Chemical control of wilding conifer seedlings in New Zealand

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Summary

Five herbicides were tested on seedlings of seven commonly occurring wilding conifer species in both summer and winter to determine the most effective chemical and season for controlling unwanted wilding seedlings. Conifer mortalities were higher when herbicides were applied in the summer than in winter. Summer applications of glyphosate, picloram, or metsulfuron achieved >80% mortality on ponderosa pine, Douglas fir, and European larch; similar results were achieved with glyphosate or picloram on lodgepole and Scots pines, and glyphosate or metsulfuron on radiata pine. Susceptibility of the conifer species to the herbicides varied considerably, with <70% Corsican pine being killed by any of the herbicides tested.

Introduction

The uncontrolled spread of wilding conifers into unimproved grasslands is causing concern in some New Zealand hill and high-country areas. In 1975 some 30 000 ha of the Central Plateau of the North Island had an 'infrequent' to 'dense' covering of lodgepole pine (*Pinus contorta*) (Hunter and Douglas 1984). However, extensive control operations have been carried out. The largest area of spread in the South Island is on the Amuri Range, where 6000 ha have been colonized by Corsican pine (*P. nigra*) (Ledgard 1988).

Immature wilding seedlings (<2 years of age) can be controlled by intensive grazing by sheep, provided it is undertaken on at least an annual basis (Crozier and Ledgard 1990). However, if seedlings are too woody for animals to sever the stem, other control methods such as fire, physical cutting, or treating with herbicides become necessary. The use of chemical control of wilding conifer seedlings is generally restricted to areas of reasonably dense seedlings with minimal surrounding vegetation, where the spraying can be done mechanically or aerially to reduce handling of toxic substances. Mechanical cutting can be effective, if all live foliage is removed. Burning is also effective, but creates an ideal seedbed, and surviving trees require a follow-up cutting.

Some information is available on herbicide effectiveness in killing pine trees. Ammonium sulphamate and arsenical poisons were extensively used by the New Zealand Forest Service for large-scale poison-thinning of pine plantations in the 1950s and early 1960s (Cruttwell 1960), but problems were encountered with slow and incomplete killing, especially of radiata pine (*P. radiata*). Preest (1985) recommended killing sparsely scattered pines up to 3 m tall by spraying with 2,4-D oil-miscible concentrate, glyphosate, or a mixture of 2,4-D ester, paraquat, diesel oil, or by applying bromacil granules to the ground around each tree. Cut stumps of mature lodgepole pine and Scots pine (*P. sylvestris*) with an intact live lower whorl have been successfully killed by either sodium chlorate powder, ammonium sulphamate, or glyphosate plus Silwet L-77 (Crozier *et al.* 1988). Sodium chlorate was effective on mountain pine (*P. mugo*), and 2,4-D plus diesel on lodgepole pine. Since the establishment of the nursery trial described in this paper, Ray and Davenhill (1991) sprayed 12 different herbicides with adjuvants on a dense stand of self-sown lodgepole pine and found that diquat plus Silwet L-77, bromacil plus BP Crop Oil, and a mixture of glyphosate, metsulfuron and Silwet L-77 were the three most effective treatments.

This paper evaluates the effectiveness of one concentration of five readily available herbicides that were selected after an examination of available research results and discussion with experts on forest herbicides. Paraquat was not selected because of its high toxicity. The herbicides were tested on seedlings of seven introduced conifer species (commonly found spreading in the high country) in summer and winter in the Rangiora Nursery, North Canterbury. A summary of these results has been published (Crozier 1990).

Method

Lodgepole, Corsican, radiata, Scots, and ponderosa pine (*P. ponderosa*), European larch (*Larix decidua*), and Douglas fir (*Pseudotsuga menziesii*) seedlings were systematically planted in rows in eight replicated strips at the Rangiora Nursery (70 m a.s.l.) in August 1986. Seedlings of all species were 2/0 nursery stock, except for the radiata pine, which was 1/0 stock. The European larch seedlings were considered to be too tall and were trimmed back to about 45 cm after planting.

Pairs of strips were systematically laid out and replicated four times, with alternate strips designated for summer and winter treatment. The strips were divided further into eight blocks (producing 64 squares) to allow the random allocation of six treatments across all strips to be repeated eight times. This provided a total of 2688 seedlings (384 of each species) with eight seedlings of each of the seven species treated in summer with the six treatments and another set treated in winter.

The summer treatments were applied after 17 months (December 1987) when seedlings had attained an average height of approximately 50 cm. The time interval since planting allowed seedlings to become well established. Glyphosate and Silwet L-77, metsulfuron and Silwet L-77, triclopyr, and 2,4-D and Triton X45 were spot-sprayed 'to wet' on allocated seedlings (Table 1). Fifty grams of picloram granules were placed at the base of seedlings selected for this treatment. An equal number of seedlings was left untreated as a control. The winter treatment was applied after 22 months (July 1988) when seedlings had attained an average height of 84.5 cm. The same treatments were applied with the exception of picloram.

The strips treated in summer were assessed four times: after the peak of the three growing seasons (February 1988, 1989, and 1990) and in July 1988 (i.e., 2, 6, 13, and 25 months after herbicide applica-

Table 1. Herbicide treatments.

Herbicide	Product	Active ingredient	Mixture
glyphosate	Roundup	360 g/l	1% glyphosate
Silwet L-77	Pulse		+ 0.5% Silwet L-77
metsulfuron	Escort	600 g/kg	25 g metsulfuron/100 litres
Silwet L-77	Pulse		+ 0.5% Silwet L-77
picloram	Tordon 2G	20 g/kg	50 g/tree
triclopyr ester	Grazon	600 g/l	0.3% triclopyr
2,4-D butyl ester		360 g/l	2% 2,4-D + 20% diesel
Triton X-45			+ 0.3% Triton X-45

Footnote:

This paper was presented at the First International Weed Control Congress, 17-21 February 1992, Melbourne, but did not appear in the proceedings.

tion). The strips treated in winter were assessed in February 1989 and 1990 (i.e., 7 and 19 months after application). Trees were visually assessed into five health categories (score 1–5, where 1 = healthy and 5 = dead), the percentage of foliage killed was estimated, and the height of live foliage was measured to ensure an assessment of the extent of herbicide effect was recorded even if death was not achieved. Mortality was ascertained from the number of trees in health category five (those with 100% dead foliage and zero height for live foliage). Percent mortality was transformed by square root before analysis.

Results were analysed by factorial ANOVA, considering the effects of herbicides, season, species, blocks, and the appropriate interactions. The a-priori pair comparisons between each treatment and its control were tested for significance using the least significance difference test. Post-hoc comparisons amongst the treatments within each summer and winter application were made using Tukey's honest significant difference (HSD) method (Einot and Gabriel 1975).

Results

Species were generally slow to respond to the herbicide application, and response time varied with species and herbicide (Figure 1). For example, lodgepole pine and Douglas fir responded quickly to summer application of glyphosate (>83% mortality 2 months after treatment), whereas the full effect of this chemical on Corsican and radiata pines was not revealed until at least two growing seasons had elapsed.

Species varied in their overall ($p<0.001$) and individual ($p<0.001$) susceptibility to the herbicides tested, even after two growing seasons when delayed reaction time was no longer a consideration for any species (Table 2). Results after two growing seasons showed that summer applications of glyphosate, picloram, and metsulfuron were the most effective in killing all seven conifer species. Glyphosate caused 100% mortality in lodgepole and Scots pines, and 69% mortality in Corsican pine, the species most resistant to this herbicide. Picloram caused 100% mortality in lodgepole pine, European larch and Douglas fir, but only 43% mortality in radiata pine seedlings. Metsulfuron did not cause 100% mortality in any species, but was most effective on ponderosa pine, radiata pine, and European larch (mortality > 96%) and least effective on lodgepole pine (mortality 34%). A number of summer and winter-treated radiata pine trees were unaffected by metsulfuron (3% were in health categories 1 and 2 at February 1990 after summer metsulfuron application, and 96% after winter application). Triclopyr killed a significant proportion of European larch seedlings only (mortality 50%) and 2,4-D was ineffective on all species (mortalities <20%).

The winter treatments were less successful than the summer ones ($p<0.001$). Of the herbicides applied in the winter only glyphosate caused significant seedling mortality (Table 2), and then only to ponderosa pine, Scots pine and Douglas fir seedlings (mortality >87%).

Death of untreated control trees was relatively high for European larch for the winter treatments (mortality 23%) (Table 2). Mortality was 11% for ponderosa pine in the same blocks and 13% for Douglas fir in the summer treatment blocks. Otherwise mortality of control trees was <4%. The high mortality can be attributed to the highly compacted soil in the nursery, and the low rainfall (680 mm mean annual rainfall), which was not particularly favourable for conifer species requiring higher rainfall for good growth.

Overall, Corsican and radiata pines were the hardest species to kill (Table 3). The best herbicides to kill radiata pine were glyphosate and metsulfuron applied in summer (> 83% mortality), but no chemical tested exceeded 69% mortality for Corsican pine. European larch was the most susceptible species when treated with herbicides in summer, but was harder to kill in winter than other species (Table 3).

The final results of the health category assessments almost mirror the percent mortality figures for the overall effectiveness of summer and winter herbicide application (Table 4). In addition, the health categories and dead foliage data provided information on the early effects of the herbicides, the number of trees which remained healthy despite herbicide (such as metsulfuron) application, and indicated that higher concentrations of herbicides (such as 2,4-D and triclopyr) would possibly be more effective, where mortality was not achieved.

Discussion

Foliage-applied herbicides are generally poorly translocated in pines (Preest 1985) and seedlings had an average height of >50 cm so a slow response is to be expected. Assessments after two growing seasons were considered to be generally indicative of long-term survival or death as the seedlings that still survived in the final assessment were generally healthy and likely to continue to survive. It is possible, however, that some of the seedlings categorized as nearly dead would not survive after the same treatment in the harsher climate of the high country.

Limitations on the trial size prevented testing more than one concentration of each herbicide. Higher concentrations of the herbicides, particularly triclopyr and 2,4-D, however, may produce higher levels of mortality. Since the establishment of this trial it has been found that triclopyr can be safely used before the onset of spring growth as a post-plant blanket spray to first-year radiata pine up to 1.8 kg/ha concentration (Saville 1989), but caused malformation to radiata pine and Douglas fir when sprayed in summer at

Table 2. Percentage mortality and herbicide effectiveness on the seven species tested, February 1990 assessment (25 months after summer and 19 months after winter application). Significances relate to the pair comparison of each treatment with its appropriate control.

Summer herbicide application

	glyphosate	picloram	metsulfuron	triclopyr	2,4-D	control
Lodgepole pine	100***	100***	34.4***	16.1 NS	6.5 NS	3.1
Corsican pine	68.8***	62.5***	62.5***	0 NS	0 NS	0
Ponderosa pine	91.3***	92.9***	96.0***	21.7 *	3.7 NS	3.9
Radiata pine	82.8***	42.9***	96.8***	3.2 NS	6.7 NS	0
Scots pine	100***	87.5***	75.0***	0 NS	0 NS	0
European larch	96.4***	100***	96.3***	50.0**	20.0 NS	4.2
Douglas fir	93.1***	100***	80.0***	23.3 NS	9.7 NS	13.3

Winter herbicide application

	glyphosate	metsulfuron	triclopyr	2,4-D	control
Lodgepole pine	40.6***	3.1 NS	0 NS	6.9 NS	3.2
Corsican pine	18.8***	0 NS	3.1 NS	0 NS	0
Ponderosa pine	89.3***	16.7 NS	7.4 NS	8.7 NS	10.7
Radiata pine	10.3***	3.7 NS	3.5 NS	0 NS	0
Scots pine	87.1***	10.3 NS	0 NS	3.2 NS	3.1
European larch	25.0 NS	20.9 NS	16.7 NS	28.0 NS	22.7
Douglas fir	88.9***	38.7**	7.1 NS	0 NS	3.5

*** significant $p<0.001$
** significant $p<0.01$
* significant $p<0.05$
NS not significant

Table 3. Scale of decreasing mortality from all herbicides, 25 months after summer treatment and 19 months after winter treatment. Species with a similar mortality (p>0.05) are linked (Tukey's HSD).

Summer treatment — mortality
- European larch
- Douglas fir
- Ponderosa pine
- Scots pine
- Lodgepole pine
- Radiata pine
- Corsican pine

Winter treatment — mortality
- Douglas fir
- Ponderosa pine
- Scots pine
- European larch
- Lodgepole pine
- Corsican pine
- Radiata pine

concentrations >0.6 kg/ha (Saville 1989, Balneaves and Davenhill 1990). Therefore, higher rates than those used in this study seem necessary to cause mortality, even with summer application and spot spraying trees 'to wet'.

Ray and Davenhill (1991) obtained adequate mortality (85%) with 1.7 kg a.i. ha^{-1} glyphosate, 0.5 % Silwet L-77 and 0.03 kg a.i. ha^{-1} metsulfuron on lodgepole pine but inadequate results with 2.04 kg a.i. ha^{-1} glyphosate and 0.5 % Silwet L-77 in the absence of metsulfuron (13 % mortality) applied in December with a hand-held boom to simulate aerial spraying. This is a contrast to the 100% mortality obtained with glyphosate and the same surfactant in my nursery trial. Ray and Davenhill (1991) suggest that the high mortality obtained with glyphosate and Silwet L-77 in my trial may be the result of smaller trees (average height 50 cm compared with 90 cm) and the much higher spray volumes used when spot spraying individual trees to the point of run-off.

The variable susceptibility of the conifer species to herbicides has management implications. Recommendations for herbicide control of unwanted wildings must be species-specific.

Picloram is the easiest chemical to apply in the high country where a water supply is not readily available, but is considerably more expensive than the other chemicals tested. Picloram and 2,4-D are also easily leached under high rainfall conditions (Hamaker *et al.* 1963); a problem not generally encountered with the other herbicides tested. Although picloram generally performed well it should not be recommended for radiata pine as it was not found to be sufficiently effective.

Applications of metsulfuron and glyphosate were more effective than picloram in killing radiata pine. However, metsulfuron is limited to producing >80% mortality on ponderosa pine, Douglas fir, and European larch. The resistance in a small percentage of radiata pine to metsulfuron has also been recorded for other species. Fifty percent of lodgepole pine they sprayed with 0.1 kg a.i. ha^{-1} metsulfuron were only slightly affected (Ray and Davenhill 1991).

Corsican pine, one of the less susceptible conifers to chemical treatment, and the least palatable to sheep of the same seven species tested (Crozier and Ledgard 1990), may require an even higher concentration of herbicides than other species.

In winter the only herbicides producing results significantly different from the untreated control were glyphosate (on all species except European larch) and metsulfuron (on Douglas fir only). Seedlings were larger when the winter treatments were applied, and there is a slight possibility of further mortality of seedlings in the nearly dead category after another growing season. However, a lower response to winter application is supported by Radosevich *et al.* (1980), who found that conifers were more tolerant to herbicides after autumn dormancy, and herbicide treatments were considerably more successful in spring or summer when moisture stress was low and photosynthesis was high. Balneaves and Davenhill (1990) also reported that trees sprayed in the dormant growth stage were less influenced by herbicide treatment than those sprayed after the spring flush started. The variation in susceptibility of European larch to summer and winter herbicide application is almost certainly linked to the absence of foliage in winter.

The use of picloram, 2,4-D, triclopyr, or metsulfuron is unlikely to kill non-target species in tussock grassland environments. However, where indigenous broad-leaved species are present, all herbicide treatments may cause unacceptable damage to the surrounding vegetation. Particularly careful application is necessary with glyphosate as it can kill grasses. Ray and Davenhill (1991) found glyphosate either alone or mixed with other chemicals markedly reduced grass and flat weed ground cover, though glyphosate and Silwet L-77 caused less damage to ground cover than glyphosate with Silwet L-7607.

Table 4. Mean health categories and herbicide effectiveness on the seven species tested, February 1990 assessment (25 months after summer and 19 months after winter application). Significances relate to the pair comparison of each treatment with its appropriate control.

Summer herbicide application

	glyphosate	picloram	metsulfuron	triclopyr	2,4-D	control
Lodgepole pine	5.0***	5.0***	2.7***	2.1 NS	1.6 NS	1.6
Corsican pine	4.3***	4.5***	3.5***	1.2 NS	1.2 NS	1.3
Ponderosa pine	4.8***	4.9***	4.8***	2.3 *	1.4 NS	1.5
Radiata pine	4.5***	3.5***	4.9***	1.3 NS	1.6 NS	1.5
Scots pine	5.0***	4.8***	4.2***	1.2 NS	1.5 NS	1.5
European larch	4.9***	5.0***	4.9***	3.3 **	2.1 NS	1.4
Douglas fir	4.8***	5.0***	4.4***	2.4 NS	2.0 NS	2.2

Winter herbicide application

	glyphosate	metsulfuron	triclopyr	2,4-D	control
Lodgepole pine	3.6***	1.7 NS	1.4 NS	1.8 NS	1.7
Corsican pine	2.9***	1.3 NS	1.3 NS	1.3 NS	1.3
Ponderosa pine	4.7***	1.9 NS	1.6 NS	1.8 NS	1.8
Radiata pine	2.3***	1.3 NS	1.4 NS	1.3 NS	1.3
Scots pine	4.7***	1.9 NS	1.4 NS	1.7 NS	1.4
European larch	2.3 NS	1.9 NS	1.8 NS	2.4 NS	2.2
Douglas fir	4.7***	2.9 **	1.8 NS	1.5 NS	1.7

*** significant p<0.001
** significant p<0.01
* significant p<0.05
NS not significant

Conclusions

Glyphosate, picloram, and metsulfuron were the most effective herbicides in killing all seven conifer species if applied in the summer when the seedlings were actively growing. Percent mortalities, however, were only >80% with glyphosate, picloram, and metsulfuron on ponderosa pine, European larch, and Douglas fir; glyphosate and picloram (but not metsulfuron) on lodgepole and Scots pines; and glyphosate and metsulfuron (but not picloram) on radiata pine.

These results can serve only as indications of herbicide effectiveness for controlling unwanted wilding conifers as the trial was limited to five herbicides at a sin-

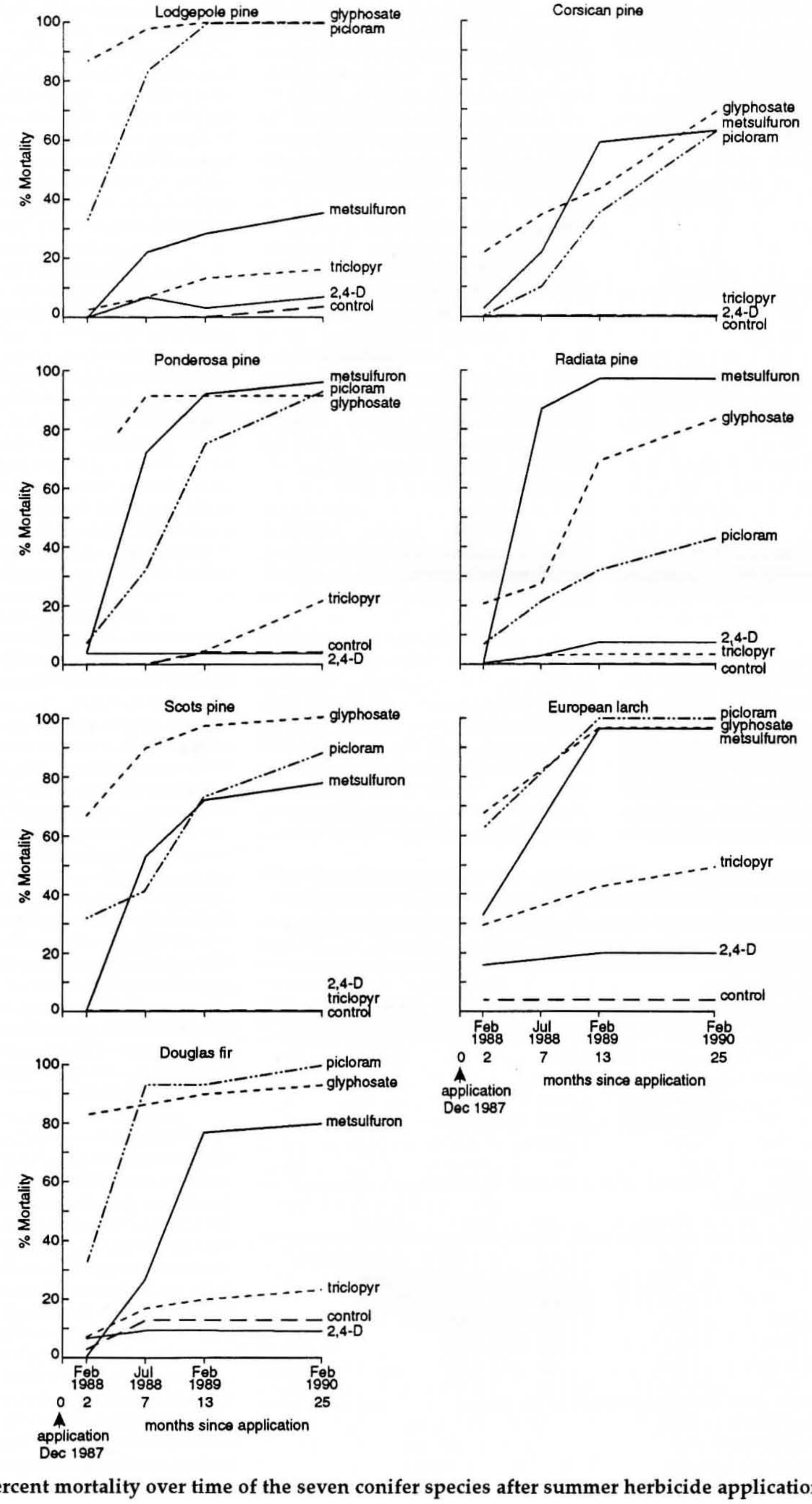

Figure 1. Percent mortality over time of the seven conifer species after summer herbicide application.

gle concentration, applied to two sizes of conifer species growing in a nursery. Indications are, however, that where herbicides are the most practical means of controlling wilding conifer seedlings, glyphosate, metsulfuron, or picloram should be considered for application during the active growing season. Further field testing is needed to produce more detailed recommendations and to determine likely impact on native grassland vegetation surrounding wilding conifers.

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Post-control regeneration of vulpia

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Summary.

The annual grass vulpia is rapidly becoming a weed of pastures and is difficult to control. A field experiment in 1988–90 comparing the effectiveness of paraquat and glyphosate as spray-topping treatments on control of *Vulpia* spp. showed that:

i) the optimum application time for glyphosate was earlier than for paraquat
ii) control can be improved by increasing the application rate
iii) control by spray-topping is transient and needs to be supplemented with other inputs (e.g., fertilizer) for longer term control.

Introduction

Vulpia (mainly *Vulpia bromoides* (L.) S.F. Gray and *V. myuros* (L.) C.C. Gmelin) is a naturalized winter growing annual grass with many undesirable attributes. Recently, it has become a major component of pastures in southern Australia.

Once it has invaded a pasture, vulpia is difficult to remove because of inherent tolerance to selective grass herbicides. Spray-topping in the spring with paraquat or glyphosate, or application of simazine in the winter, reduces the initial incidence of vulpia but the length of the control period is not well defined.

Footnote:

This paper was presented at the First International Weed Control Congress, 17-21 February 1992, Melbourne, but did not appear in the proceedings.

Materials and methods

During 1988–90, a field experiment was conducted at Bathurst NSW to investigate the longevity of control of vulpia after imposing spray-topping treatments of glyphosate and paraquat during spring 1988. The treatments were: recommended rates of glyphosate (0.16 kg ha^{-1} a.i.) and paraquat (0.1 kg ha^{-1} a.i.) and double rates, each applied at four different development stages (65, 78, 88, 90% peeping – seedhead visible); and an unsprayed control

Spray-topping is a technique where low rates of knockdown herbicide are applied to emerging seedheads of weeds (mainly annual grasses) in spring. The aim is to sterilize the seeds and reduce regeneration in the following season.

Results

Regeneration in 1989 was significantly reduced by spray-topping, the degree of control increasing as the rate of herbicide increased and as the timing of herbicide application approached the optimal time. Numbers of vulpia seedlings were reduced from 21 319 m^{-2} on the unsprayed control to 3346 and 5040 m^{-2} for recommended rates of paraquat and glyphosate, respectively and at the double rate, numbers were further reduced by 46% and 51%, respectively. Over the four application times, control on the paraquat plots increased with later application (73 to 91%) while that for glyphosate decreased (88 to 46%).

However, regeneration in 1990, after two opportunities for vulpia to seed, was greater (4193 vs. 15 535 m^{-2}) where the degree of control was higher when measured in the first season after herbicide application (1989). Indeed, where no herbicide was applied in 1988, vulpia seedling numbers, while higher in 1989, were lower in 1990 (21 319 vs. 7809 m^{-2}) when compared with the treatments sprayed in 1988.

Conclusions

Results show the importance of timing of herbicide application on degree of vulpia control obtained. Where initial control is poor, increasing the application rate may be an option.

The second year results are contrary to what is expected after spray-topping, and indicate the rapidity of regression if other factors (e.g., livestock management, fertilizer) are not also integrated into the control program to slow the rate of reinvasion.