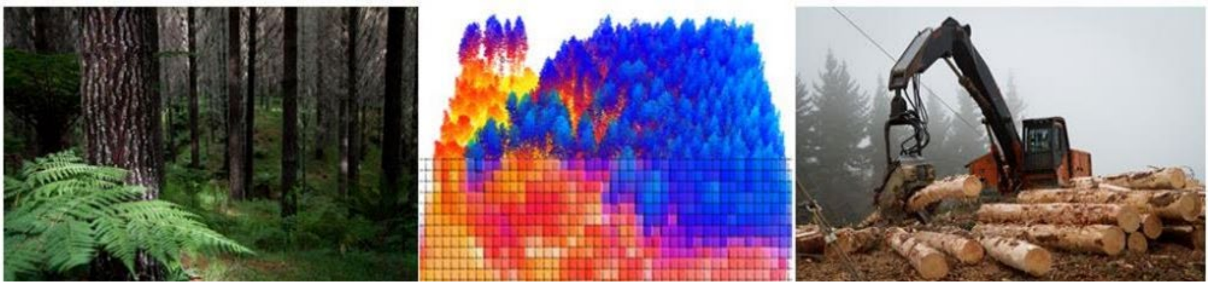
Precision Silviculture Programme

A review of the performance of the M-Planter in New Zealand

Karen Bayne[1], Julio Botero[1], Richard Parker[1], Mike Baker[2], Ben Dixon[3], Rob Schoonderwoerd[4] and Carol Rolando[1]

[1] Scion, New Zealand Forest Research Ltd., Rotorua/Christchurch
[2] Manulife Forest Management (NZ) Ltd, Rotorua, New Zealand
[3] Timberlands Ltd, Rotorua, New Zealand
[4] Rayonier Matariki Forests, Tauranga



Date: September 2023

Report No: PSP-T008

Funded by:

Ministry for Primary Industries
Manatū Ahu Matua

supported by forestgrowers commodity levy

TABLE OF CONTENTS

Funded by:

Ministry for Primary Industries
Manatū Ahu Matua

supported by forestgrowers commodity levy

Precision Silviculture Programme

EXECUTIVE SUMMARY

Anticipated changes in workforce labour availability, coupled with increased competition for planting crews due to afforestation incentives have led several forestry companies in New Zealand to investigate mechanised planting options.

This report outlines qualitatively and quantitatively an assessment on the performance of the M-Planter planting radiata pine seedlings into New Zealand rotational cutover areas. Due to site factors (e.g. soil type, frost risk, compaction on skid sites) some planting sites also require initial land preparation in the form of line raking, ripping or spot mounding prior to planting. Forestry companies see potential benefit in combining land preparation and planting activities through mechanisation with an excavator-based planting head.

Our assessment of the M-Planter was informed through international reports, interviews with the forest companies, and data provided to us by these companies from observations and learnings made while using the M-Planter.

Our interviews with forest companies testing the machine over several seasons indicated that the M-Planter requires considerable modifications of the manufactured machine to meet New Zealand cutover conditions, particularly in tools to assist in concurrent land preparation, and seedling delivery systems. The biggest learning from the first planting season was the need to get one thing at a time working, then try to add the next operation, and so on.

Trials have been undertaken to date on several soil types, indicating the M-Planter requires calibration for different soils in order to plant effectively across sites. The condition of containerised planting stock (e.g. plug integrity, seedling size), the time spent in the carousel system and the weather at the time of planting all impact the planting outcome, in terms of rejection rate due to incorrectly planted seedlings. These factors can also impact the likelihood of jams in the planting shute.

The M-Planter is best suited to planting in adjacent blocks due to the high cost in transporting the excavator and machine head between planting locations.

In terms of economics, when evaluating only the planting function (i.e. not including land prep costs), manual planting costs around $528 per hectare, while using M-Planters for planting only costs approximately $1,214 per hectare. The M-Planter begins to show its potential to compare with manual planting when it's tasked with land preparation alongside planting. However, it's critical to highlight that this multitasking approach slows down the planting operation.

A sensitivity analysis revealed that maximizing the M-Planter's productivity to 1,100 trees per day would achieve the lowest cost, settling at approximately $1,149 per hectare. Pushing its productivity further to 1,200 trees per day, however, would not be recommended due to escalating rejection rates and the subsequent costs of replanting. This was verified in the New Zealand trials, where pushing the M-Planter to 1400 trees per day saw a 25% rejection rate in planting quality. It is important to note that under the current planting and economic conditions, the M-Planter cannot match the cost of a manual planter.

Combining the M-Planter mechanisation with manual planting could help to alleviate some of the current labour pressure and long-term health impacts on the manual workforce. To plant an area of 1000 hectares using 10 manual planters and 2 M-Planters working for 100 days results in a total cost of $1,052 per hectare, by utilising M-Planters to reduce time and effort for land preparation. Another option is to utilise an M-Planter year-round (230 days) which would then allow the same level of planting, but for a reduced crew size (6 people) actively working for 100 days, with the 2 M-Planters operating across 230 days. This model projects the planting costs to $1,097 per hectare.

We make recommendations for improvements to the M-Planter that could increase its operational efficiency, which include, among others, improvements to the seedling planting tube, planting feet and operator visualisation of the terrain into which the M-Planter is planting.

INTRODUCTION

Background

New Zealand's (NZ) exotic plantation forestry sector started in the 1920's with a core purpose "to support New Zealand's domestic need for wood products", and in doing so, prevent ongoing unsustainable rates of native deforestation. One hundred years on, exotic plantation forestry remains an essential part of New Zealand's domestic economy. It provides critical supply to sectors such as construction and pulp and paper and has the highest domestic consumption of any primary sector[1]. Ninety percent of our pruned logs are consumed domestically. In addition to the domestic market, forestry exports are the fourth largest within the primary sector at $5.9Bn per annum (2020). Nearly 50% ($2.8Bn) of exports are from processed wood products, with the remaining $3.1Bn coming from log exports (NZFOA, 21/22).

Silviculture is broadly described as the practice of controlling the composition, structure, growth and quality of a forest. Silviculture is an essential part of managing and creating value from New Zealand's plantation forests yet has remained highly manual and relatively unchanged for nearly seventy years (Baker, 2018). Advancements in silviculture to enhance precision/modernisation are urgently needed yet the high cost and risky nature of investing in unproven approaches further constrain the development and adoption of new technology in New Zealand. Few single company's 'will go it alone' and invest in the research and development required to de-risk investment in automation and mechanisation solutions. As such, testing unproven solutions requires collaboration across companies, forest owners, forest contractors, engineering and agritech companies and, if successful, will provide benefits to multiple players in the industry.

The Precision Silviculture Programme was funded (by Government and industry) to transform forest management through innovative adaptation of technology for silvicultural activities in the forestry value chain. By bringing together expertise in engineering, precision technologies, innovation, and forestry, the Programme aims to provide a cohesive and collaborative vehicle to enhance knowledge transfer across New Zealands' forest industry as the industry looks to address labour challenges and automate. By providing a platform to test and modify new technologies to suit the NZ forestry environment the programme addresses the research and development investment constraints that are preventing modernisation of the silvicultural value chain.

The focus of the Precision Silviculture Programme is on radiata pine plantation forestry with five workstreams (Nursery, Planting, Pruning, Thinning and Digital/Data) defining the focus of activities within the programme. The aim of the Planting and Establishment workstream is to reduce establishment costs and increase forest value by taking advantage of opportunities offered by a multitude of new technologies to mechanise and/or improve the precision of the planting operation.

Purpose of this study

Quantifying the performance of internationally developed mechanised tree planting systems in the New Zealand environment and finding solutions to optimise their performance for New Zealand forestry is a crucial element of the Planting Workstream. Understanding the (economic/environmental/biological) performance of internationally developed mechanized planting systems will create a critical stop/go decision for the Programme on the ability to viably adapt these technologies to the New Zealand situation. If they are not suitable or bridging the economic gap is deemed too great, then either this work will be abandoned, or the feasibility of developing a fully bespoke "New Zealand-designed" system will be explored.

As of 2018, planting operations in New Zealand were carried out using 100% manual labour with hand tools (planting spades) (Baker, 2018). Around the same time, Timberlands Ltd, imported a M-Planter (planting head mounted on an excavator boom) from Finland to trial in Kaingaroa forest, the first step in recent times to re-examine the potential of mechanisation of the planting operation in New Zealand. Subsequently, MFM (NZ), along with Rayonier Matariki Forests, have also trialled the M-Planter. More recently, Pan Pac Forest Products Ltd has undertaken to import and trial the recently developed Swedish Plantma-X which could be a game changer for mechanised planting in New Zealand. The first trials with the Plantma-X commenced in July 2023.

---

[1] Approximately 40% or 13M m^3 of wood

As these machines, particularly the Plantma-X, are being tested in New Zealand for the first time, there is an opportunity to undertake an analysis to benchmark their performance (work-rate/productivity/cost) to date. In addition, quantifying the productivity required for them to compare favourably (in terms of efficiency and cost) with current manual planting systems will provide an economic benchmark for industry to consider, i.e. understand the economic conditions required for mechanisation to be adopted within the New Zealand plantation forest industry.

The purpose of this study was to specifically:

- Examine literature on M-Planter and highlight key findings of others evaluating this platform. What can we learn?
- Synthesise through interview existing knowledge from MFM (NZ), Rayonier and Timberlands on performance of the M-Planter to date and collate/analyse any trial data relevant to performance of this platform in New Zealand.
- Compare (economic) performance of M-Planter with manual planting and use sensitivity analysis to determine system requirements to overcome economic gaps of mechanical planting systems, notably for M-Planter.

The scope of this reports relates specifically to the previous experiences of New Zealand forestry companies trialling mechanised planting heads, in particular the M-Planter 160 model head attachment on an excavator.

LITERATURE REVIEW

Mechanisation of the planting operation

Tree planting is the practice of placing a plant in a suitable spot in the ground and covering the roots with soil, ensuring the tree is upright and firm. Globally, most planting activities are still manually performed with the exception of soil preparation which has been mechanised since the mid-to-late 1900s in most countries (Ramantswana, 2020). Across the forest industry, mechanisation initiatives for the planting operation have been driven by: labour shortages; pressure to reduce human exposure to pesticides; the need to improve the health and safety profile of forest operations and skill of forestry labour and the need to increase productivity of forest operations (Ramantswana, 2020; Baker, 2018; Ersson et al., 2018). Mechanisation of regeneration has lagged behind that of harvesting, however, the last two decades has seen a slow emergence of modern technologies, such as use of excavator-based planting machines, particularly in Scandinavia, the Baltic States and Brazil (Ramantswana, 2020; Errson et al., 2018).

Multiple reviews, nationally and internationally, on the history and status of technologies available for mechanisation of the planting operation have been conducted (Petro, 2022; Bayne and Parker, 2021; Baker, 2018; Ramantswana, 2020). Many of these studies highlight that successful adoption at scale of mechanised planting platforms has not yet occurred despite much effort over the last 20 years to increase their performance. This despite evidence that machine planted seedlings perform as well as those manually planted (Laine et al., 2016). Some of the factors constraining the adoption of mechanised planting technologies have been identified as: **poor contractor profitability** due to the high cost and low cost-competitiveness compared to manual tree planting (Ersson et al., 2018; Lazdina et al., 2019); **low productivity**, originating from operator inexperience, terrain type (slope, stones, slash and stumps) and seedling supply logistics (Ersson et al., 2022); and **worksite distribution**, where time spent relocating machines between sites compounds operating costs (Laine et al., 2016). Due to the high fixed costs of the mechanised planting platforms, **machine utilization** has a strong impact on contractor profitability and this is often comparatively low for planting machines (Errson et al., 2018). In 2013, productivity of mechanised planting in Finland for planting booms mounted on excavators (Brache, M-Planters and Risutecs) was estimated at 1614 seedlings per work-day assuming a 5-day work week.

Some of the factors highlighted to increase productivity of mechanised planting platforms have included: **operator training**; simultaneous **implementation of two or more operations by the same machine**, i.e., site preparation, planting, weeding and/or fertilisation; adequate utilization of the annual capacity available for planting (planting over a longer period of time and using 2x 8-hr shifts per day) or **continuous operation**; good **operations planning/logistics** for factors such as seedling supply (and working closely with nurseries), distance to the seedling stockpile, machine relocation/route planning and residue management (Laine et al., 2016; Errson et al., 2018) (see Figure 1). The collection of slash and stumps for energy purposes has the potential to make regeneration sites more suitable for mechanised planting (Hallongren et al., 2014). Even after mechanised planting has been in operation for more than 10 years in Scandinavia, Errson et al. (2018) identified that present day seedling production and delivery methods were not suitable for mechanised platforms and that there was a need for development of machine specific packaging systems. In a survey of the Finnish mechanised tree planting system, it was noted that better integration of the entire regeneration chain from nursery to out-planting would improve productivity of mechanised planting platforms (Laine et al., 2016).

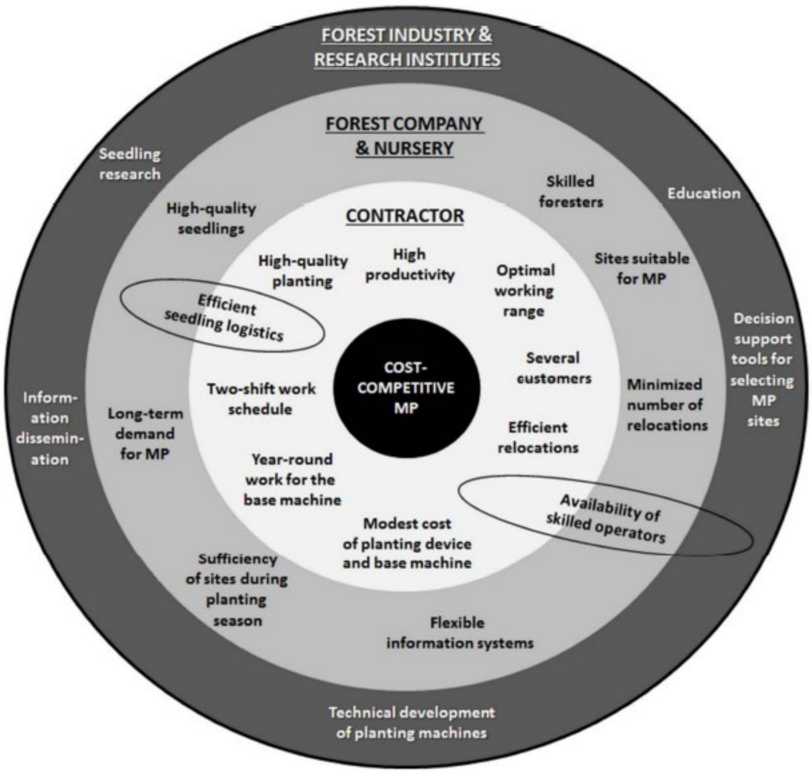


Figure 1 (From Ersson et al., 2018): A conceptual framework showing the factors leading to cost-competitive mechanised tree planting (MP) in both Sweden and Finland. The factors in the outer darker ring are those chiefly shaped by forest industry as a whole and by research institutes. The factors in the middle grey ring are those influenced by the forest company and the nursery supplying the seedlings. The factors in the inner white ring are those mainly affected by the planting machine contractor. The two encircled factors are influenced by two or three actors (contractor plus nursery, and contractor, forest company plus whole forest industry, respectively).

A brief review of the status of knowledge on the performance of the two mechanised planting platforms currently in New Zealand, the M-Planter (now three in New Zealand) and Plantma-X, follows.

The M-Planter

Introduced in 2006, the Finnish M-Planter consists of a planting head attached to the tip of a hydraulic boom mounted on an excavator and carries out both soil scarification and tree planting. Two parallel mounting blades invert soil, including humus and mineral soil, on undisturbed soil (spot mounding), after which a seedling is planted in the middle of each mound. Seedlings are manually loaded and stored in seedling cassettes (capacity ranging from 120 to 320 seedlings) placed on-top of the device. M-Planter models (M-120, M-160, M-160R, M-160M, M240 and M320) include one-headed or two headed planters with the ability to customise machines to create a mound, rip, plant, fertilize and water seedlings at planting. All platforms require containerised seedlings to be manually loaded into the planting cassettes. The performance and productivity of the M-Planter has been mainly evaluated in Scandinavia and the Baltic states and while the productivity of this machine in these regions may not be directly relevant to the New Zealand situation, it is the only published literature available to reflect on the learnings already available on this platform.

Rantala et al. (2009) evaluated the productivity of one of the first M-Planters, an M-160. Their study showed that 96% of the seedlings in the cassette were successfully planted (however the study does not include an evaluation of subsequent tree performance). “Mounding and planting” comprised 47% of the effective working time, with the average time to fill the seedling cassette estimated at 14% of the effective working time (estimate of 6 minutes to refill the carousel). Measured mean productivity of the M-Planter was 240 seedlings hr^{-1} (range from 144-351), with stoniness and number of stumps, as well as fine and/or wet soil found to reduce productivity of planting (Table 1). Percentage slash cover was found to have no significant effect on planting productivity. Fixed costs of the base machine were found to be more than 20% of the total costs of the planting work effectively meaning operators found it very difficult to make mechanised planting competitive with manual planting without finding year-round work for the base machine (Rantala et al., 2009). The study indicated that doubling the capacity of seedling cassettes or cutting the time of filling seedling cassettes into half would decrease the unit cost of the device by up to 5%. Rantala et al. (2009) acknowledged that sensor technology could offer suitable solutions for recognising appropriate planting places within the planting sites.

This initial study was followed up by a second study by Rantala and Laine (2010) to further investigate factors affecting the efficiency of the M-Planter through evaluation of several operators working across five areas where machines were already in operational use. This study found that on average 67% and 12.5 % of total machine working time was spent on primary planting work and filling the seedling cassettes with mean productivities for the units across the five areas over two years (2008/2009) estimated at 158 seedlings hr^{-1} (Table 1). High variability was observed between operators with lowest operator planting at 75 seedlings hr^{-1} versus most productive operator planting at 201 seedlings hr^{-1}. Operators with no previous experience working with an excavator or harvester showed significantly lower productivity than others. Increased stoniness, higher density of stumps and a thick humus layer were all found to decrease productivity of the machine. Post-planting assessments indicated that an average of 31.2% (range 23.8% to 39.3%) of seedlings planted expressed some kind of defect such as insufficient compaction of soil around the seedling or shallow planting, however, almost all seedlings were planted in the mounds, and almost all mounds were placed such that stones, slash or water did not adversely affect the growing conditions of the seedling. Operators cited rain as a factor that caused planting defects for two reasons, one due to impacts on the seedlings with cassette rotation where disintegration of wet root plugs resulted in poor movement of the plug through the planting tube and two because in some soils, notably soft peat lands or fine soil types, compaction after placement of the seedling did not work well where the planting tube was easily blocked with soil.

Liepins et al. (2011), evaluated the productivity and cost-effectiveness of the M-Planter in Latvia, specifically the M240, an M-Planter comprising two planting heads. Their study found that 39% of the M-Planters’ total effective working time was devoted to soil preparation and planting, 12% for driving and refilling the cassette and 37% to crane manoeuvres and other work operations. The study recorded a mean productivity of 260 seedlings hr^{-1}, and at a planting density of 2500 seedlings ha^{-1}, a productivity of 1.66 ha daily when working in two 8 hr shifts per day (Table 1). They reported planting density as one of the major factors affecting the cost of mechanisation, with costs reducing with reduced planting density (obviously not the case for a New Zealand scenario where planting density is much lower). The planting rate of ~260 seedlings hr^{-1} was considered high in comparison to other studies and was attributed to the two planting heads and lack of stones/rocky terrain. Planting costs (EUR 382: in 2011) were estimated at the equivalent of NZ (adjusted for 2023).

Lazdina et al. (2019) compared the productivity, quality and cost of using the M-Planter with manual planting (and mechanised site preparation/mounding) across three differing site types in Latvian forests. Productivity of the M-planter differed across site types, with an average of 170 seedlings hr^{-1} and ranging between 154 to 199 seedlings hr^{-1} (Table 1). On average it took 4 minutes to reload the seedling cassette with 120 seedlings. No estimate of the manual planting rate for Latvian conditions was provided, however, the study found that mechanised planting with the M-Planter took slightly more time (0.7 hrs) than mounding and manual planting. At an average planting rate for the M-Planter of 170 seedlings hr^{-1} mechanised planting was found to be more costly than manual planting with an estimated planting rate of 210 seedlings hr^{-1} required with the M-Planter to reach (economic) equivalence with manual planting.

The authors found no effect of planting method on plant survival. In a similar study Hallongren et al. (2014) compared the cost-competitiveness of mechanised tree planting with an M-Planter in Finland with manual planting in spot mounds formed with a mounding blade. Their results suggested that mechanised planting needed to increase in productivity by 25% in order to compete with spot mounding followed by manual planting.

Table 1: Summary of planting performance recorded for the M-Planter.

M-Planter Model	Productivity Seedlings hr^{-1*}	Reference
Not stated	170 (154-199)	Lazdina et al., (2019)
Not stated	158 (75-201)	Rantala and Laine (2010)
M-240	260	Liepins et al (2011)
M-160	240 (144-351)	Rantala et al. (2009)

*Assumed equivalence of calculations based on effective working time (planting and loading carousel and other activities encompassed in typical planting operation).

Plantma-X

The Plantma-X is a very recently launched planting machine that has been tested in Brazil and Sweden. The planting machine requires two operators, a driver who performs the soil preparation and a person loading the seedlings into the planting carousel. The machine has two planting arms that plant the seedlings at an interval of approximately 3 seconds (with the ability to plant up to 2000 seedlings per hr). At the bottom of each arm is a hydraulic pressure sensor, which records the planting pressure and depending on the pressure recorded an automated decision on the planting environment and position is made. For example, at high pressures the machine assumes a stone and prevents planting. If the machine can't plant at a spot it compensates for this by shortening the planting intervals for both arms, resulting in seedlings being planted closer together, thereby maintaining the target planting density per hectare. Other features of the Plantma-X include:

- A midiflex scarifier which can be used for continuous or intermittent preparation of planting mounds;
- The ability to plant into different spots in the prepared soil;
- Seedling storage capacity of up to 30,000 seedlings;
- Features that allow addition of fertilizer, water and other additives at planting, and;
- Automatic collection of information on tree location data, date/time, planting pressure etc.

No published information on the performance of the Plantma-X could be found as the machine is too recently launched for data to have been made available in the public domain.

REVIEW OF NZ INDUSTRY REQUIREMENTS FROM MECHANISED PLANTING MACHINES

Company investigations into choosing planting machines

Driven by the threat of rising labour costs, potential labour shortage of manual planters and an increasing planting programme, Timberlands Ltd. undertook a small business case study in 2017 into mechanised planter technologies. The business case study identified three main manufacturing firms selling planter heads that had been developed for use on excavators to mechanically plant seedlings: Risutec, Bracke and M-Planter. Timberlands Ltd. conducted a study tour to visit the manufacturers of these machines in Sweden and Finland to discover more about the technologies. Risutec had an attractive planter head that was developed for forestry, however, it was more expensive than the more basic M-Planter option, and came with add-ons that seemed unnecessary. Bracke had a quite different design of planter head and had developed a different technological approach to the others in the way the seedlings entered the tube and in how the ground was prepared. The Bracke option appeared to be a more complicated machine to operate, whereas Timberlands just wanted a simple and especially a robust machine to handle the NZ terrain, including harvest residue levels, and were more interested in the planting function than fertilising or utilising the various add-on features available with the Bracke head. In contrast to South American and Scandinavian forests (which are flatter with less retained slash and harvesting debris) it was important that the planting head be robust enough to work in the NZ terrain of a radiata pine cutover. M-Planter had a basic machine and seemed more willing to work with Timberlands Ltd to develop a NZ solution, rather than just sell one off the shelf. Timberlands subsequently purchased an M-Planter 160 mechanised planting head to trial and develop in New Zealand.

Meanwhile, driven by similar labour workforce concerns, MFM (NZ) conducted their own internal investigations into mechanised planting. This initially included briefly trialling, in 2019, a Risutec machine that was available in New Zealand, as well as observing Timberland's M-Planter operations. MFM (NZ) also visited Chile in 2019 to view radiata pine being planted using predominantly Risutec, but also Bracke machines. These machines were also being used to either irrigate or fertilise at planting. Based on the observations of machines working in New Zealand and Chile, MFM (NZ) decided in late 2019 to purchase a M-Planter to work in Kinleith forest in Tokoroa, commencing with the 2020 planting season. MFM (NZ)'s decision to purchase a M-Planter was similar to Timberland's. It was driven predominantly by M-Planter's perceived robustness, and the fact it had less moving parts and was simpler to operate. It was also driven by MFM (NZ)'s initial aim, which was to confirm the machine's ability to plant trees effectively and productively in New Zealand conditions, prior to focusing on any additional features such as fertilising.

More recently, Rayonier Matariki Forests (RMF) have looked to extend their planting season using hydrogel applications and mechanised planting with the M-Planter. A trial was undertaken in December 2022 using an M-Planter 160 head from Henry Fear Contracting. RMF had trialled a Risutec planting head some years back but did not have good success on the clay soils, so survival was low. RMF would be willing to trial the Risutec again if there was a machine available in New Zealand.

New Zealand experience with the M-Planter

Timberlands

Timberlands initially ordered a 160 model M-Planter machine with a ripping attachment already installed, and a small clearing rake at front. The intention was to get the machine to undertake combined spot mounding with planting operation in single pass.

2018 trials - "Let's see what it can do"

The M-Planter 160 model machine head arrived in late winter, which came pre-modified with the initial M-Planter ripper tool on the rear and a rake on front. The initial trial was simply to determine what the machine could achieve. The intention was to undertake all operations at once, spot mounding and planting, however, on the first day the pins in the ripper broke, eliminating the ripping part of the trial. The machine was subsequently moved to a pre-mounded block to trial planting into mounds. The machine planted the plants, and also fertilised at the time of planting from the granular hopper.

In hindsight, the Timberlands team felt they rushed into full operational trials faster than necessary, and experienced the following issues:

- The ripping tool provided wasn't adequate for the larger slash in a New Zealand cutover - a completely different ripper foot was needed.
- The rake tool worked but the design was not fit for purpose for NZ conditions.
- The planter head tube was not set for soil type. This resulted in seedlings being planted too shallow and loosely in the mound.
- The fertiliser unit was not functioning as we had expected and the seedlings were covered in fertiliser, due to a timing issue on fertiliser release into the hole.
- The seedlings had badly bound roots and were also planted loose as the compacter plates pressed not squeezed the soil on the mound.

Timberlands learnt a lot from these three weeks: The first lesson was not to use the ripper system supplied from M-Planter. They also found they could not form mounds with the standard machine, and the planter tube didn't allow for enough depth of soil penetration so required modification. Timberlands also committed to adjusting the rate and the timing of fertiliser release, and on developing a fit for purpose ripper.

The initial trials established a requirement for many modifications and adjustments needed for New Zealand conditions. It is important to note that these learnings motivated Timberlands to continue with the M-Planter and make the needed adjustments, probably in part due to the primary driver of future labour constraints in the industry and also the willingness of M-Planter to work with Timberlands to develop a machine suitable for New Zealand conditions.

2019 trials - "Let's get it planting"

The 2019 trials saw Timberlands going back to basics. Adjustments were made so the machine would plant into pre-formed mounds. Once the machine could plant into the mounds, Timberlands, together with HA Fear Ltd, moved onto developing a fit for purpose ripper. They also decided to order two further standard M-Planter 160s, which provided Timberlands the original machine as a prototype model head to trial and redesign without impacting production. Trials for 2019 included two new M-Planter 160s planting on already spot mounded sites, focusing on planting quality. Whilst developing the original M-Planter an additional machine was used to line rake slash in-front of the M-Planter and then the proto-type machine was simply spot mounding, planting and fertilising. At the end of the 2019 Timberlands had developed a new fertiliser system and were able to accurately fertilise directly into the hole at planting.

The biggest learning from the season was the need to get one thing at a time working, then try to add the next operation, and so on.

2020 trials - "Comparison to manual planting"

Once the M-Planter was planting reliably (two years on) the company could assess planting rates and productivity of the machine. Timberlands put in some manual planted control areas alongside the mechanised planting blocks. The initial assessment was more to do with quality of planting and mortality than production rates. Timberlands further modified the fertiliser hopper as there wasn't consistent application of fertiliser each time.

During 2021 and 2022 planting seasons, Timberlands trials were more focused on the use of hydrogels to extend the planting window and started actually planting out production blocks using the M-Planters to rake slash, spot mound, plant and fertilise. Although there is more work required on the container reload speed, the company decided not to spend any more money on developing it further at this time, as it works as a production machine.

Further steps

Now Timberlands have an M-Planter head that works, there is scope to redevelop the delivery mechanisms in terms of container reloading with preference for a system that takes whole day's stock (1000-1500 seedlings), so no reloading is required. There are also other options to consider, such as:

- Rubber tyred wheels.
- A large trailer with the containers, towed behind the head and delivering the trees into the head that can cater for 1000 trees up to 3000 trees / day.
- Use 2 rippers.

MFM (NZ)

MFM (NZ) started planting with a M-Planter in Kinleith forest in 2020 and planted approximately 100 ha each year in this forest for three seasons. Based on observations of machine productivity in Timberland's operations as well as operations seen in Chile, MFM (NZ) knew that machine planting alone would be more expensive than manual planting. Therefore, the machine would need to carry out another operation such as land preparation, or provide other benefits, to be cost-effective. Minimal spot mounding occurs in Kinleith forest (predominantly only on skids sites), while about 30%, on average, of the annual planting area is line raked. Therefore, it was envisaged that the machine could at least initially replace the requirement for a separate line-raking operation, by removing slash from the planting spot as part of the planting operation.

2020 trials

The initial MFM (NZ) approach to planting consisted of clearing the planting site with the blade on the M-Planter head by sweeping slash from the planting spot, then cultivating and then planting the seedling (without fertiliser or water added).

Initially machine productivity was slow at less than 800 trees/day, as the operator became used to operating the machine as well as working in cutover conditions. Productivity rapidly increased and by the end of the season machine productivity was at 1,350 trees/day. However, as productivity increased, the quality of planting decreased, with 25% of the trees being poorly planted. This compares to a target of less than 5% for manual planted trees. The predominant issue was loose trees i.e. trees not being fully firmed in. Other issues were planting depth (too shallow) and leaning trees (on an angle). This productivity versus quality issue was not surprising, as MFM (NZ) had also seen this during their time in Chile.

2021 trials

The focus of the next planting season was to reduce machine productivity in order to achieve planting quality of an acceptable level. Therefore, for the 2021 season, machine productivity was approximately 1000 trees/day, which resulted in less than 5% unacceptable planted trees. However, at this productivity, the cost of machine planting was nearly 2 times the cost of manual planting (and including the cost of line raking 30% of the area).

2022 trials

For the 2022 season, MFM (NZ) attempted to increase productivity while maintaining planting quality. However, productivity and quality results ended up similar to 2021 results (quality did not improve further).

Because of this, MFM (NZ) decided not to use the machine in the 2023 season due to the expense to run further trials and no perceived benefit over manual planting.

Rayonier Matariki Forests

The driver for Rayonier using the M-Planter was to test mechanisation technologies in their own operations and also determine whether a planting season could be extended through use of hydrogel application. It seemed sensible to get consistent hydrogel application through mechanisation using a planter head. Rayonier approached Henry Fear Contracting for use of the M-Planter. The trials were aimed at the driest period of the year, to best test the hydrogel efficiency. The firms' use of M-Planter is still very exploratory - they have only used the machine to plant two trials of just over 1 ha each in December 2022.

December 2022

RMF conducted two trials:

- one an extended planting season trial with hydrogels and water at Maramarua Forest;
- a second trial using the mechanised head for planting containerised radiata and radiata/attenuata planting stock.

The machine was mostly both mounding and planting. The hydrogel trial encountered issues with planting in the wet clay soil, resulting in seedlings popping out of the ground and having to be manually replanted. In the end the hydrogels were placed on top of the seedlings as it wasn't possible to get the seedlings to stay in the ground with the hydrogel – everything was just too wet. No additional fertilisers were applied in this trial.

The planting machine was operating in a medium slash load with the slash "windrowed' as the machine planted, meaning that there were 3 rows of seedlings between each raked slash pile. If the site were manually planted the site prep would possibly also include raking slash (with ripping) – so this is an additional operation that is completed at the same time as planting (increasing cost efficiency in comparison to manual planting).

Logistics and Learnings

Land preparation and site conditions

It is clear from the various trials undertaken that the M-Planter was seen as more than simply a planting machine and may provide the additionality on offer for land preparation, extending planting seasons or rates and ability to fertilise at consistent rates.

- Trials have been undertaken on a range of soil types, and there is a clear need for adjustment of the planting head pressure and compaction of the side panels to provide good seedling stability, and not have the planting tube clog with soil. The machine was operated in slopes up to 20 degrees with successful planting. Most land preparation is conducted on slopes of 0 – 8 degrees, and it is not known if the machine could successfully rake and rip steeper slopes.
- The machine is robust, but the ripping tool provided from the manufacturer is insufficient to handle the cutover conditions for New Zealand forest terrain. The machine can successfully plant directly into cutover without mounds, but at a slower production rate (much like that of a manual planter).
- The machine operator must plan for efficient movement through the block. There are places that a machine will not be able to get to, that may need to be blanked or planted manually.
- While there is an accurate GPS software available from M-Planter to show where the machine has been, it has very expensive licence fees and the firms that have trialled the M-Planter in New Zealand feel this is not cost effective, especially as drone imaging post-planting can provide the same detail. Real-time planting position information can be useful on slope, to ensure uniformity of row spacing and consistent tree spacing. There are issues where the operator is unable to see where the seedling is being planted. Some software to assist in planting (planned planting spots etc.) could be useful, or a 'cutover cam' for the cab that gives better visibility of the planter head for the operator.
- The machine is moved on a flatbed truck between sites. It can be shifted in one or two loads depending on the size of the truck. Shifting both the planting machine head and excavator in one shift requires "over size load" transport. There are significant transportation costs involved – so it is best to work through a whole compartment area and plant adjacent blocks, or plant only larger area blocks, to be cost effective. Therefore, mechanised planting heads may not be such a good option for disparate sites and woodlots.

Planting stock quality and storage

In all trials, the machine carousel was loaded manually by the operator on site. Some operators enjoyed loading the seedlings as it provided them opportunity to get out of the planting machine and move around in between the time spent planting out the carousels. The carousel requires containerised seedlings, which for MFM (NZ) and Rayonier was a change from the usual bareroot planting. Timberlands already had some experience in containerised planting, so the change was not as significant for them.

The main limitation with the containerised seedlings in the M-Planter head for some of the companies was the movement of the seedling down the planting chute especially when planting in wet clay soils. The planting feet are not well designed for planting in wet clay resulting in the planting hole not being closed-up and the seedlings popping out. Further, some of the mud gets sucked back up the planting tube resulting in the plants sticking in the planting tube. It appears not just wet clay soils are an issue, as Timberlands found soil got stuck in the tube in different soil types, so each soil type could require the mechanised head to have a slightly different pressure setting.

Other learnings around the quality of the containerised seedlings required for planting in the M-Planter included:

- The requirement for seedlings with consolidated root plugs otherwise there is the potential to jam the planting tube. Plug disintegration can occur due to plugs drying out in the carousel, poor quality and/or excessive shaking whilst in the carousel.
- The need for shorter, more sturdy seedlings rather than taller/slender planting stock, which also has the potential to jam in the planting tube.

- Consideration of the time planting stock spent between leaving the nursery and being out-planted, including time spent in the planting carousel. In sunshine the seedlings can dry out in the carousel and in heavy rain it can make the seedlings too wet and loosen the plug. Further, in really heavy rain the containers fill up with water. It may be better to keep the seedling containers in a covered conveyor system, rather than the present exposed carousel system.

Labour changes

Changes in labour from a shift to mechanisation come from the number of workers required to plant, the skills needed to operate machinery, and the nature of the work (see Table 2).

Table 2: Impacts on labour requirements, behaviours and skills through a shift to mechanisation

Manual planting crew	Excavator operator
7 person crew	Single operator, sometimes serviceman brought in for breakdowns
Working together, good camaraderie and teamwork	Working alone, or with another nearby mechanised planter operator
Outdoors, heavy labour and lots of walking	In a cab, out of weather. More mental than physical workload
Spade and fitness, QC each plant	Need excavator and mechanical skillsets; QC small subset after planting
Plants continually Dig; plant; walk Takes regular smoko and meal breaks Works 8 hr shifts	Loads carousel; plants; fixes jams. Might undertake land prep on another site first, then plant a prepared site. Works 10 hr shift, with many breaks, probably 8 hrs productive
May need to walk back for plants; sometimes plants are delivered to planter	Operator must reload carousel This takes 7 mins every 1 to 1.5 hrs of work.

Both MFM (NZ) and Timberlands used a contractor experienced in either harvesting or silvicultural operations, rather than training a manual planter to use the excavator and head. This meant that the operators had no previous planting experience, but it didn't take long to get them up to speed on good planting requirements. When using multiple operators, there was quite a variation in the time and efficiency of planting depending on which operator was operating the machine. A key lesson from Timberlands experience is to select operators that are willing to work with the forest manager or project lead to help develop and improve the machinery, rather than one dedicated on getting a quota of seedlings planted per hour, or working strictly to hourly rate. There are a lot of breakdowns and jams to fix during trials, and care in the approach required to loading and planting that needs a careful skilled operator, willing to learn and pay attention to detail. The best operator is one willing to work the test machine and modify and learn with it, not just there to do 10 hrs shift work. An operator with engineering or design capabilities is preferable as the operator is crucial to trials and the pathway for adopting automation in silvicultural tasks, they also need to communicate well and be a team player.

In addition, these operators work differently to other contractors, as they need to get in and out of the excavator a lot when undertaking these mechanised planting jobs. To load the trays, and then to restock the carousel, fix jams or unclog the planting chute, and then at the end of the cycle to do the QC, walking up and down the planted area doesn't suit workers who just want to sit in the cab all day.

Something else to consider is that once trained, mechanised planting head operators will take longer than a manual planter to become fully competent with the machine and also be harder to replace than a manual planter. In future, should all commercial exotic planting become mechanised, there will be less of them in the planting workforce pool (perhaps five to seven times fewer planters).

Work rate of M-Planter

There is a clear relationship between work rate and the quality of planting. A faster work rate of the machine needs to ensure there is good root contact when in loose soil or planting into slash. It would appear that a work rate of 800-1000 plants per day provides good planting quality. In Scandinavia, it seems they plant more trees per hectare making it difficult to compare with the NZ situation. When the work rate was at 1400 plants/day, the planting quality was poor. MFM (NZ) estimated they would need to plant at least 1800 plants/day to be economic, in areas where they would normally line rake.

ECONOMIC ANALYSIS

To understand the potential costs and benefits of the M-Planter, we performed an economic analysis to compare it with the traditional manual planting method. This analysis aims to evaluate the circumstances in which the M-Planter could break even or prove to be cost-effective.

Among the key considerations are:

- labour costs and costs of operating the M-Planter;
- the efficiency and productivity offered by manual planting versus using the M-Planter;
- the time period over which the M-Planter operates versus that of manual planting;
- additional operations that can be carried out by the M-Planter that increase overall efficiency of the machine.

In this section we use various scenarios to evaluate the costs and benefits of using the M-Planter versus standard manual planting methods.

Baseline costs
Companies that have utilised the M-Planter in their tree-planting operations in New Zealand have reported the following average values for manual planting and planting with the M-Planter (Table 3).

Table 3: Key planting inputs for the M-Planter and Manual planters.

Planting factors	Land prep	M-Planter	Manual Planter	Metrics
Raking	$600			$/hectare
Mounding	$700			$/hectare
Labour cost		$65	$60	$/hour
Labour hours		10	8	Hours/day
Planting performance		800-1100	500-900	Trees/day
Rejection rate		5%	3%	Planting failure as %
Fuel consumption		16		Litres/hour
Utilisation		80%		Active time in the M-Planter %
Maintenance		$15,000		$/year
Cartage		$5,000		$/year
M-Planter Capital cost		$90,000		$

The following points need to be noted:

- Manual planting rate is variable across terrain type: ~900 trees/day on flat terrain and ~500 trees/day on steep terrain
- The increase in daily working shift hours from 8 to 10 hours when using the M-Planter. This increase can be expected as the operator's physical strain is generally lower than manual labour, allowing for longer shift hours by the operator without excessive fatigue.
- The "rejection rate" refers to the failure to plant a seedling to an operational standard expected to pass quality control and ensure the survival of the seedling.
- The utilisation rate of the M-Planter, which can reach up to 80% full utilisation, indicating that the machine is actively working (planting) for 8 out of the 10 hours in a shift (see Literature Review).

- M-Planter productivity, which we consider a key component for the success of the M-Planter as an alternative to manual planting. At present, we have worked on an assumption that the M-Planter achieves a performance rate of between 800-1100 trees per day, depending on circumstances, which is comparable to the rate of an individual manually planting.
- While the M-Planter may not offer a significant cost advantage over manual labour in terms of planting expenses, it could provide a viable solution to overcome labour shortages, considering the current, relatively low, cost of labour.

Scenarios tested

By utilising data gathered from the New Zealand trials alongside industry benchmark costings, we conducted analyses on hypothetical scenarios to assess the cost-effectiveness of employing the M-Planter technology. Our primary focus was to identify thresholds at which the utilisation of the M-Planter could achieve cost parity with manual planting for a target area of 1000 hectares. Given our current operational constraints, we aimed to accomplish this planting goal within a reasonable timeframe of 3-4 months. To determine the necessary size of the planting crews, we factored in the planting target and the corresponding timeframe of 3-4 months (equivalent to approximately 100 days). Based on these parameters, we calculated the required number of personnel and the associated cost to achieve the desired outcome. Additionally, we examined the comparative requirements in terms of both personnel and M-Planters for the planting target, assuming a planting density of 833 (sph).

Scenarios 1 & 2-Using the M-Planter as a planting machine only

In scenario 1, we compared the manpower requirements and the number of M-Planters necessary to plant 1000 hectares within a timeframe of 3-4 months. It's important to note that this scenario focused solely on the planting operation and cost analysis of manual crews versus the utilisation of M-Planters, without considering land preparation aspects for either manual planting or planting with the M-Planter (Table 4, Scenario 1).

Table 4: Planting Scenarios 1 & 2 - Cost Comparison of Manual Planting vs. M-Planter

Scenario	1		2	
	No Land prep required		Preparation in 30% of the Land	
Planting mode	Manual	M-Planter	Manual	M-Planter
SPH	833	833	833	833
Crew - Machines	10	10	10	10
Labour cost / hour	60	65	60	65
Productivity Stems/day	800	1,000	800	1,000
Rejection rate	3%	5%	3%	5%
Days for planting	110	88	110	88
Hours/day	8	10	8	10
Utilisation		80%		80%
Planting Cost	$ 528,000	$ 1,214,000	$ 528,000	$ 1,214,000
Land prep cost			$ 363,168	$ 363,168
Total costs	$ 528,000	$ 1,214,000	$ 891,168	$ 1,577,168
Cost/ha	$ 528	$ 1,214	$ 891	$ 1,577

In Scenario 1 (Table 4) with a crew of 10 manual planters, it would take approximately 110 days to reach the planting target of 1000 hectares. The cost for manual planting would amount to $528,000, resulting in a cost of $528 per hectare.

Alternatively, if manual planters are not available and only M-Planters are used, it would also require 10 M-Planter heads operating for 88 days to complete the 1000 hectares. However, the cost for using M-Planters alone would exceed $1.2 million, resulting in a cost per hectare of approximately $1,214.

In Scenario 2 (Table 4) land preparation in 30% of the property is included as an additional activity for manual planting **and the M-Planter**. The cost of planting a hectare with a manual crew of 10 people, would be around $891. On the other hand, if only M-Planters are used, the total cost would be approximately $1,577,168. Thus, the cost per hectare, including land preparation, would be approximately $1,577.

It is important to note that in Scenarios 1 and 2 we assume a direct cost comparison between manual labour and the M-Planter. It is worth noting that these scenarios are hypothetical since they do not consider the primary purpose of the M-Planter, **which is to simultaneously prepare the land and plant**.

Scenario 3-Using the M-Planter for land preparation and planting

In Scenario 3, (Table 5) we explore the situation where the manual planting operation incurs an additional cost for land preparation, while the M-Planter has the capability to perform tasks such as line raking and mounding while simultaneously planting. In this scenario, it's crucial to highlight that we consider overall flat and easy terrain with the productivity of the M-Planter diminishing due to the necessity of performing line raking or other land preparation operations, in 30% of the terrain.

Considering the specific requirements of Scenario 3, the manual planting operation requires an additional operation for land preparation. The associated costs and time required for land preparation is thus factored into the overall analysis. In this particular scenario, where the M-Planter is employed simultaneously for land preparation and planting, it could be expected that the benefits of utilising M-Planter technology would be evident.

Table 5: Planting Scenario 3 - Cost Comparison of Manual Planting vs. M-Planter (M-Planter Used for Land Preparation)

Scenario	3 M-Planter can do the Land prep	
Planting mode	Manual	M-Planter
SPH	833	833
Crew - Machines	10	10
Labour cost / hour	60	65
Productivity Stems/day	800	970
Rejection rate	3%	5%
Days for planting	110	92
Hours/day	8	10
Utilisation		80%
Planting Cost	$ 528,000	$1,256,000
Land prep cost	$ 363,168	
Total costs	$ 891,168	$ 1,256,000
Cost/ha	$ 891	$ 1,256

However, due to the decrease in productivity per hectare, resulting from the multitasking operation, these advantages are not as substantial as anticipated. When comparing costs, manual planting combined with land preparation amounts to $891 per hectare, whereas the use of the M-Planter pushes the cost per hectare to $1,256. Thus, the expected cost-efficiency does not materialise to the full extent in this situation. It is noteworthy, however, that the utilisation of the M-Planter for land preparation operations (Scenario 3) is $321 per hectare more economical than when additional land preparation is required (Scenario 2).

So far, we have only compared the alternatives of planting solely with manual planters or solely with M-Planters, without considering a scenario that combines both. Therefore, in the following two scenarios, 4 and 5, we will consider the requirements in terms of personnel and M-Planters to achieve the goal of planting 1000 hectares within a period of 3 to 4 months or adopting a year-round planting strategy.

Scenarios 4 & 5

In Scenario 4 (Table 6), to reach a planting target of 1000 hectares in a mixed terrain where 78% of the land has a slope greater than or equal to 20°, the operation would require ten manual planters (planting 670 stems per day in steep terrain) and two M-Planters (planting 970 stems per day in flatter terrain) working for a span of 100 days. When land preparation for 30% of the terrain is incorporated for both planting methods, the cost of the manual operation amounts to $784,200, while the expense associated with using the M-Planters would be $268,000. Given the attributes of this model, to plant a thousand hectares would amount $1,052,200, or $1,052 per hectare.

In Scenario 5 (Table 6), we present an alternative planting regime that takes advantage of the year-round operational capability of the company-owned M-Planter. In this scenario, the crew size can be reduced to six people, actively working for 100 days, while the two M-Planters operate for 230 days.

Table 6: Planting Scenarios 4 & 5 - Cost Comparison of Manual Planting and M-Planter (Combined Methods)

Scenario	4		5	
	Combined Method		Combined & extended	
Planting mode	Manual	M-Planter	Manual	M-Planter
SPH	833	833	833	833
Crew - Machines	10	2	6	2
Wage per hour	60	65	60	65
Productivity Stems/day	670	970	670	970
Days for planting	100	100	100	230
Hectares Planted	780	221	470	530
Slope	≥20°	<20°	≥20°	<20°
Planting Cost	$ 480,000	$ 268,000	$ 248,160	$ 665,680
Land prep cost	$ 304,200		$ 183,300	
Total costs	$ 784,200	$ 268,000	$ 431,460	$ 665,680
Grand Total	$ 1,052,200		$ 1,097,140	
Cost/ha	$ 1,052		$ 1,097	

Leveraging the extended operational period of M-Planters might suggest the possibility of achieving substantial cost reductions in planting. In a given terrain, where 50% of the land is characterised as flat and the remaining 50% as steeper, the extended operational capacity of M-Planters offers a significant opportunity for cost savings. Under this configuration, manual planters can be strategically allocated to the steeper portions, whilst the M-Planter is designated for the flatter areas. By applying this model, the total expenditure for planting 1,000 hectares rises 4%, to $1,097,140. Beyond the economic difference, this approach delivers a strategy for pre-empting and managing potential operational disruptions. Specifically, staff shortages can be effectively mitigated through the extended use of M-Planters. This operational flexibility, achieved at a similar cost, provides a viable mechanism for adhering to established planting schedules. It is essential, however, to bear in mind that the M-Planter is optimally suited for flatter terrains.

Based on the data gathered thus far and the model's cost estimates comparing manual planting with the M-Planter, we conclude that manual planting is still the more economical approach. However, the prevailing conditions in the current labour market, which increasingly present challenges in procuring staff, must be factored in. This sentiment is echoed by one of our interviewees who stated, "We decided to try the M-Planter not because it is cheaper or more productive, but due to the need to address the shortage of personnel for tree planting."

Sensitivity Analyses

Our analysis focused on how changes in the M-Planter's performance, specifically an increase from 800 to 1200 trees per day, would influence the total operational cost per hectare, considering the original planting target of 1000 hectares (Figure 2). The purpose of these simulations was to glean insights into the cost-effectiveness and operational efficiency of the M-Planter if it were theoretically deployed at heightened levels of productivity. For this analysis we assumed that the M-Planter will handle both planting and land preparation on 30% of the land, while exclusively planting on the remaining 70%. We also factored in the rejection rate as the planting speed increases.

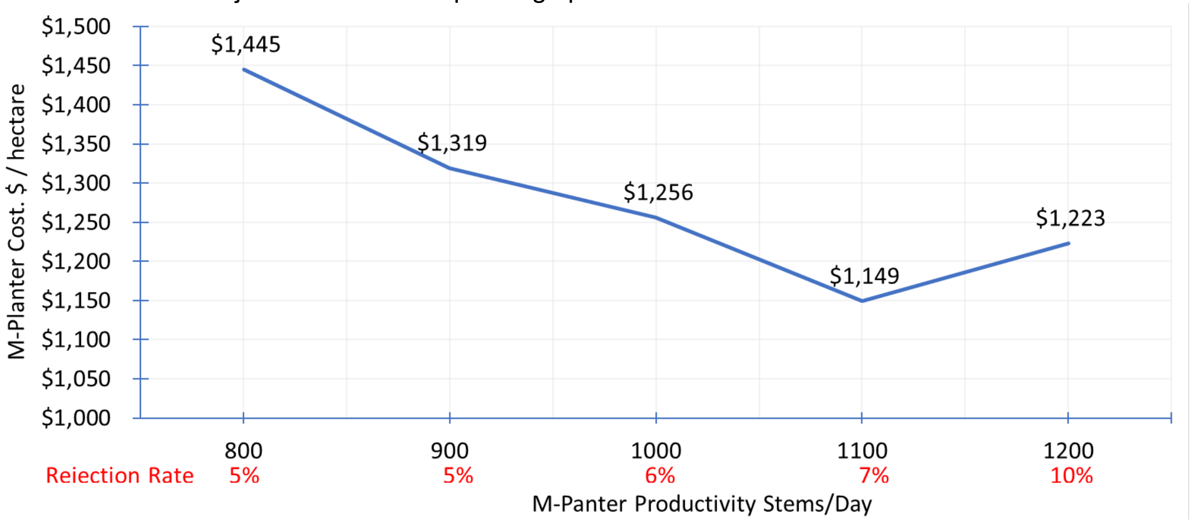


Figure 2. M-Planter Operational Costs and Rejection Rates Across Different Planting Productivity Levels

As the graph unfolds, we observe a trend of descending cost per hectare as productivity ascends from 800 to 1100 plants per day. Intuitively, this trend aligns with expectations; a surge in daily productivity should, under normal circumstances, translate to a reduced cost per hectare. The apparent sweet spot lies at 1100 plants per day, which yields the lowest cost per hectare ($1,149), before the rejection rate crosses a threshold that inversely impacts costs.

When the M-Planter is tuned to plant 1100 trees per day, despite a slight increase in the rejection rate by only 1%, the cost per hectare becomes more competitive, especially since this scenario would only require 9 M-Planters instead of 10 as in previous scenarios to plant the 1000 ha. This breakthrough showcases the potential benefits of optimising the M-Planter's productivity enabling a cost reduction where the total cost of planting 1000 hectares using 9 planters would be $1,149,301, and the timeframe for completion would be 94 days, assuming full operation over that period.

Yet, as we raise our gaze beyond productivity and cost, we encounter the third, critical variable - the rejection rate. We observe an interesting pattern where a higher planting speed correlates with an elevated rejection rate, hinting at a quality trade-off for speed. With increased haste in planting, the propensity for errors or substandard planting grows, reflected in a heightened rejection rate.

This tri-variable relationship takes a turn at 1200 plants per day. Pushing the M-Planter's productivity further may seem enticing, but studies warn of significant increases in rejection rates (Rantala & Laine, 2010; Lazdina et al., 2019). Such a scenario would require additional expenses for manually revising and replanting improperly placed trees (120 per day). Despite a further boost in productivity, both cost per hectare and rejection rate surge. This intersection signals a threshold beyond which the quest for heightened productivity becomes counterproductive for the M-Planter. Merely accelerating productivity does not necessarily correlate with cost reduction, particularly when quality (expressed through the rejection rate) is compromised. As a result, the overall costs associated with operating the M-Planter and replacing lost seedlings outweigh the potential benefits, making it an impractical choice.

This analysis serves as an important benchmark, showcasing the viability and advantages of increasing the M-Planter's productivity to 1100 trees daily. Striking the right balance between productivity, rejection rates, and associated costs is paramount when considering the M-Planter for tree planting projects in commercial radiata pine plantations.

What if the cost of labour increases or availability declines?

In our evaluation of labour costs within the forestry industry, it's vital to differentiate between the roles of manual planters and machine operators, as they are subject to contrasting pressures. The rigorous demands of manual planting—repetitive movements, labour-intensive activities, prolonged exposure to varying weather conditions, and frequent bending—can precipitate significant health issues if not executed with care (FP Innovations, 2010). Such practices can lead to increased absenteeism, underscoring the profession's strenuous nature. Moreover, demographic trends present another layer of complexity, with a significant third of the workforce aged over 50, indicating a potential upcoming deficit in seasoned labour. Alongside, the industry's pronounced reliance on migrant workers hints at broader systemic challenges (NZFOA, 2018).

Recruitment and retention difficulties further aggravate the industry's labour concerns. An overwhelming 89% of forest owners or managers encounter challenges in hiring contractors, exacerbated by a notable 21% turnover rate in the previous year (NZFOA, 2018). When employees move on, better compensation and competitive offers frequently emerge as leading motivators, emphasising a domain where nearly 40% switch roles for enhanced remuneration. Combining these challenges, wages have surged by a significant 10.2% since 2020, and majority of industry professionals anticipate worsened staff shortages in the near future (NZFOA, 2018).

In contrast, labour costs and absenteeism for machine operators are projected to increase at a more moderate rate due to factors like minor risk exposure and enhanced working conditions (Axelsson, 1998; Kaakkurivaara *et al.,* 2022). The use of machinery like the M-Planter has shifted the nature of the work away from manual labour, often resulting in a less physically demanding role. While there may be some increases tied to specialised training and maintenance, these costs and shortages are not anticipated to rise as steeply as those for manual labour.

Staff shortage isn't unique to the forestry sector; it is a widespread issue across various industries in New Zealand. Forestry finds itself in a competitive environment, competing for the same labour force as other major industries like agriculture, transport, and construction (Stuff, 2022). What makes this competition even more intense is that these industries often have a distinct advantage when it comes to location as they tend to be closer to urban areas, making them more attractive for potential employees (Stuff, 2018).

M-PLANTER REQUIRED PERFORMANCE SPECIFICATIONS

Literature from Scandinavian studies emphasise the poor contractor profitability, low current productivity and issues of machine utilisation, especially given the planting seasonality, and requirement to move the machine by transporter between blocks to be planted as factors which limit adoption of mechanised planting.

In the New Zealand situation considerations around low base productivity rates of ~900 seedlings per day are also of concern. Therefore, as shown through the economic analysis, at a minimum, the M-Planter will need to encompass some additional land preparation or other post-planting operation such as fertilisation during the same planting pass to increase cost efficiency in comparison to manual planting.

The New Zealand work-rate for the M-Planter is much lower than that reported by Rantala et al. (2009) of 1920 day^{-1}, or 1360 day^{-1} from Liepins et al. (2011). However, these studies used a much higher stocking rate than New Zealand, planting at 2500 stems ha^{-1} compared to our usual 800-1000 stems ha^{-1}. Rantala et al. (2009) also reported that percentage slash cover had no significant effect on planting productivity, while the New Zealand trials found slash cover to cause some issue for the planter heads. In particular, Timberlands required a much more robust ripping tool to be implemented than the factory supplied tool, to handle the New Zealand terrain.

Similarly to that reported by Rantala and Laine (2010), wet conditions impacted the ability of the containerised seedling to move through the tube. However, unlike the 2010 Scandinavian study, the issues in New Zealand concerned more wet mud entering the tube, and the containers filling with water and disintegration of the root plug.

New Zealand observations also pointed to a requirement for sturdier, more robust seedlings, with well consolidated plugs - a factor which remains to be tested. It is also apparent that planter heads require customisation to both terrain, soil and species being planted with a need to trial different options in the initial days of planting out to calibrate the machine to the site.

The most important insights concerning New Zealand performance specification with mechanised planting platforms is to:

- Allow time to trial various aspects of the M-Planter functions, perfecting each before attempting another function.
- Recognise that to compete with the cost of manual planting that the M-Planter would need to do more than just planting and should also undertake land preparation and other silvicultural functions. Enabling the M-Planter to undertake as many operations in the one pass as possible, will reduce the costs per tree. The M-Planter has the potential to carry out spot mounding, planting and fertilising, including applications of hydrogels and other growth enhancing products. However, as above, these will need to be trialled one at a time.
- There is currently an upper limit to planting rate in New Zealand, which appears to be around 1100-1200 stems /day. Beyond this, the reject rate is too high and would require additional manual blanking and seedling stocks.
- The machines require customisation or 'ruggedizing' to work effectively in New Zealand.

Company experience would indicate that there are improvements that could be made to the base machine to improve performance in New Zealand conditions. Some that have been suggested include:

- Improve the seedling feed mechanism (tube) and planter foot operation. Consider making the seedling feeding mechanism compatible with Ellepots to reduce damage and shock to the seedling and also modifying the planter foot to improve compaction around the planting hole (squeezing the soil as opposed to pushing down only), especially for when operating in clay soils.
- Consider mounting the planting head on a smaller lighter machine on rubber wheels for increased terrain access. This may reduce planting to 3 lines at once, rather than 4, and may mean lower productivity on these terrains, but would reduce negative site impacts.
- Reducing the size of the seedling carousel. A smaller carousel size with faster change of carousel could reduce seedling time within the carousel, thereby minimising seedling stress and potentially increasing seedling survival rates. Extended time in the carousel is also exacerbated when the machine breaks down or there are blockages etc. In contrast, in wet conditions, the carousel can take on water and the seedlings become waterlogged, impacting the integrity of the seedling plug and the ability to feed seedlings into the planting tube. A covered carousel could also be explored.
- Improving workflow planning from nursery to planting site to help increase efficiency of seedling supply.
- Considering a 'cutover cam' to increase visibility of the planting terrain for planting machine operator during planting. Currently, it is difficult for the operator see the planter head on steep slopes, and also evaluate whether rocks, stumps or high moisture levels are impeding machine operations. Additional sensors on the planter head to help locate optimal planting positions could also be useful, including a GPS unit that can accurately map the planting positions in real-time.

Some suggestions for additional trials/machine improvement include:

- Benchmarking the efficiency /work rate across various terrain types and soil types and planting situations.
- Determining the life of the planting head to enable accurate inclusion of depreciation costs into financial models.
- Evaluating post-planting metrics at 2-3 years in comparison to manually planted site.
- Including a mechanism that allows application of herbicide at the time of planting and evaluating the efficacy of this operation.

REFERENCES

Axelsson, S. (1998) The Mechanization of Logging Operations in Sweden and its Effect on Occupational Safety and Health, *Journal of Forest Engineering* 9(2), 25-31, https://doi.org/10.1080/08435243.1998.10702715

Baker, M. (2018). Mechanised silviculture. Opportunities and Challenges for the New Zealand Forest Industry. Report for Kellog Rural Leadership Programme. 35 pp.

Bayne, K., Parker., R. (2021) Latest Advances in Forest Technology. Scion, New Zealand Forest Research, Limited.

Ersson, B.T. *et al.* (2018) Mechanized Tree Planting in Sweden and Finland: Current State and Key Factors for Future Growth. *Forests* 9, 370. 10.3390/f9070370

Ersson, B.T. *et al.* (2022) Cost analysis of seedling supply systems adapted for mechanized tree planting: a case study from southern Sweden. *Silva Fennica* 56. 10.14214/sf.10663.

FP Innovations (2010). A Tree Planter's Guide to Reducing Musculoskeletal Disorders for Eastern Canada. Advantage Vol. 11 No. 21 January 2010. https://library.fpinnovations.ca/media/FOP/ADV11N21.PDF

Hallongren, H. *et al.* (2014). Competitiveness of mechanized tree planting in Finland. *Scandinavian Journal of Forest Research* 29, 144-151. 10.1080/02827581.2014.881542.

Kaakkurivaara, T., Borz, S.A., Kaakkurivaara, N. (2022). Risk Factors and Occupational Safety Failures in Forest Work in the Southeast Asian Region. *Forests*, 13(12), 2034. https://doi.org/10.3390/f13122034

Laine, T. *et al.* (2016) A survey of the Finnish mechanized tree-planting industry in 2013 and its success factors. *Silva Fennica,* 50(2), ID-1323.

Lazdina, D. *et al.* (2019) Evaluation of forest tree planting machine effectiveness. *Engineering for Rural Development*, 22, 24/05/2019.

Liepins, K. *et al.* (2011) Productivity and Cost-effectiveness of the M-Planter Tree Planting Machine in Latvian Conditions. *Baltic Forestry* 17, 308-311.

Ramantswana, M. (2020) Advances in the Mechanization of Regenerating Plantation Forests: A Review. *Current Forestry Reports,* 6,143-158.

New Zealand Forest Owners Association (NZFOA). (2018). Forestry sector labour market survey. https://www.nzfoa.org.nz/resources/file-libraries-resources/training-and-safety/659-trainingandcareers/file

New Zealand Forest Owners Association NZFOA (21/22). Facts and Figures, New Zealand Planting Forestry Industry. https://www.nzfoa.org.nz.

Petro, T. (2022). Literature review and environmental scan of precision planting technologies, Forest Growers Research, Report for PSP.

Rantala, J. *et al.* (2009). A Techno-Economic Evaluation of Bracke and M-Planter Tree Planting Devices. *Silva Fennica* 43. 10.14214/sf.186.

Rantala, J. and Laine, T. (2010). Productivity of the M-Planter Tree-Planting Device in Practice. *Silva Fennica* 44. 10.14214/sf.125.

Stuff. (2018). Worker shortage on the land as farmers compete for staff. https://www.stuff.co.nz/business/farming/102231279/primary-sector-industries-in-hunt-for-workers-as-shortfall-looms

Stuff. (2022). Every sector is screaming out for more workers. https://www.stuff.co.nz/business/129190327/every-sector-is-screaming-out-for-more-workers