

Evaluation of mānuka tolerance to several post-plant herbicide treatments applied in a field setting

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Report information sheet

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Executive summary

The problem

A trial was established to test mānuka tolerance to, and the effectiveness of, a range of aerially sprayed herbicide treatments in a collaborative project involving Andy Dick (Director, Logjitzix Limited) representing the Bay of Plenty Regional Council (BOPRC), Tai Royal (a land owner establishing mānuka at Lake Ōkāreka, Rotorua), and Scion. Specific objectives of the project were to test the following hypotheses relating to mānuka establishment, i.e.:

1. A combination of aerially applied herbicides exists that will reduce the health of gorse plants present within a young mānuka plantation, without causing major damage to the mānuka.
2. Older planted mānuka can tolerate higher doses of aerially applied herbicide than younger mānuka.
3. Interactions between mānuka and gorse or other weed species is driven primarily by competition for light.

Key results

Whilst there was evidence that mānuka growth was inhibited by intense weedy competition (CI relative height > 3) an important conclusion from this trial was that the herbicide treatments did not significantly improve mānuka growth, survival and site domination.

Factors contributing to this lack of response to herbicide treatment included:

- The comprehensive and effective pre-plant desiccation reducing the rate of gorse establishment.
- Rapid mānuka height growth relative to gorse height growth.
- A negative impact on mānuka growth from treatments that had the biggest negative effect on gorse i.e. those with 1.2 kg/ha or more of triclopyr.

The lack of statistical significance between treatments may also have been compound by both a highly variable site and initial weed cover distribution coupled with a highly variable treatment application.

After 12 months, only one treatment maintained a significantly reduced weed cover relative to the untreated control (triclopyr (1.2 kg/ha) + terbutylazine (4.0 kg/ha) + haloxyfop (0.3 kg/ha).

For sites with more vigorous weed competition (e.g. no or minimal pre-plant weed control) than observed at this site, stronger positive effects of gorse control would be expected.

Recommendations

- On moist, Central North Island sites, plant competition control treatments are recommended when plants surrounding the mānuka crop exceed (or are predicted to exceed) about 0.5 to 0.75 mānuka height.
- A comprehensive preplant site preparation to remove and reduce weedy competition will delay the necessity for post-plant releasing.
- It is recommended that release treatments employ no more than 2 L/ha triclopyr in the spray mix.

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Introduction

Mānuka (*Leptospermum scoparium* J.R.Forst & G.Forst) is an important species for New Zealand. It is a hardy plant, very tolerant of local soil and environmental conditions, and is common throughout New Zealand, from Stewart Island to the Northland, occupying lowlands to low alpine regions up to 1800 m above sea level. This site plasticity is also reflected in a highly variable growth morphology meaning mānuka can be found as a small shrub or a tree up to 10 m tall (DOC, 2022). In its larger form, mānuka met the Ministry for Primary Industries' (MPI's) criteria of a 5m+ tree for planting under the Governments One Billion Trees programme (TUR, 2018). Mānuka /kanuka shrub land accumulates significant live biomass of $2.1 \pm 0.2 \text{ t C ha}^{-1} \text{ y}^{-1}$ comparing favourably to New Zealand's indigenous conifer dominated forests and mature beech forests particularly on marginal low fertile sites (Trotter, et al., 2005).

Mānuka is considered a useful species for planting (or seeding) either in its own right, in order to create a resource for the mānuka honey industry, or to facilitate a succession to indigenous forest species. Mānuka honey is a significant contributor to NZ's economy with exports valued at about NZ\$400 M (for mono-and multi-floral mānuka honey) in 2022 (MPI, 2022). As a pioneer species, mānuka rapidly establishes on disturbed sites and with rapid canopy closure can reduce the development of unwanted 'weed' plant and enable shade tolerant indigenous forest tree species to establish. Coupling the value of carbon credits, honey production and harvesting foliage for tea tree oil returns, there is a strong economic incentive for planting mānuka in the right areas. For all these reasons, mānuka is a key species for New Zealand afforestation with additional benefits towards biodiversity conservation and enhancement.

The Bay of Plenty Regional Council (BOPRC) provided financial support for landowners to plant mānuka in the Rotorua district through the Low Nitrogen Land Use fund which aims to encourage landowners to establish a land use activity that provides profit but is also considered to have low nitrogen leaching (Phoebe Tinning, pers. coms.). Some of the areas targeted for mānuka planting were reverting farmland with heavy gorse (*Ulex europaeus* L.) infestation. Gorse is a significant weed species of New Zealand covering up to 900,000 ha and, as a nitrogen fixer capable of fixing up to 200 kg ha^{-1} per year, is a source of nitrogen load polluting the water catchment (Magesan, et al., 2012). Reducing nitrogen leaching into the waterways is a primary consideration for the BOPRC scheme and the property sits between two lake catchments, Rotorua and Ōkāreka, both of which had land use change schemes; Incentives Programme (Rotorua) and the Lakes Protection (Ōkāreka) Programme. Mānuka is a strong candidate to displace gorse because it occupies roughly a similar ecological niche (Louise Saunders (2017) and may establish and grow quickly enough to win the battle for survival. It is well known that both woody shrub and herbaceous species will compete with planted trees for water, light and nutrients, and competition will reduce both survival and growth rates (Richardson, 1993; Wagner, et al., 2006). A mānuka planting guide published in the 2017 observed that mānuka and kānuka seedlings generally have highest growth rates when competing with little vegetation cover. Dense pasture prevents germination however once the height

exceeds the surrounding pasture/weeds they require little maintenance. Taller weed species such as kikuyu grass, brush and vine weeds compete for soil nutrients and water, and smother young mānuka seedlings (Saunders, 2017). Work with planted radiata pine (*Pinus radiata* D.Don) has shown that on relatively moist and fertile sites typical of the Bay of Plenty, interactions between radiata pine and other vegetation are predominantly driven through competition for light (Richardson, et al., 1999; Richardson, et al., 1996). Hence, tall, fast growing shrub species were more competitive than herbaceous species. The relative height growth between radiata pine and weeds provided a good index of competition when modelling the effect of non-crop vegetation on tree growth (Richardson, et al., 1999) and a useful rule of thumb that was when competitors were less than 50% of tree height, effects on tree growth were small. While there is little published information on mechanisms underpinning interactions between mānuka and other plant species, it can be hypothesised that it will be sensitive to competition for light because, like radiata pine, it is a pioneer species. Gorse is a common weed species in the Bay of Plenty and often found on sites targeted for mānuka planting. While it has a slower height growth rate than other shrub species, such as buddleia (*Buddleja davidii* Franchet) and broom (*Cytisus scoparius* L.) (Richardson, et al., 1996), its height growth rate relative to mānuka has not been quantified.

Remedial management actions are required to replace gorse with mānuka and to accelerate mānuka establishment to the point of crown closure. Herbicide treatments that could be used to clear gorse prior to planting of mānuka are well known from regimes developed for forestry (Davenhill, et al., 1997) and are reasonably straightforward to apply. However, there is less knowledge of mānuka tolerance to herbicide mixes that could be applied post-planting to effectively control gorse regrowth while leaving mānuka seedlings undamaged. The mānuka planting guide states the industry standard practice, for both revegetation and plantations, is two or three releasing interventions (i.e. post plant herbicide treatments). These releases can be manual treatments but typically, especially at scale, herbicides are used. The guide has limited information on suitable herbicides citing glyphosate as an immediate knockdown treatment (presumably applied pre-plant or at least avoiding mānuka foliage) and residual herbicides such as terbuthylazine and clopyralid to provide longer-term post-plant weed control. It implies spot control is used avoiding over-spraying the trees and notes that research is ongoing to find herbicides that do not damage the mānuka (Saunders, 2017). Over-the-tree application simplifies and reduces the cost of releasing operations but requires the crop species to be tolerant of the herbicides while the primary weed species are susceptible.

Little work has been published testing New Zealand indigenous tree tolerance to herbicides, but mānuka was one of the few species where some replicated trials have been reported (Nairn, 2020b). In a pot trial testing herbicides applied over the top of mānuka and other native plants, mānuka health after 12 weeks was not significantly affected by aminopyralid, clopyralid, fluazifop, glyphosate, haloxyfop, and terbuthylazine treatments (Harrington, et al., 2007). A second experiment evaluated the tolerance of mānuka and other native plants to herbicides, by spraying around the plants whilst shielding them from overspray (Harrington, et al., 2009). In this trial, a mixture of

haloxyfop and simazine was tolerated and gave longer weed control than clopyralid/haloxyfop or glyphosate treatments. Unlike the previous study aminopyralid was not tolerated by mānuka and neither were high rates of terbuthylazine. A third trial to evaluate herbicide for mānuka establishment, again shielding the crop plants from overspray, found that residues of metsulfuron applied just before transplanting caused no adverse effects (Harrington, et al., 2015). However, the longest period of control was given by a mixture of glyphosate + simazine + clopyralid applied before planting. For post-plant releasing, clopyralid and haloxyfop were tolerated by mānuka but a potentially damaging mixture of glyphosate and simazine was a cheaper option if shielding was employed. The treatment with high rates of simazine was observed to cause chlorosis and stunting of mānuka despite shielding. Shielding crop plants from overspray can improve herbicide tolerance but dramatically increases the operational time and cost of chemical releasing.

Recent work tested very young (2-4 months) mānuka seedling tolerance to over-spray of terbuthylazine, clopyralid, mesotrione, haloxyfop and indaziflam at full and half forestry herbicide rates. The young mānuka were found to tolerate haloxyfop, and clopyralid with no observed impact on health or growth metrics. However, mesotrione produced mixed results and indaziflam and terbuthylazine adversely impacted growth measured 3 months after treatment (Nairn, 2020a). A planted field trial of older (> 1 year old) mānuka, and four other native species, found mānuka had no ill effects from the over-spray of mesotrione and only a mild reduction in growth metrics from indaziflam and a clopyralid and haloxyfop mixture (J. Nairn, unpublished data). None of these treatments showed any visual phytotoxicity. The terbuthylazine and hexazinone mixture killed roughly a third of the mānuka but those that survived remained relatively unaffected. Terbuthylazine and metsulfuron each killed the majority of the mānuka over-sprayed. Herbicide tolerance and intolerance can be circumstantial and is dependent on the stress condition and genetic stock of the plant, the environment and soil conditions, the herbicide application methods, the timing of the application and the herbicide rate and formulation.

With significant public funding being invested in afforestation (or reforestation) schemes involving mānuka planting, it is prudent to more fully understand the effect on mānuka growth and survival of herbicide treatments designed to release mānuka from gorse competition. At the same time, new information on the intensity of competition between mānuka and gorse or other weed species would help to quantify the management effort needed to meet mānuka survival and growth rate targets.

This project was a collaboration between Andy Dick (Logjitz Limited) representing the BOPRC, Tai Royal (a land owner establishing mānuka at Lake Ōkāreka, Rotorua), and Scion. The purpose of the project is to test specific hypotheses relating to mānuka establishment, i.e.:

1. A combination of aerially applied herbicides exists that will reduce the health and vigour of gorse plants present within a young mānuka plantation, without causing major damage to the mānuka.
2. Older planted mānuka can tolerate higher doses of aerially applied herbicide than younger mānuka.

3. While experiments were designed to test the first two hypotheses, an attempt was also made to test the hypothesis that interactions between mānuka and gorse (or other weed species) is driven primarily by competition for light.

Materials and methods

Site

The mānuka establishment trial was undertaken on an approximately 72 ha site next to Lake Ōkāreka, Rotorua (-38.161656° S, 176.335075° E), and with an elevation of around 450 m. The site was a rolling to steep pasture that was reverting to gorse (*Ulex europaeus* L.) in some areas although gorse distribution across the site was not uniform. The soils of the region are tephra layers (volcanic ash and Lapilli). The topsoil on site is derived from the Tarawera and lake Rotomahana eruptions in 1886. The latter is lake sediment and very fertile and the former more droughty and less fertile. The climate has a relatively mild temperature, high humidity with rainfall that varies 1400-2000 mm per year (Clarkson, et al., 1991).

Mānuka seedlings were established over two years, 2019 and 2020. The 2019 planting site was prepared by an aerial desiccant herbicide application (500g/ha metsulfuron, 10L/ha glyphosate and 1L/ha wetting agent applied in a total spray volume of 150 L/ha) in January 2019 followed by roller crushing in September 2019. The 2020 planting site received the same preplant preparation with the same timings however a second aerial desiccant herbicide application was applied in February 2020. The first establishment was planted in winter 2019, approximately 11 ha of this area were planted with small mānuka seedlings (1-0)¹, sourced from Scion in Rotorua. Planting stocking varied based on whether mānuka were planted into predominantly grass or gorse ground cover. Where gorse growth had been heavy, mānuka were planted at a 2 m x 2 m spacing (2500 sph); where grass predominated seedlings were planted at 3 x 3 m spacing (1111 sph). In May 2020, this entire 11 ha area was broadcast aurally sprayed using a herbicide mixture of 4 L/ha terbuthylazine, 4 L/ha haloxyfop, and 1 L/ha clopyralid in a total spray volume of 150 L/ha.

The following winter (2020), a further 61 ha were planted with mānuka of a similar starting age and size to the 2019 planting but sourced from Ngā Rākau Nursery in Auckland.

Treatments and experimental design

A set of eight treatments, including six herbicide combinations and two controls (Table 1), were selected based on expert knowledge of possible gorse and mānuka responses to these treatments. The underpinning hypothesis was that these treatments could be applied to control gorse around the mānuka without affecting mānuka growth. If any

¹ 1-0 refers to seedlings that are grown in the nursery for one growing season and have not been moved to a transplant bed prior to planting.

herbicide treatments did have a negative influence on mānuka growth, it was hypothesised that the scale of the effect would be greatest on the younger mānuka age class (i.e. the 2020 seedlings).

With 8 treatments, 2 mānuka age classes, and 4 blocks on each area, a total of 64 plots were required. With each age class, plots and their assigned treatments were laid out in a randomised block design with 4 blocks per age class. The age class factor was not randomised, each age class was planted in separate blocks and locations, so each were treated in separate analyses. Future analysis could consider the design as a split plot with randomised blocks within the split to see which design will give us more power of detecting treatment differences. In our current analysis we have assumed that the land within each age class was equally representative of the whole i.e. had similar potential productivity and variability. Plot sizes were 15 m x 15 m with a 5 m buffer between adjacent plots to reduce the potential for spray drift to deposit in adjacent plots.

Table 1: Herbicides and rates of treatments applied to two age classes of mānuka.

Trt	Herbicide (and ai ¹ content)	Ai applied (kg/ha)	Herbicide product names and applied rate (L/ha)
1	Terbuthylazine (500 g/L) Triclopyr (600 g/L) Haloxypop (100 g/L)	4.0 1.2 0.3	AGPRO Terbuthylazine 50 SC (8) AGPRO Triclop 600 (2) AGPRO Haloxypop 100 (3)
2	Terbuthylazine (500 g/L) Triclopyr (600 g/L) Haloxypop (100 g/L)	4.0 2.4 0.3	AGPRO Terbuthylazine 500 (8) AGPRO Triclop 600 (4) AGPRO Haloxypop 100 (3)
3	Triclopyr (600 g/L) Haloxypop (100 g/L)	1.2 0.3	AGPRO Triclop 600 (2) AGPRO Haloxypop 100 (3)
4	Terbuthylazine (500 g/L) Triclopyr (600 g/L) Haloxypop (100 g/L)	4.0 0.3 0.3	AGPRO Terbuthylazine 500 (8) AGPRO Triclop 600 (0.5) AGPRO Haloxypop 100 (3)
5	Triclopyr (600 g/L) Haloxypop (100 g/L)	0.3 0.3	AGPRO Triclop 600 (0.5) AGPRO Haloxypop 100 (3)
6	Terbuthylazine (500 g/L) Clopyralid (100 g/L) Haloxypop (100 g/L)	4.8 0.1 0.4	AGPO Terbuthylazine 500 (4.8) AGPRO Clopyralid 300 (0.1) AGPRO Haloxypop 100 (0.4)
7	No treatment		
8	Manual release		

¹All herbicide treatments were applied in total spray volumes of 150 L/ha

All herbicides were applied using a TTA Pro8 unmanned aerial vehicle (UAV) with a 20 litre tank, a pump output of about 6.5 litres/minute and fitted with four TT11003 nozzles.

Due to the terrain, the flight lines were flown manually with four passes (flight lines) per plot flown in a back and forth pattern. The manual release treatment was conducted 2-3 weeks prior to the herbicides being applied to the plots, only gorse was manually cut and removed from the plots.

Measurements

Prior to herbicide treatments, measurements were undertaken on up to 20 mānuka plants in each plot. Where possible, mānuka were selected that were not close to plot boundaries to minimise edge effects where herbicide doses could be lower than target rates. Measurements on each mānuka plant were as follows:

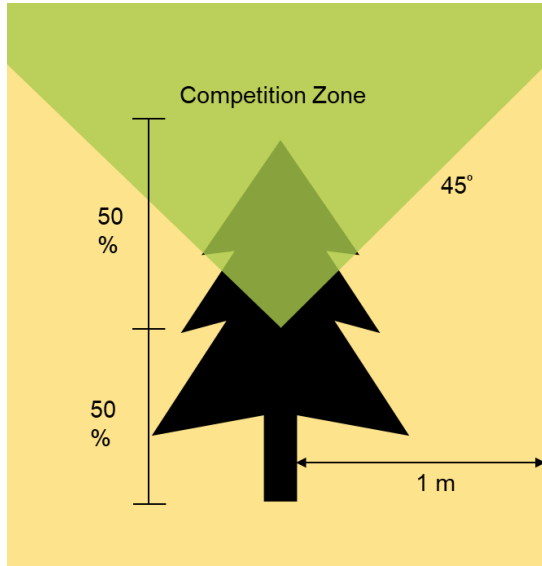
- stem ground-line diameter and height;
- health (scored as a percent green crown where 100 is full health and 0 = dead).

A second set of measurements/assessments were made to describe the non-crop vegetation with a 2 m diameter circle (3.14 m² area) centred on each measured mānuka plant. The purpose of these measurements was to both quantify treatment effects on gorse and other species health and growth and the potential effect of these species on mānuka growth. Measurements were:

- Estimated gorse ground cover (%) and health (%; using the same scale as for mānuka).
- Ground cover (%) of living grass.
- Ground cover (%) of other plants.
- Competition indices (CI): (i) CI relative height estimated as the maximum weed height / tree height summed for each of four quadrants centred on each mānuka plant; and CI50 defined as described in Figure 1.

These same measurements were repeated approximately 3 months, 6 months and 12 months after treatment.

(a)



(b)

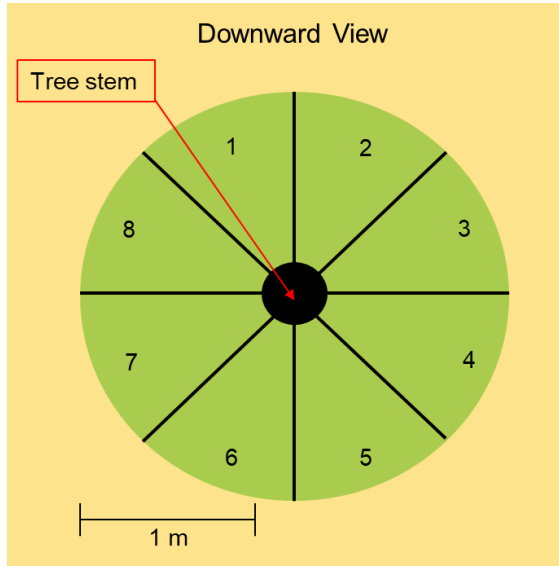


Figure 1: Competition index (CI50) estimation based on (a) imagining an inverted 90° cone extending from mid height on the mānuka plants upwards; (b) dividing the cone cross section into 8 segments and scoring 0 or 1 depending on whether any neighbouring plants are tall enough to extend into this cone. The further neighbours are away, the taller they need to be to penetrate the cone. The CI50 score is the sum of scores for all segments and has a maximum value of 8.

Analysis

All statistical computations, graphs, and data handling operations were performed using R version 4.2.0 (R Core Team, 2022). A generalised linear mixed effects model (GLMM) assuming a beta distribution based on the parameterization of Ferrari, et al. (2004) and logit link function was used to analyse treatment effects on gorse cover (%), gorse health (%), total vegetation cover (%), and competition index (CI50). Prior to analysis, the percentage of gorse, grass and other vegetation on a scale of 0 – 100 was converted into the open standard unit interval (0, 1) to satisfy conditions of the beta distribution by using $(y \times (n - 1) + 0.5)/n$, where y is the proportion of gorse, grass and other vegetation and n is the number of observations, as recommended by Smithson, et al. (2006). Models contained treatment (factor with eight levels: see Table 1 for details on treatments) as fixed effects. Block was included as random effects. All beta GLMMs were fitted by maximum likelihood via Template Model Builder (TMB), using automatic differentiation to estimate model gradients and the Laplace approximation for handling random effects [R package glmmTMB; Brooks, et al. (2017)]. Plots of Pearson residuals against the fitted values and versus each explanatory variable in the model were used for model validation.

Linear mixed-effects models (LMMs) fitted by restricted maximum likelihood (REML) were applied to evaluate treatment effects on mānuka growth (height growth, ground-level diameter growth (GLD), and stem volume index (equation 1) growth).

$$\text{Stem volume} = \text{height} \times \pi \left(\frac{\text{GLD}}{2} \right)^2 \quad (1)$$

All mānuka growth variables were log transformed prior to analysis. The analysis was conducted separately for each age class. Models contained treatment as fixed effects, and the same random effect as described above. Plots of the standardised residuals against fitted values and against each explanatory variable in the model as well as quantile–quantile plots were used to assess the model assumptions of variance homogeneity and normality.

Effects of plant competition on mānuka growth were analysed using LMMs and analysed separately for each age class. For this analysis, the mānuka growth was defined as 1) height increment and 2) ground-level diameter increment, which the increment in 1) and 2) were calculated from April to November 2021, and plant competition was calculated using average CI relative height between two time points (April and November 2021). We confined this analysis to the subset of plots that did not receive herbicide treatments, control and manually released plots, to remove any confounding effects. Both response variables were log transformed prior to analysis. Models contained average CI relative height as a fixed effect, while block was included as random effects. Graphical model validation tools were again used to check the model assumptions of variance homogeneity and normality (plots of standardized residuals vs fitted values and explanatory variables and quantile–quantile plots).

Outliers and extreme observations in the responses were detected using Cook's distances for mixed effects models from R package influence.ME (Nieuwenhuis, et al., 2012) and a cut-off value of $4/n$, where n refers to the number observations (Van der Meer, et al., 2010) was used to detect the outliers and extreme observations. The observations with the Cook's distances exceeding the cut-off value were identified as an extreme observation and they were subsequently dropped from further analysis.

For all models, the significance of the fixed terms was assessed via a backward selection approach using a likelihood-ratio test and Akaike's Information Criterion (AIC) Zuur, et al. (2009). The significant terms were followed up by applying a multiple-comparison procedure undertaken by examining the significance of least-squares mean difference tests using t -test with Tukey adjustments applied to the p values [R package emmeans (Lenth, et al. (2022))]

Results and Discussion

Treatment application

While there was no formal assessment of spray application quality from the UAV, observations and GPS flight line tracks (Figure 2) indicated that a high level of variability was likely (i.e. significant over- and under-dosing across the plots). In the examples shown (Figure 6) care must be taken in interpreting the lines as the lines represent interpolations between widely spaced GPS points and are not necessarily representative of the exact track actually flown. Nevertheless, these plots illustrate the challenge in flying accurately, especially in complex topography, when manually operating a UAV.

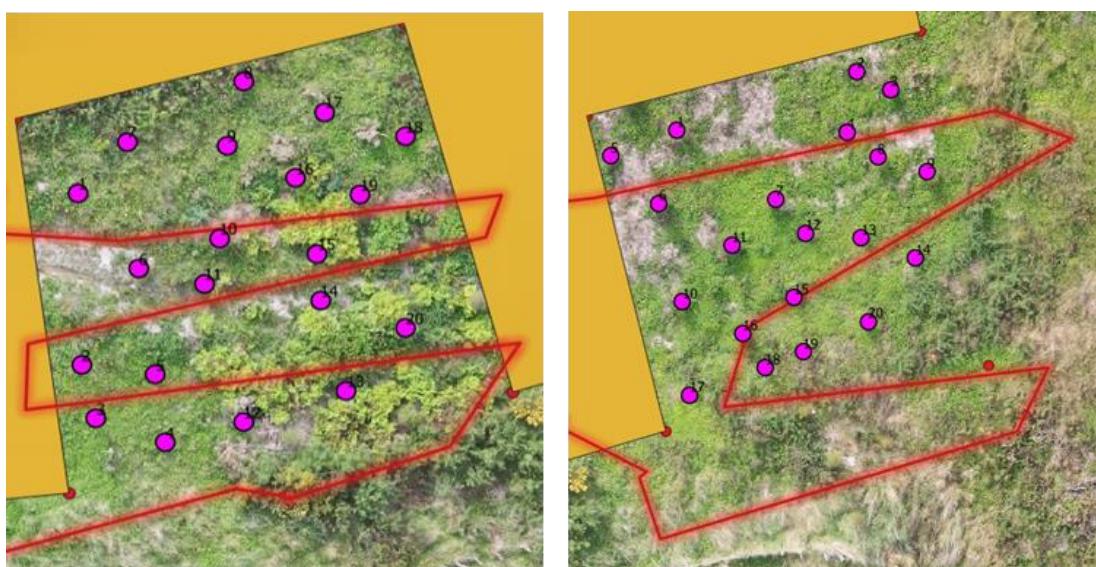


Figure 2: UAV flight (spray) lines (red lines) superimposed over two plots with position of measured mānuka plants indicated by purple circles.

Treatment effects on gorse, grass and other vegetation

Combining pre-treatment weed data across the two planting age classes, overall gorse cover was low across all treatments (Figure 3) but there was variability between treatments. The manual release treatment plots had particularly low initial gorse cover. By 12 months after treatment gorse cover was highest where there was either no treatment, manual release or low rates of triclopyr (Figure 4). While the manual release treatment had amongst the lowest gorse cover, this result reflected the relatively small amount of initial gorse present on these plots before treatment.

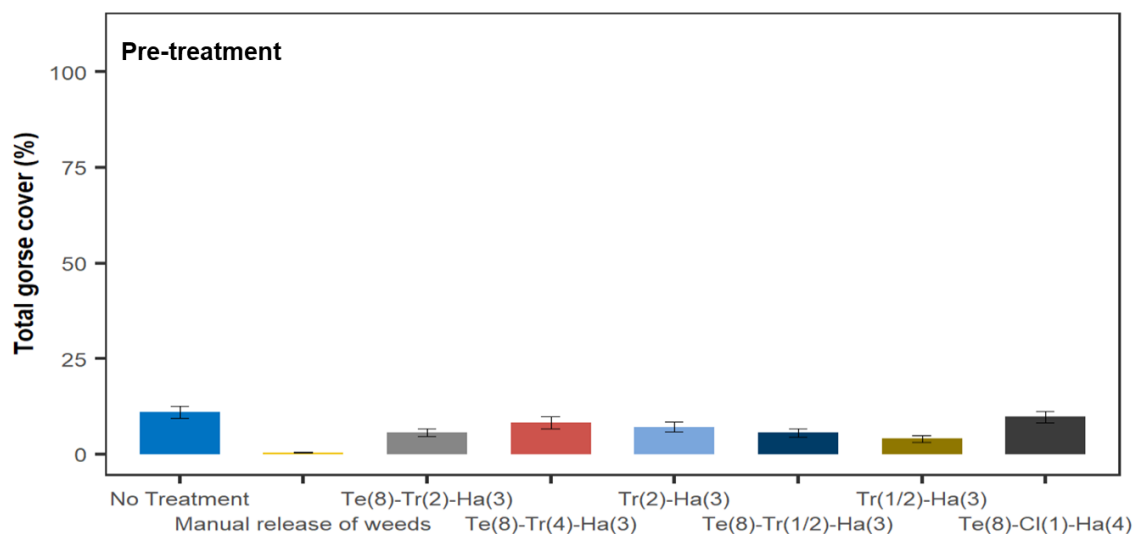


Figure 3: Initial gorse cover (%) on treatments plots prior to treatment application. Te = terbuthylazine, Tr = triclopyr, Ha = haloxyflop and Cl = clopyralid. Rate (L/ha) of each herbicide in treatment indicated in parentheses.

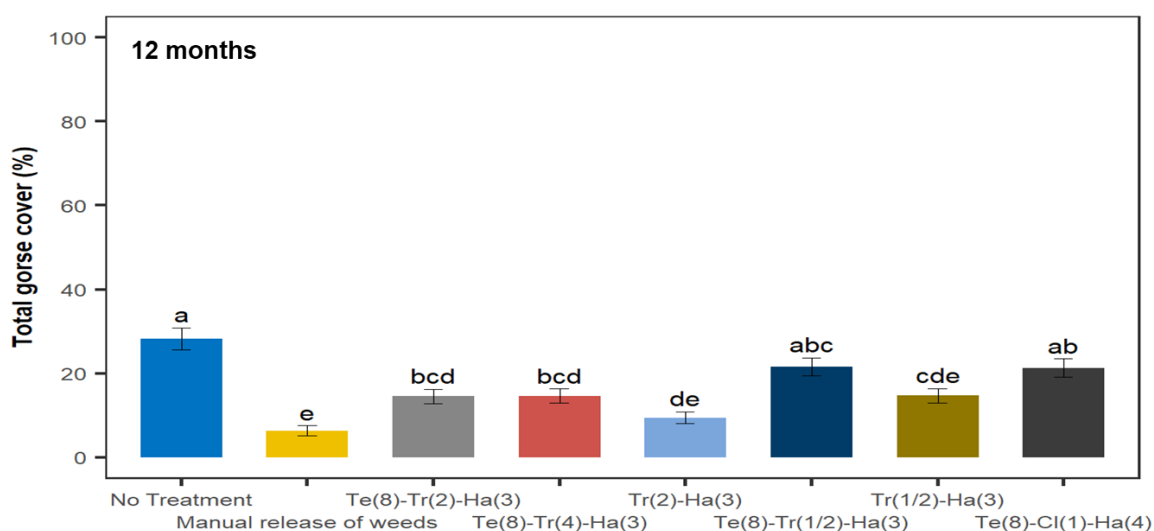


Figure 4: Gorse cover (%)12 months after treatment application. Bars topped with the same letter are not significantly different ($P > 0.05$). Te = terbuthylazine, Tr = triclopyr, Ha = haloxyflop and Cl = clopyralid. Rate (L/ha) of each herbicide in treatment indicated in parentheses.

Although early results indicated that treatments with a high (2 L or more) triclopyr rate had a negative impact on gorse health (data not shown), by 12 months gorse health was

virtually unaffected by herbicide treatment, indicating rapid recovery (at least in terms of appearance) from any initial damage Figure 5).

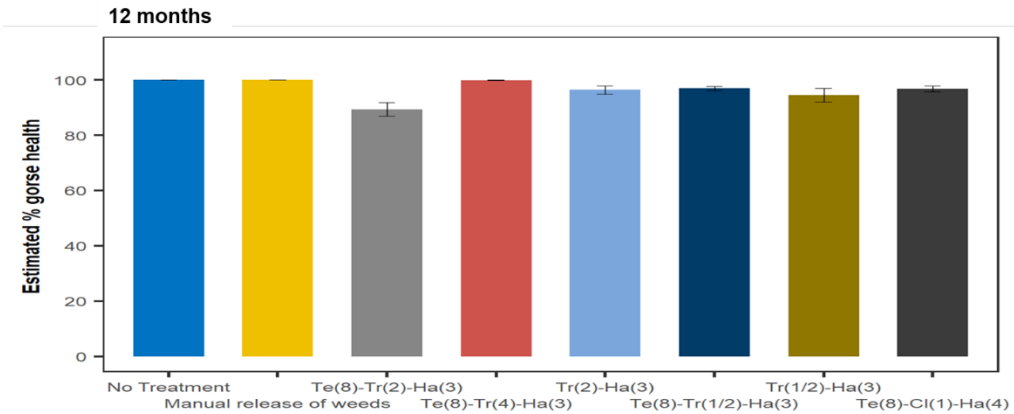


Figure 5: Gorse health (%)12 months after treatment application. Te = terbuthylazine, Tr = triclopyr, Ha = haloxyflop and Cl = clopyralid. Rate (L/ha) of each herbicide in treatment indicated in parentheses.

There were significant differences in total vegetation cover prior to treatment (Figure 6) but by 12 months after treatment remaining differences were very small and unlikely to have been of practical significance (Figure 7). Any differences in gorse cover (Figure 4), were made up by grasses and herbaceous broadleaves which, by 12 months, had occupied most of the available space in the neighbourhood of the measurement trees. The treatments that tended to have the lowest overall cover (albeit marginally) tended to have had terbuthylazine in the spray mix, which is known to have significant residual activity (Garrett, et al., 2015; Wang, et al., 2010).

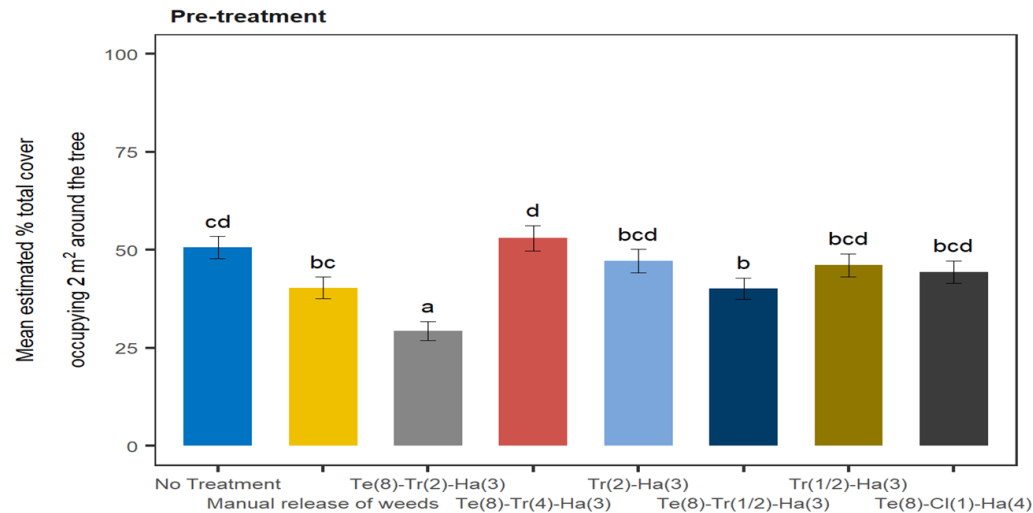


Figure 6: Mean total vegetation cover (%) on treatments plots prior to treatment. Bars topped with the same letter are not significantly different ($P > 0.05$). Te = terbuthylazine, Tr = triclopyr, Ha = haloxyflop and Cl = clopyralid. Rate (L/ha) of each herbicide in treatment indicated in parentheses.

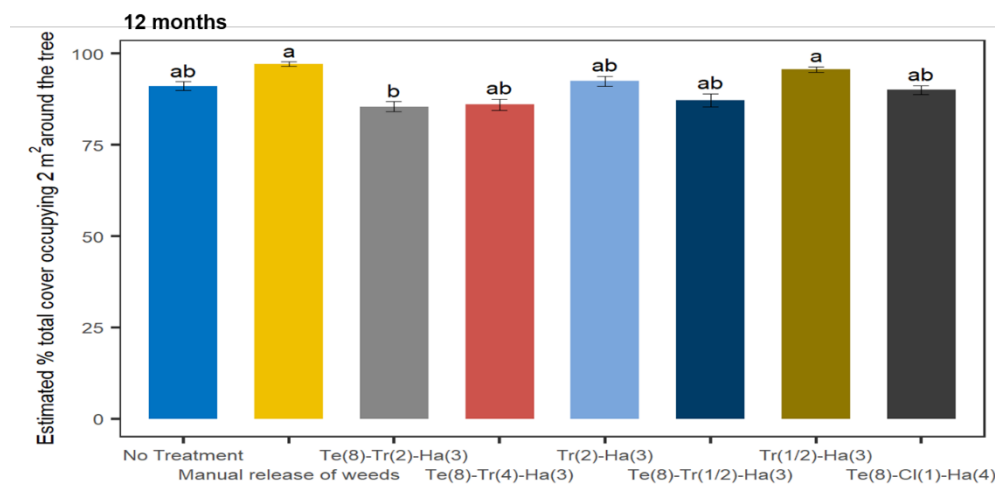


Figure 7: Mean total vegetation cover (%) 12 months after treatment application. Bars topped with the same letter are not significantly different ($P > 0.05$). Te = terbuthylazine, Tr = triclopyr, Ha = haloxyflop and Cl = clopyralid. Rate (L/ha) of each herbicide in treatment indicated in parentheses.

There were some pre-treatment differences in competition index (CI50) (Figure 8), but values were low reflecting both a low weed cover and low weed height relative to mānuka height. Twelve months post-treatment, CI50 values had more than doubled in many cases but were still relatively low (approximately values of 4 or less) (Figure 9). While there were significant differences in CI50 values among treatments, there was no clear pattern or obvious explanation for these differences.

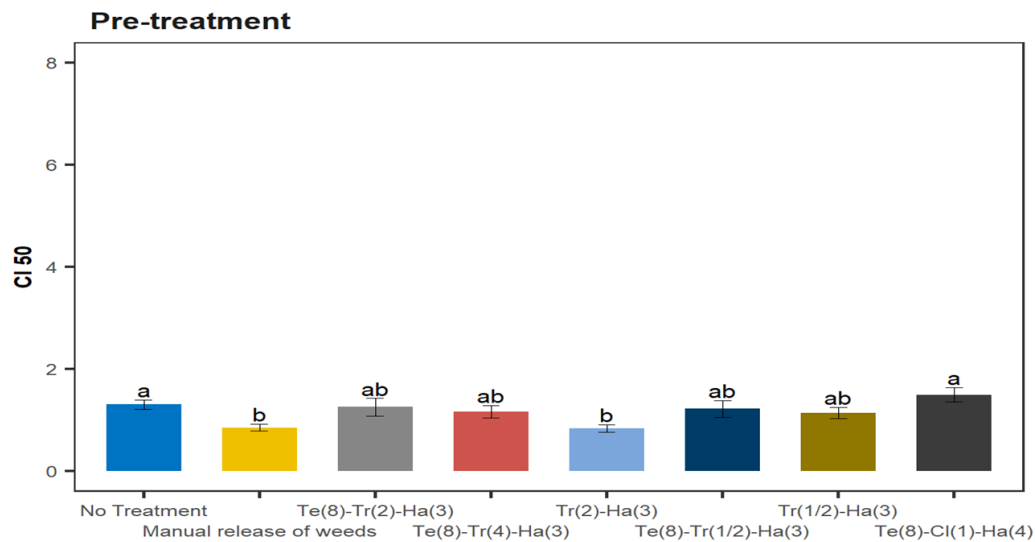


Figure 8: Mean competition index (CI50) values prior to treatment. Bars topped with the same letter are not significantly different ($P > 0.05$). Te = terbuthylazine, Tr = triclopyr, Ha = haloxyflop and Cl = clopyralid. Rate (L/ha) of each herbicide in treatment indicated in parentheses.

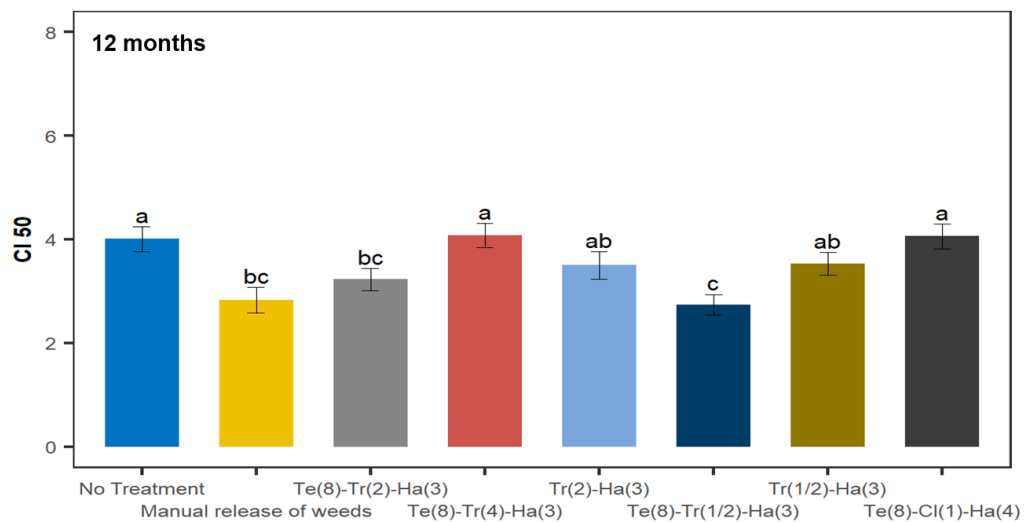


Figure 9: Mean total vegetation cover (%) 12 months after treatment application. Bars topped with the same letter are not significantly different ($P > 0.05$). Te = terbuthylazine, Tr = triclopyr, Ha = haloxyflop and Cl = clopyralid. Rate (L/ha) of each herbicide in treatment indicated in parentheses.

Summary of vegetation control effects

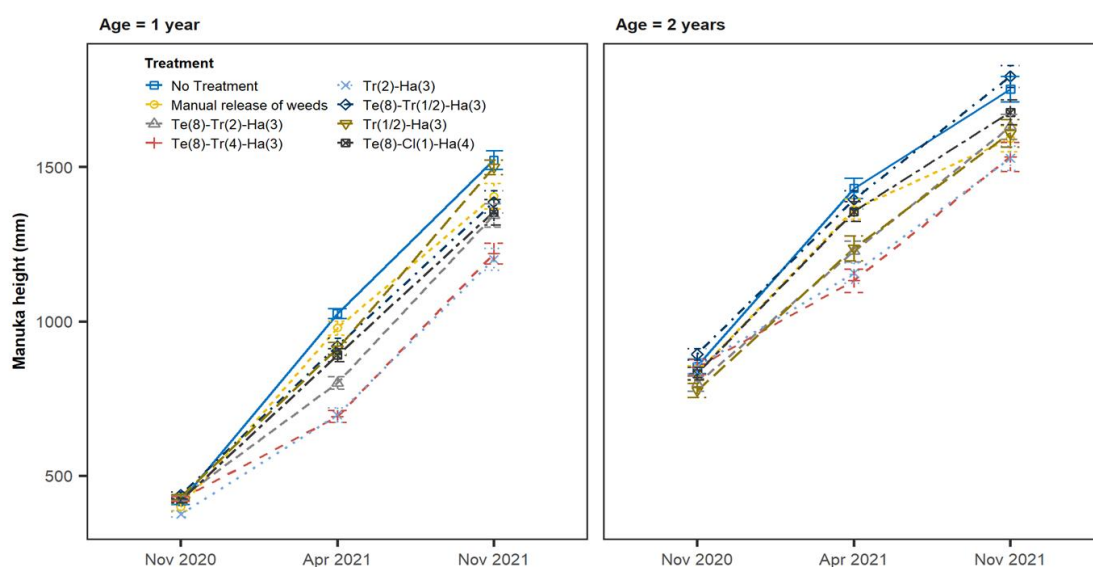
To summarise treatment effects on non-crop vegetation:

- There was no easily discerned optimum treatment. In part this result may reflect a highly variable site and initial weed cover distribution and a highly variable treatment application. However, these factors are probably also reflecting typical operational realities.
- Treatments containing triclopyr treatments had the biggest effect on gorse cover as would be expected.
- All total vegetation cover values were high after 12 months with only one treatment significantly reducing weed cover (triclopyr (2 L) + terbuthylazine (8 L) + haloxyfop (8 L). However, there was a trend for treatments with terbuthylazine in the spray mix to have slightly lower cover values.
- After 12 months, CI50 values remained relatively low. There was no discernible pattern to small treatment effects on CI50.

Treatment effects on mānuka growth

Height growth

There were significant but similar effects of treatment on mean height growth trajectories across both mānuka age classes (Figure 10). For both age classes, no treatment produced significantly greater height growth than the untreated control. However, several



treatments, particularly those with higher triclopyr rates resulted in growth suppression (Figure 11). The strongest height growth suppression was with the younger plants.

Figure 10: Mānuka height growth trajectories for each treatment for the 2019 planting (Age – 2 years) and 2020 planting (Age = 1 year). Te = terbuthylazine, Tr = triclopyr, Ha = haloxyflop and CI = clopyralid. Rate (L/ha) of each herbicide in treatment indicated in parentheses.

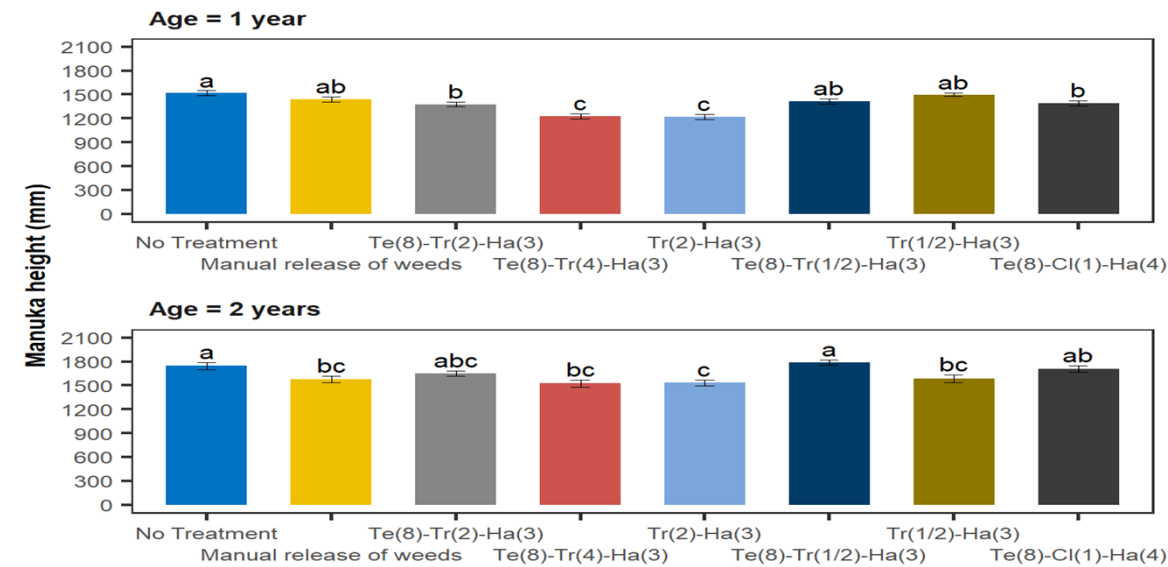


Figure 11: Mean mānuka height for each treatment and age class. Bars topped with the same letter are not significantly different (P > 05). Te = terbuthylazine, Tr = triclopyr, Ha = haloxyflop and CI = clopyralid. Rate (L/ha) of each herbicide in treatment indicated in parentheses.

Ground-level diameter growth

There were significant but similar effects of treatment on stem diameter growth trajectories across both mānuka age classes (Figure 12). For both age classes, no treatment produced significantly greater diameter growth than the untreated control (Figure 13). With the younger mānuka age class, two treatments with higher triclopyr rates (2 or 4 L) suppressed diameter growth. No treatment effects on mānuka diameter were observed with the older age class.

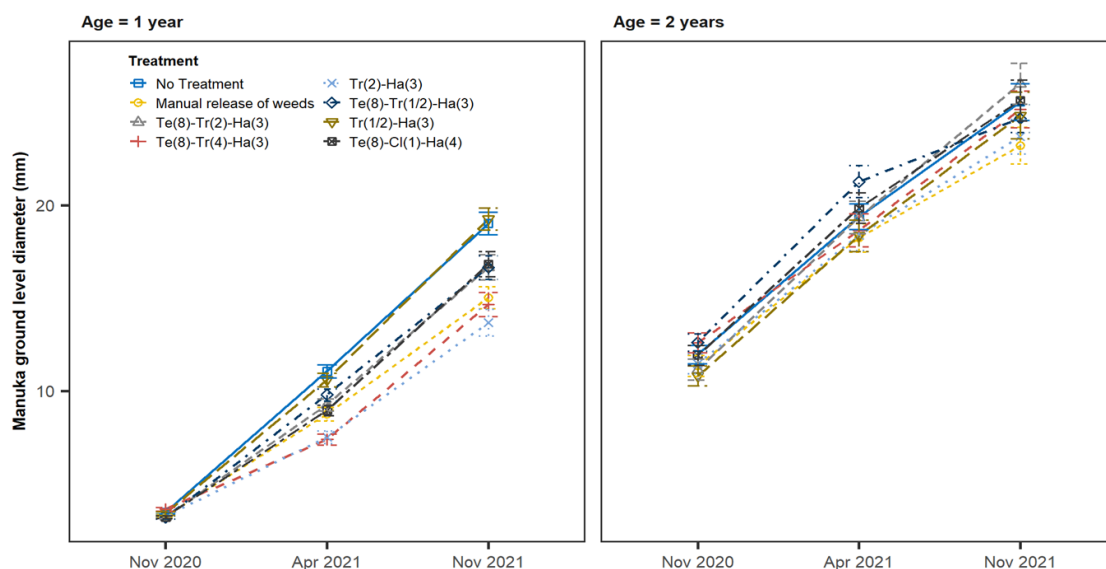


Figure 12: Mānuka ground-level diameter growth trajectories for each treatment for the 2019 planting (Age = 2 years) and 2020 planting (Age = 1 year). Te = terbutylazine, Tr = triclopyr, Ha = haloxyflop and Cl = clopyralid. Rate (L/ha) of each herbicide in treatment indicated in parentheses.

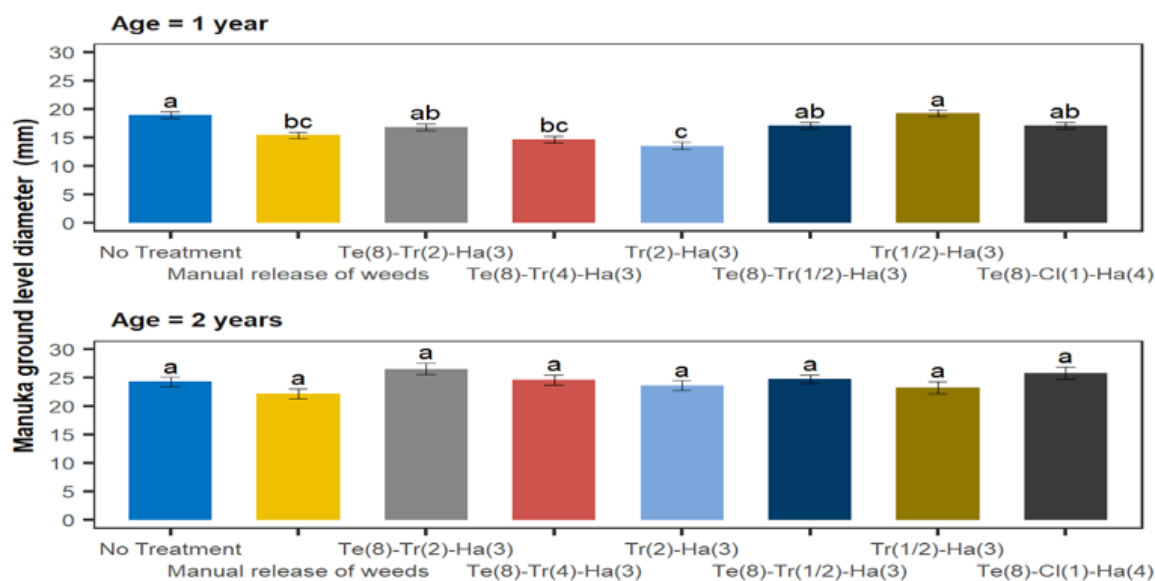


Figure 13: Mean mānuka ground-level diameter for each treatment and age class. Bars topped with the same letter are not significantly different ($P > 0.05$). Te = terbuthylazine, Tr = triclopyr, Ha = haloxyflop and Cl = clopyralid. Rate (L/ha) of each herbicide in treatment indicated in parentheses.

Stem volume index growth

Treatment effects on stem volume index were similar as for effects on height and diameter (Figures 14 and 15). Again, the important result was that no treatment resulted in growth greater than the untreated controls and there was some evidence of growth suppression with at least one triclopyr treatment and the younger age class.

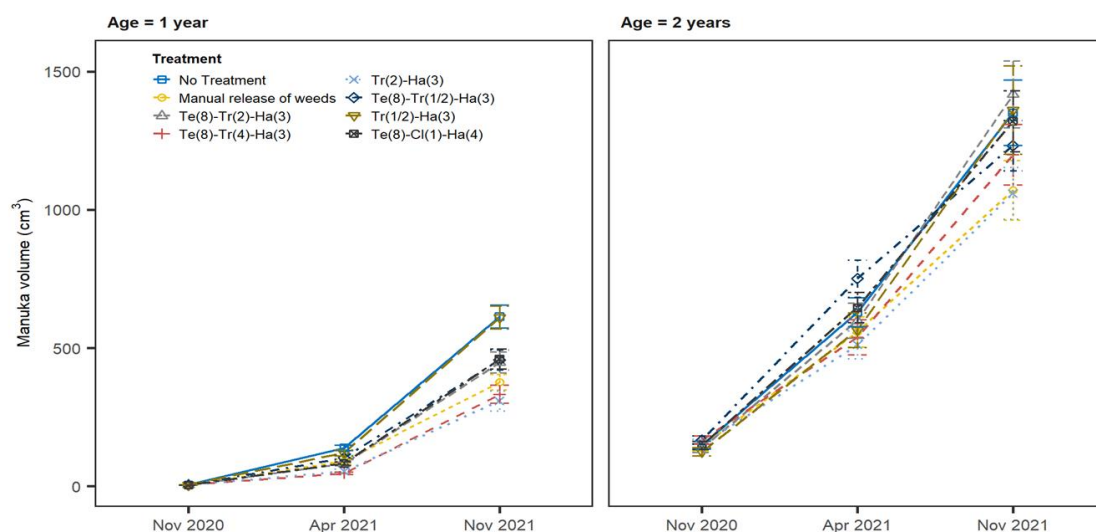


Figure 14: Mānuka stem volume index growth trajectories for each treatment for the 2019 planting (Age = 2 years) and 2020 planting (Age = 1 year). Te = terbuthylazine, Tr = triclopyr, Ha = haloxyflop and Cl = clopyralid. Rate (L/ha) of each herbicide in treatment indicated in parentheses.

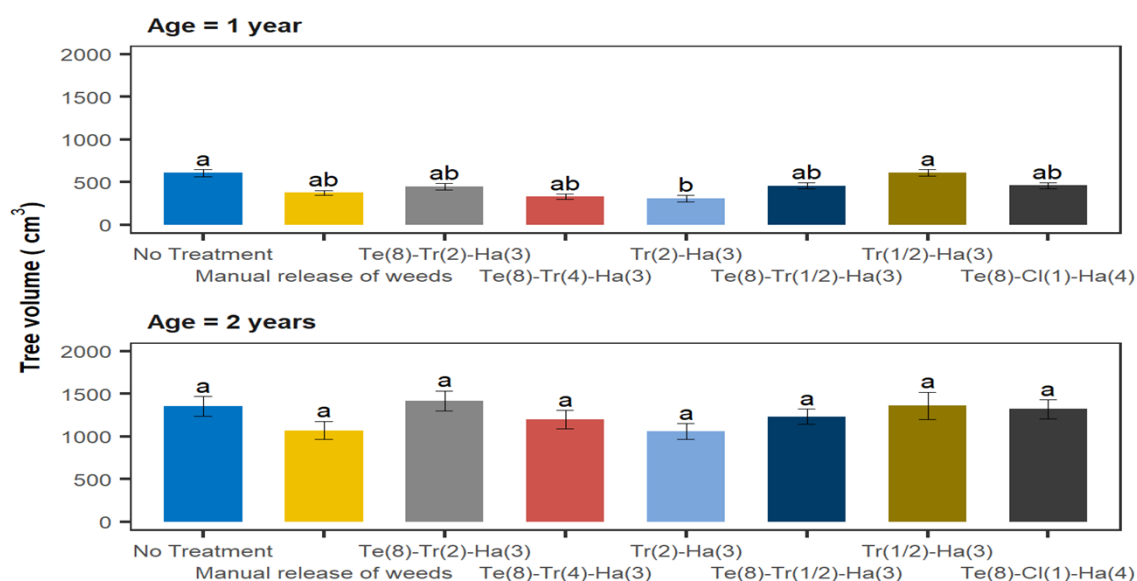


Figure 15: Mean mānuka stem volume index for each treatment and age class. Bars topped with the same letter are not significantly different ($P > 0.05$). Te = terbutylazine, Tr = triclopyr, Ha = haloxyflop and Cl = clopyralid. Rate (L/ha) of each herbicide in treatment indicated in parentheses.

Effects of plant competition on mānuka growth

To understand whether there was evidence of competition from gorse or other plants negatively affecting mānuka, growth data were compared with various measures of competition. The analysis was restricted to only those plots that did not receive herbicide treatments to remove any confounding effects i.e. herbicide treatments could reduce competition from gorse or other non-crop plants while also damaging the mānuka so potential benefits from reduced competition are not realised. Analysis demonstrated that there was no significant effect of gorse or total plant cover on mānuka growth ($P > 0.05$).

CI50 had no significant influence on mānuka growth. At low CI relative height values, less than about 2 to 3 (equivalent to a weed height of between 0.5 to 0.75 mānuka height), mānuka growth is variable, ranging from high to low for both young and old mānuka (Figures 16 and 17). At high CI relative height (> 2 to 3), growth is always low. This pattern is a typical result – growth is variable when unconstrained, but when competition (CI relative height) increases, mānuka growth is always suppressed. Given that the constraint on growth only occurs when the competing vegetation is over a certain height threshold, and is not related to total cover, it is likely that competition for light is driving this interaction.

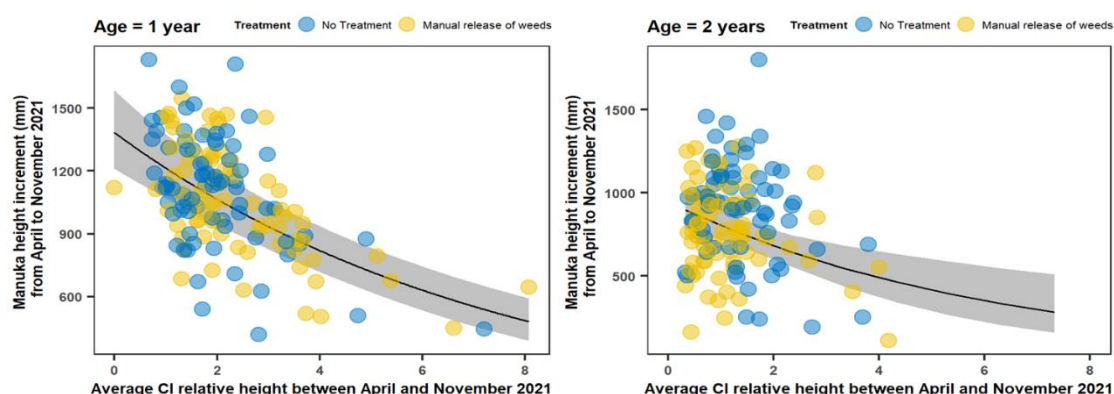


Figure 16: Effect of competition index on mānuka height growth for each age class.

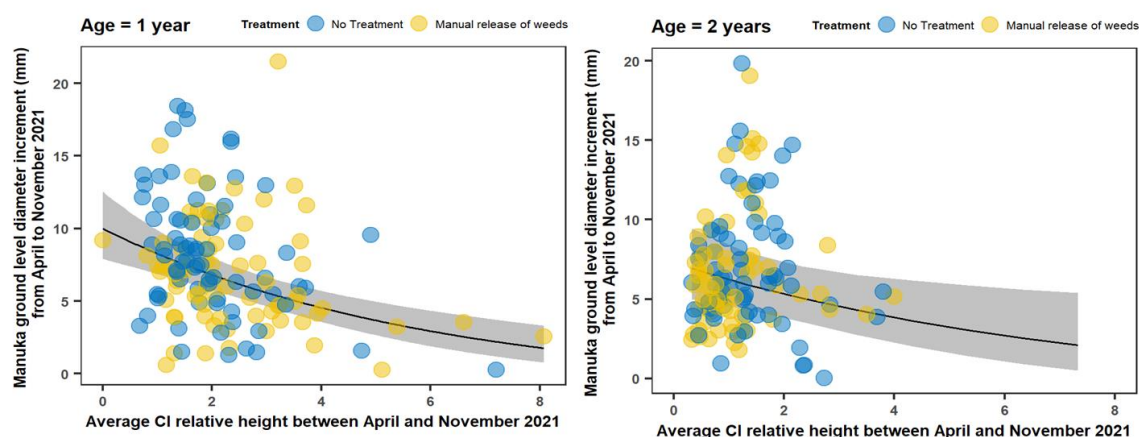


Figure 17: Effect of competition index on mānuka diameter growth for each age class.

Conclusions

Whilst there was evidence that mānuka growth was inhibited by intense weedy competition (CI relative height > 3) an important conclusion from this trial was that the herbicide treatments did not significantly improve mānuka growth, survival and site domination.

Factors contributing to this lack of response to herbicide treatment included:

- The comprehensive and effective pre-plant desiccation (500g/ha metsulfuron + 10L/ha glyphosate + 1L/ha wetting agent) and roller crushing reducing the rate of gorse establishment.
- Rapid mānuka height growth relative to gorse height growth.

- A negative impact on mānuka growth from treatments that had the biggest negative effect on gorse i.e. those with 1.2 kg/ha or more of triclopyr.

The lack of statistical significance may also have been compounded by both a highly variable site and initial weed cover distribution coupled with a highly variable treatment application.

After 12 months, only one treatment maintained a significantly reduced weed cover relative to the untreated control (triclopyr (1.2 kg/ha) + terbuthylazine (4.0 kg/ha) + haloxyfop (0.3 kg/ha).

For sites with more vigorous weed competition (e.g. no or minimal pre-plant weed control), is apparent, stronger positive effects of weed control would be expected.

It is recommended that release treatments employ no more than 2 L/ha triclopyr in the spray mix.

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References

- Brooks, M. E., Kristensen, K., Van Benthem, K. J., Magnusson, A., Berg, C. W., Nielsen, A., Skaug, H. J., Machler, M., & Bolker, B. M. (2017). glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. *The R journal*, 9(2), 378-400.
- Clarkson, B. D., Smale, M. C., & Ecroyd, C. E. (1991). Botany of Rotorua.
- Davenhill, N. A., Ray, J. W., & Vanner, A. L. (1997). *Forest weed control manual: a guide to herbicide use in forests*. FRI bulletin. Rotorua, New Zealand: Forest Research Institute.
- DOC. *Mānuka/kahikātoa and kānuka*. Retrieved 30/06/22, from <https://www.doc.govt.nz/nature/native-plants/manuka-kahikatoa-and-kanuka/>
- Ferrari, S., & Cribari-Neto, F. (2004). Beta regression for modelling rates and proportions. *Journal of applied statistics*, 31(7), 799-815.
- Garrett, L. G., Watt, M. S., Rolando, C. A., & Pearce, S. H. (2015). Environmental fate of terbuthylazine and hexazinone in a New Zealand planted forest Pumice soil. *Forest Ecology and Management*, 337, 67-76.
- Harrington, K., & Gregory, S. (2009). Field assessment of herbicides to release native plants from weeds. *New Zealand Plant Protection*, 62, 368-373.
- Harrington, K., Nurhayati, R., & Millner, J. (2015). Field assessment of herbicides to aid establishment of manuka (*Leptospermum scoparium*). *New Zealand Plant Protection*, 68, 132-138.
- Harrington, K., & Schmitz, H. (2007). Initial screening of herbicides tolerated by native plants. *New Zealand Plant Protection*, 60, 133-136.
- Lenth, R., Singmann, H., Love, J., Buerkner, P., & Herve, M. (2022). Emmeans: Estimated marginal means, aka least-squares means. *R package version 1.7.3*.

- Magesan, G. N., Wang, H., & Clinton, P. W. (2012). Nitrogen cycling in gorse-dominated ecosystems in New Zealand. *New Zealand Journal of Ecology*, 21-28.
- MPI. *New Zealand Honey Exports*. Retrieved 30/06/22, from <https://www.mpi.govt.nz/dmsdocument/42360-New-Zealand-honey-exports>
- Nairn, J., Meredith, J., Gous, C., Rolando, C. (2020a). *Towards tree establishment success: Screening herbicides for indigenous tree tolerance at rates required for effective weed control. Report prepared for Te Uru Rakau*. Rotorua, New Zealand: Scion (NZ Forest Research Institute Ltd).
- Nairn, J., Meredith, J., Rolando, C. (2020b). *A literature review of the current knowledge on phytotoxicity of herbicides to indigenous tree species of New Zealand*. Scion Report No. 27063536 prepared for Te Uru Rakau. Scion, New Zealand.
- Nieuwenhuis, R., Te Grotenhuis, H., & Pelzer, B. (2012). Influence. ME: tools for detecting influential data in mixed effects models. *R Journal*, 4(2), 38-47.
- R Core Team. (2022). *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing.
- Richardson, B. (1993). Vegetation management practices in plantation forests of Australia and New Zealand. *Canadian Journal of Forest Research*, 23(10), 1989-2005.
- Richardson, B., Kimberley, M. O., Ray, J. W., & Coker, G. W. (1999). Indices of interspecific plant competition for *Pinus radiata* in the central north island of New Zealand. *Canadian Journal of Forest Research*, 29(7), 898-905.
- Richardson, B., Vanner, A., Ray, J., Davenport, N., & Coker, G. (1996). Mechanisms of *Pinus radiata* growth suppression by some common forest weed species. *New Zealand Journal of Forestry Science*, 26(3), 421-437.
- Saunders, L. (2017). *The Mānuka & Kānuka Plantation Guide*. <https://www.trc.govt.nz/assets/Documents/Guidelines/Land-infosheets/Manuka-plantation-guide-landcare-April2017.pdf> Accessed 30/6/22. Boffa Miskell Ltd.
- Smithson, M., & Verkuilen, J. (2006). A better lemon squeezer? Maximum-likelihood regression with beta-distributed dependent variables. *Psychological methods*, 11(1), 54.
- Trotter, C., Tate, K., Scott, N., Townsend, J., Wilde, H., Lambie, S., Marden, M., & Pinkney, T. (2005). Afforestation/reforestation of New Zealand marginal pasture lands by indigenous shrublands: the potential for Kyoto forest sinks. *Annals of forest science*, 62(8), 865-871.
- TUR. (2018). *One Billion Trees Fund: Report on policy and design recommendations*. Wellington, New Zealand: Te Uru Rākau, Ministry for Primary Industries.
- Van der Meer, T., Te Grotenhuis, M., & Pelzer, B. (2010). Influential cases in multilevel modeling: A methodological comment. *American Sociological Review*, 75(1), 173-178.
- Wagner, R. G., Little, K. M., Richardson, B., & McNabb, K. (2006). The role of vegetation management for enhancing productivity of the world's forests. *Forestry*, 79(1), 57-79.
- Wang, H., Lin, K., Hou, Z., Richardson, B., & Gan, J. (2010). Sorption of the herbicide terbuthylazine in two New Zealand forest soils amended with biosolids and biochars. *Journal of Soils and Sediments*, 10(2), 283-289.
- Zuur, A. F., Ieno, E. N., Walker, N. J., Saveliev, A. A., & Smith, G. M. (2009). *Mixed effects models and extensions in ecology with R*. Vol 574. Springer.