control of natural seedling regeneration of radiata pine (*Pinus radiata* D. Don)

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Summary

Dense seedling regeneration of radiata pine (*Pinus radiata* D. Don) following wildfires must be controlled prior to replanting with genetically improved seedlings. TCA, paraquat + diquat and two formulations of dicamba were each evaluated at two rates for control of seedling regeneration in the spring and second autumn following a late summer wildfire. Total control was obtained with dicamba as the dimethylamine salt at 4.0 kg ha^{-1} and with paraquat + diquat at 0.5 + 0.25 kg ha^{-1} applied during the first spring after the fire to regeneration with an average height of 5 cm. None of the treatments gave adequate control of approximately 14 cm tall regeneration when applied in the second autumn after the fire. Mortality and height measurements of radiata pine seedlings planted 0 to 1 and 6 to 8 months after each treatment showed that sites treated with the herbicides in the first spring after a wildfire are best replanted in the following winter.

Introduction

Dense natural regeneration of radiata pine (*Pinus radiata* D. Don) seedlings generally develops when a seed-bearing stand is killed by wildfire. This regeneration is seldom managed to produce the next crop of trees, but must be controlled prior to replanting with genetically superior seedlings. Mechanical control of natural regeneration prior to replanting has met with only partial success in the past, since stumps from the previous crop constitute an obstacle to ground equipment and reshooting of slashed stems is common. Few studies have been carried out on the chemical control of young pine regeneration, though control of established trees by stem injection has been investigated (Minko, 1981).

In February 1979 a wildfire killed approximately 300 ha of radiata pine plantation in south-western Victoria and a larger area in neighbouring South Australia. A trial was laid down soon after the fire to compare the efficacy of three herbicides for the control of natural seedling regeneration. The plant-back period (i.e. the period after spraying before which it is unsafe to replant) was investigated simultaneously.

Materials and methods

The study was undertaken at a site near Rennick in south-western Victoria, where an unthinned stand of radiata pine planted at a spacing of 2.4 m x 2.4 m in 1966 had been killed by a wildfire in early February 1979. By the following July there was a dense cover of about 230 000 radiata pine seedlings per hectare about 5 cm in height on the site, which had also been recolonized by native and introduced grasses and bracken (*Pteridium esculentum* Forst.f.). The area has a rainfall of approximately 800 mm per annum and the site has a sandy soil with an organic matter content of less than 2% (Hopmans *et al.*, 1979).

Efficacy trials

The treatments listed in Table 1 were applied to seedling regeneration with an average height of 5 cm in the first spring after the wildfire (August 1979) for Trial 1 and to approximately 14 cm tall regeneration in the second autumn (March 1980) for Trial 2. A randomized block design with three replications was used for each trial with 5 m x 10 m plots separated by 2 m wide unsprayed strips. The liquid herbicides were applied in water at 500 L ha^{-1}, using a Du Pont Forestry Spotgun with a solid cone nozzle in Trial 1 and a Solo Knapsack Sprayer with a flat fan nozzle in Trial 2. The granular dicamba was bulked with coarse, oven-dry sand prior to uniform spreading by hand. The fire-killed trees were left standing, since felling them would have obstructed movement of ground equipment and a significant portion of the pine seedlings may have been protected from the herbicide by the debris.

Trial 1 was inspected in November 1979 and both trials in March, April, September and December 1980, and damage symptoms in the radiata pine regeneration recorded. Four random points were located in each plot at the first inspection following spraying, a 50 cm x 50 cm grid was centrally placed over each point and the number of living radiata pine seedlings counted at each inspection.

Plant-back period

An indication of the safe plant-back period before radiata pine seedlings could be planted following herbicide treatment was sought in both trials. Plots were split into two 5 m x 5 m sub-plots, one of which was planted soon after and the other some months after herbicide application. The sub-plots in Trial 1 were planted in August 1979 (immediately after spraying) and April 1980 (8 months after spraying), whilst the sub-plots in Trial 2 were planted in April and September 1980 (1 and 6 months after spraying respectively). Twenty-five bare-rooted radiata pine seedlings 20 cm tall were planted in each sub-plot at a spacing of 1 m x 1 m. The planted seedlings were measured for height and rated for damage on a scale of 1 (dead) to 4 (no damage) at each inspection.

Table 1 Herbicide treatments applied to seedling regeneration of radiata pine in Trial 1 (Spring 1979) and Trial 2 (Autumn 1980)

Herbicide	Trade name	Formulation	Application rate (kg ha^{-1} a.i.)
paraquat + diquat	Tryquat[1]	dichloride + dibromide monohydrate	0.125 + 0.0625 0.5 + 0.25
TCA	TCA Grass Killer[2]	sodium salt	4.2 16.8
dicamba granules	Banvel 10G Granules	free acid	1.0 4.0
dicamba liquid	Dicamba Herbicide[2]	dimethylamine salt	1.0 4.0

[1] contained 250 g L^{-1} of a non-ionic surfactant
[2] surfactant (as Plus 50) added at the rate of 1 L per 1000 L water

Results

Efficacy trials

In the first trial the mean density of natural regeneration of radiata pine was about 230 000 plants ha^{-1} at the time of herbicide applications in August 1979, approximately 6 months after the wildfire. The average height of the seedlings at this time was 5 cm. The high density of regeneration compares with a stocking of 1736 stems ha^{-1} following planting of radiata pine seedlings at 2.4 m x 2.4 m.

Herbicide treatments significantly reduced the density of natural regeneration (Table 2). Paraquat + diquat and dicamba liquid at each rate tested were the most effective treatments, though total control was only achieved when either of these herbicides was applied at the higher rate. Though most plants in the remaining treatments exhibited moderate to severe damage symptoms, a high number survived. There was an increase of 6.6% in the density of natural regeneration on control plots between August 1979 and December 1980.

In the second trial the mean density of natural regeneration was about 260 000 plants ha^{-1} when herbicides were applied in March 1980, twelve months after the wildfire. The average height of the seedling regeneration was 14 cm. All herbicides except the lower rate of the two dicamba formulations reduced the density of regeneration, with paraquat + diquat and dicamba liquid being the most effective when applied at the higher rate (Table 3). None of the treatments provided total control of the regeneration, however, with the minimum residual population being about 66 000 plants ha^{-1} for the high rate of paraquat + diquat. There was a decrease of 11.6% in the density of natural regeneration between March and December 1980 due to natural causes.

Plant-back period

Although there were significant differences between the most and the least effective herbicide treatments in the height growth of seedlings planted immediately after the herbicide applications in August 1979 (Trial 1), none of the treatments was significantly different from the control (Table 4). Mortality of newly planted seedlings was also significantly affected by the treatments, with both rates of TCA and the high rate of dicamba granules and dicamba liquid causing an unacceptable mortality (i.e. over 10%). Damage symptoms persisted in many of the surviving seedlings from these treatments. Mortality was uniformly low in all treatments for seedlings planted in April 1980 (8 months after herbicide application). Height growth of seedlings from this delayed planting was not significantly affected by any of the herbicide treatments (Table 4), and no damage symptoms were apparent by December 1980.

Height growth and mortality of radiata pine seedlings planted in Trial 2 (either April 1980 or September 1980) were not significantly affected by herbicides applied in March 1980. Mortality was uniformly low for both plantings, and only minor damage symptoms were observed.

Table 2 Effects of herbicides applied in August 1979 on natural regeneration of radiata pine (Trial 1)

Herbicide	Application rate (kg ha^{-1})	Mean no. of regenerated plants ha^{-1}			Increase or decrease (%)
		Aug. 1979	Dec. 1980	Difference	
control	nil	240 000	255 840	+ 15 840	+ 6.6
paraquat + diquat	0.125 + 0.0625	286 670	18 350	−268 320	− 93.6
	0.5 + 0.25	80 000	nil	− 80 000	−100.0
TCA	4.2	130 000	34 450	− 95 550	− 73.5
	16.8	266 670	64 000	−202 670	− 76.0
dicamba granules	1.0	280 000	186 760	− 93 240	− 33.3
	4.0	250 000	159 750	− 90 250	− 36.1
dicamba liquid	1.0	303 330	5 460	−297 870	− 98.2
	4.0	240 000	nil	−240 000	−100.0
LSD P = 0.05					96.4

Table 3 Effects of herbicides applied in March 1980 on natural regeneration of radiata pine (Trial 2)

Herbicide	Application rate (kg ha^{-1})	Mean no. of regenerated plants ha^{-1}			Increase or decrease (%)
		Mar. 1980	Dec. 1980	Difference	
control	nil	256 670	226 900	− 29 770	− 11.6
paraquat + diquat	0.125 + 0.0625	280 000	206 920	− 73 080	− 26.1
	0.5 + 0.25	303 330	65 820	−237 510	− 78.3
TCA	4.2	203 330	161 440	− 41 890	− 20.6
	16.8	276 670	131 970	−144 700	− 52.3
dicamba granules	1.0	283 330	292 110	+ 8 780	+ 3.1
	4.0	230 000	209 300	− 20 700	− 9.0
dicamba liquid	1.0	200 000	228 200	+ 28 200	+ 14.1
	4.0	296 670	95 530	−201 140	− 67.8
LSD P = 0.05					56.9

Discussion

Complete control of high densities of natural seedling regeneration is essential to minimize the costs of re-establishment using seedlings raised from genetically superior seed. Only two of the herbicide treatments examined in this study provided total control of the natural regeneration, these being 0.5 kg ha^{-1} paraquat + 0.25 kg ha^{-1} diquat and 4.0 kg ha^{-1} dicamba as the dimethylamine salt applied in the first spring (August) following the fire in February. Dicamba granules were ineffective when applied at equivalent rates to dicamba liquid, presumably because dicamba liquid was both foliar and root absorbed compared to root uptake only for dicamba granules, although formulation and better coverage may also have contributed to the significant differences in efficacy. TCA was moderately effective at both rates tested, but control was not total and was therefore inadequate.

Although peak germination of natural regeneration occurred between the fire in February and the first appli-

Table 4 Effects of herbicide treatments applied in August 1979 on height growth and mortality of radiata pine seedlings planted in either August 1979 or April 1980 and measured in December 1980 (Trial 1)

Herbicide	Application rate (kg ha^{-1})	Planted August 1979		Planted April 1980	
		Height (cm)	Mortality (%)	Height (cm)	Mortality (%)
control	nil	60.7	6.7	37.1	0.0
paraquat + diquat	0.125 + 0.0625	80.5	0.0	38.5	0.0
	0.5 + 0.25	77.0	5.3	36.4	0.0
TCA	4.2	51.9	22.7	37.7	2.7
	16.8	53.5	42.7	37.9	1.3
dicamba granules	1.0	53.7	6.7	34.3	2.7
	4.0	45.0	30.7	35.6	2.7
dicamba liquid	1.0	58.8	10.7	40.6	1.3
	4.0	49.3	28.0	43.1	1.3
LSD P = 0.05		26.8	36.1	ns	ns

cation of herbicides in the following August, a further 6.6% germination took place between August 1979 and December 1980. It would be desirable to ensure that all viable pine seed germinates prior to herbicide treatment, but none of the treatments tested on the more advanced regeneration in autumn (March) 1980 was successful.

Two of the herbicide treatments in Trial 1 totally controlled the natural regeneration, but crop tolerance problems were experienced with one of these treatments when radiata pine seedlings were planted immediately following herbicide application. The application of dicamba liquid at 4.0 kg ha^{-1} was associated with a mortality of planted seedlings of 28.0%, and height growth of surviving seedlings was reduced. Conversely, 0.5 kg ha^{-1} paraquat + 0.25 kg ha^{-1} diquat resulted in increased height growth of planted seedlings without significantly affecting mortality. The difference in height growth of planted seedlings between these treatments was significant.

Application of paraquat + diquat temporarily controlled most native and introduced grasses that recolonized the site following the fire, providing largely weed-free conditions during the first summer after planting. Woods (1976) demonstrated substantial growth responses of radiata pine to weed control during the establishment phase of plantations in the locality, and it is considered that the increased growth of the planted pine seedlings on the paraquat + diquat plots was due to reduced competition for soil moisture.

Crop tolerance problems with dicamba liquid were avoided when radiata pine seedlings were planted in April 1980, 8 months after the spring application of herbicides in Trial 1. Data from Trial 2 also indicate that the plant-back period could be reduced to about 1 month. Under operational conditions, however, a site sprayed in the first spring after a fire would not be planted until the following winter, and results show that crop tolerance problems are unlikely to occur for such a long plant-back period using either of the two herbicide treatments successful in this study.

The high volume of 500 L ha^{-1} was used in this study for all liquid herbicides. Although application costs increase with increasing spray volumes, it was considered that complete coverage of the natural seedling regeneration was necessary to achieve effective control. Results are therefore restricted to a ground application.

It is concluded that either 4.0 kg ha^{-1} dicamba as the dimethylamine salt or 0.5 kg ha^{-1} paraquat + 0.25 kg ha^{-1} diquat can be used to control dense populations of natural regeneration of radiata pine seedlings under site conditions similar to those at Rennick. A high volume application in early spring is essential, and the average height of the regeneration should not exceed 5 cm at the time of treatment. Since either dicamba or paraquat + diquat is effective, the herbicide selected is likely to be dictated by cost of product and toxicological considerations. Neither herbicide is currently registered for this purpose. Spraying is easier and more effective if the dead trees are left standing and crop tolerance problems will be avoided by replanting treated sites with radiata pine seedlings in the winter following a spring application.

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