Precision Silviculture Partnership

Investigation of extending the planting season into late March using hydrogels
Final report: 12 months

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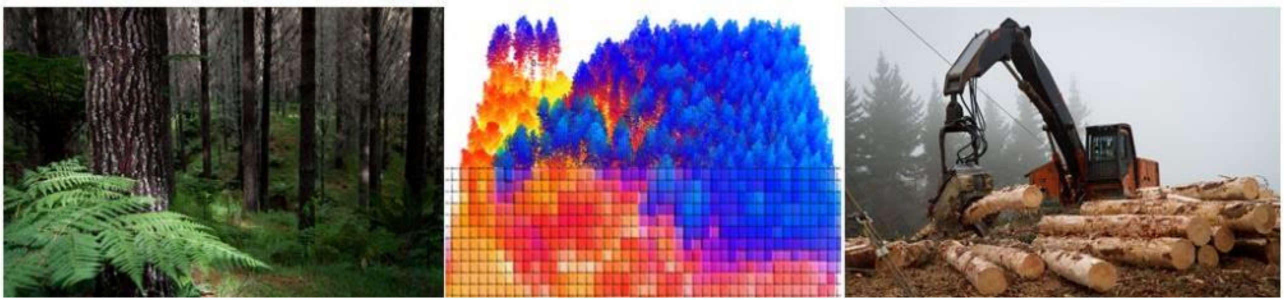

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FOREST GROWERS RESEARCH

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EXECUTIVE SUMMARY

Problem

Hydrogels have been used to aid plant establishment and growth in range of soil conditions. The potential of hydrogels to extend the planting window in New Zealand has not yet been extensively evaluated. The need to extend the planting window in New Zealand is closely aligned to potential wider adoption of mechanised tree planting systems, the cost-efficiency of which increases with increased machine utilisation.

Aim

The purpose of this project was to investigate the opportunity to widen the planting season window, into summer and autumn (December to March) using hydrogels applied with a mechanised planting system, notably the M-Planter.

Methods

A trial was implemented in Tarawera Forest in late March 2022, with an M-Planter, consisting of four treatments applied at the time of planting container grown seedlings: a control (no treatment), root zone application of water, surface application of 0.5 L hydrogel and root zone application of 0.5 L hydrogel. A pre-hydrated nano-cellulose hydrogel produced by Scion was used for the study. This gel is based on cellulose fibres extracted from seaweed. Measurements of plant health and size (height and groundline diameter) were made over the first 12 months after planting.

Results

There was no significant effect of the water or hydrogel treatment on survival at 3 months or 12 months after planting, with an overall survival of 87% at 12 months. Greater variation in survival was observed where no hydrogel was used. There were near-significant to significant effects of treatments on tree size (height, groundline diameter and biomass index) at 12 months, with hydrogel placement in the root zone showing a small positive effect on tree size and placement on the soil surface after treatment a small negative effect.

Recommendations

The study is the first part of a larger evaluation within the Precision Silviculture Programme of the potential for mechanised application of hydrogels, fertilisers and growth stimulants, applied at the time of planting, to broaden the planting season window. The results at one year of the mechanised planting trial established on the 31st March 2022 in Tarawera Forest have shown marginal benefits in survival and growth of container grown *P. radiata* in response to the application of a hydrogel at the time of planting with an M-Planter. There were multiple learnings from the trial including increased knowledge around the use of the M-Planter as well as mechanical application of hydrogels applied at the time of planting.

Assuming there is ongoing interest in using the nano-cellulose hydrogel, we recommend that further work is carried out to understand the water retention characteristics of the hydrogel and its effect on plant available water when used at different concentrations and volumes across typical forestry soils. The findings of this Go-Early study support the case for an expanded operational trial series to examine factors such as placement, quantity and timing of application of the hydrogels.

INTRODUCTION

Hydrogels, developed to increase the water holding capacity of amended media, have been used to aid plant establishment and growth in dry soils (Agaba et al., 2010, Crous, 2017). They have the potential to absorb water many times their weight, retain it and supply it to plant roots during water stress, thereby enhancing early plant survival and growth. The addition of hydrogels to soils has been shown to not only improve their water holder capacity but also to increase the supply of plant available water (Abedi-Koupai et al., 2008), for example, by up to 100% in sandy loam and loam soils (Agaba et al., 2010). The use of hydrogels to improve success of forest establishment, and/or extend the tree planting season into drier seasons, has been investigated in South Africa, Europe, Canada and the USA (Crous, 2017). While many studies have shown improved survival in response to the use of a hydrogel at planting, several studies have also shown either no and/or negative impact (Crous, 2017). Inconsistencies in survival and/or growth responses to the use of a hydrogel have been attributed to differences in weather, soil properties, the specific conditions of the application of the hydrogel, type of hydrogel, particle size of hydrogel, quantity of hydrogel, water quality, species planting and method of application. Many potentially interacting factors therefore underpin whether the application of a hydrogel will be beneficial or not.

The potential of hydrogels to extend the planting window in New Zealand has not yet been extensively evaluated (Ford et al., 2023). The need to extend the planting window in New Zealand and adapt to seasonal climate risk is closely aligned with the potential adoption of mechanised tree planting systems because their cost-efficiency improves with increased machine utilisation (Ersson et al., 2018). With increasing interest in New Zealand in the application of mechanised tree planting systems for forest establishment and re-establishment, there is also a need to evaluate potential additives, including hydrogels, that could be used to improve the success of out-of-season mechanised planting operations. Further, hydrogels could improve planting success during climate-change driven unseasonable droughts, likely to be increasing in probability.

The purpose of this project was to investigate the opportunity to widen the planting season window, into summer and autumn (December to March) using hydrogels applied with a mechanised planting system, notably the M-Planter (for full description see Ford et al., 2023). To this end, a trial with the M-Planter was implemented consisting of four treatments applied at the time of planting container grown seedlings: a control (untreated), root zone application of water, surface application of a hydrogel and root zone application of a hydrogel. A nanocellulose hydrogel produced by Scion, based on cellulose fibres extracted from seaweed, was used for the study (Ford et al., 2023).

Full details of this study, including trial design and implementation, are described in an earlier report (Ford et al., 2023) that also includes a review of previous research in New Zealand on the use of hydrogels as well as measurements made at the start of the trial. The current report focuses on the measurements of this trial made at 12 months after planting with recommendations for further work based on the outcomes of the trial at 12 months. The study is the first part of a larger evaluation within the Precision Silviculture Programme of the potential for mechanised application of hydrogels, fertilisers and growth stimulants applied at the time of planting to broaden the planting season window.

METHODS

A brief outline of the trial and treatments is provided below. For a full description of methods see Ford et al. (2023).

Site description

The trial was implemented in Tarawera Forest (-38°08’38.28” S, 176°34’21.64” E) on the Timberlands Ltd estate (Figure 1). This area of the forest (Cpt 45/2) is also known colloquially as “Death Valley” due to its harsh growing conditions and history of *Diplodia pinea* in its stressed stands. It is generally considered a hot and high stress site. Soils at the site are of pumice origin and are classified as either Typic Fluvial Recent or Buried-pumice Tephric Recent. The soils have high macro-porosity; therefore water retention is expected to be low, particularly near the soil surface. These factors made it a good choice for this establishment work.

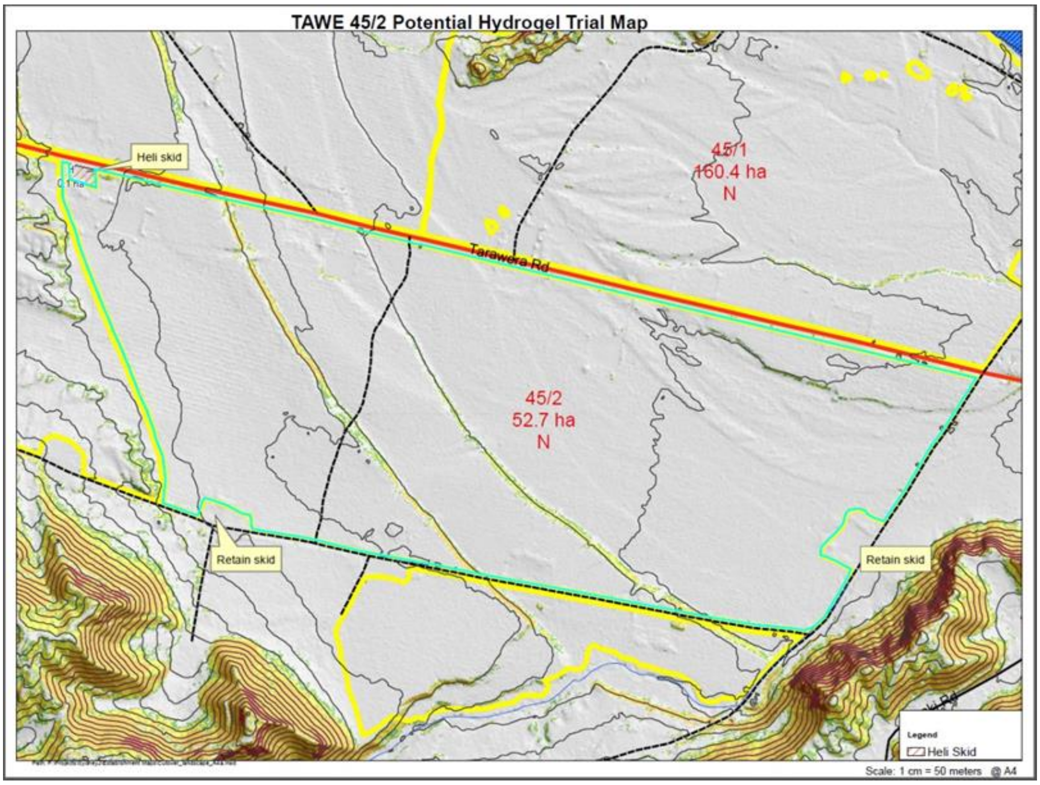

Figure 1: Map of trial site location and approximate size of trial.

Trial design and implementation

The trial was implemented as a randomised complete block (RCB) design consisting of 4 hydrogel treatments (Table 1; Figure 2), with 6 replications and ~48 trees per plot. Each rectangular plot contained 3 rows with 16 trees in each row (48 trees total) and a spacing of 4 m between rows and 3 m within rows. .

Table 1: Details of the four hydrogel treatments included in this trial.

Treatment	Description
Control (Dry)	Zero hydrogel, Zero water
Water (Water)	500 mL water applied per plant to the root zone of each plant
Surface application (H_Surf)	500 mL hydrogel solution applied over the top of each plant.
Root zone application (H_Inj)	500 mL hydrogel solution applied to the root zone of each plant

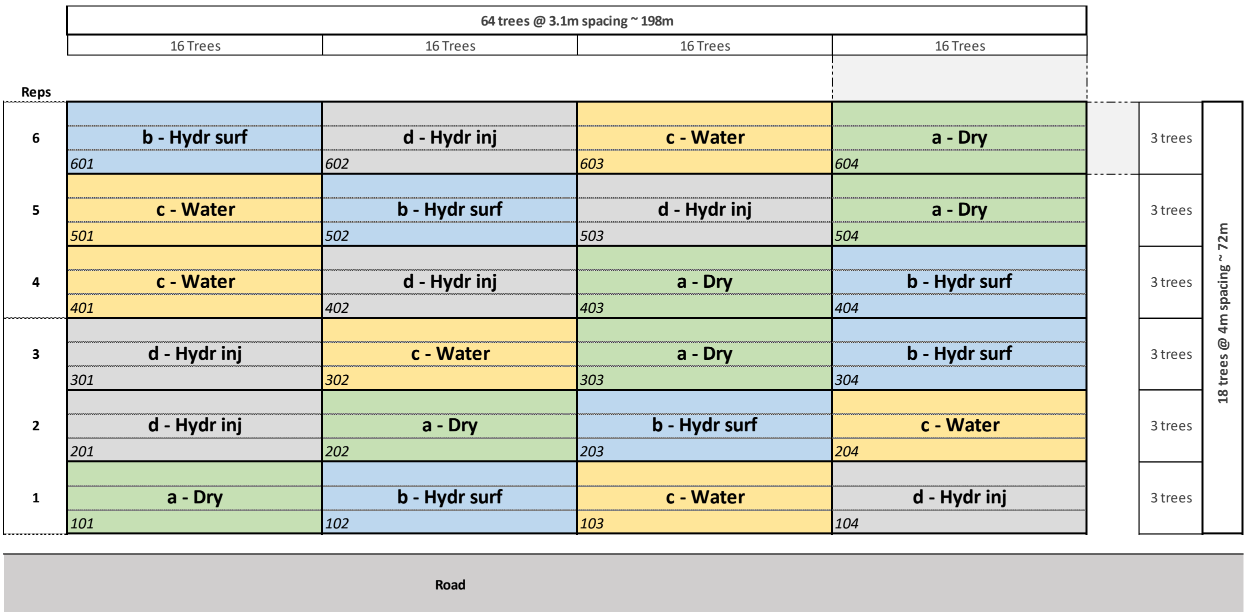

Figure 2: Trial plot layout for six replications of the four hydrogel treatments.

Containerised seedlings (mean root collar diameter 3.93 mm +/- 0.02 SE (*n* = 168) and mean (topped) height 31.1 cm +/- 0.07 SE (*n* = 1180)) were planted with the M-Planter on 31st March 2022. These seedlings were described as a good quality by the contractor (M-Planter NZ) for the mechanised planting operation. The hydrogel solution used in the trial was mixed on-site at a ratio of 5:1 achieved by mixing one 20 L bucket of hydrogel with five 20 L buckets of water.

Assessments and Analyses

Assessments of seedling size and planting depth were made at the time of planting. These results are reported in Craig et al. (2023). Tree height (cm), health and survival were assessed shortly after planting, at three months and at one year after planting, with groundline diameter (gld) (mm) assessed at one year. A biomass index was calculated for each tree at 12 months (Biomass index=gld^2 x ht).

Results were analysed using RStudio, with an ANOVA appropriate for a randomised complete block design Assumptions of normality and homogeneity of variance were checked and where appropriate data were transformed to meet these assumptions. Tukeys HSD multi-comparison test was used to test for significant differences between means where an over-all F-test was found to be significant ($p<0.05$).

RESULTS AND DISCUSSION

Weather at the time of planting.

Leading up to the establishment of the trial, there had been very little rain in Tarawera Forest, and soil moisture was extremely low (Ford et al., 2023). However, the site received approximately 138 mm of rain in the two weeks prior to planting , with 89 mm rainfall in the week prior to planting (Table 2). Although planting was delayed for 7 days to allow the soil to dry out, the rainfall in the week prior to planting may have affected trial outcomes. The week following planting was relatively dry, with only 0.4 mm rainfall, but more rainfall >10 mm occurred over the following 3 weeks (Table 2). Beyond one month after planting the season was moving into late autumn (May) and early winter when daily temperatures and evaporative demand at the site decreased, reducing the potential for extreme drought/heat stress.

Table 2. Rainfall summary around the time of planting and up to one month after planting. Data extracted from closest NIWA weather station; Whakatane Airport (station 40982).

Period	Total Rainfall (mm)
0-7 days prior to planting	88.8
0-7 days after planting	0.4
8-14 days after planting	11.4
15-28 days after planting	32.6

Tree survival

There was no significant difference in tree survival across the four treatments at 3 months or at 12 months after planting despite a slight trend for increased survival where a hydrogel was used (Table 3) (Table 3, Figure 3). Average survival for the trial was 89.6% at 3 months after planting declining to 88.6% at one year.

Table 3. Survival (%) across the four treatments at 3 months and 12 months after planting.

Date	Dry	Water	H_Surf	H_Inj
3 months*	88.1±9.3	88.3±9.5	90.8±4.8	91.4±4.5
12 months**	87.4±9.0	87.6±9.8	89.1±4.5	90.7±5.2

* DF(3/15), F=0.268, *p*=0.85; ** DF(3/15), F=0.1194, *p*=0.9

Although not statistically significantly different (Bartletts test: $p=0.413$), variation around mean survival was higher for the dry and water planted treatments than where a hydrogel (surface or root zone application) had been applied at planting (Table 3). The highest survival at 12 months occurred in the treatment where hydrogel was applied to the root zone, with a difference of 3.3% between the best and worst treatments at 12 months (Table 3, Figure 3). Variation in survival around the average is a trend worth noting for future work as lower variability in mortality under conditions of stress would be preferable. It is possible the hydrogel reduces mortality in patches with unfavourable microclimates.

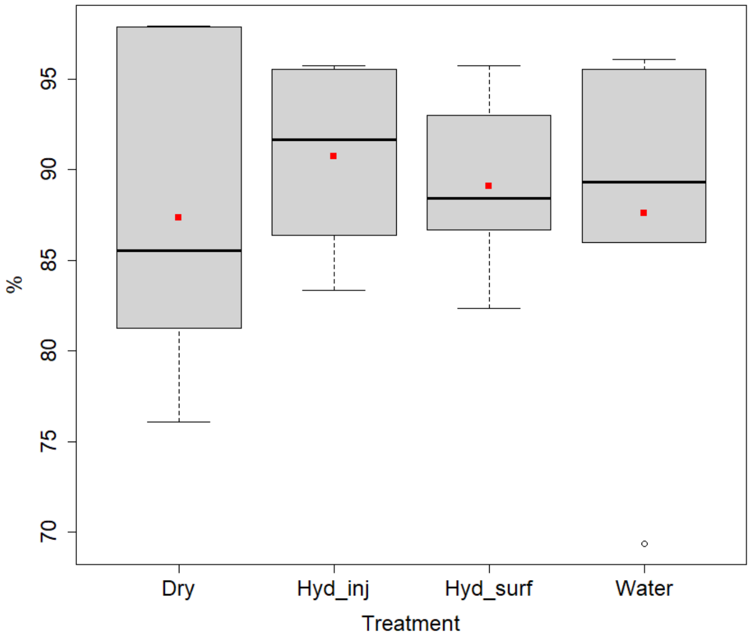

Figure 3. Boxplot showing survival across the four treatments at 12 months. Shown is the mean (red dot), median (black line), inter-quartile ranges and the highest and lowest values excluding outliers (shown as a circle).

Tree growth

There was a small but significant difference in mean tree heights across treatments at three months after planting ($F[3/1126]=8.7$, $p<0.05$) (Figure 4). Seedlings planted with hydrogel applied after planting (H_Surf) were significantly smaller than the three other treatments by effectively 1 cm (Figure 4). However, there was no significant benefit from root-zone hydrogel application compared with the control (Dry treatment).

Twelve months after planting, there were small but near-significant to significant differences in mean tree size (height, gld and biomass index) across treatments (height: $F[3,997]=2.4$, $p=0.06$; gld:$F[3,997]=2.6$, $p=0.05$, biomass index:$F[3,997]=2.9$, $p=0.03$). These differences were driven by the comparison of root zone and surface hydrogel application (Table 4) with the latter treatment reducing growth. This trend is consistent with observations made at 3 months after planting, where placement of hydrogel in the root zone resulted in larger trees than those where the product was placed after planting. However, as with the 3-month data there was no significant benefit from root-zone hydrogel application compared with the control (Dry treatment).

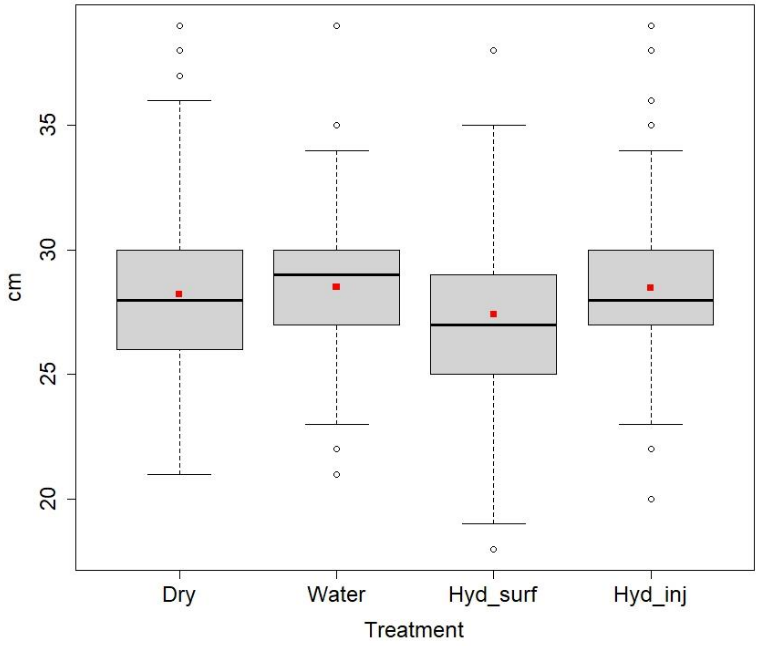

Figure 4. Boxplot showing tree height across the treatments at 3 months. Shown is the mean (red dot), median (black line), inter-quartile ranges and the highest and lowest values excluding outliers (shown as a circle).

Table 4. Summary of multiple comparison tests showing significant differences between treatments for each variable assessed at 12 months. Treatments not shown were not significantly different.

Variable	Difference	Difference	P-value
Height (cm)	H_Surf - H_Inj	-3.1 cm	0.06
GLD (mm)	H_Surf - H_Inj	-1.0 mm	0.03
Biomass index	H_Surf - H_Inj	-43.2	0.02

Ground-line diameter increased about 4.9-fold during the 12 months after planting, from an average of 3.9 to 19.3 mm. Despite an 18% in ground line diameter from the root-zone hydrogel treatment versus the untreated control, this difference was statistically non-significant (Figure 5).

Consistent with the trends in groundline diameter, overall tree height growth over the 12-month trial period indicated a marginal but non-significant benefit in growth where the hydrogel was applied to the root zone at the time of planting (Figure 6). Incorporating survival into this assessment through evaluation of total plot biomass for each treatment at 12 months also indicated no-significant benefit over the control (data not shown).

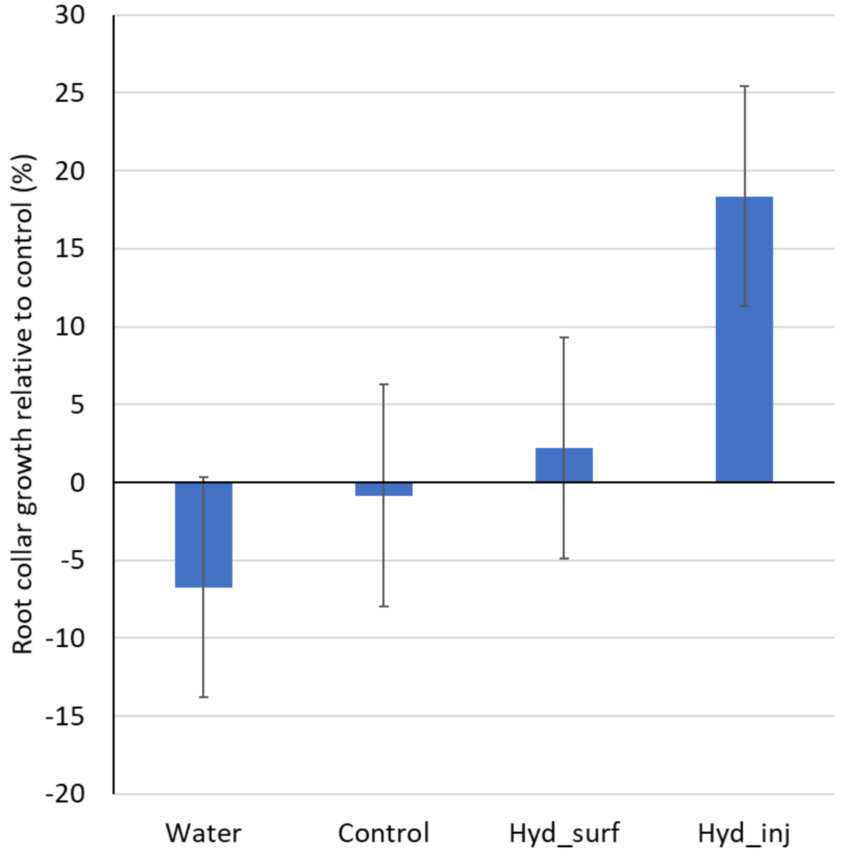

Figure 5. Least square adjusted means of root collar at 12 months, accounting for the effects of normal growth in un-treated controls and the variation introduced by individual replicates (*p* = 0.0557). Growth normalised by growth and variation across the trial site.

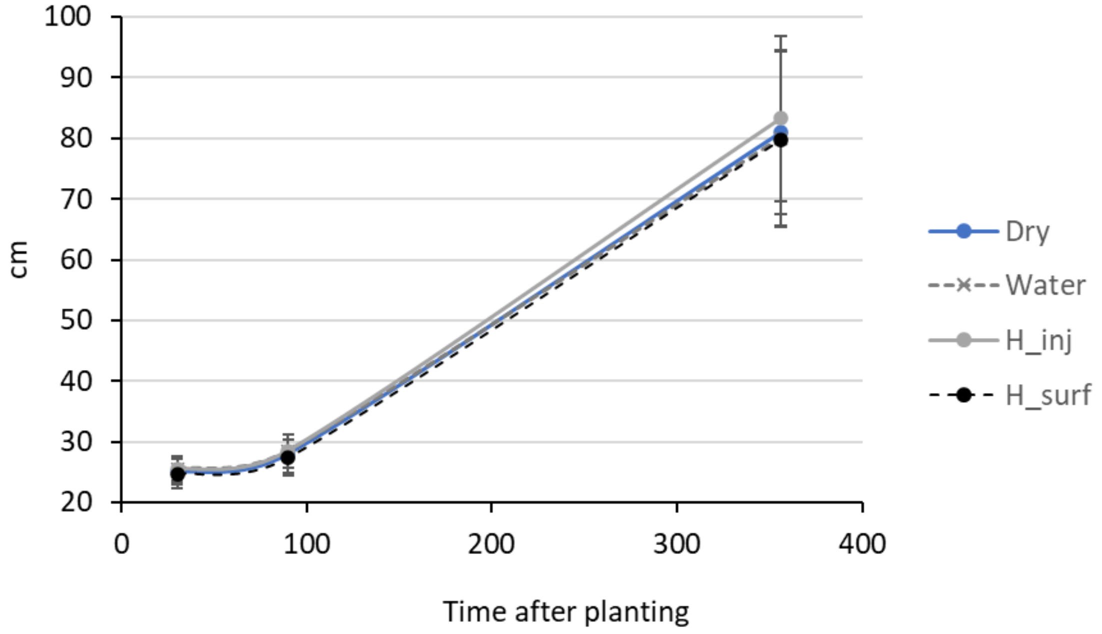

Figure 6. Tree height (cm ±sd) for four treatments over the 12 months from time of planting.

CONCLUSIONS AND RECOMMENDATIONS

Crous (2017) conducted an extensive review of the use of hydrogels in planted forests. It is recommended that those interested in pursuing the use of hydrogels review the recommendations provided by Crous (2017), but a brief summary is provided in Appendix 1.

This study shows that there were no significant differences in tree survival and marginal benefits in growth twelve months after application of hydrogel treatments during mechanised (M-Planter) planting of containerised *P. radiata* seedlings in Tarawera Forest. It is plausible that this outcome is partly a function of the wet weather surrounding the time of planting. Nevertheless, trends in the data suggested that hydrogel incorporated into the soil may both reduce variability in mortality and support a slight increase in growth rate. However, until we have a more comprehensive set of trials planted across sites and seasons, as well as a fundamental understanding of the moisture dynamics across the plant:hydrogel:soil continuum for the nano-cellulose hydrogel, it will be difficult to unpick the key factors driving survival and growth responses. This aside, learnings from implementing this trial are multiple, as forest growers have gained increased knowledge on:

- The logistics of planting using a mechanised planting system – notably the M-Planter – on pumice soils with reasonable level of harvest residues.
- The efficiency of the operating system applying the water and/or hydrogels at the time of planting and potential solutions to overcome these challenges (see Ford et al., 2023).
- The ability of the planting machine to apply water and/or hydrogels (up to 500 mL per plant) to the root zone or over the top of the planted stock during the planting operation.
- The consistency/viscosity of the nano-cellulose hydrogel required to ensure delivery through the application unit on the M-Planter (1:5 hydrogel solution:water).
- The performance of containerised *P. radiata* stock planted with an M-Planter on pumice soils (treatments aside).

Outcomes from this trial should be used to guide the next steps in understanding the potential of hydrogels to:

- Extend the planting season outside of the current range (May to October) or provide a moisture buffering capacity in the case of unseasonable droughts.
- Provide a medium for inoculating the newly planted stock with nutrients and/or beneficial microbes to increase capacity to withstand stress at the time of planting.
- Provide on-going benefits to the tree crop as they degrade *in-situ*.

If further work with the nano-cellulose hydrogel is a high priority for forest growers, we recommend that fundamental work is undertaken to understand the water retention characteristics of the hydrogel and its effect on plant available water when used at different concentrations and volumes across a range of forestry soils. Ideally, the performance of the nano-cellulose hydrogel would also be compared to a commercially available synthetic polymer, such as Aquasorb or similar. Such an approach would underpin a more structured understanding of the optimum hydration for the product(s) and the amount to apply at planting (0.25 mL or 1 L), plus enable an estimation of the period over which the hydrogel(s) is likely to provide a buffer against extreme dry weather conditions, if at all. Without this information it will be challenging to provide foresters with the decision-making tools required to estimate when to use the hydrogel, how much to use, how to apply and the period over which the hydrogel is likely to provide a buffer to extremely dry conditions. Ultimately, the decision will be driven by the cost:benefit which can only be determined when we have an estimate of: 1) the probability of improved survival/tree performance, 2) the amount of hydrogel and water required at the time of planting and 3) the cost of the product to be used.

ACKNOWLEDGEMENTS

We want to thank colleagues at Timberlands and Scion who made it possible to establish this trial in a short time window. John Sydney, Nathan Sturrock, Ben Dixon and Wayne Cameron from Timberlands identified the site and arranged for operations needed for the trial establishment. Antoinette Roberts and staff from Timberlands' Te Ngae nursery provided the tree stock. Henry Fear (H.A. Fear Ltd) modified the M-Planter so that it could deliver the different treatments and, along with his staff, actually planted the trial. The hydrogel was produced using seaweed provided by Agrisea Ltd and Scion colleagues Sean Taylor, Rob Whitton and Marie-Joo LeGuen. Carol Rolando is acknowledged for analysing the data and collating the report at 12 months.

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Appendix 1

General recommendations on hydrogels made by Crous (2017):

- The application of water is as effective as the application of a hydrogel and water. However, the addition of a hydrogel reduces the quantity of water that needs to applied to each plant and therefore the cost.
- Polyacrylate/polyacrylamide hydrogels with a K-salt are the most stable products when mixed into soil and show the least potential to have negative effects on plant growth. Starch based hydrogels are susceptible to effects from salts occurring naturally in soil or from fertiliser.
- A particle size of 0.1-0.8 mm is recommended as this range decreases the hydration time whilst minimising the effects of cations in the soil and soil pressure in water adsorption capacity.
- Hydrogels containing fertilizers have reduced water capacity, contain too little fertiliser to be of benefit to the plant, whilst increasing the product cost.
- Fertilizer should not be mixed or placed in close contact with hydrogels as it will significantly reduce the re-swelling ability of the hydrogels.
- Hydrogels should be pre-hydrated before application in order to reduce the initial influence from soil cations.
- A quantity of 6-12 g of a hydrogel mixed into 0.7-2 L water per plant is recommended, with no additional benefit from applying more than 2 L water.
- Hydrogels should be applied locally (not mixed with soil) to limit the negative effect of soil cations on water absorption capacity and to act as a barrier for root-feeding insects. However, localised placement in the bottom of the planting pit will increase the risk of pushing plants out of the planting pit when hydrogel rehydrates.
- The 3-12 g hydrogel applied to each plant contains a relatively small quantity of water (150-500 mL) under field conditions and can only provide additional water for a short period.

Crous (2017) recommended additional research is required on the application method and placement of hydrogels. One method recommended included application in topsoil as a wet mulch, application of pre-hydrated hydrogel above the seedling.