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## Preliminary screening of herbicide mixes for the control of five major weed species on certified *Pinus radiata* plantations in New Zealand.


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### Abstract

The herbicides terbuthylazine and hexazinone are widely used by the New Zealand forest industry to control a range of weeds during first year vegetation management operations. These herbicides do not comply with certain eco-certification criteria and have been placed on a list of prohibited pesticides by the Forest Stewardship Council (FSC). Currently, they cannot be used on FSC-certified land unless an approval is obtained. A pot trial was conducted to test for a combination of herbicides, not currently prohibited by the FSC, that might have the potential to provide control of a wide range of weeds, including both broadleaves and grasses, with low phytotoxicity to *Pinus radiata* D.Don. Two groups of active ingredients were included in mixes used in the trial: (1) triclopyr, clopyralid and picloram for control of broadleaves; and (2) haloxyfop and quizalofop for control of grasses. Terbuthylazine was also included in the trial in the event that an approval is obtained for continued use there-of in New Zealand. We tested the herbicide combinations at 25%, 50%, 75% and 100% of recommended rates on six species: *Pinus radiata, Cytisus scoparius* L. (broom)*, Buddleja davidii* Franchet (buddleja)*, Ulex europaeus* L. (gorse)*, Holcus lanatus* L. (fogg grass) *and Cortaderia selloana* (Schult) Asch. et Graeb. (pampas).

The results indicated that potential replacements for hexazinone and terbuthylazine during year one for the control of fogg grass, pampas, broom and gorse are haloxyfop, clopyralid, triclopyr and picloram. Terbuthylazine used in combination with triclopyr and picloram was the only combination of herbicides tested that caused mortality of buddleja. The herbicide combinations and rates require further testing both in pot and field trials before robust recommendations for field application can be made.



**Keywords:** broom; buddleja; certification; fogg grass; gorse; pampas; scrub weeds; vegetation control.


## Introduction

Management of competing vegetation during the establishment of plantation trees is the single most important silvicultural practice used to maximise timber yield (Wagner et al., 2006). Globally, 74% of long-term studies have shown gains in wood volume from 30% to 500% in response to effective vegetation management (Wagner et al., 2006). The short-term benefits of vegetation management during the establishment of *Pinus radiata* D.Don, the most widely planted commercial forest tree species in New Zealand, include a significant increase in early survival and growth. These benefits typically advance stand development in the long term by one to four years over treatments with no control of competing vegetation (Mason & Milne, 1999; Richardson et al., 1984; Squire, 1977; Wagner et al., 2006; Watt et al., 2003). Since




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New Zealand's *P. radiata* plantations are primarily managed for profit, cost effectiveness is one of the principal criteria underpinning choice of vegetation management strategy. Currently, the most cost-effective vegetation management strategies in New Zealand involve the use of herbicides, both in pre-plant site preparation treatments and for release during the first, and sometimes the second, year after planting (Rolando, et al., 2011).

Environmental considerations are starting to change the operational use of herbicides in plantation forestry (Forest Stewardship Council, 2007). Where previously responsible use of herbicides was the domain of the forest company and local authorities, the environmentally conscious consumer, or public, now play a larger role in setting the guidelines. Public demand for timber products from sustainably managed resources has led to voluntary compliance of forest companies with independent forest certification schemes, such as the Forest Stewardship Council (FSC). These certification schemes ensure forest management systems comply with environmentally aligned principles and criteria that define their operating environment (Hock & Hay, 2003). Certified wood products are increasingly attracting a price premium, particularly in the United States of America (USA) and Europe (Forsyth et al., 1999; Kollert & Lagan, 2007; Ozanne et al., 1999). Improved access for certified wood products has meant that certification is currently a priority for many forest companies (Araujo et al., 2009; Bowyer, 2008; Carnegie et al., 2005; Goulding, 2006). In New Zealand, 56% of plantations are currently certified by the FSC, an internationally recognised eco-certification body that promotes the use of sustainable forest management systems. Amongst a host of principles and criteria that define the operating environment for FSC-certified forests, Principle 6 (Environmental Impact) states that management systems should strive to avoid the use of pesticides, especially those designated as 'hazardous' according to the FSC criteria used to evaluate safety of pesticides (FSC, 2007). Two of the most commonly used herbicides in New Zealand plantation management do not meet the FSC criteria for acceptable pesticides and have been designated as hazardous (FSC, 2007; Gous, 2005). These are terbuthylazine and hexazinone (Tradenames: Valzine®, Release®, Gardoprim®). This means forest companies that are certified by FSC require approval (or derogation) for their use in vegetation control operations and, potentially, these herbicides could be prohibited for use on FSC-certified land.

Terbuthylazine ($N^2$-tert-butyl-6-chloro-$N^4$-ethyl-1,3,5-triazine-2,4-diamine) and hexazinone (3-cyclohexyl-6-dimethylamino-1-methyl-1,3,5-triazine-2,4-(1*H*, 3*H*)-dione) are currently used in New Zealand forestry to control a range of competitive weed species during the first year after planting *Pinus radiata* (Gous, 2005). The key attributes of these two herbicides, which underpin their value to the forestry sector, are: (i) their selectivity to *P. radiata* (no phytotoxic damage); and (ii) their persistence that provides activity, following either aerial or spot treatment, to reduce weed growth for up to one year. These attributes are particularly relevant for the control of some of the more competitive weeds that occur on forest plantations (Richardson et al., 1996). Some of the major species of weeds that occur in forest plantations are broom (*Cytisus scoparius* L.), gorse (*Ulex europaeus* L.), buddleja (*Buddleja davidii* Franchet), blackberry (*Rubus fruticosus* L.), bracken (*Pteridium esculentum* (G.Forst.) Cockayne) and grasses.

As 56% of the plantation forests in New Zealand are FSC certified there is a need to test suitable replacement herbicides that will conform to minimum acceptable criteria as determined by FSC. The long-term goal of eco-certification is to reduce or eliminate the use of herbicides on forest land. However, until cost-effective, non-chemical vegetation control strategies have been developed, the use of herbicides will remain the most important method of weed control for commercially managed forest operations (Rolando et al., 2011). Potential replacement herbicides for terbuthylazine and hexazinone currently registered in New Zealand include triclopyr (3,5,6-trichloro-2-pyridyloxyacetic acid), picloram (4-amino-3,5,6-trichloropicolinic acid), clopyralid (3,6-dichloropyridine-2-carboxylic acid), haloxyfop ((RS)-2-[4-(3-chloro-5-(trifluoromethyl)-2-pyridyloxy)phenoxy]propionic acid)) and quizalofop (R-2-[4-(6-chloroquinoxalin-2-yloxy)phenoxy]propionic acid). These herbicides are not listed as hazardous by the FSC (2007). Triclopyr and clopyralid are selective, systemic broadleaf herbicides (Tomlin, 2006). Haloxyfop and quizalofop are selective grass herbicides.

Some research has already been conducted to determine the potential to use triclopyr, clopyralid and haloxyfop for weed control in New Zealand plantations. Published results were mostly dose-response studies focusing on the application of a single active ingredient (triclopyr, clopyralid or haloxyfop) to *Pinus radiata* (to test for phytotoxicty) or selected forest weeds. Saville (1989) and Balneaves and Davenhill (1990) evaluated the tolerance of *P. radiata* seedlings to application of triclopyr. They found that during tree dormancy the application of up to 1.8 kg $ha^{-1}$ triclopyr had no effect on tree growth, while during active growth, rates up to a maximum of 0.6 kg $ha^{-1}$ could be applied. The New Zealand Novachem Agricultural manual recommends 0.6 to 1.2 kg $ha^{-1}$ triclopyr to control forest weeds (for example gorse, broom) during the first year after planting (Young, 2010). Davenhill (1989) evaluated various herbicides for pampas control, including haloxyfop, and recommended application rates of 1.0 – 1.5 kg $ha^{-1}$ to kill pampas that was up to 1 m tall. The New Zealand Novachem Agricultural manual


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recommends 0.75 kg $ha^{-1}$ haloxyfop for control of pampas less than 1 m high and between 0.125 and 0.25 kg $ha^{-1}$ to control *Holcus lanatus* L., fogg grass (Young, 2010). Clopyralid (1.5 kg $ha^{-1}$), used in combination with triclopyr (0.15 kg $ha^{-1}$) and picloram (0.05 kg $ha^{-1}$), is used by the forest industry to control broom in the second year after planting. However, the impact of this herbicide combination on younger trees needed to be established.

It is a generally accepted practice to first screen new herbicides and mixes under fixed environmental conditions to enable comparisons between active ingredients to be made (Copping et al., 1990). Although field trials are important, environmental conditions cannot be controlled and may show extreme variation which can alter the basic performance of active molecules. When specific interactions need to be studied, field trials and controlled studies can be run concurrently (Copping et al., 1990). The broad aim of mixture trials (where herbicides are mixed prior to application) is to define the interaction between a number of quantitative factors, such as concentration of herbicide, surfactant and oil, and determine a combination of levels, by interpolation, which gives the desired result (Copping et al., 1990). Using a tank mixture of selective herbicides can be as effective as applying broad-spectrum herbicides, whilst minimising risk of damage to young trees.

A preliminary dose response pot trial aimed at investigating alternatives to terbuthylazine and hexazinone for the release of *Pinus radiata* during the first year after planting was conducted during the summer of 2009 to 2010. Potential candidate herbicides could then be tested in subsequent aerial application field trials. Herbicides currently registered in New Zealand were tested in combinations that would provide broad-spectrum control of a wide range of weeds, including both broadleaves and grasses, with low phytotoxicity to *P. radiata*. Two groups of active ingredients were included in the trial: (1) triclopyr, clopyralid and picloram for control of the broadleaves; and (2) haloxyfop and quizalofop for control of the grasses (Table 1). Terbuthylazine was also included in the trial in the event that an approval is obtained for its continued use. A study by Watt et al. (2010) indicated that mobility of terbuthylazine in New Zealand forest soils may be limited, especially on soil with high levels of organic carbon. This means the herbicide could pass some of the FSC criteria for which it has been prohibited on FSC-certified land (FSC, 2007; Watt et al., 2010). This information could provide motivation for the continued, yet reduced use of terbuthylazine in certified forests, either alone or in combination with herbicides other than hexazinone.

TABLE 1: Summary of the active ingredients and products included in the treatments tested in the pot trial. Details of active ingredients are taken from Tomlin (2006).

<table>
<tr><th>Product</th><th>Active ingredient</th><th>Mode of Action</th></tr>
<tr><td rowspan="2">Agpro Valzine 500<br>Agpro NZ Ltd</td><td>Hexazinone: 100g $L^{-1}$</td><td>Non-selective, primarily contact post-emergence herbicide, absorbed by leaves and roots. Effective against many annual and biennial weeds.</td></tr>
<tr><td>Terbuthylazine: 400 g $L^{-1}$</td><td rowspan="2">Pre- or post emergence herbicide absorbed mainly by the roots. Effective against a wide range of weeds.</td></tr>
<tr><td>Gardoprim® 500 FW<br>Orion Crop Protection Ltd.</td><td>Terbuthylazine: 500 g $L^{-1}$</td></tr>
<tr><td>Versatill®<br>Dow Agrosciences (NZ) Ltd.</td><td>Clopyralid: 300 g $L^{-1}$</td><td>Post-emergence, selective systemic herbicide absorbed by leaves and roots. Effective against broadleaved plants in the families Polygonaceae, Compositae, Leguminosae and Umbelliferae.</td></tr>
<tr><td rowspan="2">Tordon® Brushkiller<br>Dow Agrosciences (NZ) Ltd.</td><td>Picloram: 100 g $L^{-1}$</td><td>Growth regulator. Selective systemic herbicide, absorbed by roots and leaves. Phytotoxic to most broadleaved plants.</td></tr>
<tr><td>Triclopyr: 300 g $L^{-1}$</td><td rowspan="2">Synthetic auxin. Selective systemic post-emergence herbicide, absorbed by foliage and roots. Control of woody plants and broadleaved weeds.</td></tr>
<tr><td>Grazon®<br>Dow Agrosciences (NZ) Ltd.</td><td>Triclopyr: 600 g $L^{-1}$</td></tr>
<tr><td>Gallant® NF<br>Dow Agrosciences (NZ) Ltd.</td><td>Haloxyfop: 100 g $L^{-1}$</td><td>A selective herbicide, absorbed by foliage and roots. Used for post-emergence control of annual and perennial grasses.</td></tr>
<tr><td>Targa®<br>Gowan Company</td><td>Quizalofop: 100 g $L^{-1}$</td><td>Post-emergence systemic herbicide for control of annual and perennial grasses.</td></tr>
</table>


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## Materials and Methods

### Description of the trial

The dose response pot trial was conducted at the Scion nursery, Rotorua (New Zealand). Seven combinations of herbicides were tested at five rates (0, 25%, 50%, 75% and 100% of the full rate listed in Table 2) on five major weed species and on *Pinus radiata* (Table 2). For each rate tested, each herbicide in the mix was reduced by the equivalent percentage (25%, 50% or 75%) of the full rate. Maximum rates were based on available literature (Davenhill, 1989; Gous, 2005; Saville, 1989; Young, 2010). The weed species included in the trial were buddleja, broom, gorse, pampas (*Cortaderia selloana* (Schult) Asch. et Graeb.) and fogg grass. The treatments consisted of mixes of the active ingredients triclopyr, triclopyr and picloram, and clopyralid for control of the broadleaved weeds, with some treatments including either haloxyfop or quizalofop to include control of grasses. A treatment that tested the efficacy of triclopyr and picloram as a replacement for hexazinone in the standard terbuthylazine and hexazinone mix was also included (Table 2). The treatments were benchmarked against a control (0%) and the current operational standard using terbuthylazine and hexazinone (Treatment 7; Table 2). All treatments, except Treatment 7, were applied with the organosilicone surfactant polydimethylsiloxane (Pulse™, Monsanto Ltd., Australia), a wetting agent that reduces surface tension in the spray drops resulting in a wider spread of droplets on the leaf surface. Consisting largely of pre-emergent soil active herbicides, Treatment 7 did not require addition of surfactant. Plants in the control treatment were sprayed with water only.

Seedlings of the five weeds species were grown from seed and transplanted, one each, in 0.65 L pots. They were four months old at the time of treatment application. This included a six-week hardening-off phase where seedlings were exposed to an open environment. One year old *Pinus radiata* bareroot seedlings were planted each into 6.0 L pots in June 2009 and left to establish in an open environment for the four months until treatment application such that the seedlings were at a size representative of that in the field during a first year weed control operation (Table 3).

A moving belt track sprayer, calibrated to deliver 150 L $ha^{-1}$ carrier (water), was used to apply the treatments. Each dose (0, 25%, 50%, 75% and 100%) of each treatment (Table 2) consisted of five replications of six seedlings of each of the six species, with a total of 180 seedlings (five replications x six seedlings x six species) tested per dose and 900 seedlings per herbicide treatment. Each replication of each dose was treated separately in the trracksprayer and was maintained as a separate block following herbicide application. The

TABLE 2: Treatments (100% rate) included in the dose response pot trial. All treatments were applied at 0, 25%, 50%, 75% and 100% of the listed rate on *Pinus radiata*, buddleja, broom, gorse, pampas and fogg grass. The application volume was 150 L $ha^{-1}$ for all treatments and included the organosilicone surfactant Pulse™ at 0.5 L $ha^{-1}$ in all treatments except that of no. 7.

| Treatment No. | Product and rate | Active ingredient and rate |
|---|---|---|
| 1 | Versatill® & Tordon® (5 L $ha^{-1}$ + 0.5 L $ha^{-1}$) | clopyralid (1.5 kg $ha^{-1}$), triclopyr (0.15 kg $ha^{-1}$), picloram (0.05 kg $ha^{-1}$) |
| 2 | Gallant® & Tordon® (2.5 L $ha^{-1}$ + 1 L $ha^{-1}$) | haloxyfop (0.25 kg $ha^{-1}$), triclopyr (0.3 kg $ha^{-1}$), picloram (0.1 kg $ha^{-1}$) |
| 3 | Gallant®, Tordon® & Versatill® (2.5 L $ha^{-1}$ + 0.5 L $ha^{-1}$ + 5 L $ha^{-1}$) | haloxyfop (0.25 kg $ha^{-1}$), triclopyr (0.15 kg $ha^{-1}$), picloram (0.05kg $ha^{-1}$), clopyralid (1.5 kg $ha^{-1}$) |
| 4 | Gallant® & Grazon® (2.5 L $ha^{-1}$ + 1 L $ha^{-1}$) | haloxyfop (0.25 kg $ha^{-1}$), triclopyr (0.6 kg $ha^{-1}$) |
| 5 | Gardoprim® & Tordon® (17 L $ha^{-1}$ + 0.5 L $ha^{-1}$) | terbuthylazine (8.5 kg $ha^{-1}$), triclopyr (0.15 kg $ha^{-1}$), picloram (0.05 kg $ha^{-1}$) |
| 6 | Targa™, Tordon® & Versatill® (10 L $ha^{-1}$, 0.5 L $ha^{-1}$ and 5 L $ha^{-1}$) | quizalofop (1.0 kg $ha^{-1}$), triclopyr (0.15 kg $ha^{-1}$), picloram (0.05 kg $ha^{-1}$), clopyralid (1.5 kg $ha^{-1}$) |
| 7 | Valzine® (20 L $ha^{-1}$) | terbuthylazine (8 kg), hexazinone (2 kg $ha^{-1}$) |


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TABLE 3: Minimum and maximum (± standard error) seedling height (cm) at the time of herbicide application.

| Species | Height (cm) | | | |
|---|---|---|---|---|
| | Minimum | | Maximum | |
| Broom | 5.4 | ±0.2 | 19.0 | ±1.1 |
| Buddleja | 12.8 | ±1.2 | 24.6 | ±1.0 |
| Fogg grass | 11.0 | ±0.7 | 17.4 | ±0.8 |
| Gorse | 7.9 | ±1.1 | 29.8 | ±1.6 |
| Pampas | 22.4 | ±3.6 | 58.1 | ±4.3 |
| Pine | 18.5 | ±0.4 | 35.4 | ±1.6 |

seedlings were treated with the respective herbicide treatments and rates in mid-October 2009 after which they were replaced in an open environment.

Measurements of herbicide damage on all species were made at monthly intervals for three months (0, 30, 60 and 90 days) following treatment application. A visual estimate of the percentage damage was made, scaling from 0 – 10, where 0 represented no damage and 10 represented 100% damage and mortality. Measurements of plant height (ht) were also made at the time of treatment application and three months later at trial termination. Height was measured to the growing tip or to the height of green foliage, if the growing tip was dead. Additional measures were made on the *Pinus radiata* seedlings to fully capture the effect of the treatments on tree growth. The groundline diameter (gld) and health of the *P. radiata* seedlings was assessed at all measurements. At 30 days the health of the growing tips was scored from 0 to 3 where 0 = healthy and 3 = scorched and dead. At 90 days, trees were scored for the presence/absence of multiple growing tips (where 0 = absent and 1 = present) and contorted growth (where 0 = not contorted; 1 = slightly contorted and 2 = severely contorted). The trial was terminated at 90 days after treatment application.

### Analysis of data

All data were analysed using SAS Version 9.2 (SAS Institute Inc., Cary, NC, USA). Dose response mortality was analysed with PROC GENMOD using a binomial distribution. A functional form was used to describe the dose response to ensure any threshold in mortality was adequately described by the shape of the model and interpolation between rates could be made. Both treatment rate and initial height were included in the model as continuous effects. Quadratic terms describing the effect of treatment rate on mortality were included in the model where found to be significant (Table 4).

TABLE 4: Summary of analyses of mortality for each weed species in response to herbicide rate (0, 25%, 50%, 75% and 100%) and intial height (Init. ht). Shown are *F*-values. Superscripts *, ** respectively denote significance at $P$<0.05 and $P$<0.01. Shaded areas indicate treatment effects that were not significant or where no mortality occurred.

| Weed | Source | Treatment[1] | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Broom | Init. ht | 3.1 | 1.85 | 0.19 | 0.5 | 2.78 | 66.7** | 2.23 |
| | Rate | 650.0** | 10.70** | 22.29** | 15.8** | 24.45** | 374.4** | 12.6** |
| | $Rate^2$ | | 3.16 | 7.07* | | 7.43* | | 7.0* |
| Buddleja | Init. ht | | | | | 1.4 | | 148.9** |
| | Rate | | | | | 454.2** | | 76.2** |
| | $Rate^2$ | | | | | | | |
| Gorse | Init. ht | 3.53 | 0.8 | 0.2 | 1.42 | 2.85 | 0.14 | 3.75 |
| | Rate | 8.18** | 10.3** | 38.0** | 11.3** | 10.13** | 24.3** | 15.1** |
| | $Rate^2$ | 1.45 | | | 8.6** | 2.61 | | 6.60** |
| Fogg grass | Init. ht | | 28.3** | 0.4 | 1.7 | 0.03 | | 5.8* |
| | Rate | | 392.2** | 636.7** | 77.5** | 31.65** | | 13.18** |
| | $Rate^2$ | | | | | 4.01 | | 3.38 |
| Pampas | Init. ht | | 3.8 | 1.3 | 0.0 | 3.63 | 0.0 | 0.55 |
| | Rate | | 36.3** | 64.6** | 88.3** | 19.88** | 110.8** | 98.38** |
| | $Rate^2$ | | | | | 7.01* | | |

[1] Note: 17 degrees of freedom were used in denominator where quadratic function included ($Rate^2$) and 18 degrees of freedom were used for the linear function (Rate).


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The final model(s) were variations on the following function:

$$\text{logit}(p) = \beta_0 + \beta_1 IH + \beta_2 R + \beta_3 R^2 \quad [1]$$

where p is, mortality, R treatment rate (0, 25%, 50% or 100%) and IH is the initial height (cm) of plant.

Analysis of variance was used to test the effect of rate (for each treatment) on height and biomass index of *Pinus radiata* at three months. The biomass index was calculated for each tree as follows:

$$\text{Biomass index} = gld^2 \times ht \quad [2]$$

The biomass index was used in growth analyses as it is a better indicator of tree growth in response to weed control than height measurements alone (Eccles et al., 1996). Where the *F*-test was significant, the differences between treatment means were further investigated using the least significant difference statistic ($P<0.05$). Using PROC FREQ in SAS 9.2 a chi-square test was used to test for an association between rate and tip damage (no damage, scorched or dead) for each treatment.

## Results and Discussion

### Mortality of weeds

There was a significant effect of the seven herbicide treatments on mortality of the five weed species, however, efficacy varied across weed species and, for some weeds, with plant height at the time of application (Table 4). There was no mortality of *Pinus radiata* for any of the herbicides and rates tested.

In comparison to Treatment 7, the currently used commercial standard of terbuthylazine and hexazinone, Treatment 5 (terbuthylazine, triclopyr and picloram) was the most effective across the spectrum of weeds tested providing over 70% mortality on all weed species at rates tested above 50% (Table 4; Figure 1). This treatment was the only treatment, besides the current standard (Treatment 7), that caused any mortality of buddleja (Table 4; Figure 1). There was over 95% mortality of buddleja when Treatment 5 was applied at, or above, 75% of the full rate tested. This equates to an application (in total volume of 150 L $ha^{-1}$) of 6.38 kg $ha^{-1}$ terbuthylazine, 0.11 kg $ha^{-1}$ triclopyr and 0.04 kg $ha^{-1}$ picloram. Treatment 5 induced a maximum of 73% and 87% mortality in gorse and pampas, respectively, which compares favourably to Treatment 7, where 63% and 97% was the maximum mortality (Figure 1).

Treatment 1 (clopyralid, triclopyr and picloram) was only effective against gorse and broom (Table 4; Figure 1). Near 100% mortality of broom occurred at 50% of the full treatment rate while the full treatment rate was required to cause 80% mortality of gorse seedlings. Field trials have also indicated an effective kill of broom seedlings when applied at 75% of Treatment 1, supporting thresholding of this treatment for broom seedlings below the 100% rate (Rolando et al., 2010). Treatments 3 and 6 extended the range of herbicides used in Treatment 1 to include the grass selectives haloxyfop and quizalofop, however, efficacy on the broadleaves (broom and gorse) declined in these mixes, especially that of gorse to below 50% mortality (Figure 1). Elimination of clopyralid from the mix for broadleaf control (Treatments 2 & 4), resulted in very poor control of gorse, to below 20% (Figure 1).

In Treatments 2, 3, and 4, there was 100% control of the grasses, at application rates over 50% of the full rate for fogg grass and between 25% to 50% of the full treatment rate for pampas (Figure 1). Quizalofop, used in Treatment 6, caused 100% mortality of pampas when applied at a minimum of 25% of the full rate tested but had no effect on fogg grass (Figure 1). Haloxyfop was, therefore, shown to be the preferred herbicide in this study for fogg grass. The use of fogg grass as a cover-crop is used by some forest companies to facilitate broom control and reduce the need for aerial application of herbicides (West, 1995). In these areas there may be scope for the use of quizalofop to control pampas and other grasses that may be susceptible to this herbicide. Quizalop caused 100% mortality of the pampas seedlings when applied at the equivalent rate of 0.25 kg $ha^{-1}$.

Treatments 1 and 3 provided good control of broom (97% & 100% respectively) and some control of gorse (80% & 33% respectively), but not buddleja (0% for either treatment), with the haloxyfop increasing the scope of weed control to include the grasses in Treatment 3 (Figure 1). Treatments 2 and 4 provided poor control of the broadleaves (buddleja, broom and gorse), but good control of the grasses (Figure 1). The covariate height was significant for some of the treatments, highlighting that timing of application could be an important consideration, as efficacy is a function of the size of the weeds for some treatments (Table 4). The treatment that compared most favourably to the current operational treatment was, therefore, Treatment 5.

### *Pinus radiata* phytotoxicity

Treatments 3, 4 and 5 had a significant negative effect on tree growth (ht and/or biomass index) (Tables 5 & 6). The highest reduction in biomass index (49%) occurred for Treatment 4 (haloxyfop & triclopyr) where over 0.6 kg $ha^{-1}$ triclopyr was applied to trees at the full rate tested. Previous dose response trials with triclopyr have shown moderate tree growth suppression when applied at 0.6 kg $ha^{-1}$ to actively growing trees, with minimal incidence of tree malformation (Saville, 1989). Even at the highest rate tested, Treatment 4 was not effective against the spectrum of weeds used


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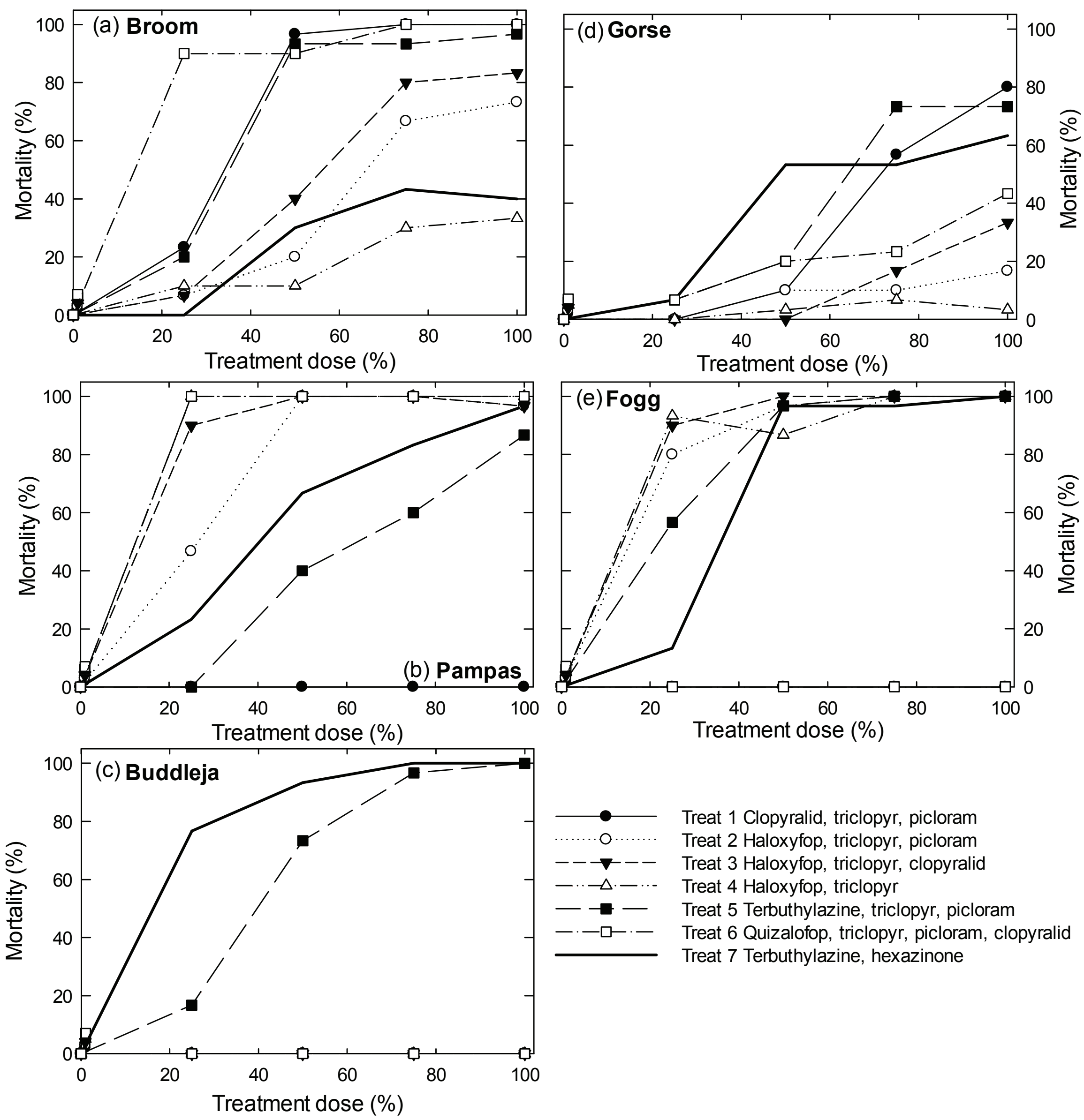


FIGURE 1: Mortality as a function of rate, for the seven treatments used, at the experiment end (three months) for: (a) broom; (b) pampas; (c) buddleja; (d) gorse; and (e) fogg grass. No mortality in response to any of the treatments was noted for *Pinus radiata*.

and therefore does not have potential as an alternative to Treatment 7. Treatment 5 (terbuthylazine, triclopyr and picloram), the most effective alternative treatment against the five major weeds, also caused a significant 22.5% loss in biomass index of *P. radiata* at rates above 50% (Table 6). Any further research for this treatment should, therefore, aim to optimise the rate of triclopyr and picloram to reduce phytotoxicity. Field trials would need to be carried out to determine whether these reductions in tree growth are carried through the rotation or if a moderate recovery would occur in the two to three years before canopy closure. Field trials would also determine whether the level of tree growth suppression caused by spraying the herbicides is outweighed by the benefit gained from the weed control provided over the long term.

Besides reductions in tree growth, significant apical damage resulting in multiple growing tips (multi-leadering) or trunk twisting can occur, especially when using the herbicide triclopyr. Both multi-leadering and twisting may produce tree malformation and an unacceptable sawlog in the mature tree. Reductions in tree growth in this trial were largely due to significant growing tip damage following herbicide applications in all treatments, except Treatment 7 (terbuthylazine & hexazinone) (Table 5; Appendix A). Despite the significant tip damage for several treatments at 30 days, however, there were no treatments where there was significantly greater multi-leadering than the controls when measured at 90 days after herbicide application (data not shown). Some treatments, particularly those where triclopyr or picloram was used, showed signs of


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TABLE 5; Summary of the analyses to determine the effect of herbicide treatment on *Pinus radiata* tip-damage at 30 days (chi-square tests) and size (F-values: Biomass index and ht) at 90 days. The symbols #, * and ** denote significance at *P*<0.1, *P*<0.05 and *P*<0.01.

| Treatment | $\chi^2$ Test | F Value[1] | |
|---|---|---|---|
| | Tip damage | Biomass index | Height |
| Treatment 1 clopyralid, triclopyr, picloram | 81.98** | 1.85 | 1.50 |
| Treatment 2 haloxyfop, triclopyr, picloram | 66.70** | 1.48 | 5.08** |
| Treatment 3 haloxyfop, triclopyr, picloram, clopyralid | 73.27** | 2.61# | 4.36** |
| Treatment 4 haloxyfop, triclopyr | 48.40** | 2.10** | 32.2** |
| Treatment 5 terbuthylazine, triclopyr, picloram | 101.52** | 5.97** | 12.52** |
| Treatment 6 quizalofop, triclopyr, picloram, clopyralid | 83.79** | 0.72 | 2.32 |
| Treatment 7 hexazinone, terbuthylazine | None | 1.14 | 1.59 |

[1] Note: 4, 16 degrees of freedom were used for the F tests.

contorted growth typical of that for these herbicides. Twisting in response to the application of triclopyr can be significantly reduced by applying the herbicide when trees are dormant (Saville, 1989). The significance of these results would need to be confirmed in a field trial which would also indicate whether these defects were carried through the rotation.

## Conclusions

The results from this trial indicate that of the herbicides currently registered in New Zealand, those with the most potential as suitable replacements to hexazinone and terbuthylazine are haloxyfop, clopyralid, triclopyr and picloram (applied as a mix). The herbicide combinations and rates used in this trial, however, would require further testing both in pot and field trials before robust and practical recommendations could be made.

In terms of efficacy Treatment 5 was the only treatment that caused mortality of buddleja and compared favourably for all species tested to the current operational treatment (Treatment 7). Treatment 5 contained terbuthylazine, triclopyr and picloram while Treatment 7 contained terbuthylazine and hexazinone. Replacement of the current operational treatment with Treatment 5, while efficacious, would not eliminate the

TABLE 6: Average biomass index for *Pinus radiata* for each rate and treatment. Numbers followed by the same letter are not significantly different.

| Treatment | Parameter | Rate (% of full rate tested) | | | | |
|---|---|---|---|---|---|---|
| | | 0 | 25 | 50 | 75 | 100 |
| Treatment 1 clopyralid, triclopyr, picloram | Biomass index | 84.6a | 86.9a | 97.0a | 83.8a | 74.2a |
| | % Change | 0 | 2.7 | 14.6 | -1.0 | -12.3 |
| Treatment 2 haloxyfop, triclopyr, picloram | Biomass index | 84.6a | 101.0a | 93.5a | 74.4a | 82.4a |
| | % Change | 0 | 19.5 | 10.4 | -12.1 | -2.5 |
| Treatment 3 haloxyfop, triclopyr, picloram, clopyralid | Biomass index | 84.6ab | 101.0a | 97.6a | 81.5ab | 71.3 b |
| | % Change | 0 | 19.3 | 15.3 | -3.6 | -15.7 |
| Treatment 4 haloxyfop, triclopyr | Biomass index | 84.6a | 63.9 b | 61.1 b | 62.9 b | 43.0 c |
| | % Change | 0 | -24.4 | -27.8 | -25.6 | -49.0 |
| Treatment 5 terbuthylazine, triclopyr, picloram | Biomass index | 84.6ab | 102.0a | 98.5a | 65.6 b | 72.4 b |
| | % change | 0 | 20.6 | 16.4 | -22.5 | -14.3 |
| Treatment 6 quizalofop, triclopyr, picloram, clopyralid | Biomass index | 84.6a | 91.4a | 79.2a | 83.6a | 77.1a |
| | % Change | 0 | 8.0 | -6.4 | 1.2 | 8.9 |
| Treatment 7 hexazinone, terbuthylazine | Biomass index | 84.6a | 110.5a | 83.8a | 97.5a | 95.0a |
| | % Change | 0 | 30.6 | 1.0 | 15.2 | 12.3 |


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use of terbuthylazine. The potential for continued used of terbuthylazine in FSC-certified forests, however, is dependent on further research to determine leaching behaviour in New Zealand forest soils (Watt et al., 2010). Treatment 5 would need to be optimised to reduce phytotoxicity to *P. radiata*.

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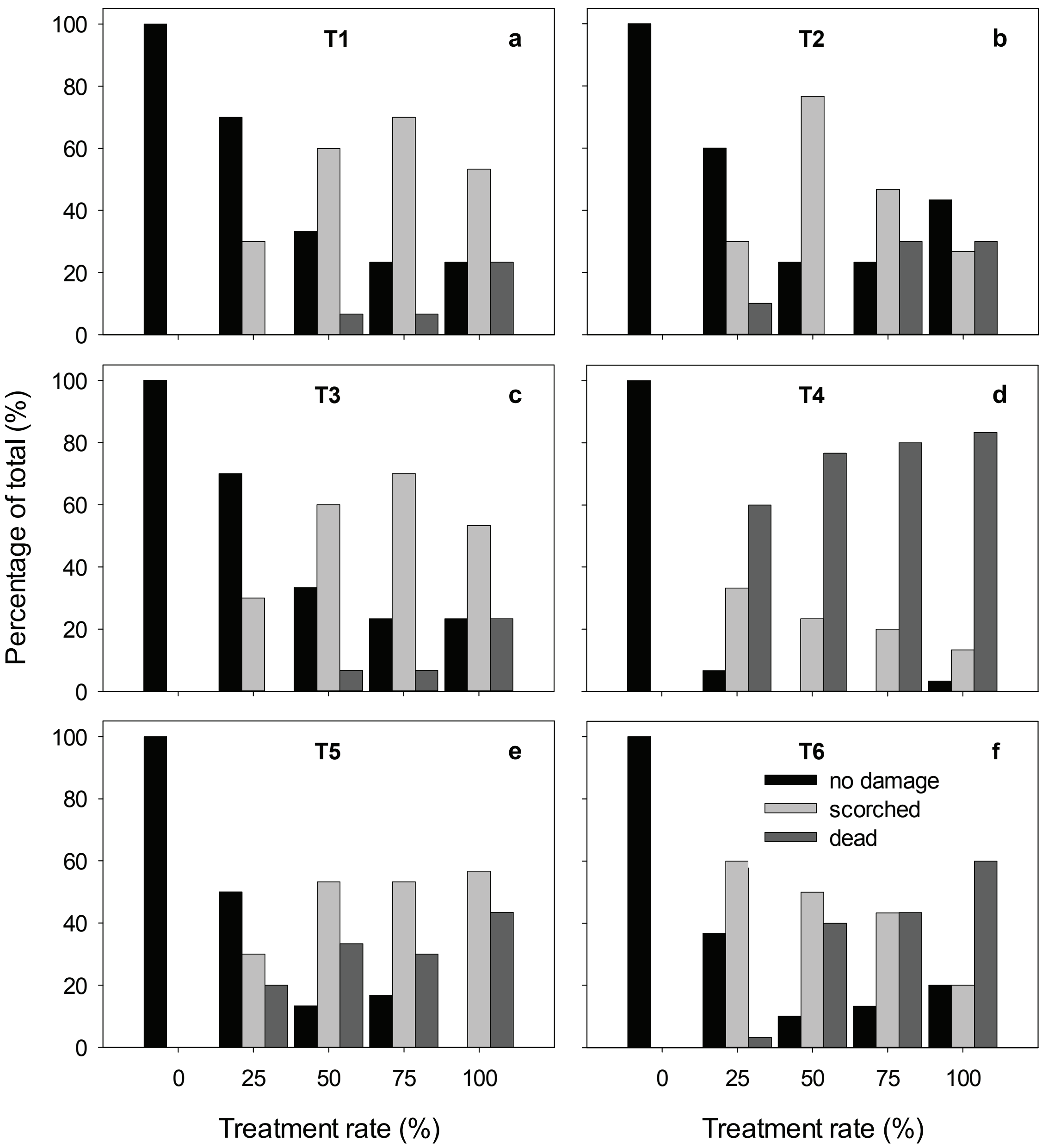
APPENDIX A: The effect of the herbicide treatments on *Pinus radiata* growing tips at 30 days after application where Figures a – f represent treatments 1 – 6 respectively: (a) Treatment 1 [clopyralid, triclopyr, picloram]; (b) Treatment 2 [haloxyfop, triclopyr, picloram]; (c) Treatment 3 [haloxyfop, triclopyr, picloram, clopyralid]; (d) Treatment 4 [haloxyfop, triclopyr]; (e) Treatment 5 [terbuthylazine, triclopyr, picloram]; and (f) Treatment 6 [quizalofop, triclopyr, picloram, clopyralid].





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