Precision Silviculture Programme

TECHNICAL REPORT

Investigation of extending the planting season into late March using hydrogels and growth promoters.

FGR - Go early milestones 2.4.1 and 2.5.1.

Craig Ford, Graham Coker, Simeon Smaill, Alex Lloyd, Toby Stovold, Kane Fleet, Stefan Hill and John Moore (Timberlands).

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FOREST GROWERS RESEARCH

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*R*eport information sheet

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Authors	Craig Ford, Graham Coker, Simeon Smaill, Alex Lloyd, Toby Stovold, Kane Fleet, Stefan Hill and John Moore (Timberlands)
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Executive summary

This project

One of the workstreams in the Precision Silviculture programme focuses on mechanised planting. Extending the planting season through the use of hydrogels and growth regulators would improve the utilisation of mechanical planting equipment and potentially offers some mitigation against extended dry periods in future. This project used "go-early" funding to establish a trial in late March to investigate the survival and growth of containerised *Pinus radiata* seedlings mechanically planted with hydrogel. This time window was chosen as soil moisture is generally at its lowest following summer.

Key results

A brief literature review of the use of hydrogels to improve survival and early growth was conducted. The review focused on both New Zealand and international studies and showed examples where the application of hydrogels led to significant increases in tree survival and growth. Based on the review and discussions among the project team, four treatments were selected: dry control (normal practice), 500 mL of water applied at time of planting, 500 mL of hydrogel applied to the root zone and 500 mL of hydrogel applied to the surface of the planting mound. Fertiliser (15 g of Osmocote) was applied to each tree across all treatments. Each treatment was applied to 48-tree plots and replicated six times in a randomised complete block design. All trees were planted using a mechanical planting machine (M-Planter) over two days (31 March – 1 April) at a site in Tarawera Forest, Bay of Plenty.

While the trial was scheduled to be established at the time when soil moisture is typically at its lowest levels, more than 150 mm of rain fell in a 3-day period in mid-March. The trial establishment was delayed by one week to try to give the soils time to dry out and anecdotally the mounds were dry during the time when the trial was planted. There was little rainfall and warm temperatures in the period shortly after planting, which is expected to create moisture stress for the trees.

Implications of results for the client

The trial has only just been established and will be monitored over the next 12 months to assess survival and early growth. However, the work done to date has already shown the ability for mechanical planting machines to be adapted to deliver a range of treatments that can aid tree survival and early growth. Another outcome of the trial has been the opportunity to test a nano-cellulose based hydrogel. While these are not yet in commercial production, they offer several potential advantages over acrylic hydrogels. They are chemically inert, and in the soil and potentially could be used as a carrier for nutrients and other micro-organisms that will aid nutrient uptake and reduce plant stress.

Further work

This trial was established to provide information on the potential of hydrogels to improve survival and early growth of trees. Over the course of the Precision Silviculture programme further detailed investigations will be undertaken to assess the potential for hydrogels in combination with other growth promoting treatments to improve survival and growth. This is likely to include additional field trials, coupled with experiments under more controlled conditions to better understand how hydrogels affect moisture retention and uptake by seedlings.

Investigation of extending the planting season into late March with use of hydrogels and growth promoters.

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Introduction

Forest Growers Research - project background

The aim of the Precision Silviculture programme is to introduce new technology and practice changes to improve safety, reduce environmental impacts, improve profitability, and reduce costs of forest operations. Reducing the sector's reliance on low skilled labour is an important driver for the programme. The programme spans four workstreams – nursery, planting, pruning and thinning – and will be supported by a digital framework spanning the four themes

The purpose of this project is to investigate the opportunity to widen the planting season window to enable greater utilisation of mechanised planting equipment and to smooth the seasonal labour requirements in nursery operations. The project will investigate whether successful establishment can be achieved under low soil moisture conditions at the end of March through the mechanical application of hydrogels at the time of mechanical planting of seedlings. It is also expected that drier conditions in the future will require changes to current establishment methods to overcome potential low soil moisture conditions. Undertaking this trial in late March will build on earlier trials and importantly avoid missing the early shoulder period of the 2022 planting season. The early planting trial, under the "go early" agreement with MPI will be part of a larger evaluation of the mechanised application of hydrogels, fertilisers and growth stimulants at time of planting aimed at broadening the planting season window. The outcome of this initial project will inform the development of the broader work plan.

Hydrogels, fertilisers and growth stimulants for forestry

At establishment, the opportunities to enhance growth are varied and depend on the site and seasonal conditions. The key physiological mechanisms are: i) water retention or drought protection, ii) nutrient deficiency and enhancement, iii) pathogen protection and iv) stimulants or growth-promoting agents. All these can be potentially applied in an efficiently targeted spray mixture. A complex mixture may also provide protection from a range of issues or seedling risks at one time. This mixture of protective mechanisms could, therefore, be applied across a wide range of sites making it operationally practical, by addressing specific issues at different sites. There are also likely to be synergistic benefits or antagonistic costs of the protective mechanisms of a complex hydrogel mixture, but these are yet to be fully quantified.

Hydrogels

The use of hydrogels for improving the survival and growth of forest species was comprehensively reviewed by Crous (2017). Of the 42 trials reviewed, a full range of negative, zero, and positive results were reported. The most successful applications were hydrogels pre-mixed with water to ensure the greatest efficiencies post application. Hydrogel applications were less beneficial to deep-rooted plants (Fan et al. 2005). Hydrogels only provide short-term relief from dry conditions and should not be relied on as a substitute for good silviculture. However, this project provides an opportunity to explore their use in NZ for extending the planting window by providing a protective period of a few weeks until autumn rains set in.

We will be investigating the potential of a nanocellulose hydrogel. Nanocellulose is the fundamental building block of all plants, macroalgae, and some bacteria. It is the most abundant polymer on the planet and has no known toxic effects. It consists of repeating sugar units. Due to its structure, it can absorb hundreds of times its dry weight in water and in doing so forms a non-toxic hydrogel. These hydrogels are made from cellulose and water. Therefore, they are suited to deployment in the environment without risk of negative impacts. Furthermore, it is believed that the new seaweed-based nano-cellulose gel has many advantages over the current commercial products, such as flowability, non-toxic, from sustainable plant-based materials and it is chemically inert, so additives do not affect the function of the gel.

Hydrogels also act in stabilising the planting substrate (Azzam 1980; Bouranis et al. 1995). This could be a core advantage in highly aerated soils like those found in Tarawera Forest. The substrate at this site is predominantly pumice, which is cultivated into mounds prior to or during planting, allowing the seedlings to be deposited above the frost zone and competing vegetation. However, the mounds are more exposed to air or water erosion which could be detrimental to early survival following high wind or rain events.

Fertilisers

The M-planter can apply both spray and granular nutrients directly to each plant. Currently, 15 grams of Osmocote(R) is applied per seedling, which is equivalent to about 50 kg ha^{-1} of product. Industry feedback has suggested that nutrients are typically non-limiting on cutover sites. Although, there are some long-term advantages of phosphorus applications, nitrogen applications are potentially advantageous when phosphorus is already abundant. Remedial fertiliser applications prior to and during establishment are the best times to get sustainable nutrient supplies in and around the roots and make efficient changes to the soil conditions, such as acidity.

Some hydrogels become less effective when mixed with fertiliser because the cations block the wetting and drying ability of the bonds that make the hydrogel. This is expected to be less of an issue with nanocellulose hydrogels.

Anecdotal observations, reported by Timberlands' site preparation contractor (H.A. Fear Ltd), suggest that Osmocote applied mechanically has a greater impact on plant growth than hand applications by planting crews. Mechanical fertiliser application will be used in this trial across all the treatments.

Growth stimulants and other products

A key opportunity for stimulants or other less conventional products (e.g. microbial inoculum), to assist establishment in low moisture conditions, is through the enhancement of stress tolerance. Pathways to this outcome include manipulating nitrogen availability to induce changes in the activity of the soil microbial community, conferring greater drought tolerance in radiata pine in glasshouse trials (Smaill and Addison 2017) and the direct application of products (e.g. aminoethoxyvinylglycine) to reduce the negative impact of *in planta* ethylene production on new tissue production under moisture stress (Zhou et al. 2018). However, these studies were based on assessing plants initially grown with adequate moisture that were then exposed to drought conditions, as opposed to stock that was planted into dry conditions. A glasshouse study under these conditions (i.e. planting stock directly into dry media and restricting water from time zero) is recommended prior to testing at field scales.

Numerous products that purport to reduce foliar moisture loss are currently commercially available, but little peer-reviewed information is available to support claims of efficacy, and none with direct relevance to coniferous tree species. Glasshouse studies to identify suitable products and rates of application are a necessary step prior to any field testing.

Results of recent experiments and field trials.

A recent unpublished study (Coker et al. 2021) identified new and slightly modified techniques that further enhanced crop survival and productivity for extended planting seasons. These improvements are based on 1) sampling of foliage nutrients for predicting nutrient limitations in supplied seedlings, 2) the application of a new nano-cellulose hydrogel with a wide range of potential benefits as a root-dip, and 3) application of a spray at planting to reduce water stress or protect from pathogens. The study highlighted the general need and benefits of more regular and wider assessment of foliage nutrients of planting material for improved survival and growth outcomes of delayed plantings. The study also found good evidence to support the use of the specific hydrogel with combined gains of survival and growth amounting to total growth benefits of up to 40%, as trees need to survive before growth is possible. The hydrogel tested increased the moisture adhesion to bare roots at planting and theoretically reduced the moisture stress of planting shock, resulting in an increased crop survival of approximately 13% based on actual field conditions.

Also, by potentially addressing some of the seedlings micronutrient limitations, the hydrogel-based treatment containing additional micronutrients increased growth by approximately 16%. These options require further development before the operational costs and benefits of modified techniques can be fully operationalised for establishment at high-risk sites.

A more recent industry-based hydrogel study (*un-published*) confirmed some survival benefits from hydrogel use, particularly for the higher risk sites. In the 150-plant comparison, across 5 locations within a new green-field estate, trees treated with hydrogel showed 20% improvement in survival on average, especially across the hardest sites.

Much earlier work, including an extensive unpublished trial was undertaken in the Forest Research nursery (Menzies and Bond 1984). Three species were lifted and dipped with Austrasorb and Aquacel hydrogels, then stored in cartons for up to four weeks in a cool store. The water potential of radiata pine, *Eucalyptus regnans* and *Eucalyptus saligna* was then determined along with plant health, survival and height growth.

Results indicated limited hydrogel benefits based on the test site (Longmile Road) and responses. The water stress at planting tended to be less for radiata pine, by 21-38% in the hydrogel treatments, compared with dipping in water alone, but because of the limited sample (10 plants per treatment), this was not determined as significant. Interestingly, the hydrogel tended to be associated with a slightly reduced height increment for *P. radiata* and *E. regnans*, suggesting the hydrogels may have influenced plant allocation when significantly water stressed, such as the four weeks of cool storing. The sensitivity of the assessments would have been improved by incorporating both height and diameter as a relative volume index increment.

It is known generally that plants are not easily pre-conditioned in the nursery to water stress (Varone et al. 2012). The potential mechanisms include osmotic adjustment using salts or fertilisers with high salt loadings, root and leaf mass manipulation (root trimming or stem topping) or increased photosynthetic capacity through nutritional optimisation.

This work hypothesises that increasing the volume of the water-containing hydrogel around the planted tree root zone provides a reservoir that will sustain plant survival under conditions of low soil moisture.

Materials and methods

Trial site selection

The site selected for this trial was in Tarawera Forest (-38°08'38.28" S, 176°34'21.64" E). 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. They have high macro porosity and, therefore, water retention is expected to be low particularly near the soil surface. These factors made it a good choice for this establishment work.

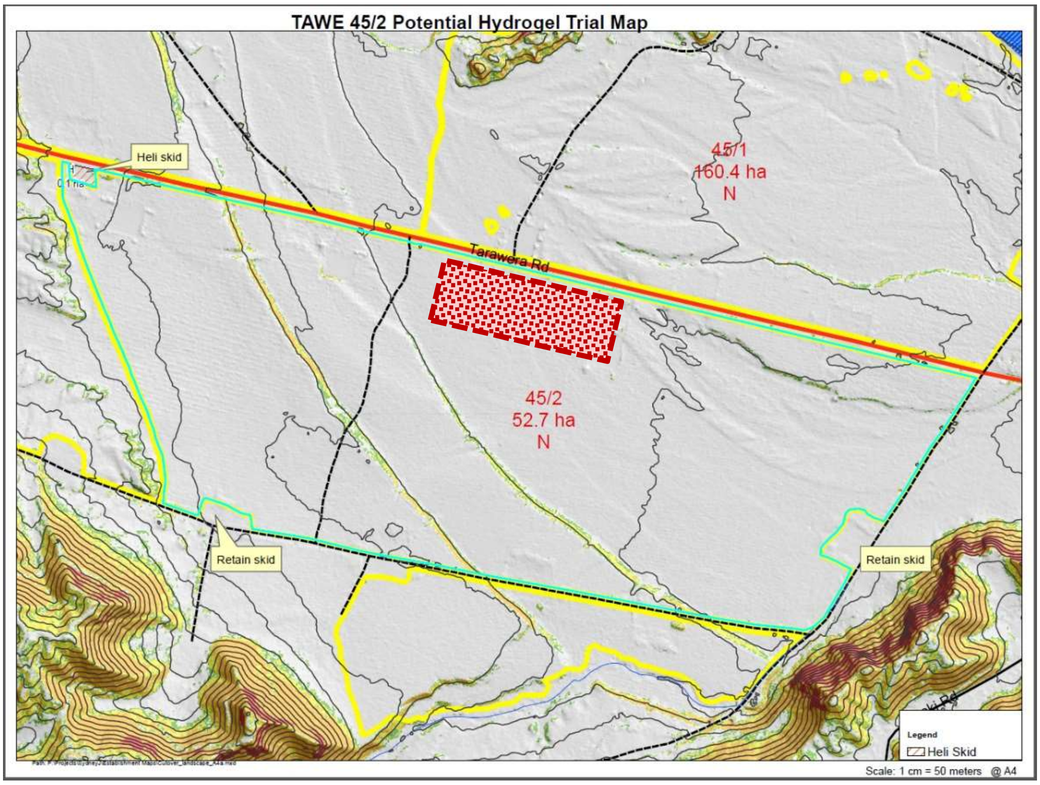

Figure 1: Map of trial site location and approximate size of trial.

Trial design

The trial was designed as a randomised complete block (RCB) design consisting of 4 hydrogel treatments (Table 1; Figure 2), with 6 replications and 48 tree plots (3 x 16 rectangular plots). A total of 1152 trees were included in this trial. Analysis of data collected on survival and growth from this trial will be completed in R, using a one-way ANOVA.

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

Treatment		Water volume per plant (mL)	Hydrogel 'concentrate' per plant (mL)	Trees	Total Water (L)	Total Hydrogel concentrate (L)
a	**Zero hydrogel, Zero water** (negative control) – dry plant.	0	0	288	0	0
b	**Surface application – Hydrogel** – 500 mL hydrogel solution per plant.	417	83	288	120	24
c	**Water treatment** – 500 mL water per plant.	500	0	288	144	0
d	**Root zone application – Hydrogel** - 500 mL hydrogel solution per plant.	417	83	288	120	24
				1152	**384**	**48**

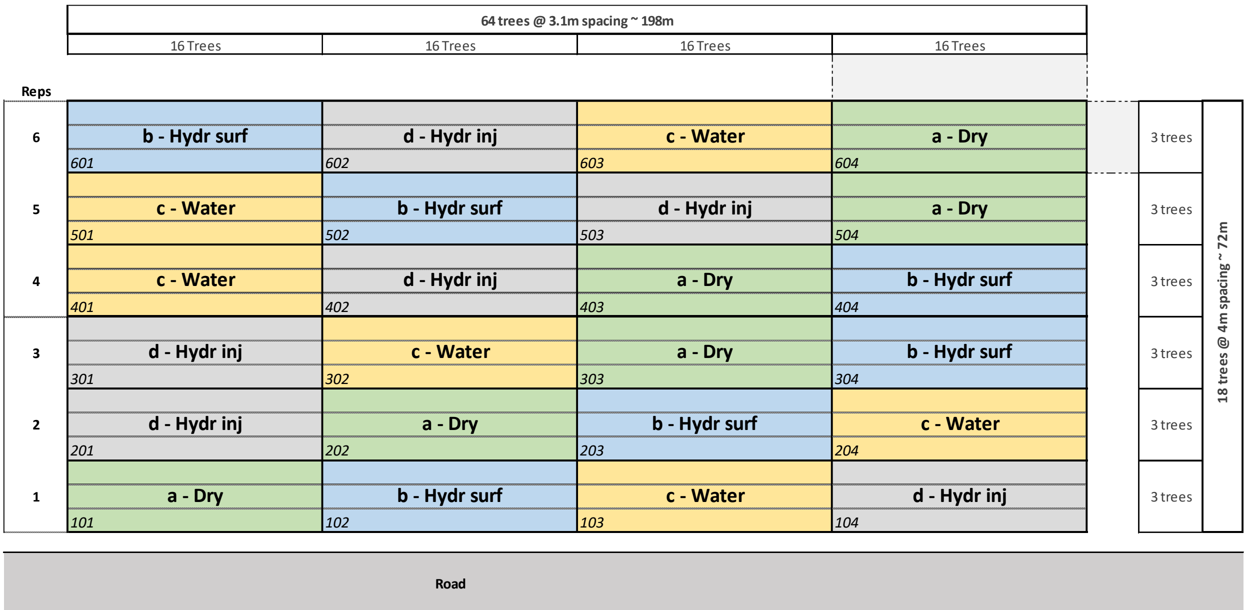

Figure 2: Planned trial plot layout for the four hydrogel treatments and six replications, used for establishment on 31 March 2022.

Plant material

The planting stock was from control pollinated *P. radiata seed*, sown during autumn 2021 (10-11 months old) into 125cc forestry trays (Transplant System 48). Plug integrity was high, allowing the root system to remain intact through the M-planter (but not so high as to be considered root bound). The media was a coir, peat, bark fines and pumice mix." Plants were maintained as per standard practices and topped four weeks prior to lifting at the end of March 2022. The material was watered daily and so pre-conditioned to moist conditions. The roots were not bound but tight in the trays. A subsample of seedlings had their root collar diameter and heights measured. The mean root collar diameter was 3.93 mm +/- 0.02 SE (n = 168) and the average (topped) height was 31.1 cm +/- 0.07 SE (n = 1180).

Table 2: Summary of the average plant heights of treatments, measured in the nursery, for the trial planting.

	Replication								
	1	2	3	4	5	6	Average	p	se
Dry plant	31.0	31.0	31.4	31.0	30.2	31.0	31.0	0.389	0.28 cm
Injected hydrogel	32.1	30.3	31.1	31.2	30.8	31.0	31.2		
Surface hydrogel	32.2	31.0	30.5	31.3	30.4	31.3	31.1		
Water	32.2	31.1	31.9	29.8	30.8	31.3	31.4		
Average	**31.9**	**30.9**	**31.3**	**30.9**	**30.6**	**31.1**	**31.1**		
p	**< 0.001**								
SE	**0.18 cm**								

Table 3: Summary of the average plant root collar diameters of treatments, measured in the nursery, for the trial planting.

	Replication								
	1	2	3	4	5	6	Average	p	se
Dry plant	4.21	4.01	4.25	3.86	3.77	3.86	3.99	0.002	0.003 mm
Injected hydrogel	3.61	3.95	4.06	3.91	3.92	3.98	3.90		
Surface hydrogel	3.81	3.80	3.91	3.88	3.78	3.84	3.84		
Water	3.98	3.96	4.14	3.78	4.00	4.03	3.98		
Average	**3.91**	**3.93**	**4.08**	**3.85**	**3.87**	**3.92**	**3.93**		
p	**0.006**								
SE	**0.05 mm**								

Figure 3: *Pinus radiata* seedlings topped, labelled, measured and ready for dispatch to the field site. Seedlings were labelled close to the root collar to ensure they remained attached while planting. Since seeing the machine in operation (with a consistent planting depth of 5-6 cm), labels attached 10-15 cm above the root collar should be adequately secure for future trials.

Hydrogel application method

In previous trials with the M-planter it wasn't possible to see when the application was missed, and this confounded results. Consistency and the large hydrated "cells" of the product caused blockages, it was found to be too viscous and the nozzle too small. The volume of hydrated hydrogel per plant selected for testing in this new trial was increased from 150 to 500 mL. Further considerations on the application of greater volumes of sprayed material within limited time frames of the automated planting was required. The primary concern was the effects of application pressure on plant material. In light of discussions around hydrogel viscosity and volume delivery, the dosing unit on the mechanised planter was improved by using a larger cylinder and piston installation.

The hydrogel was a nano-cellulose product developed from seaweed by Scion (*patent pending*), which was diluted at 1:5 (hydrogel solution:water). After dilution, 10 rounds of hydrogel were applied through the planter to check consistency. During the trial, random samples were taken to confirm delivery volumes of the hydrogel. The combination of larger delivery mechanism and well hydrated hydrogel ensured a suitably uniform delivery of the required 500 mL per plant.

Figure 4: The jet of liquid indicates the testing of the suitability of the hydrogel's viscosity for the trial.

Results and discussion

Trial establishment report

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Marking out of the field site was undertaken on the on the 16th of March, this was delayed by the large piles of slash which impeded theview of reference poles. The entire trial was physically pegged in 5 hours. Each peg was geotagged using the Arrowgold GPS receiver and GIS software (Figure 6). The soil is predominantly pumice from the Tarawera eruption which is highly permeable with low water retention, resulting in a very dry site amplified by its high exposure to sunlight and wind. Leading up to the establishment of the trial, there had been very little rain in Tarawera Forest, and soil moisture was extremely low. However, in the week following marking out the trial, the site received approximately 168 mm of rain (Figure 5). As a result, it was decided to delay planting of the trial by 1 week to give the soil the opportunity to dry out.

Figure 4: TAWE45-2 trial site as of the time of pegging. Ground surface was slightly undulating with occasional piles of slash reaching 2 metres tall and up to 8 metre wide. Stumps were consistently present across the whole site.

Planting commenced on Thursday March 31st. A short demonstration was provided by Henry Fear (contractor) and his team to show the mechanical planter (M-Planter) in operation (Figure 7), and how the machine applied the three liquid treatments. Field crew mixed120 L of hydrogel solution (hydrogel water 1:5) and shot 10 rounds through the planting implement to ensure it was sufficiently mixed ahead of planting (Figure 4). A sample of this mix was collected and compared to the consistency in the tank. The sample was also poured on top of an empty mound and the puddle remained for significantly longer than a pure water comparison, indicating the hydrogel was effective for at least short-term water retention. A cross section was dug out of a hydrogel injected mound and a good dispersion of hydrogel and Osmocote fertiliser was observed (Figure 8). It was decided that no further modifications to the machinery was required before trial planting.

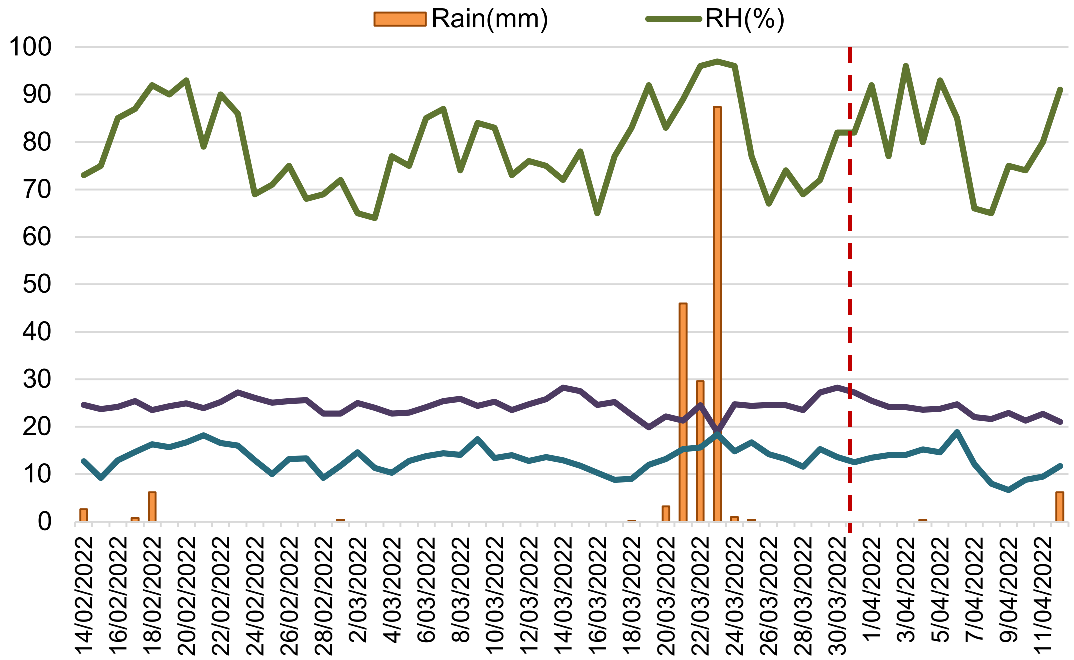

Figure 5: Weather conditions recorded at Tarawera forests closest NIWA weather station; Whakatane Airport (station 40982).

Figure 6: GPS points showing actual location of block corner markers. Planting began at block 1 which is shown as the top right point.

Previous concerns around the interference of large slash mounds were immediately dispelled after seeing the M-Planter in operation (Figure 9). The boom could clear the way ahead of planting very effectively, piling it up along the sides between reps.

The contractor, Henry Fear, noted the seedling stock was of exceptional quality for mechanical planting (Figure 7). The root plugs were sufficiently consolidated to remain intact through the implement but were not root bound.

Figure 7: Representative sample of showing seedling quality, particularly good root collar diameters and uniformity in size.

Seedling spacing was satisfactory while treatment applications were consistently good (Figure 8). The carousel was filled with 50 trees at the start of each block to reduce the risk of carrying on planting into the next block. Adjusting treatments between the blocks was complex and slowed the operation (compared to a standard commercial planting). There was one air blockage in the water feeding line which resulted in a 30-minute delay. The blockage was cleared by stretching the boom out and upwards, allowing the air pocket to rise to the top of the line and be spouted out. Interestingly, the hydrogel mix didn't have the same air blockage issues.

Figure 8: Left shows pre-trial planting demonstration. A cross section of the mound was removed to check hydrogel, water and fertiliser dispersion and the depth of planting was up to standard, requiring no amendments to the machinery. Right shows the planter while operating.

Figure 9: The mechanical planter moving piles of slash.

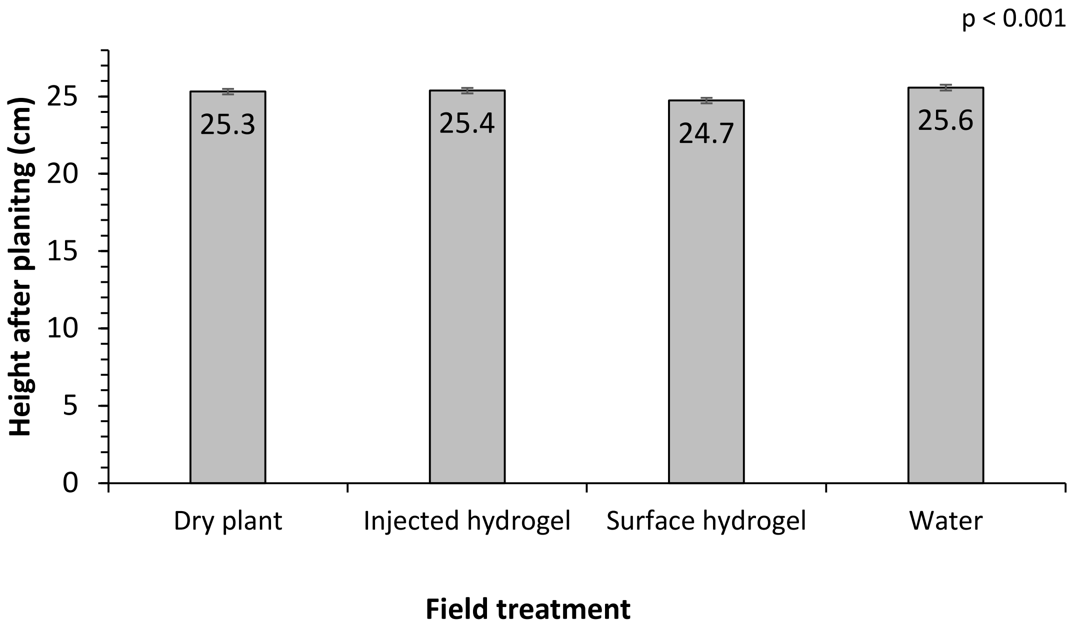

Figure10: Summary of final, in-field, tree height measurements for treatments (Error bars represent standard error of means).

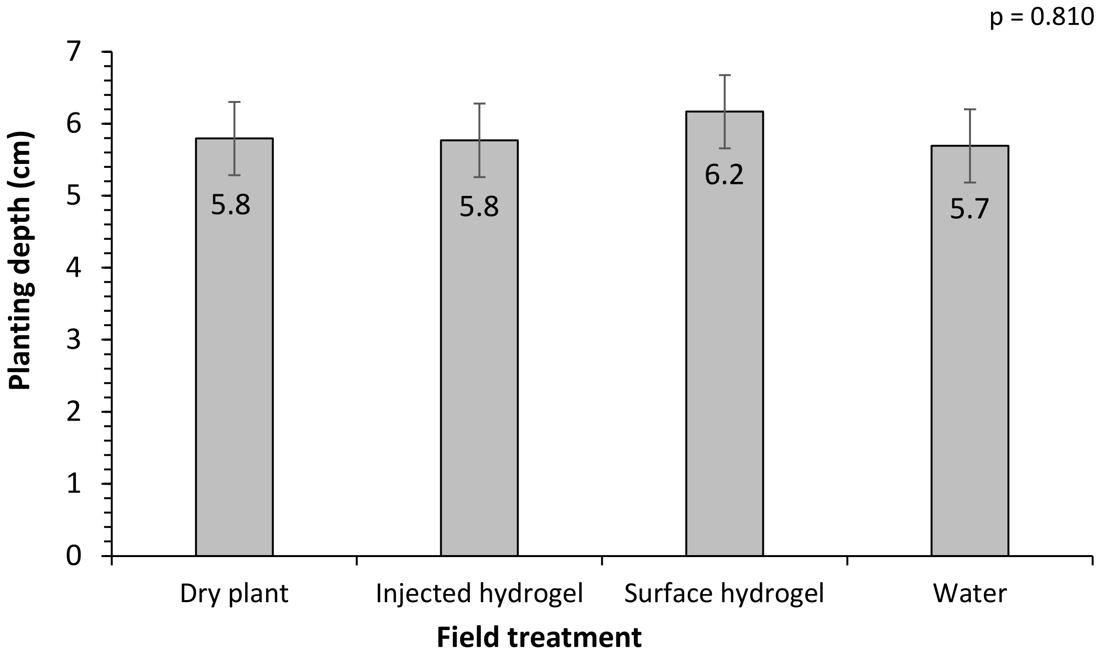

Figure11: Summary of tree planting depth for treatments (Error bars represent standard error of means).

Trial planting commentary

General observations

The planting contractors expressed a very keen interest in developing their skills on the mechanical planter. They see great opportunity for this technology to help overcome labour shortages, having worked in the industry as hand-planters for several years prior.

Successes

The mechanical planter was consistent and precise when applying the treatments and was also very capable of manoeuvring through the trial site and clearing a path through the slash. The mounds had well cultivated soil, and seedlings were deposited well above any competing vegetation.

The hydrogel solution provided by the team at Scion was perfect for the applicator. The hydrogel mixed very well on-site and didn't separate throughout the day. The ratio used for this trial (5:1) was easy to achieve by mixing one 20 L bucket of hydrogel with five 20 L buckets of water.

The plant-stock provided by Te Ngae nursery was of exceptional quality, with heights topped to ~30cm and an average root-collar diameter of approximately 4 mm. For future planting in late summer, sourcing stock of similar quality, which may also need to be sown in autumn the previous year, should help confer maximum survival.

Failures

The air blockage in the water line proved a low severity issue in this trial, which was easily overcome. Kane Fleet and the planting contractors were able to troubleshoot this issue fairing quickly, so trial implementation was only slightly delayed. However, understanding how this occurs and can be prevented ahead of its use at a commercial scale will be advantageous to the technology's uptake.

Finding the identification tags was difficult after planting. Initially, we tagged the seedlings close to the root collar so that they would hold up through the planting carousel. However, this meant the tags were occasionally buried below the mound surface. We had to find the tags without causing too much disruption to the surrounding soil and risk confounding the results of the different treatments. For future trials, as the technology currently stands, it is recommended that seedlings be labelled 10-15 cm above the root collar (to avoid burying) and only 2-3% tag-failure should be expected.

Due to unexpected delays, Kane Fleet and Alex Lloyd were unable to complete mapping by Friday April 1st. When Kane Fleet and Peter Bird returned on April 13^{th} to resume mapping, they found the top layer of soil had hardened and the soil couldn't be broken to expose the labels easily. A third attempt at finalising the map was due in the week of Tuesday the April 19th. Despite the set-back, this issue demonstrates the hydrogels efficacy at binding around the plug and slowing evaporation.

Future opportunities or changes

This hydrogel has not only demonstrated its ability to bind around the plug but has a great opportunity for inoculating mounds with beneficial microbes, particularly symbiotic mycorrhizae fungi. This is a future opportunity worth exploring.

The trial will be assessed again over the upcoming months to quantify survival. There is the opportunity to use automated seedling detection methods (based on deep learning) to map the location of individual trees and to not only determine whether there are differences in survival among treatments but also whether there are any spatial patterns associated with mortality.

Acknowledgements

We would like 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 trial establishment to take place. 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.

References

1. Azzam, R. A. I. (1980). Agricultural polymers polyacrylamide preparation, application and prospects in soil conditioning. *Communications in Soil Science and Plant Analysis*, *11*(8), 767–834. doi:10.1080/00103628009367081
2. Bouranis, D. L., Theodoropoulos, A. G., & Drossopoulos, J. B. (1995). Designing synthetic polymers as soil conditioners. *Communications in Soil Science and Plant Analysis*, *26*(9–10), 1455–1480. doi:10.1080/00103629509369384
3. Coker, G., Xue, J., Leckie, A., Henley, D., Glogoski, D., Dickson, G., et al. (2021). Managing delays in planting – the use of hydrogels. *One billion trees programme Covid-19 planting response*, *TUR_1BT_*(2021_096), 23.
4. Crous, J. W. (2017). Use of hydrogels in the planting of industrial wood plantations. *Southern Forests*, *79*(3), 197–213. doi:10.2989/20702620.2016.1221698
5. Fan, T., Stewart, B. A., Payne, W. A., Yong, W., Luo, J., & Gao, Y. (2005). Long-Term Fertilizer and Water Availability Effects on Cereal Yield and Soil Chemical Properties in Northwest China. *Soil Science Society of America Journal*, *69*(3), 842–855. doi:10.2136/sssaj2004.0150
6. Menzies, M., & Bond, S. (1984). Evaluation of Austrasorb and Aquacel as root dips to aid transplanting of bare-root seedlings. *Forest Research Institute Project record*, (Project Record 1462), 26.
7. Smaill, A. S., & Addison, S. (2017). Management options to increase radiata stress tolerance – progress to date. *FGR Technote*, *GCFF-TN019*(September).
8. Varone, L., Ribas-Carbo, M., Cardona, C., Gallé, A., Medrano, H., Gratani, L., & Flexas, J. (2012). Stomatal and non-stomatal limitations to photosynthesis in seedlings and saplings of Mediterranean species pre-conditioned and aged in nurseries: Different response to water stress. *Environmental and Experimental Botany*, *75*, 235–247. doi:10.1016/j.envexpbot.2011.07.007
9. Zhou, X., Xu, C. Y., Bai, S. H., Xu, Z., Smaill, S. J., Clinton, P. W., & Chen, C. (2018). Technical note: Manipulating interactions between plant stress responses and soil methane oxidation rates. *Biogeosciences*, *15*(13), 4125–4129. doi:10.5194/bg-15-4125-2018

Appendix A

FGR project deliverables

1. **Literature review and technology scan.**
   Undertake a literature review and technology scan to identify potential hydrogels, fertilisers and growth stimulant products, recommended application rates and the availability of products for trial application in March 2022.

2. **Review the results of recent experiments and field trials.**
   Review the results of recent experiments and field trials, identify any shortcomings in experimental design and record lessons learned from these earlier trials for use in future trials.

3. **Identify potential trial sites and develop an experimental design.** Identify potential trial sites and develop an experimental design to ensure the trial is scientifically robust. Experimental design to include any site environmental monitoring requirements.

4. **Refine system for delivering hydrogels.**
   Assess and refine system for delivering hydrogels on the mechanised planting machine, including any modifications to the delivery system and undertake calibration tests prior to trial establishment.

5. **Establish field trial.** Establish field trial by 25th March 2022.

6. **Establishment report on the planting trial**
   Prepare an establishment report on the planting trial by 31 March 2022**.**