Minimising the environmental impact of forest weed management in New Zealand

Final report on field trials

Carol Rolando, Christine Todoroki and Michael Watt

REPORT INFORMATION SHEET

REPORT TITLE	MINIMISING THE ENVIRONMENTAL IMPACT OF FOREST WEED MANAGEMENT
AUTHORS	CAROL ROLANDO, CHRISTINE TODOROKI AND MICHAEL WATT
ISBN:	978-0-478-11037-1
SCION PUBLICATION NUMBER	S0015
SIDNEY OUTPUT NUMBER	56346
SIGNED OFF BY	LINDSAY BULMAN
DATE	JUNE 2015
CONFIDENTIALITY REQUIREMENT	PUBLICLY AVAILABLE
INTELLECTUAL PROPERTY	© NEW ZEALAND FOREST RESEARCH INSTITUTE LIMITED ALL RIGHTS RESERVED. UNLESS PERMITTED BY CONTRACT OR LAW, NO PART OF THIS WORK MAY BE REPRODUCED, STORED OR COPIED IN ANY FORM OR BY ANY MEANS WITHOUT THE EXPRESS PERMISSION OF THE NEW ZEALAND FOREST RESEARCH INSTITUTE LIMITED (TRADING AS SCION).

EXECUTIVE SUMMARY

Objective

The designation of terbuthylazine and hexazinone as highly hazardous herbicides by the Forest Stewardship Council (FSC) in 2007 was the major driver for a programme of research initiated by forest owners in 2009. The aim of this programme was to identify alternative herbicides that could be used in planted radiata pine forests for weed control, particularly in the year of planting. New and already shortlisted alternatives to terbuthylazine and hexazinone were trialled in the field across a range of weed and environmental gradients with the objective of establishing successful operational prescriptions for use by all industry that were acceptable to forest certification bodies such as the Forest Stewardship Council.

Methods

Several herbicide mixes that either eliminated both the FSC designated highly hazardous active ingredients, or retained only one (terbuthylazine) were tested in seven field trials spread across New Zealand, from Rotorua to Dunedin. These were benchmarked against the current industry standard that uses terbuthylazine and hexazinone.

Key Results

The work carried out in this programme provides forest growers with: 1) data that can be used to justify continued use of certain active ingredients (due their superior performance) and 2) a database of information on the performance and efficacy of alternative active ingredients to meet the growing, and changing, list of herbicides designated as highly hazardous by the FSC. Key outcomes were:

- The current industry standard that uses terbuthylazine and hexazinone remains the most effective and low-cost treatment for first-year weed control.
- Terbuthylazine used in combination with mesotrione was the best alternative tested in the group of treatments that examined a potential replacement option for hexazinone in the current terbuthylazine/hexazinone mix. Growth losses of, on average, 10% were associated with this mix across the spectrum of sites tested.
- Treatments that do not include either terbuthylazine or hexazinone generally need to be targeted to specific types of weeds to be effective. Growth losses in excess of 30% are associated with these treatments.
- An application of clopyralid, triclopyr and aminopyralid in the spring of the second-year after planting was effective against young and emerging scrub weeds, particularly broom and gorse. There is potential that aminopyralid could be used to replace picloram, if picloram becomes prohibited for use in the current second-year standard treatment that includes this active ingredient.

This project has supported “licence to operate” by benchmarking herbicide combinations for use by the forestry industry that are acceptable to forest certification bodies such as the Forest Stewardship Council. The outcomes of this project will play an important role in economically meeting sustainability objectives by:

- Reducing use of hazardous chemicals and driving towards lower chemical use.
- Contributing towards the economic options for establishment and re-establishment of planted forests.
- Promotion of wood as an environmentally friendly and sustainably produced resource.

Further Work

To retain certification status, certified forests will need to continue to meet the criteria set by certification bodies. The work conducted in this Sustainable Farming Fund programme has provided a comprehensive database reflecting the impact, efficacy and cost of available active ingredients for weed control. This information will be useful for meeting the requirements of an ever-changing list of highly hazardous pesticides. There is little need for further herbicide application work (apart from refining the efficacy of one or two of the mixes) unless new active ingredients become available on the New Zealand market. This especially, as terbuthylazine and hexazinone were removed from FSC’s list of highly hazardous pesticides in 2015. Forest growers see the future of this project extending toward a wider examination of the fate of herbicides used in forest operations and their impact to the environment. This approach will be used to build an environmental impacts profile, or risk based framework, that can provide evidence based assessments of environmental impacts to inform best practices and, also, policy makers.

Table of contents

Introduction

Background

Forestry is of critical importance to New Zealand's current and future economic wellbeing, contributing more to GDP than pastoral agriculture on an area basis (1.47% GDP per million ha). It is currently the third largest export earner for New Zealand as well as being a direct employer of 17,700 people. Export revenue was $4.7 billion (10.9% of the total) in 2012/13 (FOA, 2012/2013). One of the most critical components of the whole forest products lifecycle is the economic and environmentally sustainable establishment of commercial planted forests. Newly planted trees need time to establish in order to survive and grow. **Control of weeds is critical during the first two years of forest establishment** to prevent competition for light, water and nutrients. **The use of herbicides is the only cost-effective and practical form of weed control on a commercial scale.** However, the need for forests to be grown sustainably is another critical component of the forest products lifecycle and this can conflict with the use of herbicides.

The use of herbicides is under threat from national and international initiatives aimed at reducing the chemical footprint of intensive land-use. National initiatives include the National Policy Statement for Freshwater Management while forest certification is managed internationally by organisations such as the Forest Stewardship Council (FSC). Certification by the FSC is currently one of the most powerful influencers of international trade in wood and wood products, and the FSC is the main forest certification body used in New Zealand. Certification ensures self-regulation of trade in sustainably produced wood and wood products but also requires a reduction in pesticide use within planted forests. This criterion poses some challenges to the New Zealand forest industry which is dependent on herbicides for cost-effective weed control. In addition to the overall herbicide-reduction requirement, two of the most widely used herbicides in New Zealand planted forests, terbuthylazine and hexazinone, were designated as "highly hazardous" in 2007 by the FSC. This meant that their use was restricted on certified land unless a special exemption, called a derogation, was obtained from the FSC (FSC, 2007).

Aims and objectives

The main objective of the work carried out in this Sustainable Farming Fund (SFF) programme was to test various herbicide treatments to control weeds under field conditions in the first year after planting *Pinus radiata* (radiata pine). The treatments were designed to reduce or eliminate the use of herbicides designated as hazardous by the FSC (mainly terbuthylazine and hexazinone). Information on the active ingredients included in this research programme and their environmental profiles is summarised in Appendix A. This work enhanced an existing industry and government funded research programme (funded by Future Forests Research and MBIE "Undermining Weeds" grant) and expanded it by implementing multi-year field trials (Watson et al., 2011; Rolando et al., 2011, Watt and Rolando, 2014). These provided a robust evaluation of newly identified and potentially more environmentally benign herbicides for use in forest management systems.

Another initial objective was to augment the use of chemical control treatments with non-chemical control methods such as the use of biological control to reduce the input of herbicides. However, complimentary work carried out in conjunction with this SFF-funded programme indicated that augmentation of chemical weed control with non-chemical methods, was not likely to be an effective, or cost efficient, weed management option in the first two years after planting (see Appendix B). Therefore, a decision was made to direct effort (and funding) on outcomes that would more likely be adopted by the forest growers (chemicals that were likely to be the way forward in the longer term) rather than focus on methods that were unlikely to gain traction with growers. ***Finding more environmentally friendly alternatives to, or reduced reliance upon chemicals in general, (and hexazinone and terbuthylazine in particular) was a key pathway to ensuring that planted forests continued to be sustainable – both economically and environmentally, see Box 1.***

BOX 1

A recent review of the indicators and thresholds for the identification of highly hazardous pesticides (HHP) by FSC resulted in changes to the FSC HHP criteria. As a result of these changes, terbuthylazine and hexazinone were removed from the list of herbicides prohibited for use on FSC certified forest land (FSC, 2015). This was a positive outcome for the forest industry and, in the short term, means that weed control during establishment of planted radiata pine forests can continue as "business as usual". However, the pressure to reduce the dependence on herbicides, prohibited or not, will continue and the forest industry needs to demonstrate a strategy to achieve a reduction in their use. Under the new HHP criteria, two different herbicides (haloxyfop and picloram) are now prohibited and will require derogation if they are to be used on FSC-certified land.

Outcome of previous work

Five field trials were conducted during the first year of this SFF programme (2012–2013). The aim of these trials was to screen a number of herbicide mixes for their potential to replace terbuthylazine, and hexazinone. The detailed outcomes of these trials are presented in Rolando et al. (2014). In summary they indicated that the following herbicide mixes:

- Terbuthylazine (Gardoprim®) used in combination with the following alternatives to hexazinone: clopyralid (Versatill®), triclopyr (Grazon®) or mesotrione (Callisto®);
- Clopyralid (Versatill®), triclopyr (Tordon®) and haloxyfop (Gallant®); and
- Indaziflam ('437') applied in combination with mesotrione (Callisto®), or other knockdown active ingredients, as a pre-emergent treatment;

should be subjected to further screening across a range of sites and in combination with second-year treatments. Based on this outcome, a range of treatment sets was developed that were tested in a second series of field trials (2013–2015).

A series of treatments applied during the first year after planting was tested in this second trial series. The treatments tested were largely selected to reflect the FSC pesticide policy as of 2013. This meant terbuthylazine was retained in a range of mixes, with alternatives to hexazinone tested. The breakdown of these treatment sets is provided in Table 1, together with the rationale supporting their implementation. One treatment using haloxyfop was retained in the event that derogation is obtained to continue using this herbicide. A second-year treatment that eliminated the use of picloram was applied across all sites. This report describes this second series of trials.

Methods

Trials were implemented at seven sites across New Zealand to test alternative herbicide mixes. Climatic and edaphic details of the seven trial sites are shown in Tables 2 and 3. In total 17 separate herbicide treatments were trialled across the seven sites during the first year after planting. The details of each treatment and the sites on which each were applied are shown in Table 4 and in Appendices D-J. Treatment 1 was used as a benchmark against which all other treatments were compared for all measured parameters. A range of additional treatments was applied at each site (Table 4). The additional treatments were designed to meet the weed spectrum expected at each site as it is likely that the alternative active ingredients will be most effective when targeted at specific weed types. The methods used to establish, spray and assess trials, as well as analyse the data, are detailed in Appendix C.

A second-year treatment (consisting of 1500 g ha^{-1} clopyralid, 150 g ha^{-1} triclopyr and 22.5 g ha^{-1} aminopyralid) was applied across all sites, except at the Okuku trial site where only grasses were present.

Table 1. Rationale for implementation of the herbicide treatment sets used in field trials 2013–2015.

Time of application	Treatment no.	Description	Rationale
First year	1	Operational Standard	Allows comparison of new treatments with existing standards.
	2	Weedy (control)	Allows assessment of the spectrum of weeds present on the site.
	3	Terbuthylazine alone	Terbuthylazine used alone was tested so that the effect of the mixing partner could be determined.
	4–8	Terbuthylazine + mix	Treatments that use terbuthylazine in combination with mesotrione, clopyralid and triclopyr were shown to have potential when compared with the operational standard in 2012/2013 trials.
	9–17	No terbuthylazine or hexazinone	Combinations of active ingredients that do not use terbuthylazine or hexazinone. This to support the principle of reducing persistent herbicide use in forest management and a move towards more modern chemicals. These treatments were aimed to be site/weed specific and therefore were not tested across all sites but grouped according to the spectrum of weeds expected at each site.
Second year	18	No picloram	Test efficacy of a second-year treatment that did not include the active ingredient picloram.

Table 2. Location and forest manager details for seven field sites where alternative active herbicide ingredients were tested. Bold text highlights trial name used throughout the document.

Region	Forest Company	Key Contact	Location and compartment
Bay of Plenty, Central North Island	Timberlands	Steve Gatenby	**Kaingaroa** forest, Murupara 119/2
Bay of Plenty, Central North Island	Timberlands	Steve Gatenby	**Whaka**rewarewa forest**,** Rotorua, 9/37
Bay of Plenty, Central North Island	OTTP New Zealand Forest Investments	Dean Witehira	**Mamaku** forest, Mamaku Airstrip Road, 4332/4
South Canterbury, South Island	Blakely Pacific Ltd	Nick Henderson	**Geraldine**, Te Moana Block, 406/1
Otago, South Island	City Forests	Ross Edgar	**Flagstaff** Forest, Dunedin, Southland, FL02340
Marlborough, Upper South Island	Nelson Forests	Mark Bryant	**Rai** valley, Marlborough, Denkers Block, 9
North Canterbury, South Island.	Rayonier	Hamish McConnon	Rocky Road, Western **Okuku** Forest, 905/26/5

Table 3. Climatic and edaphic variables for each site, including key weeds present at each site

Co-ordinates	Name	MAT[1] (°C)	MAP[2] (mm)	Elevation (m asl[3])	Max PRD[4] (m)	Soil Type (Order)	Weeds spectrum
38 10 26,84" S 176 16' 30.95" E	Kaingaroa	12.2	1537	410	0.4	Sandy loam (Welded Impeded Pumice Soil)	Annuals, fog grass, bracken, blackberry
38 33' 04.94" S 176 37' 10.28" E	Whaka	11.5	1227	400	1.5	Loam over sandy textures (Typic Orthic Allophanic Soil)	Annuals, Himalayan honeysuckle, nightshade, fog grass, bracken
38 01' 08.10" S 176 06' 40.70" E	Mamaku	11.6	2372	541	1.5	Sandy loam. (Typic Orthic Podzol)	Grass, annuals, blackberry, native regeneration, ferns, rushes
44 03' 37.35" S 171 06' 49.18" E	Geraldine	10.2	866	287	0.9	Hill soils (Orthic Brown)	Grass, gorse, annuals, blackberry, rushes
45 49' 23.65" S 170 25' 49.54" E	Flagstaff	9.7	997	193	0.9	Granular loams and clays (Maffic Brown)	Gorse, broom, rushes, blackberry, grass
41 10' 14.13" S 173 33' 46.23" E	Rai	12.1	1673	140	0.4	Steepland soils (Orthic Brown)	Gorse, broom, blackberry, fleabane
43 04' 06.55" S 172 25' 05.65" E	Okuku	10.2	937	556	1.2	Tengawai silt loam (Typic Argillic Pallic Soil)	Grass, annuals, native regeneration

1. Mean annual temperature
2 Mean annual precipitation
3 metres above sea level
4 Potential rooting depth

Table 4. Details of the 17 separate herbicide treatments used during the first year after establishment and the sites at which they were deployed.

Treatment				Site						
Type	**Products used**	**Active ingredients (g ha^{-1})**	**No.**	**Kaingaroa**	**Whaka**	**Mamaku**	**Geraldine**	**Flagstaff**	**Rai**	**Okuku**
Operational standard	17.5 L Valzine Extra	7500 g terbuthylazine & 1750 g hexazinone	1	✓	✓	✓	✓	✓	✓	✓
Weedy	None	None	2	✓	✓	✓	✓	✓	✓	✓
Terbuthylazine alone	15 L Gardoprim	7500 g terbuthylazine	3	✓	✓	✓	✓	✓	✓	✓
Terbuthylazine + mix	15 L Gardoprim & 0.188 L Grazon	7500 g terbuthylazine & 113 g triclopyr	4	✓	✓	✓	-	✓	✓	-
	15 L Gardoprim & 5 L Versatill	7500 g terbuthylazine & 1500 g clopyralid	5	✓	✓	✓	✓	✓	✓	✓
	15 L Gardoprim & 0.75 L Callisto	7500 g terbuthylazine & 360 g mesotrione	6	✓	✓	✓	✓	✓	✓	✓
	15 L Gardoprim & 0.6 L Tordon PastureBoss[2]	7500 g terbuthylazine, 120 g triclopyr & 18 g aminopyralid	7	✓	✓	✓	-	✓	✓	-
	15 L Gardoprim & 1 L Tordon Max	7500 g terbuthylazine & 30 g aminopyralid	8	-	-	-	✓	-	-	✓
No terbuthylazine or hexazinone	3.8 L Versatill, 0.38 L Tordon Brushkiller & 2.5 L Gallant	1125 g clopyralid, 113 g triclopyr & 250 g haloxyfop	9	✓	✓	✓	✓	✓	✓	✓
	3.8 L Versatill & 1.0 L Callisto	1125 g clopyralid & 480 g mesotrione	10	✓	✓	-	-	✓	✓	-
	0.6 L Tordon PastureBoss[2] & 1.0 L Callisto	120 g triclopyr, 18 g aminopyralid & 480 g mesotrione	11	✓	-	-	-	-	-	-
	3.8 L Versatill & 1.0 L Tordon Max	1125 g clopyralid & 30 g aminopyralid	12	-	-	-	-	✓	✓	-
	[1]0.6 L '437' [1] & 1.0 L Callisto	300 g indaziflam & 480 g mesotrione	13	-	✓	✓	✓	-	-	✓
	[1]0.6 L '437' & 0.6 L Tordon PastureBoss [2]	300 g indaziflam, 113 g triclopyr & 17 g aminopyralid	14	-	-	✓	✓	-	-	-
	[1]0.6 L '437' & 5 L Versatill	300 g indaziflam &1500 g clopyralid	15	-	-	-	✓	-	-	-
	[1]0.6 L '437' & 1 L Sequence	300 g indaziflam & 240 g clethodim	16	-	-	-	-	-	-	✓
	2 L Guardian & 0.75 L Callisto	80 g nicosulfuran & 360 g mesotrione	17	-	-	-	-	-	-	✓

[1] This active ingredient is not registered for use in New Zealand.

[2] This product does not have registration for aerial application in New Zealand.

Results of the second trial series

This section summarises the key outcomes of the trial series across the profile of sites to build the generic recommendations while results for individual trials are shown in Appendices D-J. It is recommended that the reader examines the results and key outcomes for each trial in order to understand the diversity of responses across sites as these results reflect site-specific responses. A detailed summary of the data in spreadsheet form has also been made available to the technical team managing this programme and can be used to further interrogate the trial results[1].

Tree and weed growth across all sites

The lowest biomass of weeds was sampled from the Mamaku site, where competitive vegetation consisted mainly of grasses and herbaceous broadleaved weeds. The Flagstaff site had the highest biomass of weeds 18 months after trial initiation. These were predominantly the scrub-weeds, broom and gorse (Figure 1).

Both tree biomass (using the derived variate of biomass index) and above-ground weed biomass varied across the seven sites 18 months after trial initiation (Figure 1). Using the operational standard (Treatment 1) as a reference treatment across sites, the greatest tree growth occurred at the Whakarewarewa site while the least growth occurred at the Okuku site.

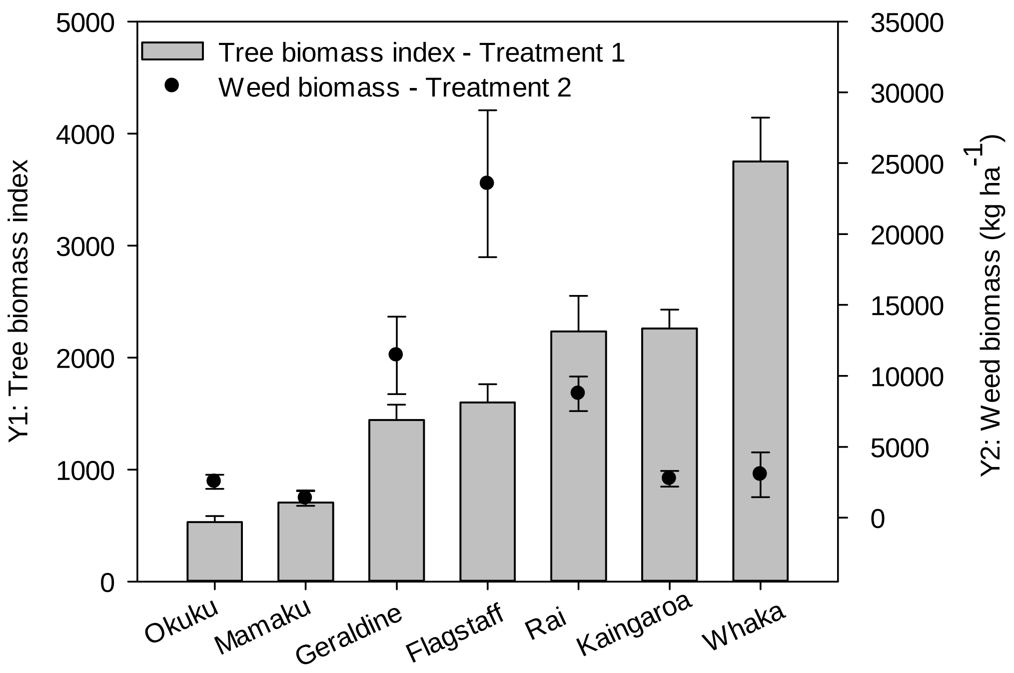

Figure 1. Biomass index for the operational standard (Treatment 1) across all seven sites (Y1). Also shown is the weed biomass across all sites harvested from the plots that received no herbicide (Y2).

[1] please contact Kit Richards (kit.richards@pfolsen.com) or Carol Rolando (carol.rolando@scionresearch.com) to obtain access to the summarised trial data.

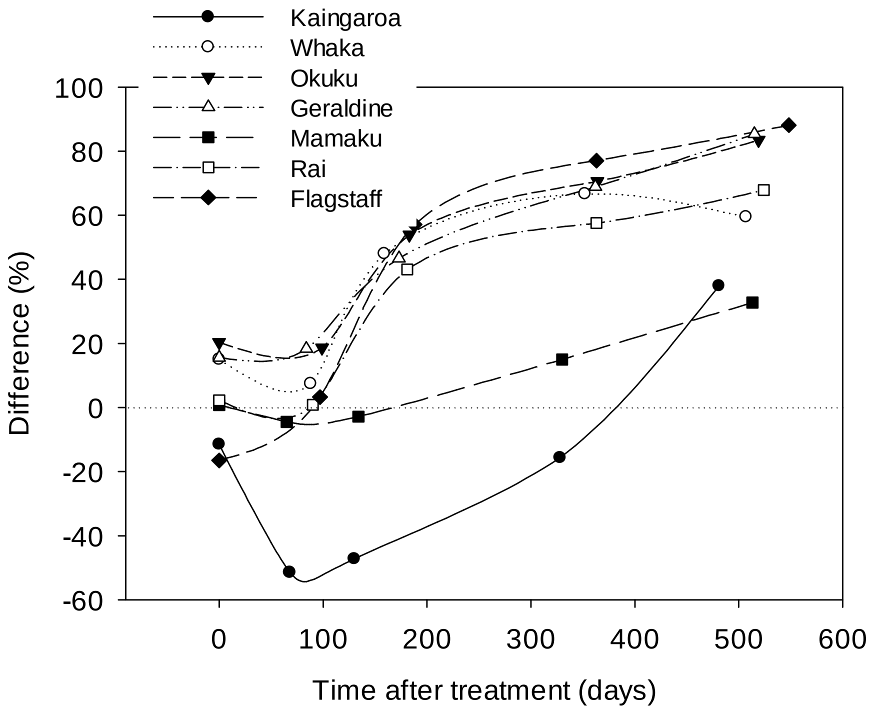

Figure 2. Difference in tree size between the operational standard (Treatment 1) and the no herbicide control (expressed as a percentage of Treatment 1) over time for each of the seven trials.

The difference in tree biomass between the operational standard and the no treatment control (expressed as a percentage) across sites provides an indication of the difference in level of competition across sites (Figure 2). This difference varied from as low as 33% at 18 months (~ 540 days) at the Mamaku site to a maximum of 88% at the Flagstaff site.

Performance of alternative treatments

A summary of the results for each trial at 18 months after trial initiation was made by ranking herbicide treatments for their performance in relation to tree size and weed competition at each site (Table 5). **The reduction in tree biomass resulting from each treatment relative to the operational standard is also shown in Table 5 and Appendix J.** This is a useful metric for judging the performance of the trees in plots treated with alternative herbicide treatments. The data in Table 5 were used to develop an index of recommended treatments, which is shown in Table 6. The amount of active ingredient and cost of each treatment is shown in Table 7.

A rationale supporting the rankings in Tables 5 and 6 is provided in the pages that follow.

Table 5. Ranking of treatments 18 months after trial initiation using the derived parameters Biomass Index (BI), Competition Index (CI) or Weed Cover (C). Shaded cells were significantly different from the operational standard for either one (light grey) or more (dark grey) of the derived parameters BI, CI or C at either 6 or 18 months (i.e. unshaded treatment were never significantly different to the operational standard (17.5 L Valzine) for any measured parameters). The percentage reduction in tree biomass index relative to the operational standard at that site is shown in brackets after each treatment. Negative numbers indicate trees were larger than the operational standard (also shown in Appendix K).

Treatment				Site						
Type	**Products used**	**Active ingredients (g ha^{-1})**	**No.**	**Kaingaroa**	**Whaka**	**Mamaku**	**Geraldine**	**Flagstaff**	**Rai**	**Okuku**
Operational standard	17.5 L Valzine Extra	7500 g terbuthylazine & 1750 g hexazinone	1	A	A	C	A	C	A	A
Weedy	None	None	2	I (38)	J (60)	J (33)	J (85)	J (88)	J (68)	J (83)
Terbuthylazine alone	15 L Gardoprim	7500 g terbuthylazine	3	H (32)	F (57)	F (25)	B (59)	D (7)	B (42)	B (-2)
	15 L Gardoprim & 0.188 L Grazon	7500 g terbuthylazine & 113 g triclopyr	4	G (50)	G (66)	D (41)		G (15)	F (37)	
	15 L Gardoprim & 5 L Versatill	7500 g terbuthylazine & 1500 g clopyralid	5	C (16)	D (33)	G (44)	D (53)	A (-35)	D (31)	G (-1)
Terbuthylazine + mix	15 L Gardoprim & 0.75 L Callisto	7500 g terbuthylazine & 360 g mesotrione	6	B (-14)	C (22)	E (-25)	E (50)	B (-5)	C (32)	D (12)
	15 L Gardoprim & 0.6 L Tordon PastureBoss	7500 g terbuthylazine, 120 g triclopyr & 18 g aminopyralid	7	F (22)	I (47)	I (49)		E (-14)	E (22)	
	15 L Gardoprim & 1 L Tordon Max	7500 g terbuthylazine & 30 g aminopyralid	8				C (60)			E (5)
	3.8 L Versatill, 0.38 L Tordon Brushkiller & 2.5 L Gallant	1125 g clopyralid, 113 g triclopyr & 250 g haloxyfop	9	E (-5)	E (34)	H (24)	G (63)	F (24)	G (46)	H (24)
	3.8 L Versatill & 1.0 L Callisto	1125 g clopyralid & 480 g mesotrione	10	J (25)	H (21)			H (30)	H (49)	
	0.6 L Tordon PastureBoss & 1.0 L Callisto	120 g triclopyr, 18 g aminopyralid & 480 g mesotrione	11	D (5)						
	3.8 L Versatill & 1.0 L Tordon Max	1125 g clopyralid & 30 g aminopyralid	12					I (63)	I (46)	
No terbuthylazine or hexazinone	0.6 L '437' & 1.0 L Callisto	300 g indaziflam & 480 g mesotrione	13		B (37)	B (18)	F (73)			F (35)
	0.6 L '437' & 0.6 L Tordon PastureBoss	300 g indaziflam, 113 g triclopyr & 17 g aminopyralid	14			A (17)	I (82)			
	0.6 L '437' & 5 L Versatill	300 g indaziflam &1500 g clopyralid	15				H (65)			
	0.6 L '437' & 1 L Sequence	300 g indaziflam & 240 g clethodim	16							C (16)
	2 L Guardian & 0.75 L Callisto	80 g nicosulfuran, 360 g mesotrione	17							I (75)

Table 6. A quick guide to the performance of alternative treatments across seven sites. The Relative Performance column is an average of tree size relative to the operational standard (expressed as a percentage) across all sites tested. It is recommended that readers refer to Table 5 as well as Appendices C-K to get the full account of treatment performance across sites.

KEY: Recommended | Alternative – growth loss possible (see Appendix K) | Potential (needs more testing) | Not recommended

Treatment group	Products (L ha^{-1})	Active ingredients (g ha^{-1})	Treat No.	Recommendation			Relative Performance across sites (%)[3]
				Scrub[1]	HBL[2]	Grass	
1st year treatments							
Operational standard	17.5 L Valzine Extra	7 500 g terbuthylazine and 1750 g hexazinone	1	Recommended	Recommended	Recommended	100
Treatments that use terbuthylazine	15 L Gardoprim & 0.75 L Callisto	7500 g terbuthylazine & 360 g mesotrione	6	Alternative	Alternative	Alternative	90
	15 L Gardoprim & 5 L Versatill	7500 g terbuthylazine & 1500 g clopyralid	5	Alternative	Alternative	Alternative	80
	15 L Gardoprim & 0.6 L Tordon PastureBoss[4]	7500 g terbuthylazine,120 g triclopyr & 18 g aminopyralid	7	Potential	Not recommended	Not recommended	75
	15 L Gardoprim & 1 L Tordon Max	7500 g terbuthylazine & 30 g aminopyralid	8	Not recommended	Potential	Potential	68
	15 L Gardoprim & 0.188 L Grazon	7500 g terbuthylazine &113 g triclopyr	4	Not recommended	Not recommended	Not recommended	58
Treatments that do not use terbuthylazine or hexazinone	3.8 L Versatill, 0.38 L Tordon Brushkiller & 2.5 L Gallant	1125 g clopyralid, 113 g triclopyr & 250 g haloxyfop	9	Alternative	Not recommended	Not recommended	70
	3.8 L Versatill and 1.0 L Callisto	1125 g clopyralid & 480 g mesotrione	10	Not recommended	Not recommended	Not recommended	69
	3.8 L Versatill & 1.0 L Tordon Max	1125 g clopyralid & 30 g aminopyralid	12	Not recommended	Not recommended	Not recommended	46
	0.6 L '437' & 1.0 L Callisto[5]	300 g indaziflam & 480 g mesotrione	13	Not recommended	Potential	Potential	60
	0.6 L '437' & 0.6 L Tordon PastureBoss[4,5]	300 g indaziflam, 113 g triclopyr & 17 g aminopyralid	14	Not recommended	Potential	Potential	51
	0.6 L '437' & 5 L Versatill[5]	300 g indaziflam &1500 g clopyralid	15	Not recommended	Not recommended	Not recommended	35[6]
	0.6 L '437' & 1 L Sequence[5]	300 g indaziflam & 240 g ha^{-1} clethodim	16	Not recommended	Not recommended	Potential	84[6]
	0.6 L Tordon PastureBoss & 1.0 L Callisto	120 g triclopyr, 18 g aminopyralid & 480 g mesotrione	17	Potential	Not recommended	Not recommended	95[6]
2nd year treatment							
Treatment that does not include picloram[7]	5 L Versatill & 0.5 L Tordon PastureBoss[4]	1500 g clopyralid, 150 g triclopyr & 22.5 g aminopyralid	18	Recommended	Not recommended	Not recommended	Not tested

[1] Scrub weeds includes broom and gorse as dominant weeds, but other perennial, woody species were included in this category.
[2] Herbaceous broadleaves (HBL) includes a wide spectrum of annuals.
[3] This is an average of performance across sites. Performance was variable and the reader should examine Appendix K.
[4] Tordon PastureBoss is not registered for aerial application. This will need to be addressed with DOW AgroSciences should users want to apply this product.
[5] Indaziflam is an active ingredient not yet registered for use in New Zealand.
[6] Treatment only tested on one site, variation across environments not known.
[7] Picloram is prohibited for use in planted forests

Table 7. Amount of active ingredient (g) applied with each treatment and an indicative cost of the chemicals. Note that it is not possible to get actual costs of these products from suppliers. Instead, the data presented are indicative costs obtained from the rural merchants Farmlands/PGG Wrightsons. Grey squares indicate no cost available as the product is not sold in New Zealand at present.

	Treatment		Amount active ingredient (g)	Cost (NZD)
No.	Products	Active ingredients		
1	17.5 L Valzine Extra	7 500 g terbuthylazine and 1750 g hexazinone	9250	328
4	15 L Gardoprim & 0.188 L Grazon	7500 g terbuthylazine &113 g triclopyr	7613	177
5	15 L Gardoprim & 5 L Versatill	7500 g terbuthylazine & 1500 g clopyralid	9000	662
6	15 L Gardoprim & 0.75 L Callisto	7500 g terbuthylazine & 360 g mesotrione	7860	364
7	15 L Gardoprim & 0.6 L Tordon PastureBoss	7500 g terbuthylazine,120 g triclopyr & 18 g aminopyralid	7638	203
8	15 L Gardoprim & 1 L Tordon Max	7500 g terbuthylazine & 30 g aminopyralid	7530	256
9	3.8 L Versatill, 0.38 L Tordon Brushkiller & 2.5 L Gallant	1125 g clopyralid, 113 g triclopyr & 250 g haloxyfop	1488	1008
10	3.8 L Versatill and 1.0 L Callisto	1125 g clopyralid & 480 g mesotrione	1605	631
11	0.6 L Tordon PastureBoss & 1.0 L Callisto	120 g triclopyr, 18 g aminopyralid & 480 g mesotrione	618	289
12	3.8 L Versatill & 1.0 L Tordon Max	1125 g clopyralid & 30 g aminopyralid	1155	458
13	0.6 L 437 & 1.0 L Callisto	300 g indaziflam & 480 g mesotrione	780	
14	0.6 L 437 & 0.6 L Tordon PastureBoss	300 g indaziflam, 113 g triclopyr & 17 g aminopyralid	430	
15	0.6 L 437 & 5 L Versatill	300 g indaziflam &1500 g clopyralid	1800	
16	0.6 L 437 & 1 L Sequence	300 g indaziflam & 240 g clethodim	540	
17	2 L Guardian & 0.75 L Callisto	80 g nicosulfuran & 360 g mesotrione	460	269

Operational Standard

Using weed cover and tree size as indices, **the operational standard** (17.5 L Valzine) **Treatment 1** was the best performing treatment on five out of the seven sites. No treatments were significantly better than the operational standard for measures of weed cover and tree size at the two sites (Mamaku and Flagstaff) where this treatment was not the best. **Therefore, it is recommended that this treatment continues to be the treatment of choice where possible.**

Terbuthylazine plus alternative active ingredient(s)

Treatment 6

Treatment 6 (7500 g ha^{-1} terbuthylazine and 360 g ha^{-1} mesotrione i.e. 15 L Gardoprim and 0.75 L Callisto) compared well with the operational standard in terms of weed cover and tree size. In terms of tree size, this treatment outperformed the operational standard at three sites (Kaingaroa, Mamaku and Flagstaff) and resulted in a significant reduction in tree size (49%) relative to the operational standard at only one site (Geraldine) (Appendix K). **The recommendation here is that mesotrione be considered as an alternative active ingredient in the terbuthylazine mix across most sites. However, testing should be done on small areas to confirm efficacy and phyto-toxicity before proceeding to operational scale control.** An advantage of this mix is the overall reduction in the amount of active ingredient applied to the site. **The estimated cost for this treatment indicates a 10% increase over the current standard.**

Treatment 5

Treatment 5 (7500 g ha^{-1} terbuthylazine and 1500 g ha^{-1} clopyralid i.e. 15 L Gardoprim and 5 L Versatill) compared reasonably well with the operational standard, particularly on sites where the scrub weeds broom and gorse predominated. This treatment appeared to outperform the operational standard at the Flagstaff site but the difference was not significant. There was a significant reduction in tree size relative to the operational standard at only one site (Geraldine). **Therefore, it is recommended that this treatment be considered as an alternative to the operational standard, particularly on sites dominated by broom and gorse.** However, application of this treatment does not result in an overall reduction in the amount of active ingredient applied to the site. Reductions in tree growth relative to the operational standard may occur (average reduction of 20% measured across sites). **The price of Versatill means that this treatment could incur up to 50% increase in herbicide costs.**

Treatment 4 & 8

The performance of treatments where **7500 g ha^{-1} terbuthylazine** (15 L Gardoprim) was applied in combination with **113 g ha^{-1} triclopyr** (0.188 L Grazon) **Treatment 4** or **30 g ha^{-1} aminopyralid** (1 L Tordon Max) **Treatment 8** or **120 g ha^{-1} triclopyr and 18 g ha^{-1} aminopyralid** (0.6 L Tordon Pastureboss) **Treatment 7** was more variable than expected across all sites. These treatments were not significantly different from the operational standard at three sites (Flagstaff, Rai and Okuku). However, they were among the poorer treatments at four sites where significant reductions in tree growth occurred (Kaingaroa, Whakarewarewa, Mamaku and Geraldine-see Appendix K). It is likely that these active ingredients, applied either alone or in combination, are slightly phytotoxic to young pines. Furthermore, they are effective against a narrower spectrum of weeds meaning their efficacy likely to be more site specific. **Thus, these combinations of treatments have not been recommended as potential alternatives to the current operational standard.** With further testing, it may be possible to determine the type of sites where the highest efficacy would be achieved. This will most likely be on the sites where perennial woody weeds are predominant. None of these treatments would potentially incur any additional costs.

Treatments that do not include terbuthylazine or hexazinone

Treatment 10

The treatment consisting of **1125 g ha^{-1} clopyralid and 480 g ha^{-1} mesotrione** (3.8 L Versatill and 1.0 L Callisto) **Treatment 10** was tested across four sites (Kaingaroa, Whakarewarewa, Flagstaff, and Rai). This treatment was targeted as an alternative treatment on sites where herbaceous or perennial broadleaved weeds (including the scrub weeds broom and gorse) were expected. This treatment resulted in significant reduction in radiata pine growth at two sites (Rai and Kaingaroa) compared with the operational standard, with an average reduction in tree size across sites of 31%. This reduction in growth is most likely due to the higher levels of interspecific weed competition resulting from the lack of residual herbicide control provided by the two active ingredients in this treatment. **Therefore, this treatment is not recommended as an alternative on sites that are dominated by broadleaves, gorse and broom *while there are more-effective treatment options available.*** More than one spraying operation within the first season would need to be considered in order to make this treatment effective. One advantage is that this treatment substantially lowers the amount of active ingredient applied to the site but the high costs of both of these products indicate an up to 50% increase in treatment costs could be possible.

Treatment 9

The treatment containing **1125 g ha^{-1} clopyralid, 113 g ha^{-1} triclopyr and 250 g ha^{-1} haloxyfop** (3.8 L Versatil, 0.38 L Tordon and 2.5 L Gallant) **Treatment 9** was tested across all seven sites. This treatment was targeted as an alternative treatment for sites with a broad spectrum of weeds (grasses, annuals and scrub weeds). Tree size was reduced compared with the operational standard (average reduction of 30%) across all sites but this reduction was significant at only two sites (Geraldine and Rai). As with Treatment 10, the lack of residual control provided by any of the active ingredients used means that the competitive vegetation re-establishes shortly after application, affecting tree growth. **Therefore, this treatment is not recommended *while there are more effective treatment options available*.** However, in the event that the operational standard cannot be used, this treatment would be a possible alternative on sites where perennial broadleaves or scrub weeds (broom and gorse) would dominate. One advantage of **Treatment 9** is that it lowers the amount of active ingredient applied to the site. However, the high costs of products indicate an over 50% increase in treatment costs could be possible.

Treatment 12

The treatment with **1125 g ha^{-1} clopyralid and 30 g ha^{-1} aminopyralid** (3.8 L Versatill and 1.0 L Tordon Max) **Treatment 12** was applied at two sites (Flagstaff and Rai). This treatment was targeted at broom and gorse dominated sites. Across both sites where this treatment was applied tree growth was significantly less than the operational standard (average loss of 54%). **This treatment is not recommended as an alternative treatment.**

Treatment 13 & 14

The treatments of **300 g ha^{-1} indaziflam and 480 g ha^{-1} mesotrione** (0.6 L 437 & 1 L Callisto) **Treatment 13** and **300 g ha^{-1} indaziflam, 113 g ha^{-1} triclopyr and 17 g ha^{-1} aminopyralid** (0.6 L '437' and 0.6 L Tordon PastureBoss) **Treatment 14** were applied across four (Whakarewarewa, Mamaku, Geraldine and Okuku) and two (Mamaku and Geraldine) sites respectively. Treatments 13 and 14 were targeted at sites dominated by grasses and annual broadleaved weeds. There were reductions in tree size relative to the operational standard at all sites where these two treatments were applied but these reductions were only significant at one site (Geraldine) where gorse was prevalent. ***While there are more effective treatment options available*, we do not recommend either of these treatments**. However, in the event that the operational standard cannot be used, wider testing of the potential of this combination of active ingredients should be considered for sites where grasses and annual herbaceous weeds dominate. One advantage is that both these treatments substantially lower the amount of active ingredient applied to the site. Unfortunately, indaziflam is not registered for us in New Zealand.

Treatment 17

The treatment **300 g ha^{-1} indaziflam and 240 g ha^{-1} clethodim** (0.6 L '437' and 1 L Sequence) **Treatment 17** was applied only at the Okuku site, where there was an almost 100% cover of grass. While trees in this treatment were 16% smaller than those in the operational standard, this difference was not significant. **This treatment is not recommended *while there are more effective treatment options available.*** However, in the event that the operational standard cannot be used, wider testing of the potential of this combination of active ingredients should be considered for sites where grasses dominate. One advantage is that this treatment lowers the amount of active ingredient applied to the site.

Second-year treatment

Treatment 18

The application of **1500 g ha^{-1} clopyralid, 150 g ha^{-1} triclopyr and 22 g ha^{-1} aminopyralid** (5 L Versatill and 0.75 L Tordon PastureBoss) **Treatment 18** in the second spring after planting (October) was effective at all sites where there was a dominant cover of broom and/or gorse (Geraldine, Flagstaff and Rai). There were slight indications of phytotoxicty at some sites, with yellowing of needles shortly after treatment application, but the trees had recovered by the final measurement made at 18 months. This treatment is essentially targeted at scrub weeds (broom, gorse and young perennials) and is most likely to be effective where there is a strong re-emergence of these weeds following the first spraying operation in the summer after planting. This treatment was tested because the current industry second-year weed treatment uses a product that contains picloram. Picloram is now prohibited by FSC and a suitable alternative needs to found. Consultation with the chemical company DOW AgroSciences (DAS) supported aminopyralid as an alternative active ingredient to picloram "*Aminopyralid is generally regarded as twice as active as picloram and at least as active against radiata pine*".

The results from these trials support the use of aminopyralid to replace picloram in the second-year application at use rates below 30 g ha^{-1} (22.5 g ha^{-1} used in these trials). *However, it is important to note that the product (Tordon PastureBoss) tested in this trial series is not registered for aerial application.* This issue will need to be addressed should the forest industry fail to obtain derogation for the use of picloram. Representatives from DAS have suggested tank mixing a combination of Grazon (600g/L triclopyr ester) and Tordon-Max (30 g/L aminopyralid) to make the equivalent of Tordon PastureBoss (30 g/L aminopyralid + 200g/L triclopyr amine salt). Both Grazon and Tordon-Max have claims for aerial application. DOW AgroSciences have commented that there will not be much difference in efficacy and crop safety between the triclopyr ester & amine in the presence of Boost (organo-silicone) penetrant. Further testing should be carried out to fully explore the potential of aminopyralid as a replacement for picloram.

Key outcomes of the trial series

- The current industry standard remains the most effective and low-cost treatment for first-year weed control.
- Terbuthylazine used in combination with mesotrione was the best alternative tested in the group of treatments that examined a potential replacement option for hexazinone in the current terbuthylazine/hexazinone mix. Growth losses of, on average, 10% were associated with this mix across the spectrum of sites tested.
- Treatments that do not include either terbuthylazine or hexazinone generally need to be targeted to specific types of weeds to be effective. Of the treatments tested, the best alternatives to the current industry standard were:
    - A mixture of clopyralid, triclopyr and haloxyfop (Treatment 9) applied to sites dominated by the scrub weeds broom and gorse. Previous work has indicated that the timing of application is critical for this treatment to be effective (Watt and Rolando, 2014). Tree growth losses of, on average, 30% were associated with this mix across the spectrum of sites tested.
    - Indaziflam applied in combination with either mesotrione or a mix of triclopyr and aminopyralid (Treatments 13 and 14) applied to sites where grasses and herbaceous

broadleaves predominate. Tree growth losses of, greater than 50% were associated with these treatments across the spectrum of sites tested. Further work would be needed to fully define the potential of indaziflam. This active ingredient is not currently registered for use in New Zealand.

  - Indaziflam applied in combination with clethodim (Treatment 16) applied to sites dominated by grass. This treatment was only tested at one site where it performed very well with only 16% tree growth loss relative to the operational standard. This treatment would need to be tested more widely to fully understand its potential across a range of sites dominated by grasses.
  - A mixture of triclopyr, aminopyralid and mesotrione (Treatment 11) applied to sites dominated by scrub weeds. However, *this treatment was only tested at one site* where it performed very well with only 5% growth loss relative to the operational standard. This treatment would need to be tested more widely to fully understand its potential across a range of sites dominated by scrub weeds.
- An application of clopyralid, triclopyr and aminopyralid in the spring of the second year after planting was effective against young and emerging scrub weeds, particularly broom and gorse. There is potential that aminopyralid could be used to replace picloram if it becomes prohibited for use in the current second-year standard treatment that includes this active ingredient.

Concluding Comments

The removal of terbuthylazine and hexazinone from the list of prohibited herbicides by FSC in 2014 was a great outcome for the forest industry. It is possible that this outcome is partly attributable to the investment forest growers made towards understanding the role of herbicides in the establishment process and also their impact to the environment (Rolando et al., 2013; Garrett et al., 2015; Baillie et al., 2015). To this end, the forest growers have supported work to not only understand the financial impact of non-chemical alternatives to the industry but also to determine the potential of alternative chemicals to those currently used as well as understanding the fate of terbuthylazine and hexazinone in the environment.

This work indicated that:

- Non-chemical control was not economically viable.
- Alternative chemicals are available but come with a cost accrued through either losses in tree growth or an increase in the cost of chemicals used.
- Terbuthylazine and hexazinone do not pose a risk to soil and water quality in planted forest catchments when used according to label instructions for forestry.

Certified forests will need to continue to meet the current criteria set by certification bodies in order to retain certification status. History has shown that criteria can change frequently regarding herbicide use so there is an on-going need for forest growers to address which herbicides to use and how much, if at all. In addition to the forest certification issue, there is growing pressure from regional and national bodies to address the off-site impacts of intensive land-use. Pesticides (including herbicides) are increasingly being highlighted as environmental contaminants. The work conducted in this Sustainable Farming Fund programme has provided a comprehensive database reflecting the impact, efficacy and cost of available active herbicide ingredients for weed control in planted forests. This information will be useful for meeting the requirements of an ever-changing list of highly hazardous pesticides. There is little need for further herbicide application work (apart from refining the efficacy of one or two of the mixes) unless new active ingredients become available on the New Zealand market. Instead, forest growers see the future of this project extending toward a wider examination of the fate of herbicides used in forest operations and their impact to the environment. This approach will be used to build an environmental impacts profile, or risk based framework, that can provide evidence based assessments of environmental impacts to inform best practices and, also, policy makers.

References

Forest Owners Association. (2012/2013). *New Zealand Plantation Forest Industry: Facts and Figures.* Wellington: Ministry for Primary Industries.

Forest Stewardship Council. (2007). *FSC Pesticide Policy: Guidance on implementation: Forest Stewardship Council*. (GSC_GUI-30_001 Version 2-0 EN). Available at http://www.fsc.org.

Forest Stewardship Council. (2015). *Indicators and Thresholds for the Identification of 'Highly Hazardous' Pesticides (HHP).* (FSC-STD-10-001 V1-0 EN). Available at http://www.fsc.org

Rolando, C. A., Gous, S. F., & Watt, M. S. (2011). Preliminary screening of herbicide mixes for the control of five major weed species on certified pinus radiata plantations in New Zealand. *New Zealand Journal of Forestry Science, 41*, 165-175.

Rolando, C. A., & Watt, M. S. (2014). Herbicides for use in management of certified *Pinus radiata* plantations in New Zealand. *Australian Forestry*, *77*(2), 123–132.

Watt, M. S., & Rolando, C. A. (2014). Alternatives to hexazinone and terbuthylazine for chemical control of *Cytisus scoparius* in *Pinus radiata* plantations in New Zealand. *Weed Research*, *54*(3), 265-273. doi: 10.1111/wre.12081

Watson, M. C., Watt, M. S., Withers, T. M., Kimberley, M. O., & Rolando, C. A. (2011). Potential for *Cleopus japonicus* to control the weed *Buddleja davidii* in plantation forests in New Zealand. *Forest Ecology and Management, 261*(1), 78-83.

Acknowledgements

The authors would like to acknowledge:

- All technical staff who assisted with the implementation and management of these trials, particularly Liam Wright, Tia Uaea, Dave Henley and Alan Leckie.
- All forest industry members and companies that provided land and support for the implementation of the trials.
- Ruth Falshaw for critical review and formatting of the report.
- The Sustainable Farming Fund Contract 12-038, FOA and all other co-funders, for the financial support to conduct these trials.

Appendix A: Chemical and eco-toxicity parameters of the active ingredients tested

Table A1. Active ingredients (in alphabetical order) tested for first-year weed control in a series of field trials, including those active ingredients currently widely used by the forest industry.

Active ingredient	Product	Rate ($g\ L^{-1}$)	Class and mode of action	Rates tested ($g\ ha^{-1}$)
aminopyralid	Tordon Pasture Boss®[2]/Max®	30	Carboxylic acid: Systemic herbicide absorbed by leaves and roots. Synthetic auxin causing epinasty. Some residual activity.	18; 30
clethodim	Sequence®	240	Hexanedione: selective systemic herbicide absorbed by foliage. Post emergence control of grasses.	240
clopyralid	Versatill®	300	Carboxylic acid: Absorbed by leaves and roots. Post- emergence control of selected broadleaf weeds (legumes)	1125; 1500
haloxyfop	Gallant®	200	Phenoxyproprionate: post-emergence control of annual and perennial grasses.	250
hexazinone	Valzine® Extra	100	Triazine: Broad spectrum systemic and contact post-emergent control of weeds	1750
indaziflam [1]	'437'	500	Alkylazine: Broad spectrum pre-emergent. Can be used in post-emergent applications when used in a mix.	300
mesotrione	Callisto®	480	Triketone: Systemic herbicide with foliar and root uptake. Pre- and post-emergent control of weeds.	360; 480
nicosulfuran	Guardian®	40	Sulfonylurea: selective systemic herbicide absorbed by foliage and roots.	80
terbuthylazine	Gardoprim®	500	Triazine: Broad spectrum pre- or post-emergent control of weeds.	7500
triclopyr	Grazon®	600	Carboxylic acid: selective systemic herbicide absorbed by foliage and roots – affects broadleaved weeds.	113

[1] This active ingredient is not yet registered for use in New Zealand.

[2].This product is not registered for aerial application in New Zealand.

Table A2. Chemical and eco-toxicity parameters of the active ingredients tested in the seven field trials for first-year weed control. Dashes indicate parameters for which data could not be found.

Active ingredient	**Parameter [1]**								
	Water solubility ($g\ L^{-1}$)	**DT50 water (days)[2]**	**DT50 soil (field) (days)**	**EC_{50} (48 hr) Daphnia ($mg\ L^{-1}$) [3]**	**LC_{50} (48 hr) Daphnia ($mg\ L^{-1}$) [4]**	**LC_{50} (96 hr) Fish ($mg\ L^{-1}$)**	**Kow (log P) (pH7, 20°C) [5]**	**BCF [6]**	**Koc (mLg^{-1}) [7]**
aminopyralid	205 at pH 7	Stable	25	>100		>100	-2.87 [8]	100	-
clethodim	5.45, 20°C	300 at pH 7	1 to 3		>120	67	4.14 [8]	2.1	-
clopyralid	143 at pH 7, 20°C	>30 at pH 5-9, 25°C	8 to 66	225		103.5	-2.63 [8]	1	5.0
haloxyfop	0.00159 at pH 5, 20°C	Stable to hydrolysis	major metabolite 90	-	96.4	>800	-	-	75
hexazinone	29.8 at pH 7, 25°C	Stable at pH 5-9	1–6 months	-	152	320	1.17 [8]	7 [8]	54 [8]
indaziflam	isomer a 0.0028 isomer b 0.0012 pH9, 20°C	4	10 to 80	>9.88	-	0.32	2.8 [8]	Low risk [8]	1000 [8]
mesotrione	15 at pH 6.9, 20°C	Stable to hydrolysis, pH 4-9	4	>900	-	>120	0.11 [8]	Low risk [8]	122 [8]
nicosulfuran	7.4 at pH 7	15 at pH 5. Stable at pH 7 & 9 .	19.3	-	90	65.7	0.61 [8]	Low risk [8]	30 [8]
terbuthylazine	0.009 at pH 7.4, 25°C	205 at pH 7, 25°C	17.4	≥69.3		2.2	3.4 [8]	34 [8]	224
triclopyr	8.10 at pH 7. 20°C	Stable to hydrolysis	46		133	117	4.62 [8]	0.77 [7]	27 [8]

[1] Sourced from: MacBean, C. (Ed.). (2012). *The Pesticide Manual*. (16th ed.). Hampshire, UK: British Crop Protection Council, unless otherwise specified.
[2] DT_{50} is the time for pesticide concentration to decrease by 50%.
[3] EC_{50} is the median effective concentration.
[4] LC_{50} (lethal concentration) is the concentration in water that kills 50% of the test organisms.
[5] Kow (octanol-water partition coefficient) is the ratio of the concentration of a chemical in octanol and in water at equilibrium.
[6] BCF - bio-concentration factor http://sitem.herts.ac.uk/aeru/ppdb/en/index.htm. Accessed 4/6/2014.
[7] Koc (Kfoc) – organic carbon sorption constant: ($mL\ g^{-1}$). Koc / Kfoc measures the affinity for chemicals to sorb to organic carbon. The higher the value, the stronger the tendency to attach to, and move with soil. Koc / Kfoc values greater than 1,000 indicate strong adsorption to soil. Chemicals with lower Koc / Kfoc values (less than 500) tend to move more with water than adsorbed to sediment. For some chemicals, Koc / Kfoc will be very sensitive to pH. (http://sitem.herts.ac.uk/aeru/ppdb/en/docs/Background_and_Support.pdf).
[8] Sourced from: Pesticide Properties Database, http://sitem.herts.ac.uk/aeru/ppdb/en/.

Appendix B: Non-chemical weed control

This text paraphrases a justification that was sent to the SFF project team in June 2013 to amend Milestone 4 for Project 12_038

Background

The original Milestone 4 of the SFF project included a suggestion that field trials conducted between 2013 and 2015 include some form of non-chemical weed control method. However, this option was not considered in a subsequent recent research plan approved by the SFF project Technical Steering Team in 2013. It was instead agreed to carry forward the results of the 2012 chemical screening trials to try to refine FSC-compliant chemical prescriptions. This appendix provides some background to that progression.

What was known at time of the SFF application

Prior to 1970, non-chemical weed-control methods (such as mechanical and manual control) were widely used in forest-weed management (Rolando et al unpublished[2]). Herbicides became available for large-scale use during the 1970s and have since been used almost exclusively for forest-weed control because of their efficiency and low cost. Other methods of non-chemical weed control tested for use in New Zealand forestry include the use of grazing, mulches, mycoherbicides and oversowing (Rolando et al. [2]). All methods have potential to control weeds in certain situations but none of these is able to compete with the efficiency and cost of chemicals so they have not been adopted by the forest industry to date.

Cost of non-chemical control: A review conducted in 2011 reported the costs of non-chemical control, and estimated the potential impacts on the internal rates of return (IRR) for forest companies (Table B1, Rolando et al., 2011). This review was used as justification for moving away from blanket herbicide treatment towards reduced chemical use through spot control plus other alternatives such as oversowing. In addition, there was a move towards the use of herbicides that are not prohibited by FSC – as opposed to a move towards exclusive use of non-chemical control methods.

Table B1. Cost of weed control regimes and their potential impact on internal rates of return.

Method	**Total cost to 'free to grow' ($ ha^{-1})**	**IRR [1]**	**Profitability (%)**
Current weed control	740	6.2	0
Spot control	450	5.1	-17
Manual	2385	4.3	-31
Mechanical	3307	3.9	-37
Weed mats	3473	3.6	-42

[1] Indicative change in internal rate of return for a medium yielding *P. radiata* site for forest companies using different weed control regimes

Biological control: The use of biological control in forest-weed management is one non-chemical control method that has not been widely explored in New Zealand forestry, and there was interest in including this type of control in the suite of treatments to be field trialled from 2013-2015. In particular, biological control showed promise for a key weed species (*Buddliea davidii*) in the North Island, for which a relatively successful biocontrol agent, *Cleopus japonicus*, has already been released. To this

[2] Rolando, C. A., Zabliewicz, Z. A., & Watt, M. S. *A review of the vegetation management practices for the New Zealand Forestry sector and the cost implications for compliance to the FSC pesticide policy.* Contract Report for Future Forests Research 2010. Rotorua, New Zealand: Scion.

end, a separate pilot trial was conducted (outside this SFF project) to determine the impact of *C. japonicus* on the growth of *B. davidii* during the first three years of *P. radiata* establishment (Watson et al., unpublished data).

What is known now

Manual and mechanical control: It was decided not to implement these treatments in the trials conducted due to existing knowledge on their cost and their limited applicability to the New Zealand planted forest environment (steep terrain) (Rolando et al., 2011). Besides cost, a key consideration for the use of non-chemical weed control is the high demand for labour required to complete the task – a requirement that exceeds the current availability of labour. At this point it is not known if any new non-chemical, manual methods warrant testing see Box B1

BOX B1

Extract from FSC Database on Alternative methods for weeds at establishment

- alternative type **Specific strategy** method **Removal** active ingredient **All** tree species **E. globulus** in trial **Y** country **Australia** Trialed 'scalping' physical removal of suface 10 cm of soil for 50 cm on either side of the planting line as an alternative to chemical weed control. Weeds encroached rapidly from unscalped edges, in some areas resulted in erosion, restricted growth due to r … read more
- alternative type **Specific strategy** method **Reduction** active ingredient **Simazine** tree species **E. globulus** in trial **Y** country **Australia** Trialled a reduction in the width of pre-plant weed control swathe from 2 m to 1.5 m or 1 m. Smaller swathe widths were found to give inferior weed control … read more
- alternative type **Specific strategy** method **Replacement** active ingredient **Simazine** tree species **E. globulus** in trial **Y** country **Australia** A pre-emergent screening trial on second rotation sites to test efficacy of traditional first rotation herbicide prescriptions found the most effective prescription was the combination of simazine and mesotrione which allows for a 50% reduction in the use of s … read more
- alternative type **Specific strategy** method **Reduction** active ingredient **Simazine, glyphosate, sulfomet** tree species **E. globulus** in trial **Y** country **Australia** Elders Forestry has piloted a system of taking harvest residues deposited at harvest landings after in field chip operations and mulching and re-distributing them across the site to provide a mulched layer which suppresses weed growth … read more

Oversowing and spot weed control: Several trials are currently underway in existing field programmes to investigate the use of these treatments so additional information on this aspect of weed control is not required. These methods will be included in any recommendations that come out of this SFF programme as they are methods that reduce the requirement for chemicals.

Biocontrol: Results of the *Buddliea davidii* bio-control pilot study indicated that the *Cleopus japonicus* biocontrol agent significantly reduced the growth of *B. davidii* but the rate of spread and population growth of the biocontrol agent was not sufficient to reduce the requirement for chemical control (unpublished data). This result, coupled with the wide spectrum of weeds that emerges following forest planting, meant that removal of just one competitive weed species did not reduce the overall requirement for herbicide treatments to optimise the growth of the crop.

Motivation for the current SFF trials

For next year's trials, non-chemical methods have not been included because:

- The potential of methods already known has been assessed previously, and retesting existing methods is unlikely to reveal any novel information that is not already available to the forest industry. A review of the FSC international database **http://pesticides.fsc.org/strategy-database/#results** set up to record new ways developed to trial pest control strategies produced only four tests for plantation establishment. These all originated in Australian Eucalypt plantations did not appear satisfactory or did not indicate a new novel approach. They were also applicable only on gentle topography.

- Including biological control as an option was an original goal, but recent data does not support this as a viable, weed-management option for intensive forestry (as distinct from long-term pest or noxious weed reduction and control).

Therefore, the current set of trials is focused on the aim of achieving the best possible assessment of the viability of a number of herbicide mixes across a range of site types. It is critical that the forestry industry is provided with robust alternative herbicide options in case terbuthylazine and hexazinone are permanently prohibited. Furthermore, recent changes in FSC Highly Hazardous (HH) Chemical Thresholds indicate that terbuthylazine may be removed from the HH list. This means that an opportunity now exists to devise and secure workable operational chemical prescriptions that minimise or eliminate the use of one HH active ingredient and may be fully FSC compliant and more benign in all others even though chemical use is not completely eliminated. Growers are interested in economically viable solutions that will enable them to retain their licence to operate as certified by the Forest Stewardship Council so this approach has the support of the steering committee set up to guide research within the SFF. With this aim in mind, the objective of this research is to find herbicides that will meet the requirements of the FSC and combine these chemicals with recommendations around currently used effective non-chemical management practices, such as oversowing (where practised). It is hoped that the impact of herbicide use on the planted forest environment will be minimised by using this type of integrated approach.

Options if required under the SSF contract

We have sufficient prior knowledge to recommend the use of alternative herbicides in conjunction with oversowing where possible, to reduce the overall input of active ingredients. If it is still deemed necessary to increase the component of the research around non-chemical control we recommend two options:

Option 1: Include manual brush-cutting**.** Outside the methods discussed above we are not aware of any non-chemical methods being used elsewhere (internationally) that need investigation. Manual brush-cutting is used in Europe and Canada to some degree and we could implement this as a treatment in our current trials to provide an up-to date comparison with chemical control. However in doing so we may well simply be spending resources to accurately account for the site specific significance of the degree to which this method is more costly and uneconomic rather than the estimated degree.

Option 2: Trial non-chemical methods: In a separate trial implemented during spring 2014 we could aim to test any emerging non-chemical technologies, such as bioherbicides or organic herbicides (non-selective preplant), that might be available and have potential for the forest industry. A review of the literature would need to be conducted to identify new technology that we are not currently aware of. Though research is in progress, there are currently no mycoherbicides registered for commercial use in New Zealand. However, given the success over the last year in identifying a large number of alternative herbicide options we would prefer to use SFF funds to finalise recommendations around these alternatives than pursue non-chemical treatments that are unlikely to be economically viable options.

References

Rolando, C.A., Watt, M.S., & Zabkiewicz, Z. A. (2011). The potential cost of environmental certification to vegetation management in plantation forests: A New Zealand case study. *Canadian Journal of Forest Research. 41,* 986-993.

Appendix C. Implementation of field trials

Description of trials

The details of all trial sites are shown in Tables 2 and 3 (p. 7) of the main body text. Prior to trial establishment, all trials received an aerial pre-plant spray in late summer/early autumn consisting of a mix of glyphosate and metsulfuron applied at approximately 3.3 kg ha^{-1} and 0.12 kg ha^{-1} respectively in 150 L water.

Experimental treatments

A total of 18 herbicide treatments plus a control (no herbicide) were studied in this set of trials. Seventeen of these were applied in the first spring after planting. Details of each of the first-year treatments are shown in Table 4 (p. 8) of the main body text along with the site(s) at which each treatment was applied. Five herbicide treatments, and the control, were applied across all seven sites as a set of core treatments. The first treatment (Treatment 1) in each trial was the current operational standard consisting of the herbicides terbuthylazine and hexazinone applied at the equivalent of 7.5 and 1.75 kg ha^{-1}. Treatment 1 was used as a benchmark against which all other treatments were compared for all measured parameters. A range of additional treatments was applied at each site (Table 4) resulting in a total of nine treatments at each site. The additional treatments were designed to meet the weed spectrum at each site. All treatments were arranged as a completely randomised design of three or four replicates.

The size of each trial was approximately 2 ha. For each plot, each treatment was applied over ten trees (two rows of five trees) with a buffer of two rows between adjacent plots. Pre-emergent treatments were applied in the equivalent of 200 L ha^{-1} water in spring before any weeds had emerged. No adjuvants were included in the pre-emergent treatments unless the subsequent herbicide treatment contained mesotrione. Post-emergent treatments were applied in the equivalent of 200 L ha^{-1} water in spring (mid-October) when the average height of weeds was 10 cm. All treatments were applied using an appropriate adjuvant (organosilicone at between 0.1% to 0.25% total volume). Treatments using mesotrione (Callisto®) were applied with the recommended crop oil adjuvant Synoil™ (Orion Crop Protection Ltd, New Zealand) at 1% volume of the spray mix.

A second-year treatment was applied across all sites, except at the Okuku trial site where only grasses were present. This treatment consisted of clopyralid, triclopyr and aminopyralid applied at the equivalent of 1500 g, 150 g and 22.5 g ha^{-1} in 150 L water. This treatment was applied aerially at three sites. In these cases, plastic sheets were used to cover the weedy plots to protect them from spray. The treatment was applied manually using a calibrated knapsack where aerial treatment was not possible.

Measurements and assessments

Measurements of tree height ($ht_{1\text{-}4}$) and groundline diameter ($gld_{1\text{-}4}$) were taken before treatment application, and at **approximately** 3, 6, 12 and 18 months after treatment application. Measurements commenced in September 2013 prior to application of the first (post-planting) herbicide treatments and were completed by 30 April 2015. Measurements of *ht* and *gld* were used to calculate a biomass index (BI), calculated as:

$$BI=(gld^2)*ht$$

Measurements of weeds were taken within a circle of 1 m radius around each tree. The 1 m circle was subdivided into four quadrants centred around the tree and the height of the tallest weed in each quadrant was recorded. These four values were averaged to determine the mean weed height (*Av_ht*). The percentage weed cover within each quadrant was estimated (*Av_cov*) and the proportion of cover in: (1) grasses; (2) herbaceous broadleaves (HBL); and (3) scrub weeds (broom, gorse, blackberry, buddleia, native woody plants, and Himalayan honeysuckle) was identified. Following the method of Richardson et al. (1999), these values were used to calculate a competition index, CI. The proportion of cover of grasses (*cov_grass*), herbaceous broadleaves (*cov_HBL*) and scrub weeds was calculated as a proportion of the total cover estimated for each tree.

Assessments of the weeds in the inter-row were made in two 1 m^2 sub-plots in each treatment plot before treatment application, and again 3, 6, 12 and 18 months after treatment application. The percentage cover in: (1) grasses; (2) herbaceous broadleaves (HBL); and (3) scrub weeds (as above) was identified. The above-ground biomass in all plots was harvested at six months and 18 months after treatment application.

Analyses

Linear mixed-effects models were applied to examine relationships between herbicide treatment and either tree- or weed-growth characteristics at specific dates following application of the herbicide treatment. The dependent variables in the analysis were: Biomass index (Bi); Competition Index (CI); or weed cover (C); the independent variable was Treatment, and random effect was due to plot. Functions (natural logarithms, square roots and fourth roots) that transformed Bi (or CI or C) were determined through inspection of plots to select transforming variables that resulted in linearity and constant variance with increasing mean values of the dependent variable. Models were fitted with and without multiple variances, and comparisons were made with the Akaike Information Criterion (AIC, 1974) to select the optimal model. The mixed effects models were fitted using the method of REML, and all modelling was performed using R (R Development Core, 2013).

References

Akaike, H. (1974). New look at the statistical model identification. *IEEE Transactions on Automatic Control, 19(6)*, 716-723.

R Core Team. (2013). *R: A language and environment for statistical computing.* Vienna, Austria: R Foundation for Statistical Computing. URL http://www.R-project.org/

Appendix D: Kaingaroa Trial Site

There was a diversity of weeds at the Kaingaroa site with a mixture of grasses (mainly Yorkshire fog grass), herbaceous broadleaves (foxglove, fleabane and jersey cudweed) and scrub weeds (blackberry and bracken).

A description of treatments applied at the Kaingaroa trial site is shown in Table D1. All treatments applied in were applied in October when weeds were emerging and below 10 cm. Shaded treatments indicate core treatments repeated across most sites. All treatments with mesotrione were applied with the adjuvant Synoil at 1%.

Table D1. Treatments applied at the Kaingaroa trial site

No	Treat Name (L ha^{-1})	Year 1 (g ha^{-1} active ingredient)	Year 2 (g ha^{-1} active ingredient)
1	Operational practice	7 500 g terbuthylazine and 1750 g hexazinone	1500 g clopyralid ,150 g triclopyr & 22.5 g aminopyralid
2	Weedy	No treatment	No treatment
3	15 L Gardoprim	7500 g terbuthylazine	1500 g clopyralid and 150 g triclopyr and 22.5 g aminopyralid
4	15 L Gardoprim & 0.188 L Grazon	7500 g terbuthylazine &113 g triclopyr	
5	15 L Gardoprim & 5 L Versatill	7500 g terbuthylazine & 1500 g clopyralid	
6	15 L Gardoprim & 0.75 L Callisto	7500 g terbuthylazine & 360 g mesotrione	
7	15 L Gardoprim & 0.6 L Tordon PastureBoss	7500 g terbuthylazine,120 g triclopyr & 18 g aminopyralid	
9	3.8 L Versatill, 0.38 L Tordon Brushkiller and 2.5 L Gallant	1125 g clopyralid, 113 g triclopyr & 250 g haloxyfop	
Additional treatments			
10	3.8 L Versatill and 1.0 L Callisto	1125 g clopyralid & 480 g mesotrione	1500 g clopyralid ,150 g triclopyr & 22.5 g aminopyralid
11	0.6 L Tordon PastureBoss and 1.0 L Callisto	120 g triclopyr, 18 g aminopyralid & 480 g mesotrione	

Results: Kaingaroa

Effect of treatment on vegetation at the Kaingaroa site (weed cover and biomass)

- Percentage cover of weeds in the plots that received no treatment was up to 52% 130 days after trial initiation (Figures D1 a).
- Weed cover was lowest at 130 and 418 days after treatment in plots that were treated with terbuthylazine and hexazinone (Treatment 1), terbuthylazine and clopyralid (Treatment 5) and terbuthylazine and mesotrione (Treatment 6), (Figure D1b).
- By 418 days after trial initiation, and following the application of triclopyr, clopyralid and aminopyralid at 12 months, most plots were dominated by a cover of grass, with over 50% cover of weeds in all treatment plots (Figure D1). At 418 days weed cover in treatments 5, 6 and 8 was not significantly different from that in the operational standard.

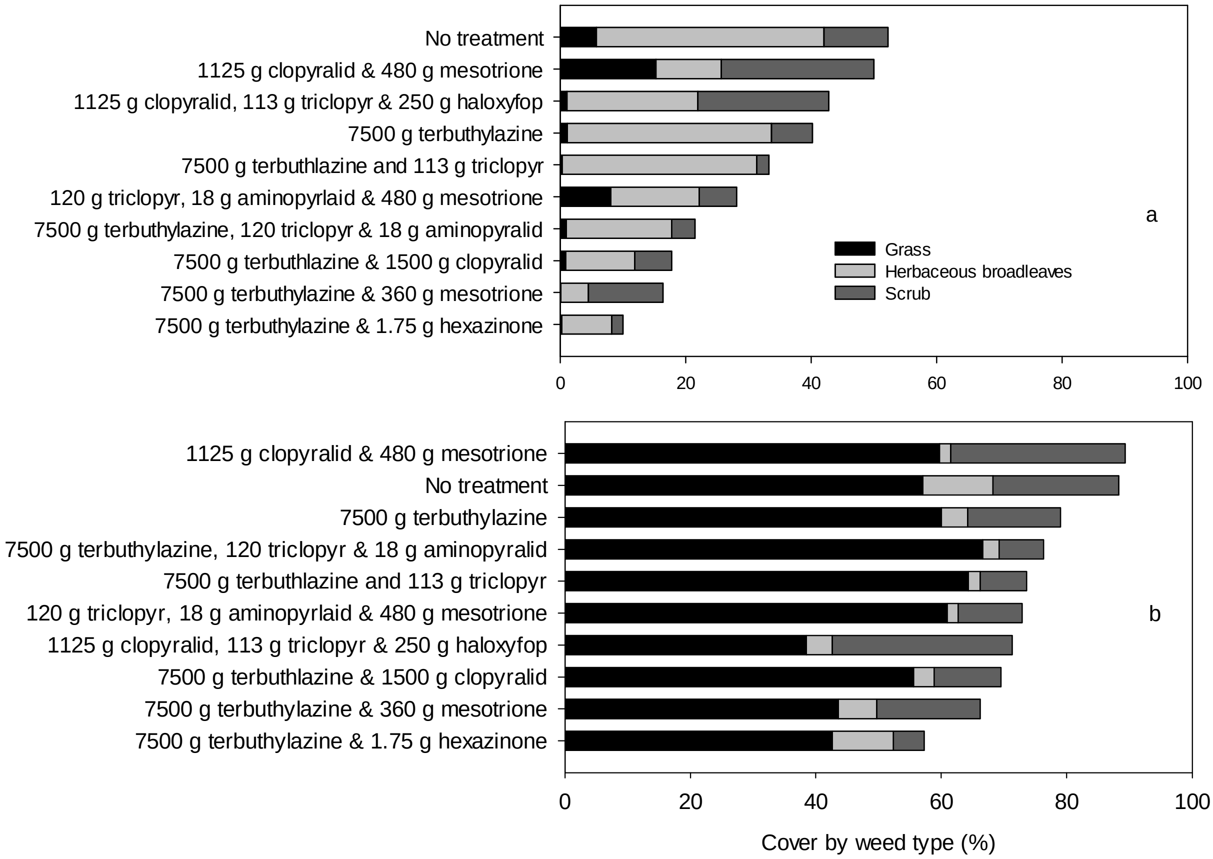

Figure D1. Weed cover by functional type at (a) 130 days and (b) 418 days after treatment initiation.

Tree size

- The difference in tree size between the operational standard and the no treatment control was 37.9% (Figure D2).
- At 418 days after trial initiation, the best alternatives to the operational standard were the mixes of terbuthylazine and mesotrione (Treatment 6), terbuthylazine and clopyralid (Treatment 5), clopyralid, triclopyr and haloxyfop (Treatment 9) and triclopyr, aminopyralid

and mesotrione (Treatment 11). These treatments did not have a significantly different biomass index to that of the operational standard. However, there was up to a 15.5% decrease in tree size for Treatment 5 (see Appendix K; Figure D2).

- Trees were more than 30% smaller than those in the operational standard where terbuthylazine was applied alone or in combination with triclopyr, (Figure D2). This difference was significant where terbuthylazine was applied alone.
- The use of clopyralid and mesotrione (Treatment 10) as a combination was not effective and trees were significantly smaller than the operational standard by 25%. Weed cover in these plots was not significantly different from the no treatment control (Figure D2).

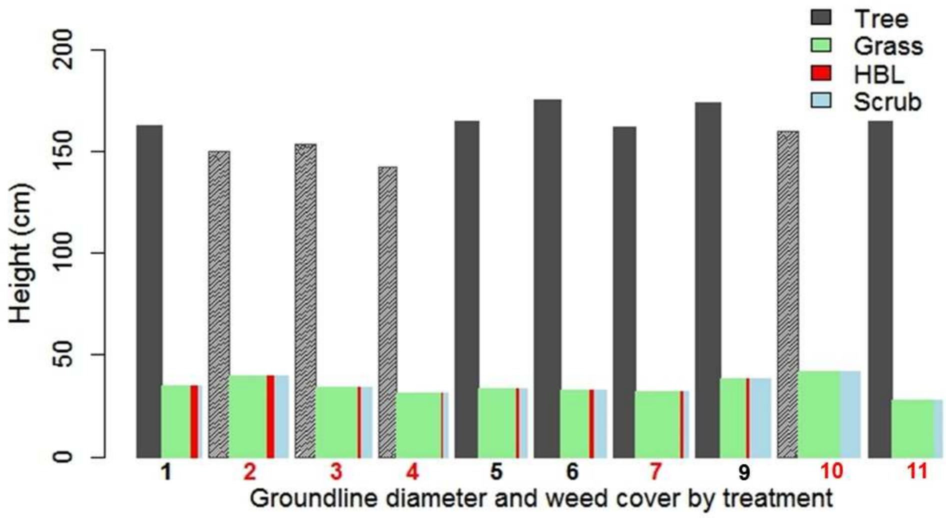

Figure D2. Composite representation of tree size (height and groundline diameter) and weed cover by type for treatments. Tree bars (shaded in grey) show treatments where the tree Biomass Index (a function of tree height and groundline diameter) was significantly different to the operational standard (Treatment 1). *Note that both the height and width of bars represent tree size.* Treatment numbers in red indicate where cover of weeds was significantly different to the operational standard. *Note that the width of cover bars represents percentage cover while the height of the bars the average height of the weeds. Treatments are shown in Table D1*.

Key outcomes from Kaingaroa trial

- The best first-year post-planting treatment was the operational standard.
- The best alternative first-year post-planting treatments that eliminated use hexazinone but retained terbuthylazine were treatments 5 and 6, where terbuthylazine (7.0 kg ha^{-1}) was applied in combination with either clopyralid (1.5 kg ha^{-1}) or mesotrione (0.36 kg ha^{-1}) respectively.
- The best first-year alternative treatments that did not use either terbuthylazine or hexazinone were Treatment 9 where clopyralid was applied in combination with triclopyr and haloxyfop and Treatment 11 where triclopyr was applied in combination with aminopyralid and mesotrione.
- The second-year treatment of clopyralid, triclopyr and aminopyralid was not particularly effective at this site, as the treatment is designed to largely target broom and gorse. These scrub weeds were not present at this site. We would not recommend this treatment to be applied at sites with a similar spectrum of weeds as that which occurred at Kaingaroa.

Appendix E: Whakarewarewa Trial Site

As at the Kaingaroa site in the Central North Island region, there was a diversity of weeds at the Whakarewarewa site with a mixture of grasses (Yorkshire fog grass, Bay grass and sedges), herbaceous broadleaves (Jersey cudweed, Australian fireweed, Inkweed, Dandelion, Fleabane, Black nightshade) and scrub weeds (Himalayan honeysuckle, Lotus and Bracken).

A description of treatments applied at the Whakarewarewa trial site is shown in Table E1. All treatments were applied in late October, when weeds were emerging or below 10 cm, except Treatment 3 (which was applied in late September as a pre-emergent treatment). Shaded treatments indicate core treatments repeated across most sites. All treatments with mesotrione were applied with the adjuvant Synoil at 1%.

Table E1. Treatments applied at the Whakawerawera site.

No	Treat Name (L ha^{-1})	Year 1 (g ha^{-1} active ingredient)	Year 2 (g ha^{-1} active ingredient)
1	Operational practice	7500 g terbuthylazine & 1750 g hexazinone	1500 g clopyralid, 150 g triclopyr & 22.5 g aminopyralid
2	Weedy**	No treatment	No treatment
3	15 L Gardoprim**	7500 g terbuthylazine	1500 g clopyralid, 150 g triclopyr & 22.5 g aminopyralid
4	15 L Gardoprim & 0.188 L Grazon	7500 g terbuthylazine &113 g triclopyr	
5	15 L Gardoprim & 5 L Versatill	7500 g terbuthylazine & 1500 g clopyralid	
6	15 L Gardoprim & 0.75 L Callisto	7500 g terbuthylazine & 360 g mesotrione	
7	15 L Gardoprim & 0.6 L Tordon PastureBoss	7500 g terbuthylazine,120 g triclopyr & 18 g aminopyralid	
9	3.8 L Versatill, 0.38 L Tordon Brushkiller & 2.5 L Gallant	1125 g clopyralid, 113 g triclopyr & 250 g haloxyfop	
Additional treatments			
10	3.8 L Versatill & 1.0 L Callisto	1125 g clopyralid & 480 g mesotrione	1500 g clopyralid,150 g triclopyr & 22.5 g aminopyralid
13	0.6 L 437 & 1.0 L Callisto	300 g indaziflam & 480 g mesotrione	

Results: Whakarewarewa

Effect of treatment on the vegetation at the Whakarewarewa site (weed cover and biomass)

- Percentage cover of weeds in the plots that received no treatment was up to 48% 159 days after trial initiation (Figure E1).
- Weed cover was lowest throughout the trial in the plots that were treated with the operational standard (Treatment 1), terbuthylazine applied with either clopyralid (Treatment 5) or mesotrione (Treatment 6) and where indaziflam and mesotrione were applied in combination (Treatment 13) (Figure D1 a & b). Weed cover in these three treatments (5, 6 & 13) was not significantly different from the operational standard at 159 days after treatment application.
- At 507 days after trial initiation, and following the application of triclopyr, clopyralid and aminopyralid at 12 months, weed cover in most treatments was not significantly different from the operational standard with the exception of the no treatment control, Treatment 7 and Treatment 10.Lowest weed cover continued to be in Treatments 5 (terbuthylazine and clopyralid), 6 (terbuthylazine and mesotrione) and 13 (indaziflam and mesotrione) (Figure D1 b).

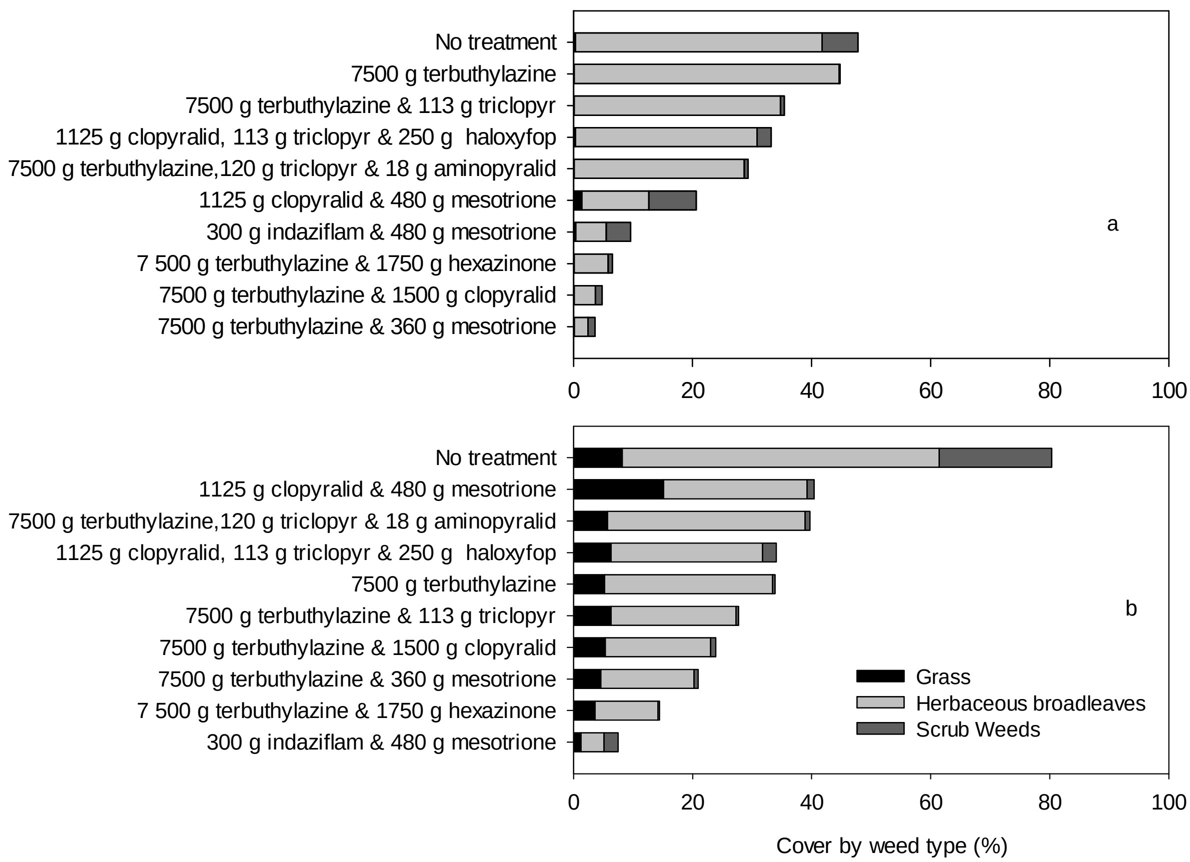

Figure E1. Weed cover by functional type at a) 159 and b) 507 days after treatment initiation.

Tree size

- The difference in tree size between the operational standard and the no treatment control at 507 days after treatment was significant, with trees in the no treatment control 59.5% smaller than the operational standard (Figure E2).
- At 507 days after trial initiation the best alternatives to the operational standard, as indicated by using tree Biomass Index, were Treatments 5 and 6 (terbuthylazine applied in combination with clopyralid or mesotrione respectively), Treatment 9 (clopyralid, triclopyr, haloxyfop), Treatment 10 (clopyralid and mesotrione) and Treatment 13 (indaziflam and mesotrione). These treatments did not have a significantly different biomass index to that of the operational standard. However, despite the low cover of weeds in these treatments, there was between 20 to 37% loss in tree size in comparison to the operational standard across these treatments (Figure E2 and Appendix K).
- Where terbuthylazine was applied alone, in combination with either triclopyr or triclopyr and aminopyralid, trees were significantly smaller than those in the operational standard by more than 40% (Figure E2 and Appendix K).

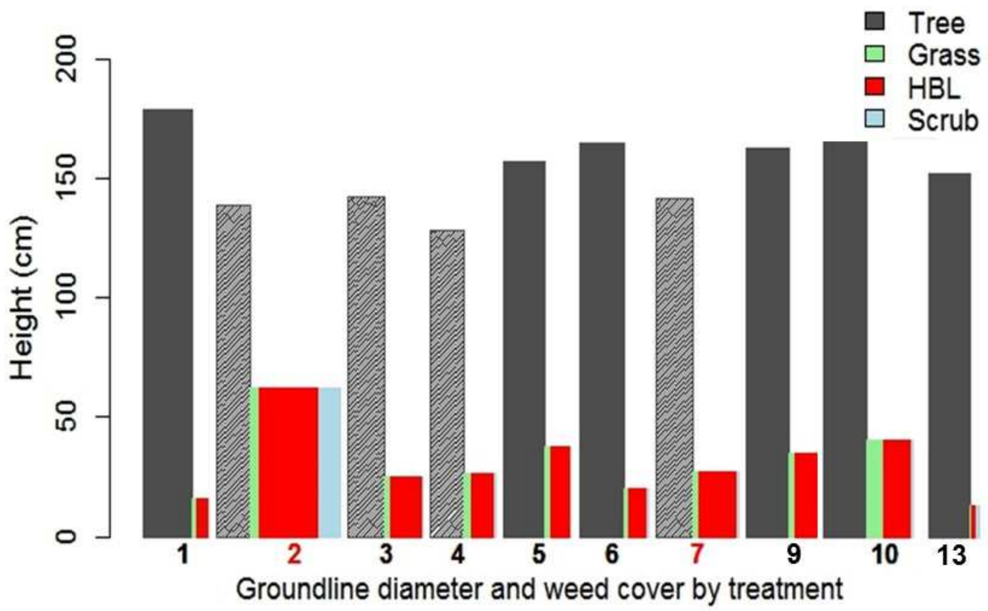

Figure E2. Composite representation of tree size (ht and groundline diameter) and weed cover by type and treatment. Tree bars shaded in grey show treatments where the tree Biomass Index (a function of tree height and groundline diameter) was significantly different to the operational standard (Treatment 1). *Note that both the height and width of bars represent tree size.* Treatment numbers in red indicate where cover of weeds was significantly different to the operational standard. *Note that the width of cover bars represents percentage cover while the height of the bars the average height of the weeds. Treatments are shown in Table E1.*

Key outcomes from Whakarewarewa trial

- The best first-year post-planting treatment was the operational standard.
- Best first-year post-planting treatments, that eliminated use hexazinone but retained terbuthylazine, were those where terbuthylazine was applied in combination with either clopyralid or mesotrione (Treatments 5 and 6 respectively) (Figure E2).

- Best first-year alternative treatments that did not use either terbuthylazine or hexazinone were those where mesotrione was applied in combination with either clopyralid or indaziflam (Treatments 10 and 13) or clopyralid was applied with triclopyr and haloxyfop (treatment 9) (Figure E2).
- Whilst not all significant, all alternative treatments resulted in tree growth reductions of greater than 20% relative to the operational standard (Appendix K)
- The second-year treatment of clopyralid, triclopyr and aminopyralid was not particularly effective at this site, as the treatment is designed to largely target broom and gorse. These scrub weeds were not present at this site. We would not recommend this treatment to be applied at sites with a similar spectrum of weeds as that which occurred at Whakarewarewa.

Appendix F: Mamaku Trial Site

As at the two other Central North Island sites, there was a diversity of weeds at the Mamaku site, however, these were predominantly grasses (Yorkshire fog grass) and herbaceous broadleaves (Jersey cudweed, Australian fireweed, hawksbeard, foxglove, verbena) with few scrub or woody weeds (mainly lotus and bracken).

A description of treatments applied at the Mamaku trial site is shown in Table F1. All treatments applied in late October, except for treatments 13 and 14, which were applied in late September as a pre-emergent treatment. Shaded treatments indicate core treatments repeated across most sites. All treatments with mesotrione were applied with the adjuvant Synoil at 1%.

Table F1. Treatments applied at the Mamaku trial site.

No	Treat Name (L ha^{-1})	Year 1 (g ha^{-1} active ingredient)	Year 2 (g ha^{-1} active ingredient)
1	Operational practice	7500 g terbuthylazine & 1750 g hexazinone	1500 g clopyralid, 150 g triclopyr & 22.5 g aminopyralid
2	Weedy**	No treatment	No treatment
3	15 L Gardoprim**	7500 g terbuthylazine	1500 g clopyralid, 150 g triclopyr & 22.5 g aminopyralid
4	15 L Gardoprim & 0.188 L Grazon	7500 g terbuthylazine &113 g triclopyr	
5	15 L Gardoprim & 5 L Versatill	7500 g terbuthylazine & 1500 g clopyralid	
6	15 L Gardoprim & 0.75 L Callisto	7500 g terbuthylazine & 360 g mesotrione	
7	15 L Gardoprim & 0.6 L Tordon PastureBoss	7500 g terbuthylazine & 120 g triclopyr & 18 g aminopyralid	
9	3.8 L Versatill, 0.38 L Tordon Brushkiller & 2.5 L Gallant	1125 g clopyralid, 113 g triclopyr & 250 g haloxyfop	
Additional treatments			
13	0.6 L '437' & 1.0 L Callisto	300 g indaziflam & 480 g mesotrione	1500 g clopyralid,150 g triclopyr & 22.5 g aminopyralid
14	0.6 L '437' & 0.6 L Tordon PastureBoss	300 g indaziflam, 113 g triclopyr & 17 g aminopyralid	1500 g clopyralid,150 g triclopyr & 22.5 g aminopyralid

Results: Mamaku

Effect of treatment on the vegetation at the Mamaku site (weed cover and biomass)

- Percentage cover of weeds in the plots that received no treatment was 25% 134 days after trial initiation (Figure F1a). Overall, weed growth at this site was lower than that at the other two central North Island sites (Kaingaroa and Whaka), as indexed by a lower weed biomass (Figure 1, main body of document).
- Following 513 days after trial inititiation, weed cover in the plots treated with terbuthylazine and mesotrione (Treatment 6) was low (3.6%) and not significantly different from the operational standard (2.8%) (Treatment 1). Weed cover in all other treatments was significantly higher than the operational standard, albeit not very high cover. In terms of lowest cover, the pre-emergent treatments where indaziflam was applied in combination with either mesotrione or a mix of triclopyr and aminopyralid (Treatments 13 &14 respectively) were among the top five treatments (Figure F1a).
- At 513 days after trial initiation, and following the application of triclopyr, clopyralid and aminopyralid at 12 months, there was no significant difference in weed cover across all treatments. The site was dominated by a cover of Yorkshire fog grass, with the lowest cover assessed in the treatments where indaziflam had been applied (Treatments 13 and 14) (Figure F1b).

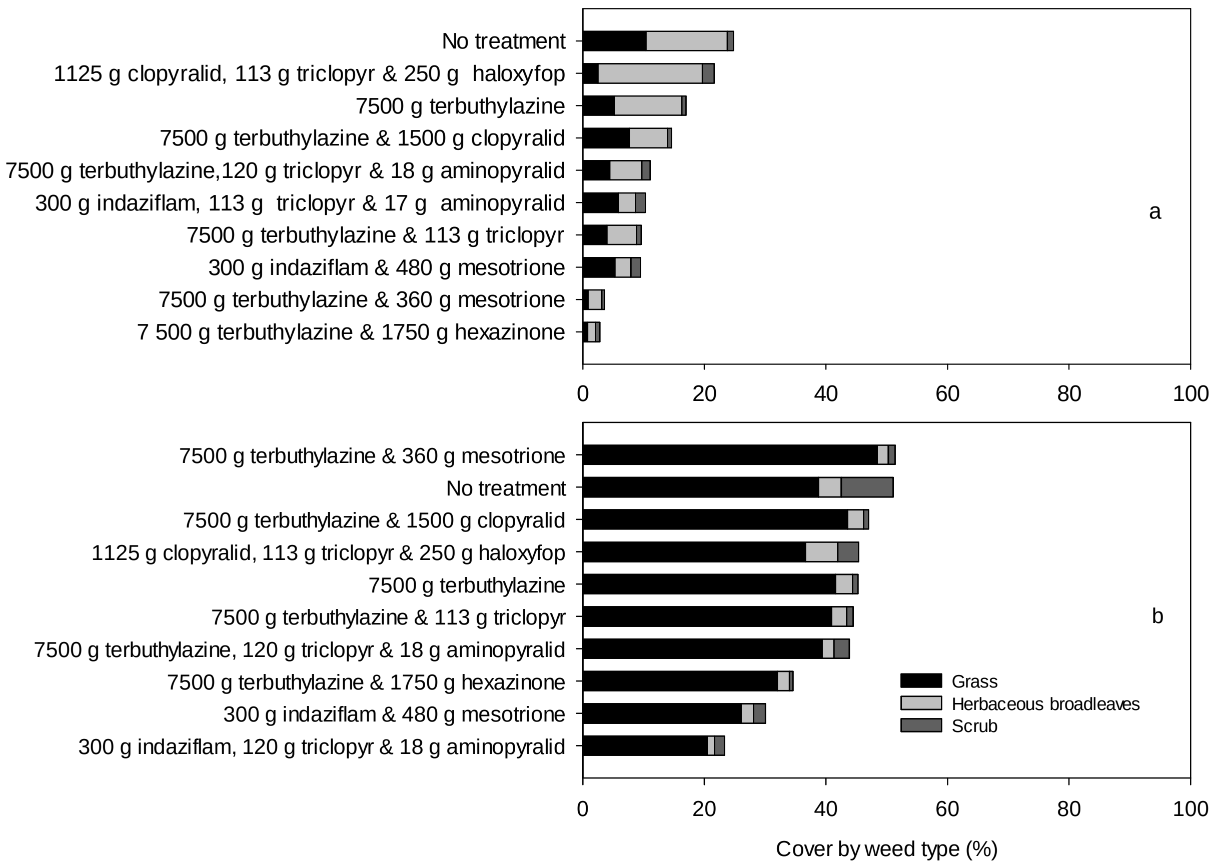

Figure F1. Weed cover by functional type at a) 134 and b) 513 days after treatment initiation.

Tree size

- The difference in tree size between the operational standard and the no treatment control was 33% - a relatively small difference as a consequence of the lower level of interspecific competition at this site. Also, the difference in biomass index of the operational standard and the no treatment control was not significant (Figure F2).
- At 513 days after trial initiation, the only treatment that was significantly different to the operational standard, for tree biomass, was Treatment 7, where terbuthylazine was applied in combination with aminopyralid and triclopyr. The smaller size of trees in this treatment most likely reflects a slight phytotoxic effect on radiata pine, as the cover of weeds was not significantly different for this treatment compared with other treatments (Figure F2).
- The best performing trees relative to the operational standard occurred where terbuthylazine was used in combination with mesotrione (Treatment 6) (Figure F2). Following this, tree growth in the two pre-emergent treatments (Treatment 13 & 14) compared well with the operational standard (Figure F2).

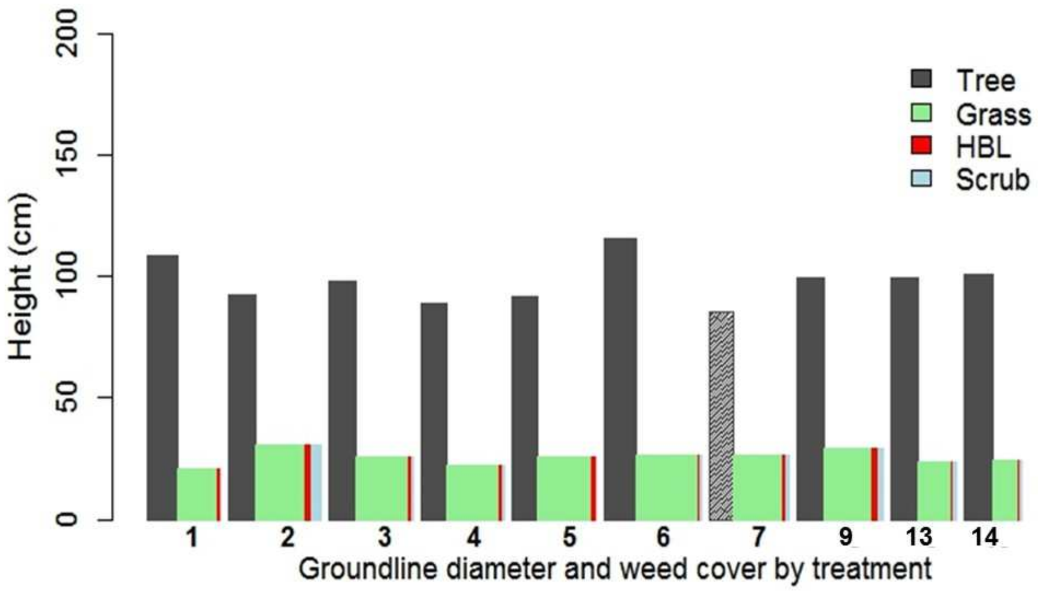

Figure F2. Composite representation of tree size (ht and groundline diameter) and weed cover by type for treatments. Tree bars shaded in grey show treatments where the tree Biomass Index (a function of tree height and groundline diameter) was significantly different to the operational standard (Treatment 1). *Note that both the height and width of bars represent tree size*. Treatment numbers in red indicate where cover of weeds was significantly different to the operational standard. *Note that the width of cover bars represents percentage cover while the height of the bars the average height of the weeds. Treatments are shown in Table F1.*

Key outcomes from Mamaku trial

- Best first-year post-planting treatment, that eliminated use of hexazinone but retained terbuthylazine, was that where terbuthylazine was applied in combination with mesotrione (Treatment 6). This treatment was not significantly different to Treatment 1, for any parameters assessed.

- Best first-year alternative treatments that did not use either terbuthylazine or hexazinone were those where indaziflam was applied in combination with either mesotrione or a mix of triclopyr and aminopyralid (Treatments 13 & 14).
- Whilst not all significant, all alternative treatments, except Treatment 6, resulted in tree growth reductions of greater than 15% relative to the operational standard. Of particular note are those treatments where terbuthylazine was applied in combination with triclopyr or triclopyr and aminopyralid (Treatments 4 & 7 respectively) (Figure F2 and Appendix K).
- The second-year treatment of clopyralid, triclopyr and aminopyralid was not particularly effective at this site, as the treatment is designed to largely target broom and gorse. These scrub weeds were not present at this site. We would not recommend this treatment to be applied at sites with a similar spectrum of weeds as that which occurred at Mamaku. The low level of competition at this site means that the benefits of a second-year spray are unlikely to realised.

Appendix G: Geraldine Trial Site

There was a wide spectrum of weeds at the Geraldine site, with grasses, herbaceous broadleaves (annuals, thistles, clover) and scrub weeds (gorse, broom, honeysuckle and blackberry) present.

A description of the treatments applied at the Geraldine trial site is shown in Table G1. All treatments were applied in late October, except for treatments 13, 14 and 15 which were applied in late September as a pre-emergent treatment. Shaded treatments indicate core treatments repeated across most sites. All treatments were implemented at the equivalent of 150 – 200 L ha^{-1} using organosilicone adjuvant applied at 0.2% total volume, except where mesotrione was applied where the equivalent of 1 L ha^{-1} Synoil was used.

Table G1. Description of treatments applied at the Geraldine site.

No	Treat Name (L ha^{-1})	Year 1 (g ha^{-1} active ingredient)	Year 2 (g ha^{-1} active ingredient)
1	Operational practice	7500 g terbuthylazine and 1750 g hexazinone	1500 g clopyralid, 150 g triclopyr & 22.5 g aminopyralid
2	Weedy**	No treatment	No treatment
3	15 L Gardoprim**	7500 g terbuthylazine	1500 g clopyralid, 150 g triclopyr & 22.5 g aminopyralid
5	15 L Gardoprim & 5 L Versatill	7500 g terbuthylazine & 1500 g clopyralid	
6	15 L Gardoprim & 0.75 L Callisto	7500 g terbuthylazine & 360 g mesotrione	
8	15 L Gardoprim & 1 L Tordon Max	7500 g terbuthylazine 30 g aminopyralid	
9	3.8 L Versatill, 0.38 L Tordon Brushkiller and 2.5 L Gallant	1125 g clopyralid, 113 g triclopyr & 250 g haloxyfop	
Additional treatments			
13	0.6 L '437' & 1.0 L Callisto	300 g indaziflam & 480 g mesotrione	1500 g clopyralid, 150 g triclopyr & 22.5 g aminopyralid
14	0.6 L '437' & 0.6 L Tordon PastureBoss	300 g indaziflam, 113 g triclopyr & 17 g aminopyralid	
15	0.6 L '437' & 5 L Versatil	300 g indaziflam, 1500 g clopyralid	

Results Geraldine

Effect of treatment on vegetation at the Geraldine site (weed cover and biomass)

- Percentage cover of weeds in the plots that received no treatment was 67% 173 days after trial initiation (and up to 75% at 18 months). Overall, weed growth at this site was relatively high, as indexed by a high weed biomass (Figure 1, main body of document).
- One hundred and seventy three days after trial initiation, weed cover in the plots treated with the operational standard was lowest (10%). Weed cover where terbuthylazine was applied alone, or in combination with clopyralid, mesotrione or aminopyralid (Treatments 3, 5, 6 & 8 respectively), and where indaziflam was applied with mesotrione (Treatment 13) was not significantly different from the operational standard (Figure G1a).
- At 515 days after trial initiation, and following the aerial application of triclopyr, clopyralid and aminopyralid at 12 months, cover in the operational standard continued to be the lowest (32%). Cover in Treatments 2, 5, 14 and 15 was significantly higher than operational standard (Treatment 1) (Figure G1b).
- The second-year treatment consisting of clopyralid, triclopyr and aminopyralid was effective in managing the broom and gorse at this site, particularly the younger and emerging plants, and a percentage cover of grass increased where the treatment was applied (Figure G1b; Figure G2).

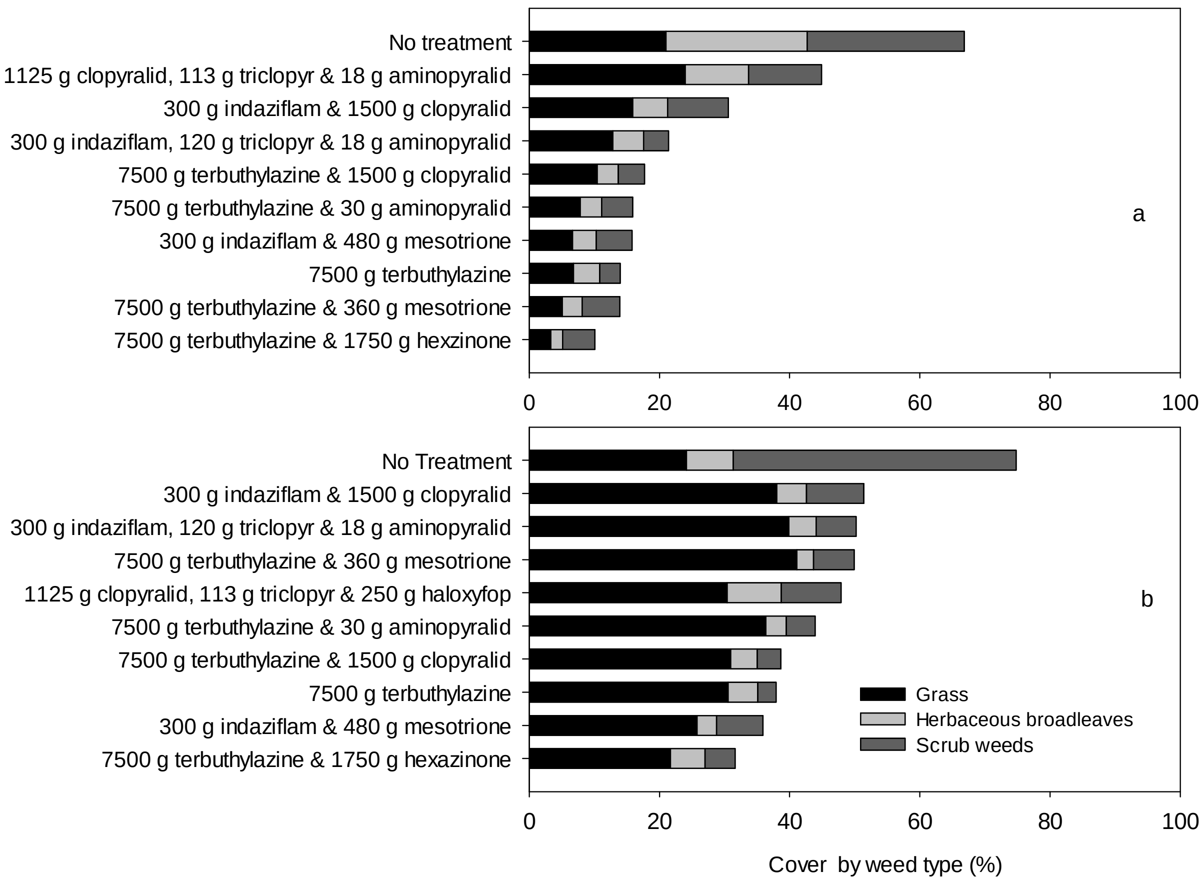

Figure G1. Weed cover by functional type at a) 173 and b) 515 days after treatment initiation.

Figure G2. Two examples of weed cover and type at 515 days after trial initiation: Treatment 1 (left) and Treatment 2 (right).

Tree size

- At 515 days after trial initiation, the difference in tree size between the operational standard and the no treatment control was 85%- a reflection of the high level of interspecific competition at this site. The difference in tree Biomass Index of the operational standard and the no treatment control was significant (Figure G3).
- At 515 days after trial initiation, tree size in all treatments was significantly reduced relative to the operational standard (Treatment 1) (Appendix K). This was the only site where this result occurred. Reductions in tree size relative to the operational standard were between 49% and 85%. Given that a similar trend in responses was not seen in the cover of weeds, these large reductions can be attributed only to an effect from the herbicides or some other site effect not assessed. At least 30% of plots were located on a skid line and this may have severely affected the growth of trees and weeds across the site (resulting in poor growth). In the analysis of this site, it was noted that there was high variability in tree growth among treatment plots, making it difficult to interpret the outcome of the treatments across the site.
- Severe differences in tree size aside, the best performing trees relative to the operational standard (Treatment 1) occurred where terbuthylazine was used in combination with clopyralid or mesotrione (Treatments 5 and 6 respectively) (Figure G3).

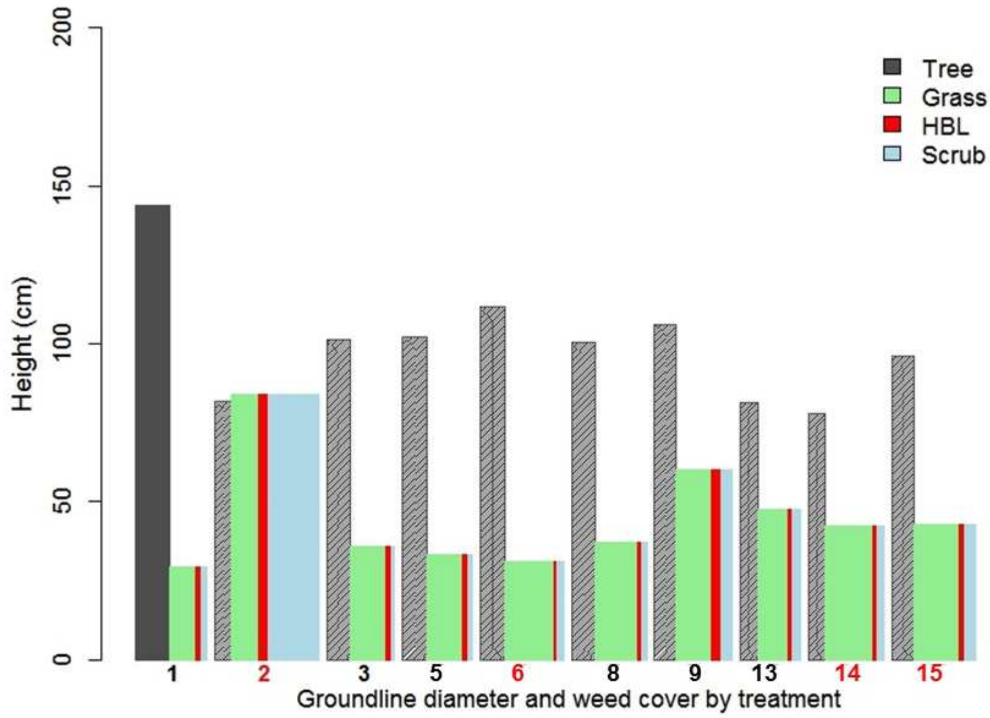

Figure G3. Composite representation of tree size (ht and groundline diameter) and weed cover by type for treatments. Tree bars shaded in grey show treatments where the tree Biomass Index (a function of tree height and groundline diameter) was significantly different to the operational standard (Treatment 1). *Note that both the height and width of bars represent tree size*. Treatment numbers in red indicate where cover of weeds was significantly different to the operational standard. *Note that the width of cover bars represents percentage cover while the height of the bars the average height of the weeds. Treatments are shown in Table G1.*

Key outcomes at Geraldine

It is difficult to define the outcomes at this site due to the substantial reductions in tree size in treated trees relative to those in the operational standard.

- Best first-year post-planting treatment, that eliminated use of hexazinone but retained terbuthylazine, was that where terbuthylazine was applied in combination with mesotrione, or clopyralid (Treatments 5 and 6 respectively).
- The second-year treatment of clopyralid, triclopyr and aminopyralid was effective at this site, and removed the gorse. This encouraged a cover of grass at this site (Figure G1b). These results indicate that aminopyralid may be a viable alternative if picloram needs to be eliminated from the current second-year “5,5,5” mixture. The trees did not show signs of severe phytotoxic effects.

Appendix H: Flagstaff Trial site

In contrast to the Central North Island sites, this site was dominated by the scrub weeds gorse and broom with fewer grasses and herbaceous broadleaved weeds.

A description of treatments applied at the Flagstaff trial site is provided in Table H1. All treatments applied in late October. Shaded treatments indicate core treatments repeated across most sites. All treatments were implemented at the equivalent of 150 - 200 L ha^{-1} using organosilicone adjuvant applied at 0.2% total volume, except where mesotrione was applied where the equivalent of 1 L ha^{-1} Synoil was used.

Table H1. Description of treatments applied at the Flagstaff trial site

<table>
<tr><th>No</th><th>Treat Name (L ha⁻¹)</th><th>Year 1 (g ha⁻¹ active ingredient)</th><th>Year 2 (g ha⁻¹ active ingredient)</th></tr>
<tr><td>1</td><td>Operational practice</td><td>7000 g terbuthylazine & 1750 g hexazinone</td><td>1500 g clopyralid, 150 g triclopyr & 22.5 g aminopyralid</td></tr>
<tr><td>2</td><td>No treatment</td><td>No treatment</td><td>No control</td></tr>
<tr><td>3</td><td>15 L Gardoprim**</td><td>7500 g terbuthylazine</td><td rowspan="6">1500 g clopyralid, 150 g triclopyr & 22.5 g aminopyralid</td></tr>
<tr><td>4</td><td>15 L Gardoprim & 0.188 L Grazon</td><td>7500 g terbuthylazine &113 g triclopyr</td></tr>
<tr><td>5</td><td>15 L Gardoprim & 5 L Versatill</td><td>7500 g terbuthylazine & 1500 g clopyralid</td></tr>
<tr><td>6</td><td>15 L Gardoprim & 0.75 L Callisto</td><td>7500 g terbuthylazine & 360 g mesotrione</td></tr>
<tr><td>7</td><td>15 L Gardoprim & 0.6 L Tordon PastureBoss</td><td>7500 g terbuthylazine,120 g triclopyr & 18 g aminopyralid</td></tr>
<tr><td>9</td><td>3.8 L Versatill, 0.38 L Tordon Brushkiller and 2.5 L Gallant</td><td>1125 g clopyralid, 113 g triclopyr & 250 g haloxyfop</td></tr>
<tr><td colspan="4">Additional treatments</td></tr>
<tr><td>10</td><td>3.8 L Versatill & 1.0 L Callisto</td><td>1125 g clopyralid, 360 g mesotrione</td><td rowspan="2">1500 g clopyralid, 150 g triclopyr & 22.5 g aminopyralid</td></tr>
<tr><td>12</td><td>3.8 L Versatill & 1.0 L Tordon Max</td><td>1125 g clopyralid, 30 g aminopyralid</td></tr>
</table>

Results: Flagstaff

Effect of treatment on the vegetation at the Flagstaff site (weed cover and biomass)

- Percentage cover of weeds in the plots that received no treatment was 68% 188 days after trial initiation (and up to 88% at 548 days). Overall, weed growth at this site was the highest, as indexed by the weed biomass (Figure 1, main body of document).
- The operational standard did not perform as well as expected at this site, making interpretation of the alternative treatments difficult. At 188 days after trial initiation, weed cover in the plots treated with terbuthylazine and mesotrione (Treatment 6) was the lowest (13.8%) and not significantly different from the operational standard (22.5%) (Treatment 1).This was followed by that where terbuthylazine was applied in combination with either clopyralid (Treatment 5) (16.7%) or a mix of triclopyr and aminopyralid (Treatment 7) (20%). All treatments that contained no terbuthylazine (9, 10,12) had significantly higher weed cover than the operational standard (Figure H1a).
- At 548 days after trial initiation, and following the application of triclopyr, clopyralid and aminopyralid at 12 months, there was no significant difference in weed cover across all treatments where terbuthylazine was applied, with the terbuthylazine and mesotrione mix having the lowest cover (Figure H1b)
- The site was dominated by a cover broom and gorse, and the second-year treatment consisting of clopyralid, triclopyr and aminopyralid was effective in managing these weeds, particularly against the younger and emerging plants (Figure H2).

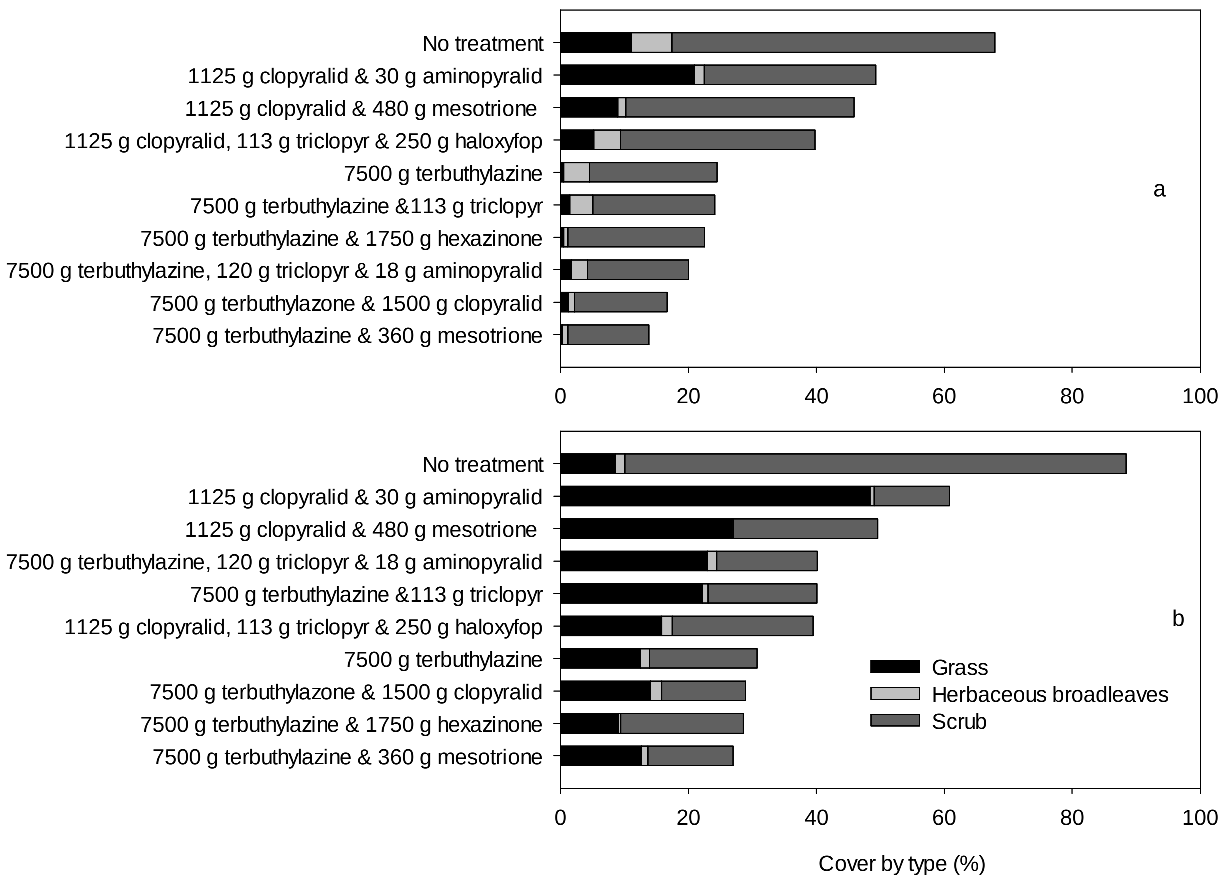

Figure H1. Weed cover by functional type at a) 188 and b) 548 days after treatment initiation.

Figure H2. The impact of the second-year application of clopyralid, tripclopyr and aminopyralid on the gorse at Flagstaff trial site. Applied October 2014.

Tree size

- At 548 days after trial initiation, the difference in tree size between the operational standard and the no treatment control was 88%, which was a reflection of the high level of interspecific competition from scrub weeds (mainly gorse) at this site. The difference in biomass index of the operational standard and the no treatment control was significant.
- At 548 days after trial initiation, the only treatment that was significantly different to the operational standard, for tree biomass, was Treatment 12, where clopyralid was applied in combination with aminopyralid (Appendix K, Figure H3). Significantly smaller trees in this treatment most likely reflect the high level of interspecific competition in this treatment, as weed control was poor.
- Although tree biomass was not significantly different from the operational standard for all other treatments, there was between a 20 to 30% loss in tree biomass where terbuthylazine was not applied (Treatments 9 &10) (Appendix K, Figure H3)
- The best performing trees relative to the operational standard grew in plots where terbuthylazine was used in combination with either clopyralid or mesotrione, or a mix of triclopyr and aminopyralid (Treatments 5, 6 and 7 respectively) (Appendix K, Figure H3).

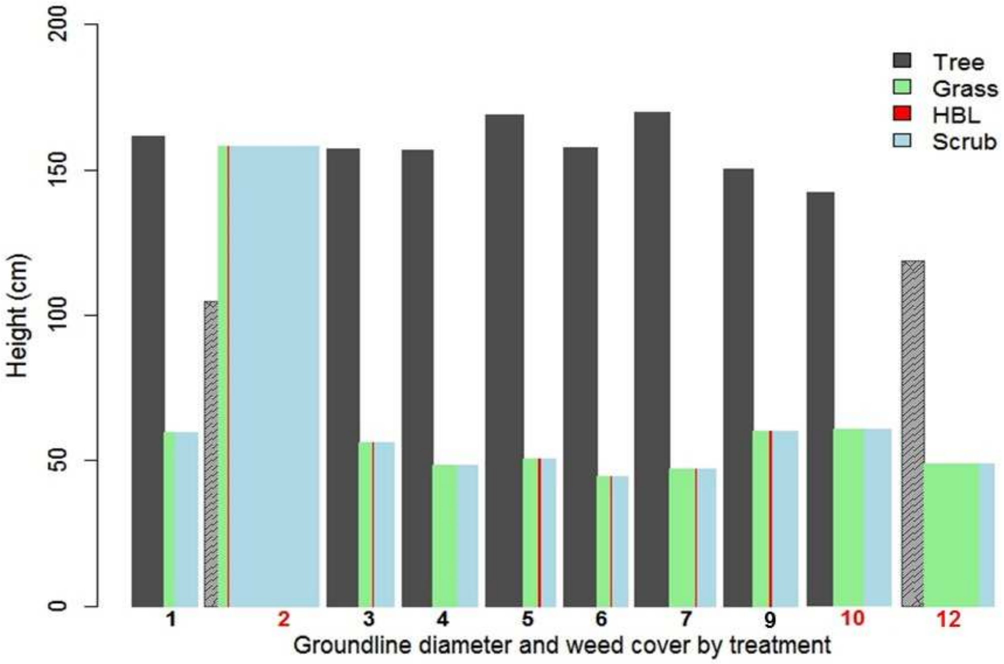

Figure H3. Composite representation of tree size (ht and groundline diameter) and weed cover by type for treatments. Tree bars shaded in grey show treatments where the tree Biomass Index (a function of tree height and groundline diameter) was significantly different to the operational standard (Treatment 1). *Note that both the height and width of bars represent tree size*. Treatment numbers in red indicate where cover of weeds was significantly different to the operational standard. *Note that the width of cover bars represents percentage cover while the height of the bars the average height of the weeds. Treatments are shown in Table H1.*

Key outcomes from Flagstaff trial

- Best first-year post-planting treatment, that eliminated use of hexazinone but retained terbuthylazine, was that where terbuthylazine was applied in combination with either clopyralid or mesotrione or a mix of triclopyr and aminopyralid (Treatments 5, 6 and 7 respectively).
- Best first-year alternative treatment that did not use either terbuthylazine or hexazinone was a mix of clopyralid, triclopyr and haloxyfop (Treatment 9). This treatment resulted in a 23.5% growth loss relative to the operational standard at approximately 18 months.
- Clopyralid applied in combination with either mesotione or aminopyralid (Treatments 10 & 12 respectively) was not effective.
- The second-year treatment of clopyralid, triclopyr and aminopyralid was particularly effective at this site, as the site was dominated by a cover of gorse. These results indicate that aminopyralid may be a viable alternative if picloram needs to be eliminated from the current second-year "5,5,5" mixture . The trees did not show signs of severe phytotoxic effects.

Appendix I: Rai trial site

As at the Flagstaff site, this site was dominated by the scrub weeds broom and gorse with fewer grasses and herbaceous broadleaved weeds.

A description of treatments applied at the Rai trial site is shown in Table I1. All treatments were applied in late October. Shaded treatments indicate core treatments repeated across most sites. All treatments were implemented at the equivalent of 150 - 200 L ha^{-1} using organosilicone adjuvant applied at 0.2% total volume, except where mesotrione was applied where the equivalent of 1 L ha^{-1} Synoil was used.

Table I1. Description of treatments applied at the Rai trial site

<table>
<tr><th>No</th><th>Treat Name (L ha^{-1})</th><th>Year 1 (g ha^{-1} active ingredient)</th><th>Year 2 (g ha^{-1} active ingredient)</th></tr>
<tr><td>1</td><td>Operational practice</td><td>7000 g terbuthylazine & 1750 g hexazinone</td><td>1500 g clopyralid, 150 g triclopyr & 22.5 g aminopyralid</td></tr>
<tr><td>2</td><td>Weedy**</td><td>No treatment</td><td>No treatment</td></tr>
<tr><td>3</td><td>15 L Gardoprim**</td><td>7500 g terbuthylazine</td><td rowspan="6">1500 g clopyralid, 150 g triclopyr & 22.5 g aminopyralid</td></tr>
<tr><td>4</td><td>15 L Gardoprim & 0.188 L Grazon</td><td>7500 g terbuthylazine &113 g triclopyr</td></tr>
<tr><td>5</td><td>15 L Gardoprim & 5 L Versatill</td><td>7500 g terbuthylazine & 1500 g clopyralid</td></tr>
<tr><td>6</td><td>15 L Gardoprim & 0.75 L Callisto</td><td>7500 g terbuthylazine & 360 g mesotrione</td></tr>
<tr><td>7</td><td>15 L Gardoprim & 0.6 L Tordon PastureBoss</td><td>7500 g terbuthylazine,120 g triclopyr & 18 g aminopyralid</td></tr>
<tr><td>9</td><td>3.8 L Versatill, 0.38 L Tordon Brushkiller and 2.5 L Gallant</td><td>1125 g clopyralid, 113 g triclopyr & 250 g haloxyfop</td></tr>
<tr><td colspan="4">Additional treatments</td></tr>
<tr><td>10</td><td>3.8 L Versatill & 1.0 L Callisto</td><td>1125 g clopyralid, 360 g mesotrione</td><td rowspan="2">1500 g clopyralid, 150 g triclopyr & 22.5 g aminopyralid</td></tr>
<tr><td>12</td><td>3.8 L Versatill & 1.0 L Tordon Max</td><td>1125 g clopyralid, 30 g aminopyralid</td></tr>
</table>

Results: Rai

The same set of treatments was applied at the Flagstaff and the Rai trial sites. Both these sites had similar sets of weeds and the key outcomes from both trials were very similar.

Effect of treatment on the vegetation at the Rai site (weed cover and biomass)

- Percentage cover of weeds in the plots that received no treatment was 28% six months after trial initiation (and up to 47% at 18 months). Overall, weed growth at this site was slightly higher than average in comparison to other sites, as indexed by the weed biomass (Figure 1, main document).
- At 181 days after trial initiation, weed cover in the plots treated with terbuthylazine applied alone (Treatment 3) or with a second active ingredient (Treatments 4-8) was the lowest (<10%) and not significantly different from the operational standard (5.8%) (Treatment 1).This was followed by the treatment where a mixture of clopyralid, triclopyr and haloxyfop was applied (Treatment 9). The treatment where clopyralid was applied with mesotrione (Treatment 10) had significantly higher cover than the operational standard (Figure I1a)
- At 542 days after trial initiation, and following the application of triclopyr, clopyralid and aminopyralid at 12 months, there was no significant difference in weed cover across all treatments, barring that where clopyralid was applied in combination with aminopyralid (Treatment 12) (Figure I1b).
- The site was dominated by a cover broom and gorse, and the second-year treatment consisting of clopyralid, triclopyr and aminopyralid was effective in managing these weeds, particularly against the younger and emerging plants (Figure I2).

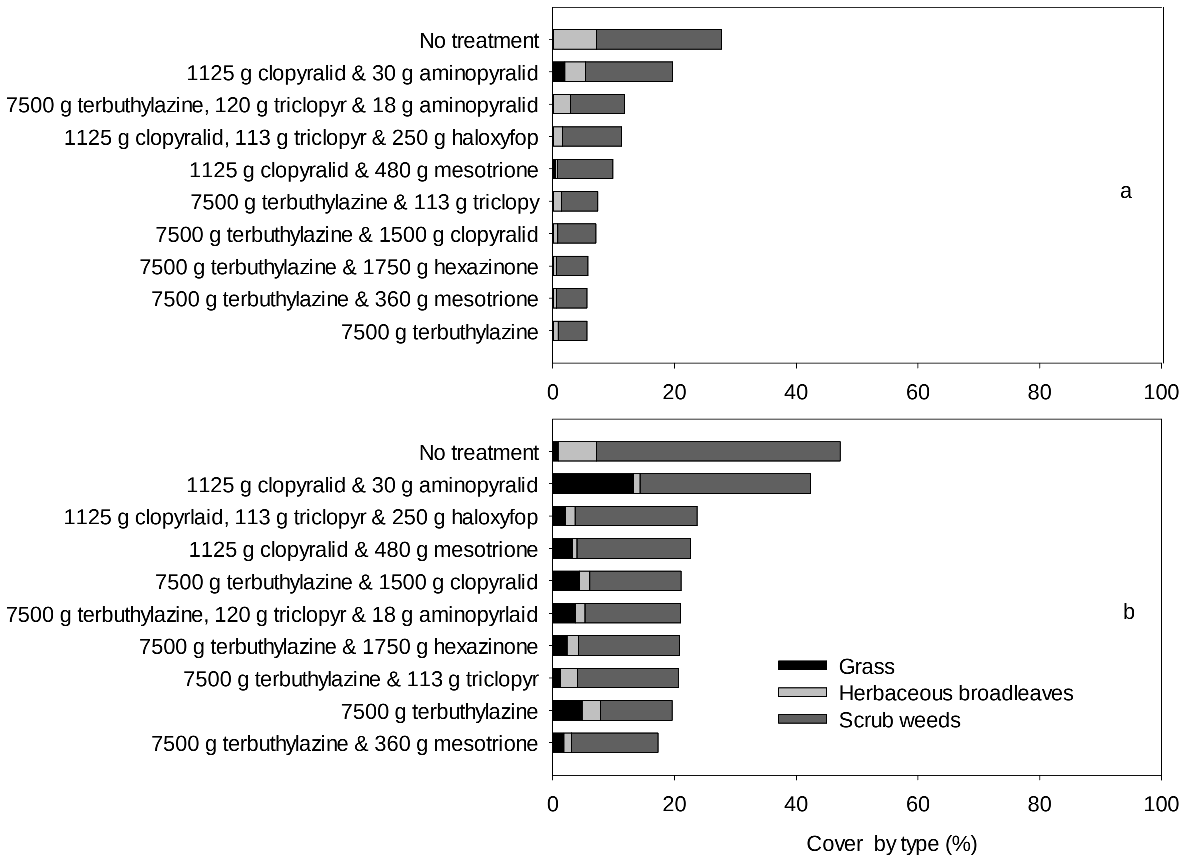

Figure I1. Weed cover by functional type at a) 181 and b) 542 days after treatment initiation.

Figure I2. The efficacy of the second-year treatment of clopyralid, triclopyr and aminopyralid (respectively applied at 1500 g, 150 g and 22.5 g ha^{-1}) against broom at Rai. The no treatment control (centre of image, was not treated).

Tree size

- At 542 days after trial initiation, the difference in tree size between the operational standard and the no treatment control was 68%, which was a reflection of the level of interspecific competition from scrub weeds (mainly broom) at this site. The difference in biomass index of the operational standard and the no treatment control was significant.
- At 542 days after trial initiation, the only treatment that was significantly different to the operational standard, for tree biomass, was Treatment 10, where clopyralid was applied in combination with mesotrione (Appendix K, Figure I3). There was a 49% difference in tree size between this treatment and the operational standard at 18 months.
- Although tree biomass was not significantly different from the operational standard for all other treatments (Treatments 3-9, 12), there was between 20 to 46% loss in tree biomass relative to the operational standard (Treatment 1) (Appendix K, Figure I3).
- Similar to the Flagstaff site, the best performing trees relative to the operational standard occurred where terbuthylazine was used in combination with clopyralid or mesotrione, or a mix of triclopyr and aminopyralid (Treatments 5, 6 and 7 respectively) (Figure I3). However, it is notable that the trees in these treatments were respectively 30.7%, 22.2% and 31 % smaller than the operational standard (Appendix K). These differences were not observed at the Flagstaff site but the operational standard did not perform as expected at that site.

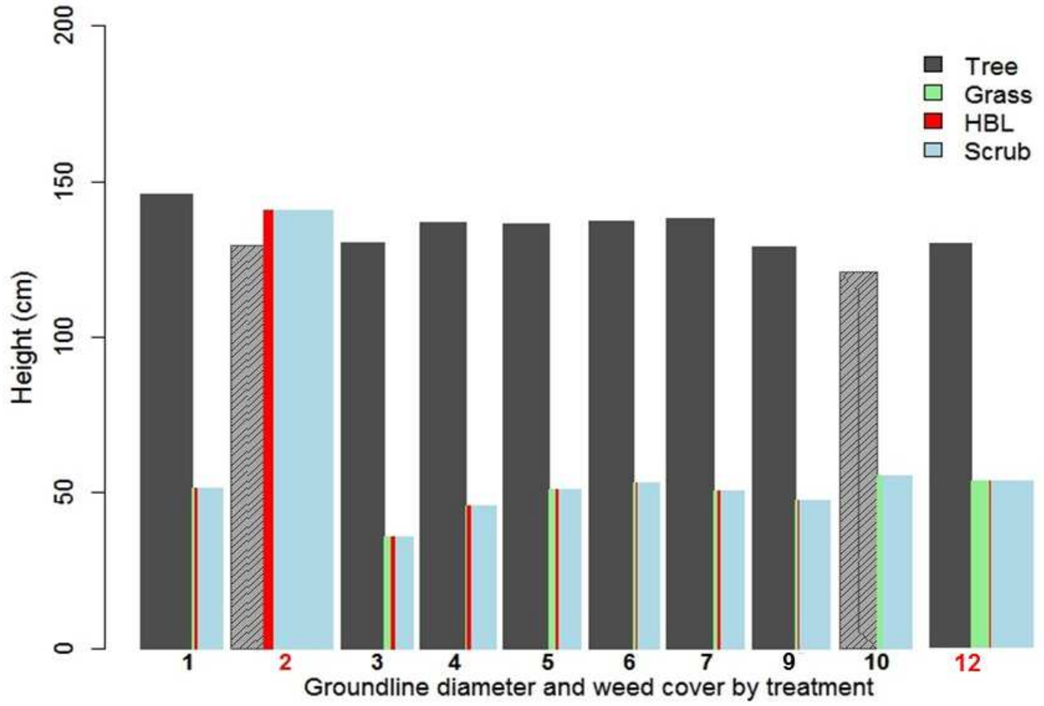

Figure I3. Composite representation of tree size (ht and groundline diameter) and weed cover by type for treatments. Tree bars shaded in grey show treatments where the tree Biomass Index (a function of tree height and groundline diameter) was significantly different to the operational standard (Treatment 1). *Note that both the height and width of bars represent tree size.* Treatment numbers in red indicate where cover of weeds was significantly different to the operational standard. *Note that the width of cover bars represents percentage cover while the height of the bars the average height of the weeds. Treatments are shown in Table I1.*

Key outcomes from Rai trial

- Best first-year post-planting treatment, that eliminated use of hexazinone but retained terbuthylazine, was that where terbuthylazine was applied in combination with clopyralid, mesotrione or a mix of triclopyr and aminopyralid (Treatments 5, 6 and 7).
- The substantial reduction in tree size relative to the operational standard meant no first-year alternative treatments that did not use either terbuthylazine or hexazinone could be considered as viable alternatives at this site. Treatments 9, 10 and 12 were not effective.
- The second-year treatment of clopyralid, triclopyr and aminopyralid was particularly effective at this site, as the site was dominated by a cover of broom and gorse. These results indicate that that aminopyralid may be a viable alternative if picloram needs to be eliminated from the current second-year “5,5,5” mixture. The trees did not show signs of severe phytotoxic effects.

Appendix J. Okuku trial site

The Okuku trial site was different from the other sites in that it was dominated by a cover of grass only.

A description of treatments applied at the Okuku trial site is shown in Table J1. All treatments applied in late October, except treatments 13 and 16 which were applied in late September as a pre-emergent treatment. Shaded treatments indicate core treatments repeated across most sites. All treatments were implemented at the equivalent of 150 - 200 L ha^{-1} using organosilicone adjuvant applied at 0.2% total volume, except where mesotrione was applied where the equivalent of 1 L ha^{-1} Synoil was used.

Table J1. Description of treatments applied at the Okuku trial site.

No	Treat Name (L ha^{-1})	Year 1 (g ha^{-1} active ingredient)	Year 2 (g ha^{-1} active ingredient)
1	Operational practice	7500 g terbuthylazine and 1750 g hexazinone	1500 g clopyralid, 150 g triclopyr & 22.5 g aminopyralid
2	Weedy**	No treatment	No treatment
3	15 L Gardoprim	7500 g terbuthylazine	1500 g clopyralid, 150 g triclopyr & 22.5 g aminopyralid
5	15 L Gardoprim & 5 L Versatill	7500 g terbuthylazine & 1500 g clopyralid	
6	15 L Gardoprim & 0.75 L Callisto	7500 g terbuthylazine & 360 g mesotrione	
8	15 L Gardoprim & 1 L Tordon Max	7500 g terbuthylazine 30 g aminopyralid	
9	3.8 L Versatill, 0.38 L Tordon Brushkiller and 2.5 L Gallant	1125 g clopyralid, 113 g triclopyr & 250 g haloxyfop	
Additional treatments			
13	0.6 L '437' & 1.0 L Callisto	300 g indaziflam & 480 g mesotrione	1500 g clopyralid, 150 g triclopyr & 22.5 g aminopyralid
16	0.6 L '437' & 1 L Sequence	300 g indaziflam, 240 g ha^{-1} clethodim	
17	2 L Guardian & 0.75 L Callisto	80 g nicosulfuran, 360 g mesotrione	

Results Okuku trial

Effect of treatment on the vegetation at the Okuku site (weed cover and biomass)

- Percentage cover of weeds in the plots that received no treatment was 68% six months after trial initiation and 23% at 18 months. Overall, weed growth at this site was low compared to other sites, as indexed by the weed biomass (Figure 1, main body of text). There was a decline in the cover (and mass) of competitive vegetation during the second season due to a severe drought in the summer (data not shown).
- At 183 days after trial initiation, weed cover in the plots treated with terbuthylazine applied alone (Treatment 3) or in combination with either clopyralid or mesotrione or aminopyralid (Treatments 4, 5 & 8 respectively) was the lowest (<3%) and not significantly different from the operational standard (1%) (Treatment 1) (Figure J1a).This was followed by the treatments where indaziflam was applied with either clethodim (Treatment 16) or mesotrione (Treatment 13) where cover was 11% and 14% respectively, but significantly different from the operational standard (Figure J1a).
- At 183 days after trial initiation, with no second-year treatment applied at 12 months, there was no significant difference in weed cover across all treatments, although trends were still visible. Cover in most treatments was 10% or below (Figure J1b).

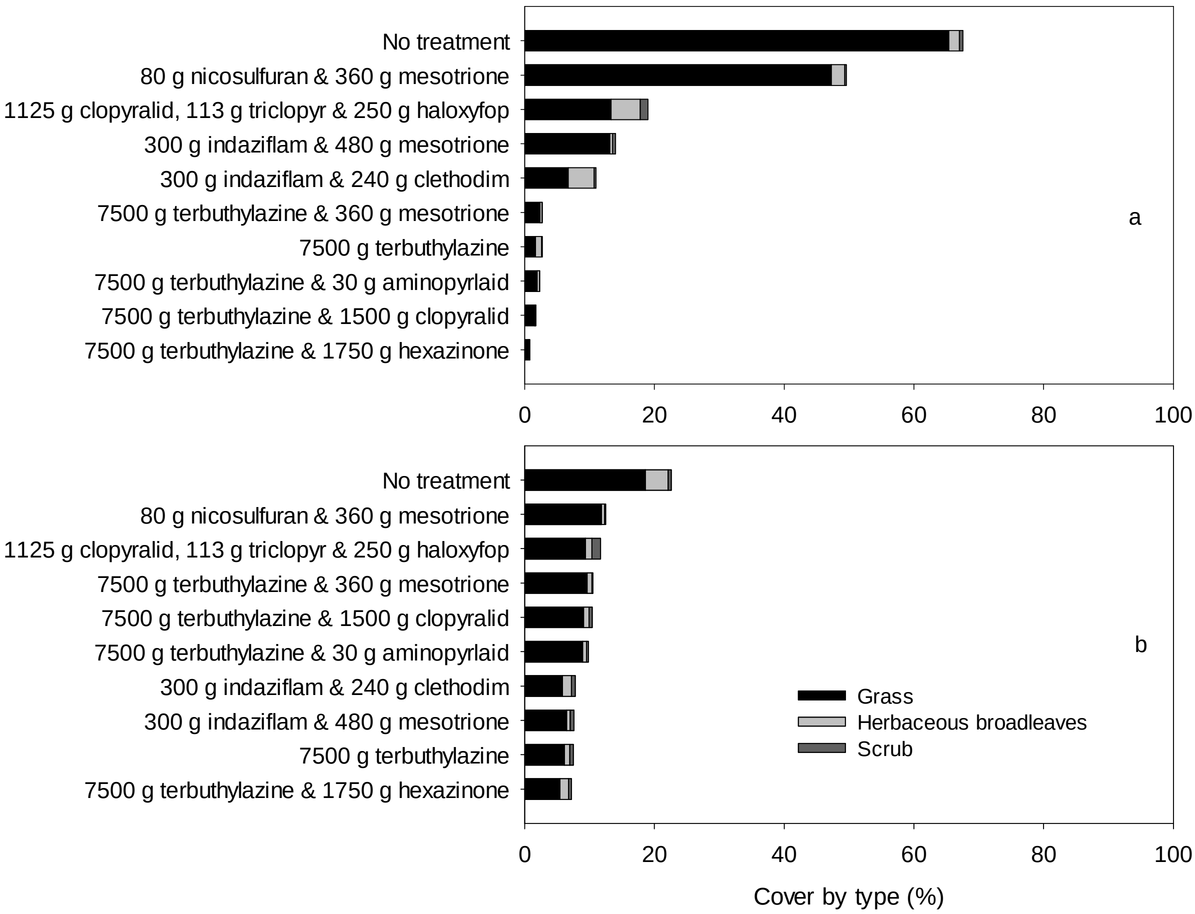

Figure J1. Weed cover by functional type at a) 183 and b) 519 days after treatment initiation.

Tree size

- At 183 days after trial initiation, the difference in tree size between the operational standard and the no treatment control was 83%, which was a reflection of the impacts of competition from grasses on dry sites. Note that Okuku was one of the driest sites trialled with less than 1000 mm mean annual precipitation. The difference in biomass index between the operational standard and the no treatment control was significant.
- At 183 days after trial initiation, the only treatment that was significantly different to the operational standard, for tree biomass, was Treatment 17, where mesotrione was applied in combination with nicosulfuran (Appendix K, Figure J3). There was a 75% difference in tree size between this treatment and the operational standard at 18 months.
- Tree biomass was not significantly different from the operational standard for all other treatments (Treatments 3-9) at 18 months. However, for all treatments barring Treatments 3 and 4, there was a loss in size of between 5% and 35% relative to the operational standard (Treatment 1) (Appendix K, Figure I3).

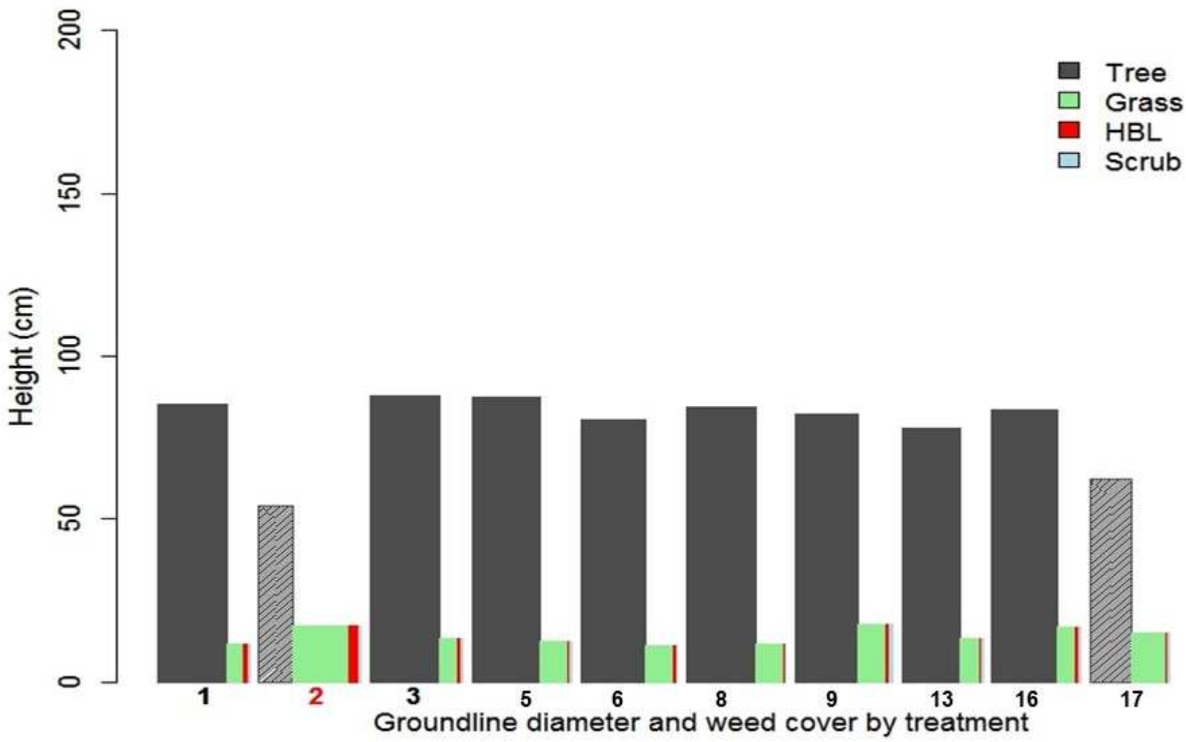

Figure J2. Composite representation of tree size (ht and groundline diameter) and weed cover by type for treatments. Tree bars shaded in grey show treatments where the tree Biomass Index (a function of tree height and groundline diameter) was significantly different to the operational standard (Treatment 1*). Note that both the height and width of bars represent tree size.* Treatment numbers in red indicate where cover of weeds was significantly different to the operational standard. *Note that the width of cover bars represents percentage cover while the height of the bars the average height of the weeds. Treatments are shown in Table J1.*

Key outcomes from Okuku trial

- Best first-year post-planting treatment, that eliminated use of hexazinone but retained terbuthylazine, was that where terbuthylazine was applied alone (Treatment 3) or in combination with either clopyralid, or mesotrione, or aminopyralid (Treatments 5, 6 and 8).

- The best alternative treatment that did not use either terbuthylazine or hexazinone, was that where indaziflam was used in combination with clethodim (Treatment 16). There was a 15% loss in tree size in this treatment.
- Mesotrione applied together with nicosulfuran (Treatment 17) was not effective.

Appendix K: Summary of tree size at 18 months relative to the operational standard across all sites.

Table K1. Biomass index of trees expressed as a percentage relative to the operational standard (Rel).

No.	Description	Rel(%) [1]	Possible alternative treatment [2]
Kaingaroa			
6	15 L Gardoprim & 0.75 L Callisto	-13.9^ns^	Yes
9	3.8 L Versatill, 0.38 L Tordon Brushkilller and 2.5 L Gallant	-4.6^ns^	
11	0.6 L Tordon PastureBoss and 1.0 L Callisto	5.4^ns^	
5	15 L Gardoprim & 5 L Versatill	15.5^ns^	Yes
7	15 L Gardoprim & 0.6 L Tordon PastureBoss	22.3^ns^	
10	3.8 L Versatill and 1.0 L Callisto	25.3**	
3	15 L Gardoprim	32.2**	
2	No treatment	37.9**	
4	15 L Gardoprim & 0.188 L Grazon	49.9**	
Whakarewarewa			
10	3.8 L Versatill & 1.0 L Callisto	20.8^ns^	Yes
6	15 L Gardoprim & 0.75 L Callisto	21.6^ns^	Yes
5	15 L Gardoprim & 5 L Versatill	33.1^ns^	Yes
9	3.8 L Versatill, 0.38 L Tordon Brushkiller & 2.5 L Gallant	33.5^ns^	
13	0.6 L ‘437’ & 1.0 L Callisto	36.8^ns^	Yes
7	15 L Gardoprim & 0.6 L Tordon PastureBoss	46.8**	
3	15 L Gardoprim	56.8**	
2	No treatment	59.5**	
4	15 L Gardoprim & 0.188 L Grazon	65.8**	
Mamaku			
6	15 L Gardoprim & 0.75 L Callisto	-24.6^ns^	Yes
14	0.6 L ‘437’ & 0.6 L Tordon PastureBoss	17.1^ns^	
13	0.6 L ‘437’ and 1.0 L Callisto	17.8^ns^	
8	3.8 L Versatill, 0.38 L Tordon Brushkiller and 2.5 L Gallant	24.3^ns^	
3	15 L Gardoprim	24.9^ns^	
2	No treatment	32.7^ns^	
4	15 L Gardoprim & 0.188 L Grazon	40.9^ns^	
5	15 L Gardoprim & 5 L Versatill	44.2^ns^	
7	15 L Gardoprim & 0.6 L Tordon PastureBoss	48.8^ns^	
Geraldine			
6	15 L Gardoprim & 0.75 L Callisto	49.2**	
5	15 L Gardoprim & 5 L Versatill	52.5**	
3	15 L Gardoprim	58.9**	
8	15 L Gardoprim & 1 L Tordon Max	59.0**	
9	3.8 L Versatill, 0.38 L Tordon Brushkiller & 2.5 L Gallant	62.8**	
15	0.6L ‘437’ & 5 L Versatil	65.4**	
13	0.6 L ‘437’ & 1.0 L Callisto	72.6**	
14	0.6 L 437 & 0.6 L Tordon PastureBoss	81.5**	
2	No treatment	85.3**	

[1] Indicates treatments significantly different to the operational standard are indicated by **. [2] The column “Alt” shows whether the treatment can be considered as an alternative and was based on no significant difference between any measured parameters at 6 and 18 months.

No.	Description	Rel(%) [1]	Possible alternative treatment [2]
Flagstaff			
5	15 L Gardoprim & 5 L Versatill	-34.5ns	
7	15 L Gardoprim & 0.6 L Tordon PastureBoss	-14.3ns	
6	15 L Gardoprim & 0.75 L Callisto	-4.9ns	
3	15 L Gardoprim	7.0ns	
4	15 L Gardoprim & 0.188 L Grazon	14.9ns	
9	3.8 L Versatill, 0.38 L Tordon Brushkiller and 2.5 L Gallant	23.6ns	
10	3.8 L Versatill & 1.0 L Callisto	30.0ns	
12	3.8 L Versatill & 1.0 L Tordon Max	62.8*	
2	No treatment	88.1*	
Rai			
7	15 L Gardoprim & 0.6 L Tordon PastureBoss	22.2ns	Yes
5	15 L Gardoprim & 5 L Versatill	30.7ns	Yes
6	15 L Gardoprim & 0.75 L Callisto	31.7ns	Yes
4	15 L Gardoprim & 0.188 L Grazon	37.0ns	Yes
3	15 L Gardoprim	41.8**	Yes
9	3.8 L Versatill, 0.38 L Tordon Bruskiller 2.5 L Gallant	45.7**	
12	3.8 L Versatill & 1.0 L Tordon Max	46.2**	
10	3.8 L Versatill & 1.0 L Callisto	49.4**	
2	No treatment	67.8**	
Okuku			
3	15 L Gardoprim	-1.7ns	
5	15 L Gardoprim & 5 L Versatill	-1.1ns	Yes
8	15 L Gardoprim & 1 L Tordon Max	4.8ns	
6	15 L Gardoprim & 0.75 L Callisto	12.1ns	
16	0.6 L '437' & 1 L Sequence	15.8ns	
9	3.8 L Versatill, 0.38 L Tordon Brushkillerand 2.5 L Gallant	24.4ns	
13	0.6 L '437' & 1.0 L Callisto	34.5ns	
17	2 L Guardian and 0.75 L Callisto	74.7**	
2	No treatment	83.4**	

[1] Indicates treatments significantly different to the operational standard are indicated by **.
[2] The column "Alt" shows whether the treatment can be considered as an alternative and was based on no significant difference between any measured parameters at 6 and 18 months.