Precision Silviculture Programme

TECHNOLOGY REVIEW

MODERN NURSERY TECHNOLOGY FOR CONTAINERISED AND BARE ROOTED PRODUCTION SYSTEMS

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Modern nursery technology for containerised and bare rooted production systems.

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Report information sheet

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Executive summary

The challenge

By 2050 tree growth and forest production efficiency is to be doubled and forestry's licence to operate will continue to have widespread support. These strategic goals of the NZ Forest Owners Association require innovative solutions.

Client initiatives

Forest Growers Research Limited (FGR) in partnership with the Ministry for Primary Industries is funding a seven-year Sustainable Food and Fibre Future Partnership programme investigating mechanisation and automation in Precision Silviculture. The programme spans four workstreams – nursery, planting, pruning and thinning – and will be supported by a digital framework spanning the four themes. The aim of this Programme is to introduce new technology and practice changes to improve safety, reduce environmental impacts, improve profitability and reduce costs of forest operations.

This project

The purpose of this project is to provide a preliminary review of technology developments that have potential application in the New Zealand commercial forest nursery context and to summarise the state of current domestic nursery developments. This review covers technology applicable to both containerised and bare-rooted nursery systems and aims to inform pathways for change as part of the nursery workstream within the programme.

Key results

Case study examples of both international (348.4M plants/year) and local automation and mechanisation do suggest significant opportunities for improving nursery crop flow and quality control in New Zealand. The potential for automation and mechanisation is especially high in containerised nursery systems. Key pathways for change are driven by a current need to extend the planting season, to suit planting mechanisation, skill and labour shortages and optimise native seedling establishment. Importantly, containerised plants must provide forest managers with greater flexibility and reduce risks significantly during establishment in the field. Additionally, automated container nurseries can be run much more environmentally friendly regarding disease control, run-off, fungicides, and herbicides which improves social license to operate.

This review provides guidance on most of the critical decisions for designing an automated crop flow plan and supports the growing body of evidence, that nursery automation, mechanisation and digital monitoring and artificial intelligence will enable more environmental nursery practices, more control over resource use and most importantly optimise plant quality, but the gains at the beginning of the value chain are yet to be adequately quantified.

This report describes the nursery production systems status in New Zealand and its recent developments towards more containerisation and automation. Furthermore, it provides international nursery automation developments and case studies. Finally, we give an overview of global suppliers of nursery automation equipment like Ellepot, BCC and TTA which usually provide nurseries with targeted equipment and products that suit the nurseries needs and offer a wide range of opportunities for nursery automation on the global market.

Implications of results for the client

There are plenty of opportunities highlighted in this report to use modern technology in bare root or containerised nurseries. However, it is paramount for anyone looking to automate or mechanise work in the nursery to consider the whole system and where or if using technology in any of the processes is (most) beneficial. The conditions and situations for every nursery are different (e.g. species and their different root systems, specifications, number of plants produced, employees, space, capital…) and this should be taken into consideration and evaluated carefully before introducing new systems.
The upfront costs of implementing new systems are high, therefore prior to introducing some form of mechanisation, it is advisable to learn from existing case studies provided in this report. In addition, inviting specialist companies (examples listed in the report) to visit your business and provide expert input can be very insightful.

Further work

Most aspects of this report focus on large nurseries producing a limited number of plantation tree species with a single specification for each species. Especially for the production of native trees with a range of potential specifications and species with very different root systems automation is more challenging. Specifications of optimal container sizes for alternative production species, sites and stock types for New Zealand situations are not adequately investigated. More nursery automation research for efficient utilisation of native tree species is required.

Key nursery requirements are to provide evidence and guide industry specifications on:

1. Optimal container sizes for the new range of stock types and species.
2. Determine growth rate and product quality expectations for the new range of stock types and species.
3. Determine a range of site-specific media mixes for New Zealand situations, so precision management can be further enabled.
4. Compare new nursery options with seed pod applications.
5. Quantify benefits of nursery automation and containerisation passed along the value chain.

Modern nursery technology for containerised and bare rooted production systems.

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Introduction

Future proofing production forests is a key priority of FGR's strategy to ensure that the forest-growing industry is resilient to the declining availability of labour, and the increased focus on worker safety and well-being (FGR Science and Innovation Strategy 2020-2035, Theme 3). New Zealand's forestry industry is gearing up to introduce precision silviculture and automation in all areas such as pre-establishment, silviculture (planting, thinning and pruning), harvesting and post-harvesting. Forestry, like many other industries, will use robotic and automated machines in the near future (Parker, Bayne, & Clinton, 2016). To date a major focus has been the development of autonomous systems for planting. Automated planting systems such as the mechanical “M Planter” have already been trialled by forestry companies in New Zealand.

Nursery production systems play a key role in the whole-of-forestry supply-chain. Large scale afforestation programs for mitigating climate change are also heavily reliant on efficient and high-quality nursery stock production systems.

Basically, two steps of the operations in nurseries and greenhouses can be enhanced with technology: i) mechanisation and ii) automation. While mechanisation describes the replacement of a human task with a machine, automation, involves the entire process of integrating several operations and ensuring that different elements communicate with each other to ensure smooth operations (Josefsson, 2019; Posadas et al., 2008).

Automation or automatic control is the use of various control systems for operating equipment for increasing production efficiencies and thereby profitability. There are two key drivers for nursery mechanisations and automation. Firstly, to address shortage of labour and improving ergonomics in the workplace. The extent of labour issues in NZ nurseries was highlighted by Smaill (2018), based on a survey of nursery managers. Secondly, increasing legislative and social pressures to lessen the impacts on the environment and to maintain nurseries' licence to operate will be a major driver towards precision automation of nursery processes.

The labour needed to produce forestry crops represents a significant percentage of the overall cost, hence, reducing the amount of labour required to create a product, can also result in increased profitability. Improved nursery production efficiencies are critical to meet the challenging demands arising from afforestation programs such as the 1 Billion Trees (1BT) program. Additional challenges of the Covid-19 pandemic and opportunities exist for extending the traditional planting window and year-round operations. Automation is seen as a great solution to tackle such problems. Automation and ergonomic improvement in the workplace would also have high interest where nursery managers want to create better and more attractive working conditions in the nursery.

In comparison to production forestry in New Zealand, other horticulture and agriculture industries are generally much more advanced in automation and mechanisation, with a range of solutions harnessing data for smarter decision making. Data is collected from scaled IOT (Internet Of Things) sensor networks transported through wireless communications and analysed using artificial intelligence, machine learning and deep learning to address issues like crop diseases, storage management, pesticide control, weed management, irrigation and water management (Jha, Doshi, Patel, & Shah, 2019). Innovative New Zealand companies such as Robotics Plus in collaboration with University of Auckland have developed prototype unmanned ground vehicles and robots for harvesting kiwifruit and automated solutions are available for packing, grading of fruits with substantial efficiency gains for the industry. (https://www.newshub.co.nz/home/new-zealand/2018/01/fruit-growers-turn-to-robots-to-solve-labour-shortage.html).

Around the globe, as will be discussed later, countries are increasingly embracing automation in forestry stock production to increase the efficiency of nursery practices, and it is timely that New Zealand explore automation to stay competitive and to maximise its contribution to global afforestation.

The objectives of the report are:

1. *Undertake a literature review of international technology that is currently available or being developed for both containerized and bare rooted nursery production systems that may be applicable to the NZ commercial forestry sector.*
2. *Review domestic developments in forest and horticultural/cropping nurseries, progress made, potential for further development and record any learnings from such developments.*
3. *Identify opportunities to modify, enhance or scale technologies to the New Zealand nursery context.*

Since there are very few peer-reviewed publications on forest nursery automation this report is largely based on interviews with the key suppliers of automation equipment, information sourced from the supplier websites and site visits to nurseries.

Areas of focus

The review spans the following areas and highlights key considerations for automation within each:

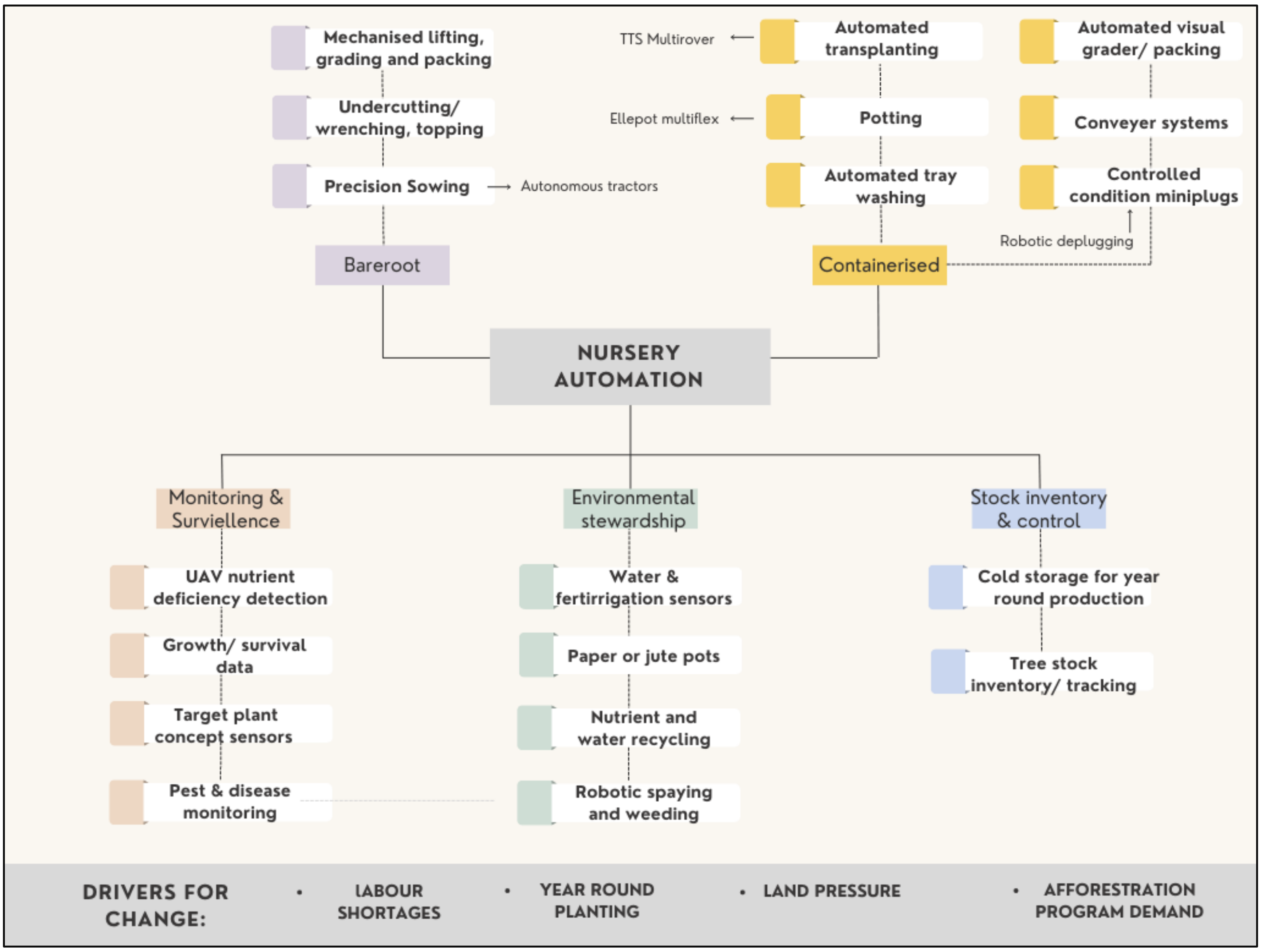


Figure 1. Key considerations identified for nursery automation referenced in this survey.

Automation and key considerations

The operations in nurseries and greenhouses that can be enhanced with technology can be divided into two main categories: i) mechanisation and ii) automation.

i) Mechanisation is defined as the replacement of a human task with a machine (Porter, 2002), although people can still be critical throughout the entire process. Mechanisation of an operation can provide mechanical power, speed, repetition, safety, and a greater potential for consistency and quality control. Some examples include seeding machines, bed formers, tray washers, potting machines, conveyor systems, watering systems, de-pluggers etc. The outcomes are immediate and tangible, such as significant efficiency gains, labour savings and the consistency delivered by machinery can result in a better-quality product that can be sold for premium prices. Mechanisation can be an appealing option for small scale to large scale production nurseries. As illustrated by an industry survey in the USA there are significant barriers to investment in mechanisation and automation technologies (Posadas et al., 2008). The first and most significant is the cost of purchasing the required equipment and/or infrastructure, and secondly and most notably for bareroot crops is a lack of suitable options for current operations (Figure 2). Discussion of technologies for nurseries should therefore focus on cost reduction and development of suitable industry relevant interventions which address high priority bottlenecks and have a good business case support for investment. However, ensuring good plant quality in each process is paramount.

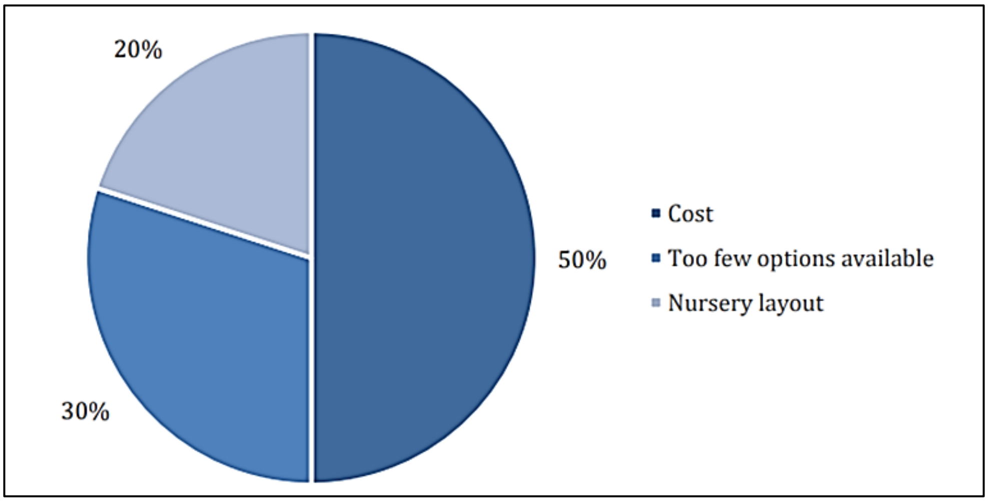


Figure 2. Survey results of a USA study on barriers to investment in mechanisation and automation in bareroot nurseries (from Josefsson (2019); and Posadas et al. (2008))

ii) Automation involves the entire process, integrating several operations and ensuring that various parts communicate with each other to ensure smooth operation with minimal human assistance (Posadas et al., 2008). This includes bringing material to and from the mechanised equipment. True automation requires re-evaluating and changing current processes rather than simply mechanising them. Automated modules with a range of different technologies such as GPS (Global Positioning Systems) technologies, machine vision, navigation, actuation, monitoring, communication, and control technologies best suited for mass production. Globally the horticulture industry is embracing these technologies and it is likely they can be adapted for forestry. However, the capital costs of full automation can be seen as prohibitively expensive for NZ nurseries, as the scale of production is significantly lower in comparison to the horticulture industry.

Benefits of automation:

- Increases the efficiency by faster and more prolific production.
- Reduces the risks of climatic exposures (cold and hot extremes) and provides safer working environments, less trips and slips.
- Automation combined with appropriate sensor technologies for improved product quality and consistency. Poor quality plants can be identified and removed.
- Replaces repetitive or complex tasks.
- Increases the ability of nursery managers to deploy labour smartly.
- Upskilling staff by moving them away from hard, repetitive work and engage them in managing the process.
- Sustainable production through precise control and efficient use of water and fertiliser.
- Automation and use of greenhouses help to meet increasing demand for land.

When automating a process, considerations should include:

- ✓ Current and future production capacity;
- ✓ Consideration as to whether (full) automation is necessary;
- ✓ Cost of the capital investment versus revenue gains due to increased efficiency.

It is important to evaluate the entire production process to identify existing and potential bottle necks. Automation at one point of the production line might create additional bottle necks down the line. Most nurseries we interviewed showed around 80% mechanised production and 20% manual production, to achieve optimal cost-benefit results.

Automation and mechanisation can also encompass lean manufacturing processes, and procedures, improving efficiencies and reducing biosecurity risks while also creating ergonomically suitable work for employees and eliminating repetitive strain.

Some of the key tasks suited to automation include: Media preparation; Filling containers with substrate; Cutting and seed collection; Cutting and seed preparation; Placing plant liners; sticking cuttings and planting seed; Environmental control; Moving containers from potting to transport vehicle for movement within the nursery; Transporting containers within nurseries; Removing containers from transport vehicle and placing in the field; Spacing of plants and containers; Harvesting and grading production; Picking plants up and loading onto transport vehicle at time of sale; Removal of plants from transport vehicle and placing in holding area; Picking up plants from holding area/transport trailers and loading onto delivery vehicles; Plant pruning; Fertiliser application; Pesticide application; Irrigation application and management (Posadas et al., 2008).

When prioritising investment in improved mechanisation and automation we recommend ranking the processes, such as those listed above, by proportion of time spent by employees in each area.

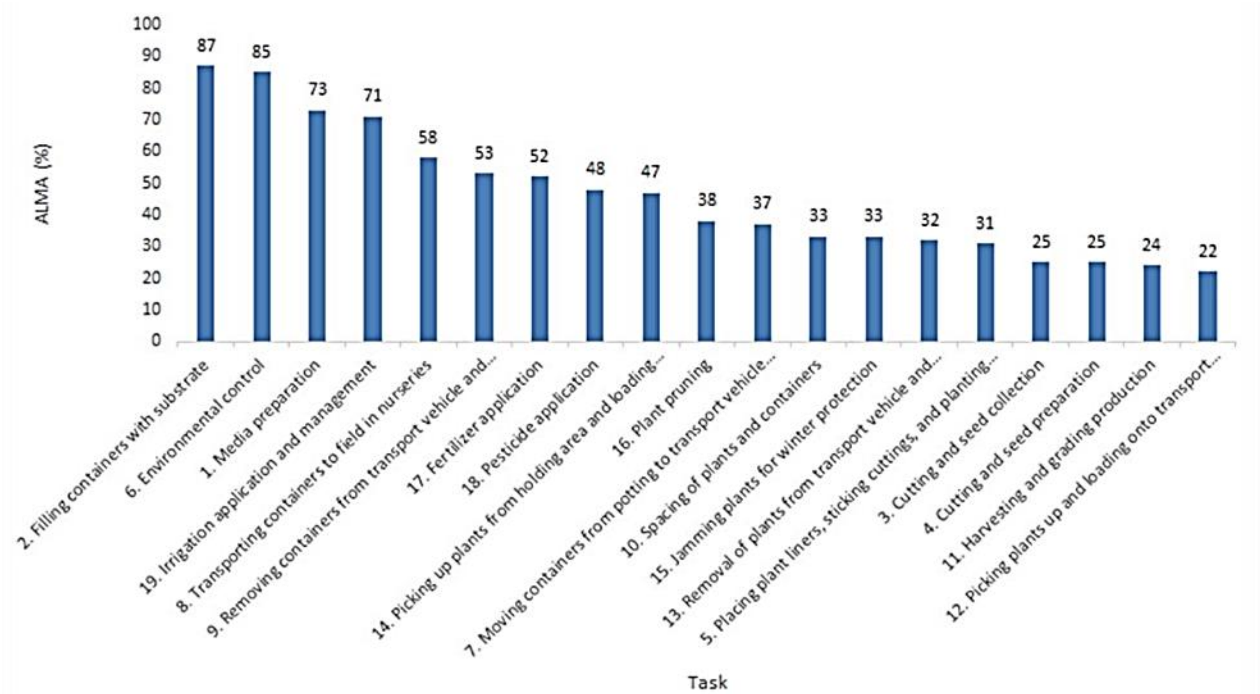


Figure 3. Survey results of a USA study on level of mechanisation in activities in containerised nurseries, ranked from highest to lowest (from Josefsson (2019); and Posadas et al. (2008)).

Prior to introducing some form of mechanisation, it is a good idea to visit peers, trade shows, overseas nurseries and learn from them; sharing challenges and solutions. Inviting specialist companies (listed in the second to the last section) to visit your business and provide expert input can be very insightful. In this report we have provided weblinks for nurseries and links to YouTube videos for further information.

The following are key critical hardware components when planning for automation:

- The choice of growing method/container – does it have the correct features to achieve required species specifications?
- Mechanised production system – balancing the scale of automation and mechanisation based on the production requirements.
- Propagation facilities – type of growing facilities (e.g. greenhouse, tunnels and net houses), features to be included, surface areas, layout and orientation, etc.
- Support systems – gutters, fixed tables, rolling benches or stationary growing frames
- Handling systems – most applicable equipment and facilities needed? does it dovetail with the production line and support systems? are operational flows optimised in the nursery?
- Irrigation and fertigation – most appropriate system for the specific propagation stage.

Overview of common New Zealand forestry systems mechanisation and automation states

The two main nursery production systems used in New Zealand have varying degrees of mechanisation and automation in their current operations. Table 1 illustrates a general view on the degree of mechanisation and automation of these nurseries in New Zealand. There are some exceptions to the generalisations listed below, and these are discussed further later in this report.

In general, bareroot nurseries have successfully employed mechanisation to address some bottlenecks in their operations, like bed preparation and sowing, but have struggled to mechanise other operations like lifting and packing. The nature of the open-air operation and lack of mechanisation in some areas has meant that automation of operations has been very limited in bareroot nurseries. The most significant development in bareroot automation has been the advent of satellite navigating, self-driving tractors doing bed preparation and sowing operations, as first employed at Patrick Murry's Nursery in Tararua. One of the main difficulties with mechanisation and automation of bareroot operations is that, other than the USA which is at a similar level of development to New Zealand, there has been little global development of bareroot associated technologies, and hence would often need to be developed from scratch by individuals in the industry. For smaller operations, without and industry co-ordinated effort, this is often prohibitively expensive.

Containerised forestry nurseries in New Zealand have, for the most part, taken their lead from other international forestry nurseries as well as general horticultural practice but have adapted to grow *P. radiata* seedlings and cuttings to meet the New Zealand forestry need (which is significantly shaped by our long history in bareroot production). Most of the containerised nurseries in New Zealand are a combination of fully enclosed (and automated) propagation greenhouses and open growing tables. As with the bareroot crop, some key bottle necks like tray filling and seed sowing have already been mechanised and partially automated using industry standard (and readily available) horticultural machinery. Partial mechanisation at lifting also applies here where de-plugging is completed by a machine but final lifting and packing is done by hand. One of the main benefits of containerised growing, in terms of being able to mechanise and automate operations, is that almost all the opportunities have been developed and tested elsewhere in other horticultural applications.

Table 1. Most common present state of mechanisation and automation in bareroot and containerised nurseries in New Zealand.

	Bareroot Nurseries	Container Nurseries
Fully Mechanised and Automated		• Environmental control (Temperature, Humidity) • Frost protection
Fully Mechanised and Partially Automated	• Irrigation	• Filling containers with media • Sowing seed • Irrigation and fertigation
Fully Mechanised but not Automated	• Soil/Media preparation • Bed shaping • Sowing seed • Loading and offloading containers • In-nursery transport of plants • Topping • Fertiliser and pesticide application • Stoolbed maintenance	• Soil/Media preparation • Loading and offloading containers • In-nursery transport of plants • Topping • Fertiliser and pesticide application • Stoolbed maintenance
Partially Mechanised and Partially Automated	• Frost protection • Undercutting and lateral pruning	
Partially Mechanised but not Automated		• Lifting[1] • Plant packaging for dispatch
Not Mechanised and not Automated	• Cutting collection and transport • Cutting and seed preparation • Sticking cuttings • Environmental control (Temperature, Humidity) • Pest and disease monitoring and management • Nutrient status monitoring and management • Lifting • Plant grading / quality assessment at lifting • Plant packaging for dispatch	• Cutting collection and transport • Cutting and seed preparation • Sticking cuttings • Pest and disease monitoring and management • Nutrient status monitoring and management • Plant grading / quality assessment at lifting

[1] Lifting describes the process of extracting seedlings from the nursery and preparing them for storage (short or long term) so they are available for planting. Bareroot and container seedlings go through different lifting processes. In contrast to container seedlings bareroot seedlings are typically exposed to a number of operational steps during lifting that can affect their root system (Grossnickle & El-Kassaby, 2016).

International forestry nursery production systems

Historic global trends and drivers in propagation technology changes

New Zealand plantation forestry systems are often compared to parts of Australia, South Africa and countries in South America due to similar growing conditions and species. Recent studies show that these countries have almost entirely moved away from bare-root production and are successfully using containerised growing systems (Klinger, 2022; Klinger, Ford, Lloyd, & Nanayakkara, 2021).

In recognition of the critical role of forests in addressing challenges imposed by climate change the Bonn Challenge and The New York Declaration of Forests aim to restore 350 million ha worldwide by 2030 (Grassi et al., 2017). Many other countries have joined such global efforts in afforestation e.g. Chile has pledged "to afforest 100,000 ha mainly with native species" by 2030 (Acevedo et al., 2021) or Canada's 2 billion tree programme. This scenario has created increased demands for forestry nurseries to produce larger quantities of high-quality planting stock. For these reasons automation and mechanisation combined with containerised production have become increasingly important in production forestry in countries such as Australia, South Africa, Argentina, Spain and some Asian countries such as Indonesia.

Traditionally, in Europe, much of the bareroot stock was produced by government-owned nurseries, while container stock was often produced by privately owned nurseries (Mattsson et al., 2010). In many European countries, cost efficiency in the production of forest regeneration materials is low due to the broad range of species, provenances and stock types which have reduced capital investment.

Modern greenhouses in horticulture are intensive farming systems designed to achieve high efficiency and productivity, where plants are produced year-round by maintaining the environment at or near optimum levels regardless of external weather conditions (Nemali, 2022). Numerous discoveries and technological advancements over the past two centuries paved the way for current state-of-the-art greenhouses with improvements like climate-specific structural designs and improved glazing materials, and temperature control, artificial lighting, and hydroponic production systems (Nemali, 2022).

Research in plant specifications and establishment trials have also led to changes and different requirements for plant material from nurseries. Scion has recently undertaken container-type trials (Ford, Lloyd, & Klinger, 2022) to address New Zealand's dependence on large containers (such as the 1200cc+ PB2) for effective indigenous plant establishment. Large containers, despite its inefficiencies is deeply ingrained in forestry requirements due to historical failures in shifting to smaller plant stock and the additional precautions required to manage just prior to planting. An important hurdle is also the inability of smaller stock to compete with weeds. In addition, poor plant quality in regard to root development (e.g. spiralling) resulting from mistakes made in container design in the early days of container growing. Despite being resolved, it has led to a reluctance to use small containers (Harris, Clark, & Matheny, 2004; Mathers, Lowe, Scagel, Struve, & Case, 2007; Wezel, 2013). However, with more research in land preparation, silviculture, site suitability and post-planting maintenance, we are finding that some species can be established consistently well in small retail grade containers (125cc). This is a significant cost reduction of 89.6% in growing media alone. Cost savings, however, exist across the whole forest establishment pipeline with smaller trees grown at a higher density requiring less space within the nursery, less trips for transport. Additionally, at planting, teams can safely carry ~100 seedlings at once compared with a handful of PB2's. Furthermore, only seedling trays can maximise current and emerging automation and mechanisation technologies. Shifting towards smaller grade seedlings for large-scale indigenous forest establishment is the most practical and efficient solution for achieving the 1 Billion Trees commitment by 2030, while also reducing our reliance on single-use of plastics in indigenous horticulture.

Indigenous planting efforts have increased in recent years and this will be hastened by the governments proposed amendments to definitions of permanent forests under the emissions trading scheme. An adjustment which, if successful, will result in an immense demand for indigenous planting stocks, putting pressures on an industry which is not yet operating at that scale.

For nurseries in New Zealand to grow to meet this inevitable demand for indigenous planting stock, sustainably, requires a collaborative effort across many industries and government. The possibility to shift away from cumbersome retail-grade container types to smaller grades is no better demonstrated than in Podocarpus totara, an indigenous conifer with huge potential for commercial timber production and great suitability for smaller container grades (Figure 4). In recent field trials, some species demonstrated poor survival in smaller containers, but we believe these seedlings (i.e. wineberry), spent too long in too small containers, and their poor survival in the field was a result of root deformation in the nursery. This research has led to a further round of trials which will include raising period as a co-variate, thereby demonstrating whether some species can cope well in smaller containers when the crop raising period is reduced. The results of this next round of trials will assist in generating recommendations for the commercial production of indigenous species. In addition, some matching of species and their rooting habits (woody versus fine feeding roots) to pot type and size is likely to be required. Whether a single regime and specification will be found across all species is yet to be determined.

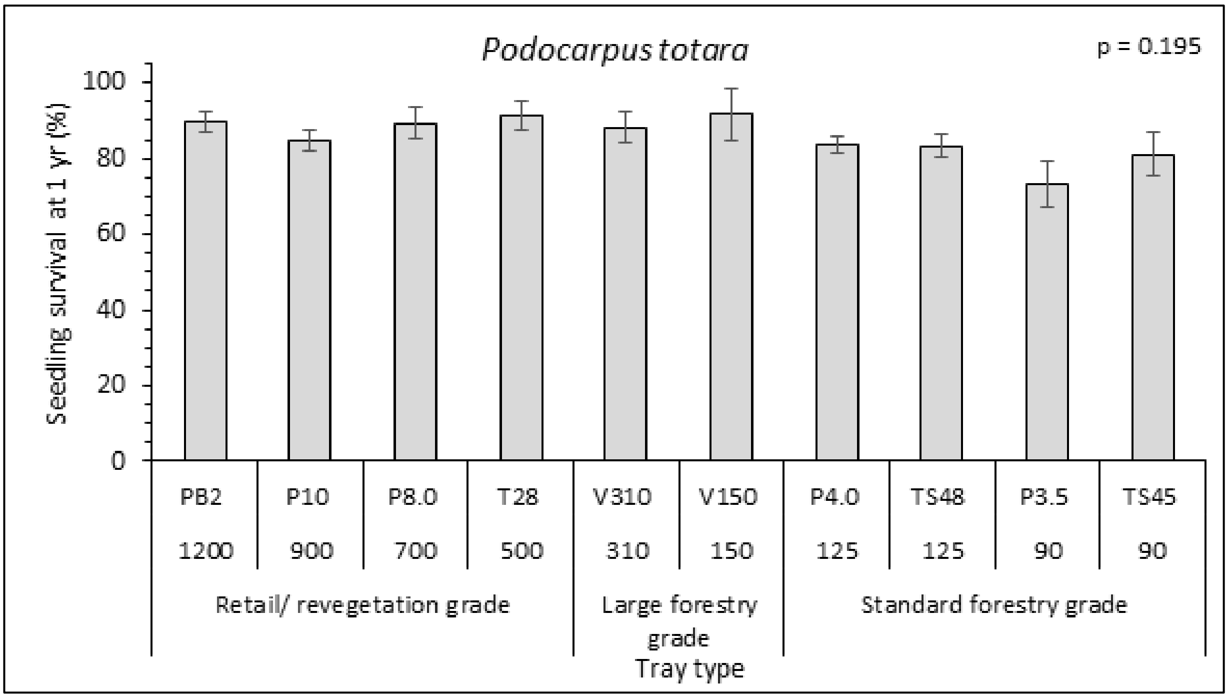


Figure 4. 1 Year seedling survival (%) of *P. totara* by container type (note the *p* value suggests no significant differences). From Ford et al. (2022)

Miniplug growing systems

A miniplug system is a pre-cultivation method for year-round production of forestry stocks. The term 'plug' describes a plant raised in a container where a root mass is produced that holds the rooting medium together by the time plants are ready to be dispatched. Miniplugs are used to establish seedlings into larger containers or grow further in bareroot growing facilities. Seedlings are cultivated in mini-containers (plug volume 16-33 ml, depending on the species) in closed growth facilities, or "plant factories", where growth conditions (temperature, humidity, light intensity and quality, and duration of photoperiod) can be optimized according to the requirements of each plant species. Miniplugs are cost-efficient and environmentally friendly.

The benefits of using miniplug nursery systems has been clearly demonstrated over time, such as fewer culls, high plant density per production area, maximum efficiency of seed or cutting use, shorter crop rotation, improved stock quality and the ability to withstand cold storage (Landis, Dumroese, & Haase, 2010; Mattsson et al., 2010). An additional benefit of miniplug seedling production is that it enables automated transplanting, either in the field or into larger cells (plug to plug automated systems). The PREFOREST project in Europe has developed a functional prototype for mechanisation of large scale forest stock production by integrating a miniplug system, grading technology and a deplug robot (Mattsson et al., 2010). The system has been developed for year-round production and functions in the same way, independent of climatic variations in different parts of Europe. Increasing labour, biosecurity and environmental pressures have begun to phase out bareroot nurseries. For example, where Europe has traditionally cultivated bareroot stock, the proportion has been in decline since the 1990s (Mattsson et al., 2010).

Miniplug transplanting

Transplant Systems (Australia and New Zealand) and Transplanting services (Netherlands) provides a range of automatic outdoor transplanters, which are called multi-rowers. https://youtube.com/channel/UCmLkYv9caUqBsmPcsvVTSzA

High-density transplanter designed for planting forest cuttings raised in 256 cell trays (https://www.transplantsystems.com.au/nursery/trays/injection-molded/forestry-1/ts-256f) planting 8 rows across the bed with 10 cm between the rows and 5 cm between the plants along the row. The plant spacing between the rows is fixed at 10 cm and plant spacing along the bed can be adjusted. The only labour required is the tractor driver and an operator to feed the full trays into the receiving cassette and remove the empty trays. The cell form is square with a central raised fin from top to bottom on two opposing walls. The base of the cell has no media catch to prevent root distortion as roots go straight through and are air pruned.
https://youtube.com/shorts/x8hU-T-MRTs?feature=share

Figure 5. *HD 256* Automated transplanter. https://www.transplantsystems.co.nz/field/automatic-planters/Auto

International case studies in forestry propagation

Case Study 1: Maelor Forest Nurseries Ltd, UK

Maelor Forest Nurseries Ltd is the largest commercial forest tree nursery in the UK – selling approximately 35 million trees a year from its 200 hectare site in Wrexham, on the Welsh Borders and 70 hectare site based in Forres, Scotland. The nursery has invested £4 million in a new miniplug production facility, consisting of three elements: a seed sowing line, covered growing area, and outdoor hardening off space. All three elements are connected by a roller bench system, significantly reducing manual handling of trays.

Maelor successfully conducted field trials which included auto-planting over 5 million miniplugs between October 2020 and April 2021. Those trials demonstrated excellent yield and consistency of the crop and enabled approval to be given to the creation of the new facility. Work on the construction of the miniplug facility was commenced in summer 2021 with a target completion date of spring 2022. The first crops from the facility are expected to be dispatched to customers in winter 2023/24.

https://www.maelor.co.uk/resource-hub/blogs-and-articles/who-is-maelor-forest-nurseries/

https://www.maelor.co.uk/resource-hub/our-news/new-tree-production-facility-to-fulfil-industry-leading-aspirations/

Case study 2: Fibria, Brazil

Figure 6. Fibria nursery in Brazil, lifting frame

Fibria a Brazilian forestry company and the world's leading eucalyptus pulp producer has a fully automated nursery attached to Três Lagoas Unit in Fibria, located in the state of Mato Grosso do Sul. Fibria has partnered with Dutch consortium Hortikey (https://hortikey.nl/?lang=en), which develops large-scale automation projects for companies in the international market. The nursery features latest-generation technology from the Netherlands for automating the entire eucalyptus seedling production process and is an unprecedented initiative in the industry. The facility has approximately 48,000 m² of greenhouses and fully automated transportation (conveyor belts), handling, selection, irrigation, nutrition and climate-control processes. This nursery is equipped with two Ellepot- NGL fully automatic productions systems capable of potting 50,000 paper pots per hour combined with robotic planting capable of producing 43 million seedlings per year, planted for pulp production.
https://www.youtube.com/watch?v=-gQFVR_QhYc

This nursery has state-of the art automation, such as high precision control of irrigation and climate via the use of automated panels, and machinery equipped with 3D vision to monitor the development of the seedlings and improve cultivation efficiency. The new system will generate statistics on the genetic material and development of each plant, which will assure Fibria greater quality control of the seedlings.

The following 8 case studies (No. 3-10) were provided by Darran Stone (Ellepot)

Case Study 3: Sappi Forests, South Africa

Sappi is a global forestry company, headquartered in South Africa. It is the largest forestry company in South Africa and propagates 60 million plants per annum from its four nurseries. Sappi has been on a modernisation drive at its nurseries, having completed the rebuild of their Clan and Ngodwana nurseries, with a focus on clonal hybrid cuttings. Sappi purchased two of Ellepots latest technology for Forestry, the FlexAIR machine, which provide industry leading production capacity (28,000 pots per hour for a ø30mm x 90mm pot) and produce a softer paper pot, that is better suited to cutting propagation. A custom designed Ellepot forestry tray was developed to be compatible with their existing infrastructure and logistics. There are plans to further modernise nursery operations and the movement of plants from nursery to field as field mechanisation is increasingly adopted.
Degree of automation: Medium (60-70%)
https://www.woodbizafrica.co.za/february-2021-issue-1/#wba-feb-2021-issue-1/4/

Case Study 4: Montes del Plata, Uruguay

Montes del Plata in Uruguay adopted, in 2011, the Ellepot technology for their 100% Ellepot based forestry nursery for Eucalyptus cuttings production. They have the capacity to produce 20 million plants each year. Integration with a rolling bench system allows for increased efficiency through all stages of production.
Degree of automation: High (80%)
https://www.youtube.com/watch?v=DJcVuXdKa-U

Case Study 5 – Rumpin Central Nursery, Indonesia

The Rumpin Central Nursery in Indonesia, designed and constructed by Ellepot Indonesia partner Massgro, has a capacity of 12 million seedlings per annum. An Ellepot H111 is installed to produce Ellepots with diameters of ø50mm using the Ellepot Global Air Trays. Commissioned by the Indonesian government, the aim of the Rumpin Central Nursery is to highlight examples of modern automation techniques.
Degree of automation: Medium (50%)
https://www.youtube.com/watch?v=eZaWE9EW090

Case Study 6: Sinarmas Forestry, Indonesia

In 2015 Sinarmas began working together with Ellepot to implement paper pot technologies in their nurseries. An Ellepot H111 is installed at one of their central nurseries producing approximately 450,000 Ellepots per month. Ellepot developed a 96-cell Forestry tray specifically for the Indonesian Forestry Industry for use by Sinarmas and other Indonesian Forestry companies.

Case Study 7: CPS Seedlings, South Africa

CPS Seedlings is one of the leading forestry nurseries in South Africa, producing approximately 15 million forestry seedlings and cuttings for forestry companies. CPS have modernised their seeding & cutting production facilities and invested in an Ellepot FlexAIR production line that produces paper pots for both seeding and cuttings. Ellepot and CPS have worked together to optimise the seeding operations on the paper pot line, leading to significant gains in nursery yields and plant uniformity.

Degree of automation: Medium (60-70%)
https://www.woodbizafrica.co.za/april-2021-issue-3/

Case Study 8: TWK Sunshine Seedling Services, South Africa

Sunshine Seedlings is part of the TWK group, one of South Africa's leading agricultural companies. Sunshine Seedlings produce 17 million forestry plants per annum, 10 million of which are clonal hybrid cuttings. Sunshine Seedlings have installed Ellepot's new 16 Line FlexAIR technology to meet industry's demand for paper pots.
Degree of automation: Medium (60%)

Case Study 9: Ezigro Seedlings, South Africa

Ezigro Seedlings is another leading supplier of forestry plants to the South African forestry industry, with several propagation sites across the country. Ezigro produces approximately 30 million forestry plants per annum, consisting of softwood and hardwood seedlings, clonal hybrid cuttings and pine hybrid cuttings. Ezigro have adopted Ellepot's new Flex AIR production line and forestry trays to meet industry demand for paper pots. The high production capacity of Ellepots 16 line machine provides the required efficiency in seeding and placing operations.
Degree of automation: Medium (60%)

Case Study 10: Sutherland Seedlings, South Africa

Sutherland Seedlings is a leading supplier of forestry plants to the South African forestry industry and propagates approximately 8 million forestry plants per annum. Sutherland Seedlings have adopted Ellepot's reliable EPM production line, capable of producing Ellepot for cuttings and seeding.
Degree of automation: Medium (60%)

The following case studies (No. 11-15) were provided by Heinz Reinstorf, Africa/South East Asia area manager of BCC and Forest Nursery Specialist, in conversation with BN on 22-03-22.

Case study 11: Kerinci Central Nursery 2, Indonesia

Kerinci Central Nursery 2 – one of the four central nurseries owned by RAPP (Riau Andalan Pulp and Paper), Indonesia. RAPP's nursery technology allows production of acacia and eucalyptus trees from eight to twelve-week-old seedlings to harvest within five years. 40-50 million/yr and 250,000-300,000 cuttings per day.

Fully integrated nursery (Tray washer, tray stacker/destacker, batch mixer coupled with a flexifiller), with flow through roller bench systems using conventional tray-inserts and vegetative propagation. Cutting and setting is done manually in covered space and trays loaded by hand to trolleys and sent over to humidity-controlled greenhouses with misting and kept for 3-4 weeks for rooting. Then the cuttings are sent over to 2nd stage of propagation area with plastic covers on the top but with

side openings to air for 2 weeks, Finally they are transferred to open air space and kept for 4-6 weeks and irrigated with booms.
Grading and packing are done manually.
Handling inserts in the production system is labour intensive.
Degree of automation: medium level of automation (60-70%)
https://jakartaglobe.id/opinion/trees-making-closer-look-rapps-central-nursery

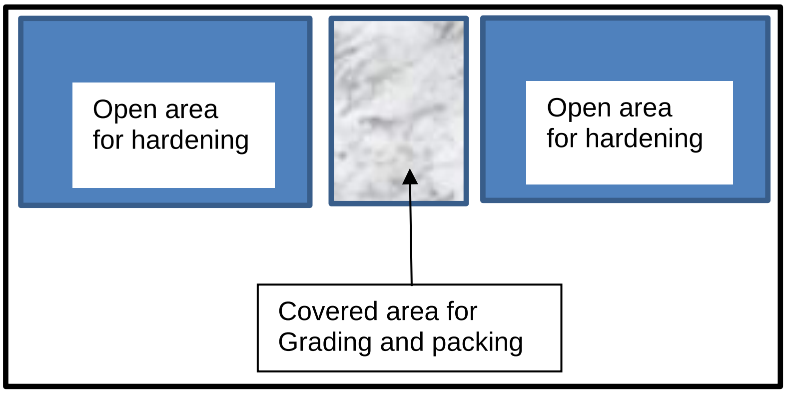


Figure 7. Nursery layout of Kerinci Central Nursery

Case study 12: Sinarmas Forestry, Indonesia

Sinarmas Forestry in Indonesia operates a range of nurseries from decentralised small-medium units (10-15 million plants annually) to large centralised nurseries (30-50 million plants annually).
The company has been increasing its mechanisation over the past two years and installed new integrated production lines for 6 of their nurseries (based on conventional trays with inserts).
The company has further implemented the degradable paper growing system provided by BCC, FiberCell, in their central nurseries producing 30-50 million/yr. To date three units of 8-Row Fibercell fully automated integrated production lines have been installed and commissioned.
Manual grading and selection, spacing of plants and packing.
Degree of automation: 80-90%

Case study 13: Government nursery Rumpin, Indonesia

A government nursery with 12 million/yr capacity in Rumpin, Bogor.
The production line consists of a complete tray washer, batch mixer with feeding belt, FlexiFiller and manual workstation (for setting cuttings). The nursery uses a locally manufactured tray with individual inserts which required customisation of the BCC FlexiFiller.
Degree of automation: 50%
https://www.bccab.com/2022/03/14/new-modern-forest-nursery-up-and-running-in-rumpin-bogor-regency-in-indonesia/

Case study 14: Arauco, Chile

Radiata pine nursery in Concepcion, Chile owned by Arauco pulp and paper. Nursery produces about 300-350k cuttings/day, and 25- 50 million/yr. The nursery is about 1.5km long (covers more than 12ha). It started as a bareroot nursery and is now fully containerised and has a mix of about 30% tray-inserts and 70% paper pots. There have been stepwise changes in the production such as introduction of 2007 tray-insert automation system from BCC followed by Ellepot paper pots in 2011 and in 2015 FibreCell line was installed, which has led to the significant increase in the production (Figure 13). The nursery is in the process of evaluating automated grading solutions and has plans to use iso robots for setting cuttings (https://www.iso-group.nl/en/machines/iso-robot-plug-planting-machine). This nursery is an example where a mix of technologies are used simultaneously.

Degree of automation: 80%.

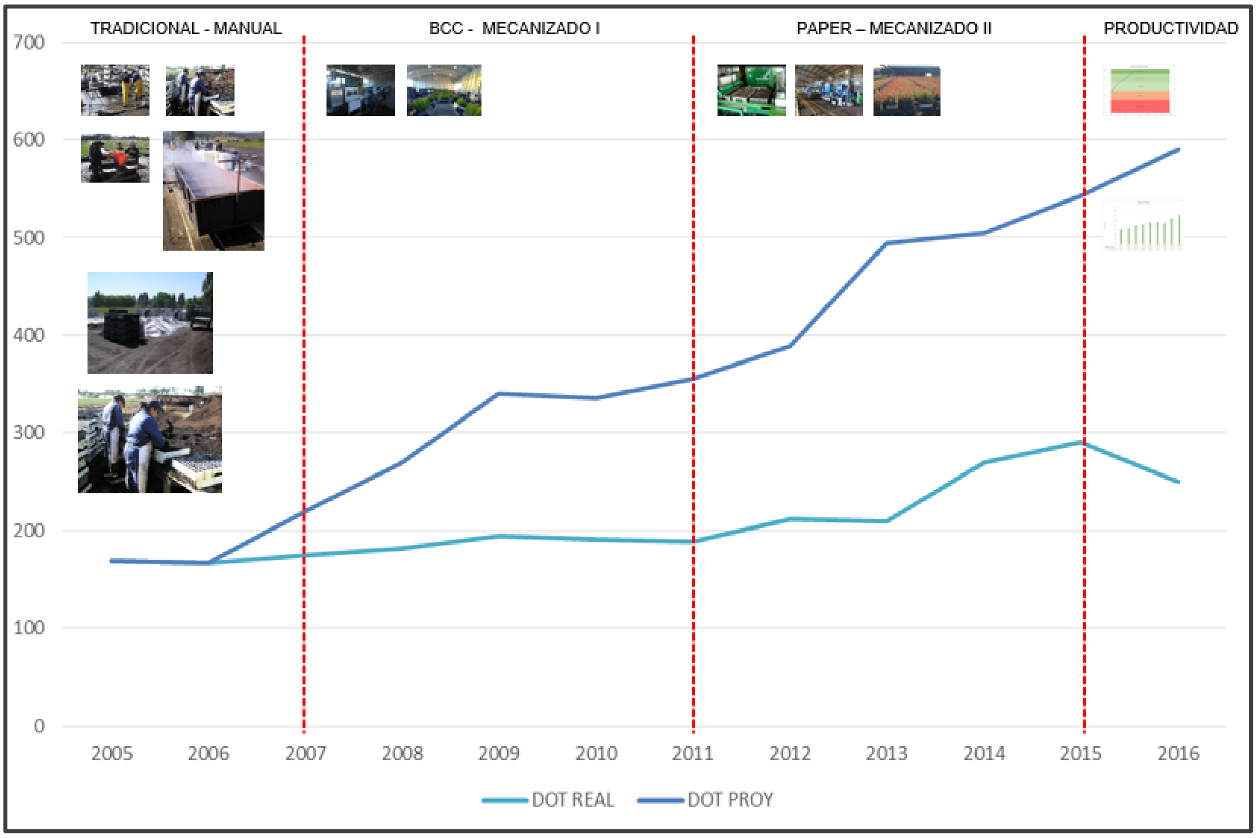


Figure 8. The relative increase in productivity using progressive introduction of different automation systems (dark blue) in comparison to the scenario of manual production (light blue).

Case study 15: Fully automated Nursery, Sweden

A fully automated nursery in Sweden with miniplugs and transplanting systems (10-20 million/yr). A real success story of efficient use of greenhouse space and energy by using high density miniplug systems for seeding in greenhouses in March when there is still snow on the ground. Nursery has steel frames for storing miniplugs that can be stacked on top of each other as pallets. Pallets are moved around with forklifts. After germination of the miniplugs, pallets are moved back to the central production shed where miniplugs are automatically transplanted to larger trays (90cc cavity). Trays are automatically placed onto pallets and moved into the open holding areas for growing.

At the end of the growing season, plants are moved back to the central production shed where seedlings are treated with glue and sand (Conniflex) as a protection mechanism against pine weevil. (https://www.bccab.com/products-planting/conniflex-2/).

Sweden forestry is free of chemicals.

After treatment, fully automatic packing of seedlings into cardboard boxes including palletising and wrapping before seedlings are moved to cold storage facilities for overwintering before transplanting in spring.

Degree of automation: 95-100%

Case study 16: Lieco Group, Austria/Germany

Lieco Group ('Lieco containerised seedlings' and 'Luerssen forest plants') is the leading enterprise for successful afforestation in the DACH region (Germany, Austria and Switzerland) with over 30 years of experience and expertise. Currently they sell more than 28 million seedlings annually which are cultivated on more than 335 hectares with around 250 employees in 6 locations in Germany and Austria (LIECO Group, 2022).

Lieco containerised seedlings are market- and technology leader for containerized forest seedlings in central Europe. Unlike New Zealand plantation forestry with predominantly one species Lieco produces over 30 different forestry tree species, several shrub species and has up to 70 different provenances for a single species (Hartleitner, 2022, pers. comm). Trees grow in the nursery for 2-4 years before dispatch which requires transplanting to bigger containers usually after 1-1.5 years. In addition, different container types have been developed by Lieco to account for the various species-specific characteristics and to tailor the root needs of the respective tree species. Therefore, transplanting is also carried out manually.

Figure 9 (right). Different container types are used for different species and stock types; this makes automation in the nursery a challenging task, Small L67 containers (~50 cm^3) are used for sowing (brown). After germination and growth, the plants are transplanted into the bigger L15 containers ("L15 red" - optimized for pine, larch and Douglas fir; "L15 blue" - optimized for fir and hardwood); Image © Lieco

Figure 10 (left). Germination in small sowing containers L67 in controlled environment before transplanting to larger container types; Image © Lieco

This diversity of species, provenances and species-adjusted containers makes automation a challenging task. Despite of this complexity Lieco has automated several processes in its containerised nursery.

Automation processes

The high-quality seed is sown fully automated in the LIECO containers. The containers are automatically filled with a specifically designed substrate mixture. After sowing, the containers are automatically placed on a ventilation frame via a conveyor belt. These are then brought into the greenhouses with forklifts. In the greenhouse's germination takes place under optimized and controlled conditions (approx. 4 - 8 weeks) which enables LIECO to achieve high yields and make the best possible use of the valuable seeds while maintaining genetic variation.

Figure 11. Controlled environment and automated irrigation and nutrient supply; Image © Lieco

After germination in the greenhouse the plants are transferred to the open spaces for outdoor growing. Depending on tree species and origin, outdoor cultivation can take up to 2.5 years to produce a suitable target plant; all container sites are equipped with computer-controlled irrigation systems which ensure an even water supply for all plants. This technology and an optimized nutrient solution ensure a natural nutrient supply. With this system, plants continue to grow in the larger containers for another ~2 years and form a non-undercut root system.

It is important to recognise Lieco doesn't use an automated process for de-plugging seedlings in the nursery for dispatch. Their experience suggests using an automated de-plugger compresses and therefore harms root development and leads to instability of the trees after planting (Ramskogler 2022, pers. comm.). Lieco deliberately uses recycling container trays which allow the seedling to remain in the trays until they are planted in the field. To facilitate that with an ergonomic and practical-oriented approach, Lieco has also developed a carrying system and a special planting spade for their containers.

Forestry nursery production systems status in New Zealand

Recent developments in forestry propagation in New Zealand

In 2019, 88.8 million plants were sold of which 95% was radiata pine with the rest made up of Douglas fir, hardwoods and other exotic species such as coastal redwood and cypress (Ministry for Primary Industries, 2020). According to a recent survey around 88% of radiata have historically been produced as bareroot and 12% containerised, although in 2020/2021 production season this has increased to 18% (Bayne, 2021). There is an increasing trend towards containerised systems due to many advantages over bareroot systems (Klinger et al., 2021). The first step towards the automation of nursery automation should be the culture shift of bareroot production to containerised production (Klinger, 2022). The most cited reasons in literature to move away from bare-root technology are the reduced production period with containers in the nurseries and an increased use of cuttings (Klinger, 2022; Mead, 2013). However, according to nursery managers in Chile, Argentina, Australia, South Africa and New Zealand, labour shortages, skills, automation and the ability to extend the planting season using container-grown trees seem to be the key drivers to implement containerised growing systems (Klinger, 2022; Klinger et al., 2021). In addition, mechanised planting, which is of growing relevance for some companies, requires containerised plants (Klinger et al., 2021). Ergonomics at the workplace is becoming more important especially when labour shortages arise, and the labour demand is expected to rise. Thus, automation and containerisation can lead to more pleasant and ergonomic working conditions in sheds and at elevated propagation tables compared to crouching in the bare-root beds (Klinger, 2022).

A review on automation in NZ nurseries was carried out in 2018 under the GCFF program (Smaill, 2018). This report was mainly focussed on the automation at one nursery to their bareroot production system. It was reported that progress made in automation varies significantly with major NZ nurseries using bareroot production systems that are mechanised to varying degrees. Some simple systems are already in operational use, and more complex systems are starting to be used to carry out multiple nursery tasks. However, it was emphasised that more time and resources will be required to produce the packages of automated systems required for a step-change in nursery management.

Case studies of NZ nursery automation

Bareroot production:

Case Study 17: Murrays nursery in Tararua

This is a bareroot pine nursery at the forefront of automation of bareroot seedling production with virtually all aspects of operations now automated except lifting. A 39-ha nursery producing around 15 million seedlings per year with a maximum capacity of 17 million. Automation of production has enabled an increase from 9 million to 15 million units. One of the main reasons for automation was to be resilient to changing demands of forestry stock as operations can be scaled up or down without having to deal with labour issues. With the current automation only two staff members are required to produce 5-7 million seedlings. The nursery has invested heavily in the automation of key processes such as seed sowing, topping, root pruning/undercutting and spraying, enabled with various attachments, specifically designed by Murray's nursery engineers, to a GPS guided tractor with a single operator. Use of GPS has enabled positioning of seed down to 20 mm accuracy and the speed of pruning and undercutting is been exponentially increased using tractor speeds of 7km/h. Production capacity has also been significantly increased by having 10 row beds instead of standard 8 row beds (Figure 12). This was achieved by designing and engineering a 10 row vacuum seed sower and the installation of RTK GPS system with implement steering for precision sowing. Robotic harvesting of seedlings can be possible with this degree of precession. A GPS driven tractor would cost around $250k and the full system with various attachments would cost around $500-600k. Taking into consideration the price of land in the area ($50,000/ha) the productivity gains will easily pay back the investment. Patrick Murry has formed Energise Technology for developing a range of automation such as setting up plugs and harvesting, which might be available for sale.
https://www.murraysnurseries.co.nz/pine-tree-nursery-growing-pine-tree-stock.html
https://www.youtube.com/watch?v=luoVrN5lAWs

Figure 12: 10 row seedling beds retrieved from https://www.murraysnurseries.co.nz/ on 05-04-22

Northland Forestry Nursery (Kevin Strawbridge) - Northland Forestry Nursery - YouTube

Figure 13. GPS guided tractor with bed preparation (back) and seed planting (front) modules. All modules are mounted on lateral actuators that precisely maintain the position of the modules relative to the seed bed being formed. Retrieved from https://www.murraysnurseries.co.nz/ on 05-04-22

Containerised systems

Case study 18: KT (Kaingaroa Timberlands), Te Ngae Nursery, Rotorua

This nursery produces 2-3 million containerised stock out of the gate annually. Three million is the upper limit and two is more common. Production is a mix of clonal or family cuttings and seedlings. Containerised systems have advantages for expanding the planting window and the compatibility with automated out-planting in KT's forest estate e.g. M-Planter. The automated nursery system is designed as a lean flow system, people are stationary, and the machine moves trays around. The system cost about $5 million in 2016 and with current labor costs the automation would be paid off in around 5 years (Roberts, personal comms). Though this nursery is presented as a containerised case study, Te Ngae's main production is bareroot stock (5 million) without any automation except tractors.

For efficient use of automation for a single species, a single type of tray must be used throughout the process and careful thought must be given in selecting the type of tray, then other components could be built around it. Potting media is sourced from Daltons which contains bark derived from Kaingaroa Timberlands forest, ranging from fines to 8mm pieces**.** The large media feed hopper (outside the shed) is from Demtec in Belgium.

This nursery uses TS48-F trays with a 120 ml plug size and is ideally suited for softwood cuttings and seeds. This tray was originally developed by Transplanting Systems New Zealand in conjunction with nursery managers and staff from Scion and Australia. Its design supports air pruning which prevents aggressive root formation and root deformities and allows the inoculation of symbiotic mycorrhizae. The tray is made from high density polyethylene (HDPE) virgin resin with UV protection.

Figure 14. TS-48F tray used for automation. Retrieved from https://www.transplantsystems.co.nz/products/ts-48f-seedling-tray/

Automation system:

Automation was provided by Transplant systems. The production is 80% automated with Italian made Urbinati (https://www.urbinati.com/en/) integrated production line and a packing line, combined with conveyor belts and a rolling bench system for moving trays to an outside hardening area. The post and rail rolling bench system is from KG Systems in the Netherlands.

Visual oversight ensures that the automated seed sower is accurately placing seed (and avoiding blanks/ double-ups) and labor is required for manually setting cuttings. These propagules are not manually handled again until the final stage of production which is the grading and packing prior to dispatch. After seed sowing or planting cuttings the trays move on the conveyor for topping and watering. The automation line is 38 m long and has a T design. It is composed of a tray de-stacker, tray filler, dibbler, drum seeder, covering seed with coarse sand and a final watering station (Figure 15). Once planted the trays are moved on conveyor and loaded automatically onto the KG benches by an Urbinati bench loader for moving to outside roller benches. There are 1500 benches with 60 trays able to be fitted to each bench. Watering is automated with five Urbinati irrigation booms which are 150 m long. Seedlings are topped at a height of 25 cm and the process is automated.

After 9 -12 months hardening, seedlings and trays are moved back into the conveyor, and trays move in the opposite direction, towards the T junction that gets diverted to de-plugging and packing line**.**

Production efficiency: Trays 650/hr
Seedlings 150,000 - 200,000 cells/day
Cuttings 33,000/day

Figure 15.. Automation production line in the Te Ngae nursery (top) and grading and packing line (bottom).

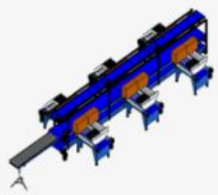
 Urbinati ND de-stacker	 Urbinati RE14 Tray Filling Machine	 Urbinati NI Dibbler
 Urbinati YPSILON65 Drum Seeder	 Urbinati covering unit	 Urbinati ESTREA Automatic Plug Popper
 Urbinati Packing line		

Figure 16. Urbanati equipment range used in creating fully integrated transplanting line. Please note these are not the exact models of automation equipment used in the Te Ngae Nursery. Retrieved from https://www.transplantsystems.co.nz/products/categories/nursery/ on the 25-03-22.

Global suppliers of containerised forest nursery automation equipment

Listed below are the two key suppliers of nursery automation equipment that offer full integration of multiple operations for maximum efficiency. When designing an integrated nursery automation system, it might be necessary to mix and match various makes and models to automate each of the individual steps in the entire production process, to suit the identified needs.

An example of a fully automated transplanting line is given in Figure 17. Starting from the left a typical line would consist of automatic de-stackers for trays, which can be connected by means of a conveyor to a flat filling machine (orange box) that fills the destination trays with soil and levels it. The flat filler could be connected by conveyor to an automatic transplanter (blue box). A second conveyor could be used to feed source trays into the transplanter. After transplanting, the destination trays would move onto another conveyor, which could then go through a watering tunnel before being placed onto a final conveyor to be staged for delivery to the greenhouse, a process that can also be automated using rolling benches. The transplanter itself will normally account for 50-60 percent of the total cost of the line.

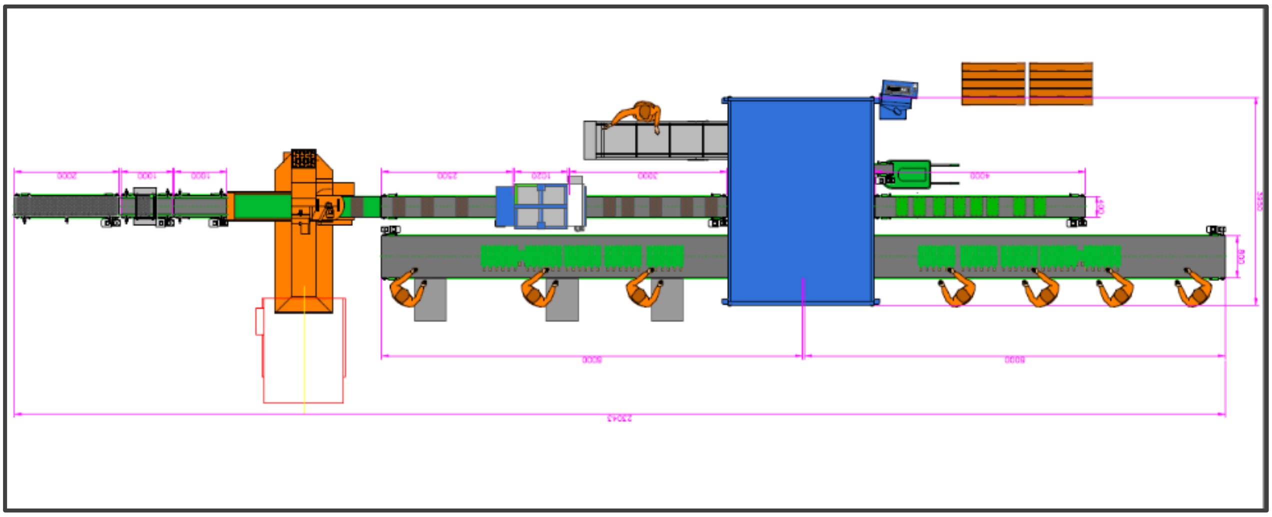


Figure 17. A layout of an integrated nursery automation system (provided by Geert Murray TTA).

Ellepot (https://www.ellepot.com)

This Denmark-based company has developed a range of mechanisation to support fully or semi-automated paper plug production and tray filling. Founded in 1993, Ellepot is considered one of the original paper pot technologies. Their technology is adaptable to a vast range of plug sizes, with a plug diameter range from ø15mm up to ø120mm with a maximum pot depth of 300mm, depending on the type of Ellepot machine. A PB 2 equivalent ø10cm Ellebag (only 900ml volume, but equivalent in survival and growth), among other sizes, is also available. Paper-pot technologies such as these have a lower environmental impact than other production systems which rely on single-use plastic. Also, as the root system is planted in the field without removing the degradable paper, transplant shock is minimised (no disruptions to the roots) and the plant can establish faster in the field site. The Ellepot system is appropriate for most methods of propagation. At Scion, we have used the 125cc ø40mm x 100mm Ellepot paper pot to root *Pinus radiata, Eucalyptus bosistoana*, *Sequoia sempervirens* and indigenous cuttings, as well as exotic softwood tissue culture shoots (derived from organogenesis (OG) and somatic embryogenesis (SE)). Nurseries around the world have had exceptional success and invested heavily in Ellepot systems due to their reliable and highly mechanised production, as well as the benefits paper pots have for grading, sorting, and consolidating (i.e. handling). Ellepot has a team of highly experienced propagators, spanning industries such as forestry, viticulture, agriculture, and horticulture, and can provide exceptional support through its distributors. Ellepot has a local sales, service and support presence in New Zealand, through their Ellepot New Zealand partner Advanced Hort (https://advancedhort.co.nz/pages/about-ellepot) who carry a local stock of Ellepot spare parts, paper and trays for fast and efficient service.

Ellepot has a wide range of machinery available, to cater to all sizes of nursery production (https://ellepot.com/ellepot-products/ellepot-machines/). Ellepot can supply additional equipment for a fully automated forestry seeding and cutting paper pot production - from substrate mixing, to seeding to sticking lines:

- Soil mixers, bale breakers and peat bunkers
- Tray stackers and de-stackers
- Dibblers and drill units
- Drum and needle seeders
- Vermiculite units (for seed covering)
- Pot irrigation units
- Sticking lines

The single-line H111 is Ellepots base model which can produce ø40mm x 100mm (125cc) Ellepots at approximately 2,000 pots per hour semi-automatically (placing of Ellepots into trays by hand). The human labour required to operate the machine is – filling the hopper with media, replacing the paper when required, and lifting the plugs off the line and placing them in the trays. The modular Ellepot Multiflex can be added onto the H111 to automatically place the Ellepots into the tray and allows for production speeds of approximately 2,500 pots per hour (ø40mm x 100mm Ellepot). The technician maintains responsibility for refilling the hopper and paper and loading up and removing trays on the conveyor. With a Multiflex installed, it is then possible to add any other required automation onto the Ellepot conveyor such as tray de-stackers, seeders, dibblers etc. The Ellepot H111 and Multiflex system is modular, meaning that nurseries do not have to invest in the fully automatic system at the start but can simply begin with the H111 and add the additional automation at any stage, as and when required and/or possible.

The double-line Ellepot H112 and Turbo-Multiflex can be used if twice the daily production capacity is required, with production speeds of a ø40mm x 100mm pots of up to 5,500 per hour.

Figure 18. The semi-automatic Ellepot H111 and Multiflex

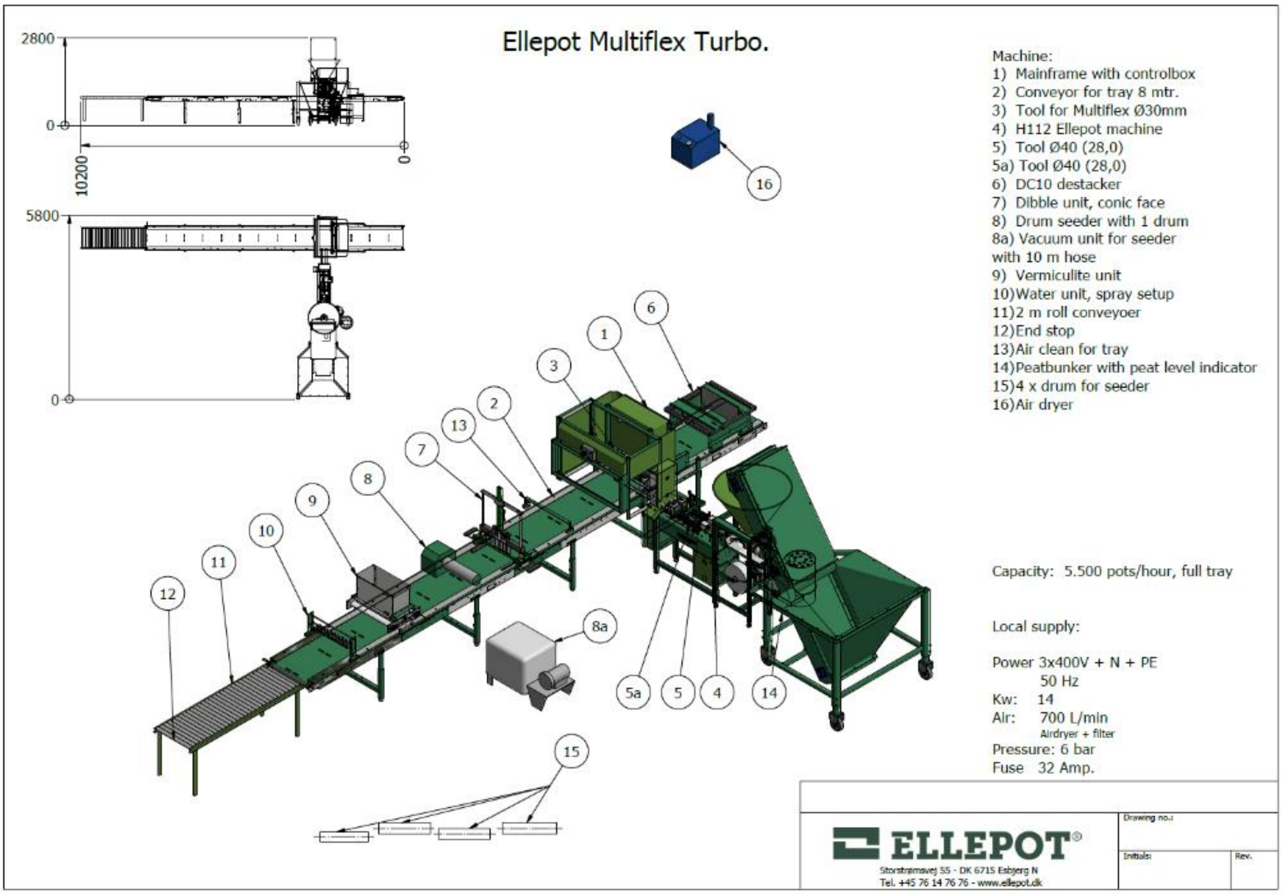


Figure 19. Example layout of a fully automatic Ellepot Turbo Multiflex system with seeder.

Ellepot also offer dedicated fully automatic systems for high-capacity production of up to 40,000 pots per hour, with their multi-line, touch-screen controlled EPM and latest technology FlexAIR machines (https://ellepot.com/ellepot-products/ellepot-machines/fully-automatic-machines/):

Figure 20. Ellepot fully automatic systems for high-capacity production

BCC (https://www.bccab.com/)

This is a Swedish company that are specialists in forestry production and designs and manufactures the entire range of automation options for each step of the containerized nursery production system. BCC offers full integration of growing systems when planning and designing nursery facilities worldwide (https://www.bccab.com/product-development-bcc-plant-the-planet/#)

BCC product range:

1. The choice of growing systems is key for the automation and needs to be decided early in the process. A wide range of trays systems are available and latest developments help to produce better root system and avoid root deformations. (https://www.bccab.com/products-planting/growing-systems/)

- Hiko range
- Plantek range
- Aircells

- Fibrecell paper potholders. Fibrecell prime medium paper pots are suitable for forestry with longer propagation times.

2. Nursery production systems can be produced by selecting all or several of the modules and connecting them with conveyors, for a full integrated transplanting line, where every piece of equipment in the line is connected not only physically but also electronically and such line can be run by only one or two people (https://www.bccab.com/products-planting/nursery-production-system/).

- Tray washer
- Tray de-stacker
- Batch mixer of growing media
- Flexifiller. **(**https://www.bccab.com/wp-content/uploads/2018/09/FlexiFiller-English.pdf**).** Unlike other machines Flexifiller has two compaction levels to suit different root depths.
- Dibbler
- Precision seeder, drum seeder, manual workstations and setting lines.
- Tray covering
- Watering tunnel
- Cone and seed handling
- Pottiputki planting equipment
- Conniflex seedling treatment system

3. FibreCell system
a. Includes a range of Semi-automatic and Fully automatic Fillers (https://bccfibercell.com/**).**
b. FiberCell paper – range of different composition and degradation rates
c. FiberCell holders

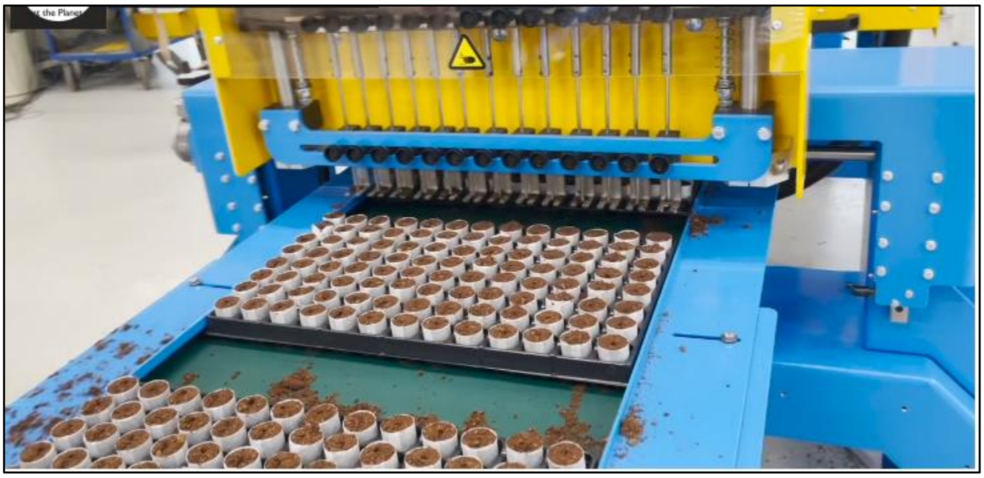


Figure 21. 4-line automatic fibre cell filling line. Retrieved from https://bccfibercell.com/fully-automatic-fibercell-filling-machine/

4. Packaging lines for packing of seedlings into cardboard boxes or similar type of boxes.
Fully automatic and semiautomatic packing lines. (https://www.bccab.com/products-planting/packaging/

5. Transplanting and sorting machine (https://bccfibercell.com/transplanting-2/). This part is handled by one of BCC partners, Flier Systems. Transplanting and sorting machine equipped with AI (Artificial Intelligence) advanced vision technology for consistent sorting results. The plants are graded with Chlorophyll Fluorescence advanced vision technology and the flexible plant fingers provide options for different types of output. It has high capacity of up to 900 cycles per hour and the ability to handle small plugs.

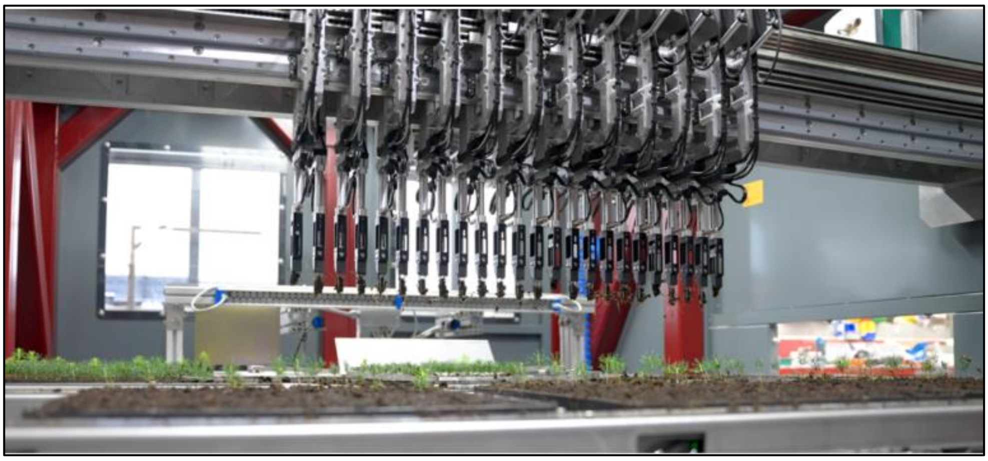


Figure 22. Multiline gripper fingers of transplanting and sorting machine. Retrieved from https://bccfibercell.com/transplanting-2/ on 110422

Primehort is the NZ agent for BCC: https://primehort.co.nz/shop/nursery-automation

TTA (https://www.tta.eu/sectors/forestry)

This Netherlands-based company specialises in Forestry (broadleaf, conifers and eucalyptus) as well as horticulture nursery automation. They are specifically focussed in automation of plant handling and selection areas, i.e. transplanting, grading and packing.

1. Transplanters
A range of transplanters, that can be run with a single operator, capable of handling paper plugs or loose plugs, suitable for small to large scale nurseries is available. For example, Pack planter-S, ideal for smaller nurseries to optimise their manual transplanting process (10,000-20,000 plugs/day), and Pack planter wireless, a high-tech transplanter for nurseries aiming for maximum speed and flexibility (10,000- 60,000 plugs/day).

Figure 23. PackPlanter S (Retrieved from https://www.tta.eu/equipment/transplanting on 11-04-22)

Figure 24. PackPlanter Wireless transplanting system (Retrieved from https://www.tta.eu/equipment/transplanting on 11-04-22)

Transplanters can be combined with multi-scale grading/selecting systems that have RGB and IR (Infrared) cameras and vision Plus software, to ensure quality control. However, the cost of these systems alone can be 4-5 times higher than the transplanting system.

A major problem of direct sowing is missing cells, which can lead to weed problems such as liverwort mosses and tray sanitation issues. MidiVision is a grading system for 100% transplanting. The grading system has the ability to check the tray top for the presence of enough green leaves

by digital cameras and use image processing programs to fill the gaps and achieve 100% tray fill. This can lead to 10% of tray cleaning costs.
https://www.tta.eu/equipment/selecting

Figure 25. MidiVision transplanting system (Retrieved from https://www.tta.eu/equipment/transplanting on 11-04-22)

2. Grading and packing lines

FlexSorter is a fully automated packing line which only selects and touches the root plug once, minimising the plant shock as the pine seedling can be very sensitive compared to spruce. Also, deformed plugs can lead to low planting success. Plants are extracted with grippers assisted by pusher pin system from below. Each plant gripper is driven by its own individual motor unit and a microprocessor providing dynamic positioning of attached planting grippers. The grippers give space for presenting the plant to the camera for an artificial intelligence (AI) quality assessment. Grading is determined with 2 laser lines and accepted plants are directed to new belts lines according to their grade. The number of classifications is dependent on number of destination belts. The machine can have a maximum of four lines. Discarded plants and empty plugs are also directed to separate lines.

The machine can count and pack, resulting in savings in boxes required. A range of plastic and biodegradable boxes are currently available for packing seedlings.
A complete system could cost around half a million NZ dollars.
https://www.tta.eu/equipment/selecting/flexsorter

Figure 27. FlexSorter with 3,000 – 12,000 plug capacity. Retrieved from https://www.tta.eu/equipment/projects/packing-line-for-trees

Transplanting systems in NZ are the agents for TTA equipment- Colin Purchase. https://www.transplantsystems.co.nz/products/categories/forestry/

Nurseries using the TTA equipment:
Hancock Victorian Plantation Pvt Ltd - https://www.hvp.com.au/hvp-forest-management/hvp-tree-nurseries/
Qeensland Australia - https://www.pohlmans.com.au/about-pohlmans-the-plant-people/ - Rob Pohlman
Auckland - https://www.zealandia.co.nz/contact/ - Vince.W@zealandia.co.nz
Auckland -https://www.kauripark.com . TTA vision grading packing line is currently been installed.

Opportunities for improvement in New Zealand forestry nursery production systems

In summary, automation provides a significant opportunity for improving nursery crop flow and quality control. Sizeable upfront investments in mechanisation can be off-putting for nursery owners who have established protocols and infrastructure to suit traditional production methods. However, once set up, an automated system can reduce a nurseries overall labour costs while achieving consistently high qualities and throughputs. In addition, automated container nurseries can be run much more environmentally friendly in regard of disease, run-off, fungicides, and herbicides. With more interest developing in automation across several plant production sectors; comprehensive local support is growing throughout New Zealand for many of the technologies discussed throughout this document.

The importance of working with a standardised containerised stock-type has been reiterated throughout our discussions with industry (an issue which doesn't apply to bareroot). Changing stock type, container size and species between crops can be difficult to accommodate using a highly automated system. It is recommended that nurseries wishing to implement or upgrade their automation to accommodate anticipated increasing workloads decide on their plant specifications and design a model crop flow system which would supports this.

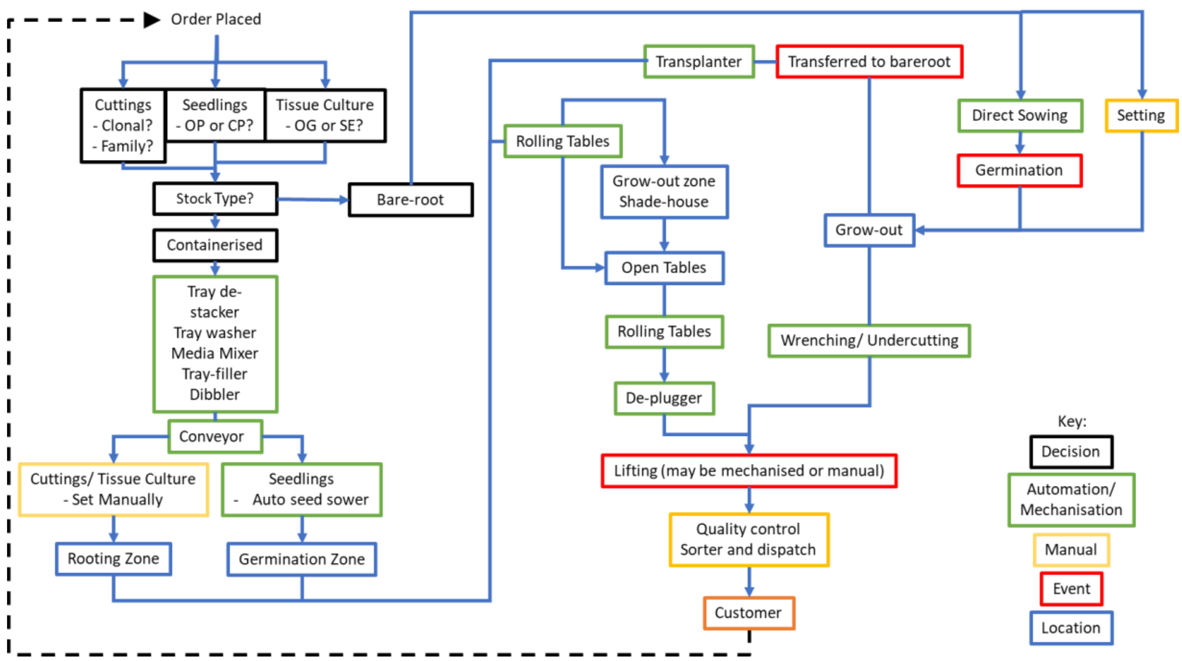


Figure 28. Nursery workflow for bareroot and containerised *P. radiata* production. OP (open pollinated), CP (control pollinated), OG (organogenesis), SE (somatic embryogenesis).

For example (Figure 28), a nursery wishing to produce 1 million containerised *Pinus radiata* seedlings annually must consider the seed sowing window. If sowing is going to occur in Autumn (for a 10-month rotation and dispatch in April), then additional infrastructure like an enclosed germination tunnel (as seen in the Lieco case study) should be considered. Conversely, if the entire million will be sown in spring, then the capital will be better spent on automation to support intensive sowing, and an additional germination tunnel may not be necessary. Establishing a crop flow plan should help highlight what areas/ tasks would benefit from automation, and which tasks are best kept manual. 100% automation provides little flexibility for when crops, stock types and specifications change, so unless crop production is for a vertically integrated company, complete automation can be risky. Therefore, it must be balanced so that repetitive and laborious tasks are automated, but human input is still required. This also means that staff must visually inspect plants and double-check that the automation is working as it should (irrigation, humidity and light control), as malfunctions and breakdowns outside of the nurseries control can occur even with the most sophisticated technologies.

Once the target species and specifications have been decided, selecting tray type is more straightforward. Technologies for tray filling, range from the loose-filling Urbinati conveyor belt (Figure 10) to paper plug based systems like the Ellepot H111. Paper plug systems are typically slower and more technical than standard tray fillers, but result in a high-quality plant which is easy to re-consolidate within the nursery. Air-pruning of roots in paper plugs also benefits early seedling establishment and long-term stability, but the cell size within the trays must allow for this air flow. Paper plugs have great potential for extending the planting season, which will be a distinct advantage as planting labour decreases in future years. Also, Ellepot trays are available which both promote air pruning, are modelled for automatic tray filling and have a shape which maximises automation. However, the investment in paper pot systems will only be financially viable if the cost is recuperated by selling a premium plant ($2+), such as clonal Eucalyptus and Redwoods or indigenous forestry species (e.g., totara), and may not be relevant for large scale P. radiata production @ ~ $0.50c. Research is currently being done to determine the advantage paper pots have over the traditional small forestry trays (TS48) for extending the planting window; the early results are promising. Trays also require a huge capital investment so buying many in a bulk order would be financially effective but would come with a big financial commitment. Implements specific to dibbling, sowing, capping, and watering can be added to the tray-filling options outlined in this report (Urbinati and Ellepot). These upgrades can be made once the base model has been tested or installed from the outset. Space can be a limiting factor once upgrades to the sowing line are installed, so consider how the final system will run and what utilities it will require.

Plant stock is generally transferred to a grow-out zone once the seedling has germinated or the cuttings have rooted. Retractable roofing options can provide great protection from extremes in temperatures and frosts, while also giving the nursery full control over water availability to the crop. However, full grow-out environmental control is generally unnecessary in New Zealand for forestry crop production, as our forestry species cope well against the elements (as seen in bareroot production), though climate control can be helpful in reducing pathogen populations. With New Zealand imposing stringent rules on agrichemical use for environmental and human health, investing in integrated pest managements approaches (such as accurate climate control) may pay off financially, as well as socially.

Automation using artificial intelligence (AI)

AI is commonly used across many sectors but most notably medical science, education, finance, agriculture, industry and security. Implementation of AI involves learning processes within machines. It is what often makes a machine “smart” and enables a greater level of decision making. Machine learning is a sub-domain in the field of AI. The sole purpose of machine learning is to feed the machine with data from past experiences and statistical interpretation so that it can perform its assigned task. Within forest nurseries the implementation of machine learning is best suited to tasks where humans have clear criteria for decision making when conducting the task manually. Areas which provide clear opportunity in this space are:

- Crop stress: machine learning models utilse remotely sensed data to monitor and provide early warnings of disease, crop stress and resource deficiencies such as nutrients or water.
- Inventory and stock management: seedling counting, survival and competition characterisation
- Pesticide control: models to provide more accurate and individual precision approaches to pesticide control from remote sensed data at tray and cell levels.
- Weed management: target weed control through more controlled and individual approaches from remotely sensed data.

When reviewing technology solutions for enhanced mechanisation and automation the opportunity for data capture and enhanced analysis from artificial intelligence should be considered as part of the future business case.

The opportunity starts with a first proactive step. This report provides wide ranging examples and options to suit most requirements. The solution to increasing demands for more efficient plant supplies of highest quality is more automation.

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Appendix A

Production systems background reading

Some of the most comprehensive publications available on forest nursery practices were produced in the USA by a cooperative project of the Nursery Technology Cooperative (Department of Forest Science, Oregon State University, Corvallis) and the U.S.D.A. Forest Service (State and Private Forestry, Pacific Northwest Region, Portland, Oregon). There are two pivotal pieces of work, edited by Mary L. Duryea and Thomas D. Landis, which provide an excellent outline of forestry nursery basics; "*Forest nursery manual— Production of Bareroot Seedlings*" and "*The container tree nursery manual*".

Forest nursery manual - production of bareroot seedlings.

'Forest Nursery Manual' presents state-of-art information about current bareroot-nursery practices and research in the northwestern United States and Canada.

Chapter 1- Development of the Forest Nursery Manual - A Synthesis of Current Practices and research
Chapter 2: Nursery-Site Selection, Layout, and Development
Chapter 3: Equipment for Forest Nurseries
Chapter 4: Assuring Seed Quality for Seedling Production- Cone Collection and Seed processing, Testing, Storage, and Stratification
Chapter 5: Establishing a Vigorous Nursery Crop - Bed Preparation, Seed Sowing, and Early Seedling Growth
Chapter 6: Physical Properties of Forest-Nursery Soils - Relation to Seedling Growth
Chapter 7: Soil Fertility in Forest Nurseries
Chapter 8: Soil and Tissue Analysis - Tools for Maintaining Soil Fertility
Chapter 9: Nursery Soil Organic Matter - Management and Importance
Chapter 10: Cover and Green Manure Crops for Northwest Nurseries
Chapter 11- Water Management
Chapter 12: Irrigation in Forest-Tree Nurseries - Monitoring and Effects on seedling Growth
Chapter 13: Land Drainage
Chapter 14: Plant Physiology and Nursery Environment - Interactions Affecting Seedling Growth
Chapter 15: Nursery Cultural Practices - Impacts on Seedling Quality
Chapter 16: Plug + 1 Seedling Production
Chapter 17: Genetic Implications of Nursery Practices
Chapter 18: Weed Management in Forest Nurseries
Chapter 19: Pest Management in Northwest Bareroot Nurseries
Chapter 20: Mycorrhiza Management in Bareroot Nurseries
Chapter 21: Lifting, Grading, Packaging, and Storing
Chapter 22: Nursery storage to Planting Hole - A Seedling's Hazardous Journey
Chapter 23: Assessing Seedling Quality
Chapter 24: Planting-Stock Selection - Meeting Biological Needs and Operational Realities
Chapter 25: Sales and Customer Relations
Chapter 26: Improving Productivity in Forest Nurseries
Chapter 27: Nursery Record Systems and Computers
Chapter 28: Designing Nursery Experiments
Chapter 29: Problem Solving in Forest-Tree Nurseries

The container tree nursery manual

The Container Tree Nursery Manual (CTNM) consists of seven volumes, all under the same series number-USDA Agricultural Handbook 674. Each volume contains chapters on closely related subjects concerning the production of tree and woody shrub seedlings in containers.

Volume 1 - Nursery Planning, Development, and Management (1995)
Volume 2 - Containers and Growing Media (1990)
Volume 3 - Atmospheric Environment (1992)
Volume 4 - Seedling Nutrition and Irrigation (1989)
Volume 5 - The Biological Component: Nursery Pests and Mycorrhizae (1990)
Volume 6- Seedling Propagation (1999)
Volume 7- Seedling Processing, Storage, and Outplanting (2010)