The University of Waikato
Te Whare Wānanga o Waikato

Dibbling Machine for ArborGen
Produced by
Waikato AgriTech group

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Background

ArborGen’s nursery, located in Tokoroa, supplies approximately 6 million seedlings per year to the forestry industry (figure 1). The vast majority of seedlings are Pine Radiata but they also supply Plug Plus and Douglas fir. In peak season, they plant up to 120,000 seedlings per day that each require a straight vertical hole of certain depth and spacing, (depending on seedling type). For example the most common seedling, Radiata pine, requires holes of approximately 10mm diameter x 40mm deep (figure 2).

Figure 1 160 metre long planting beds with Radiata pine seedlings

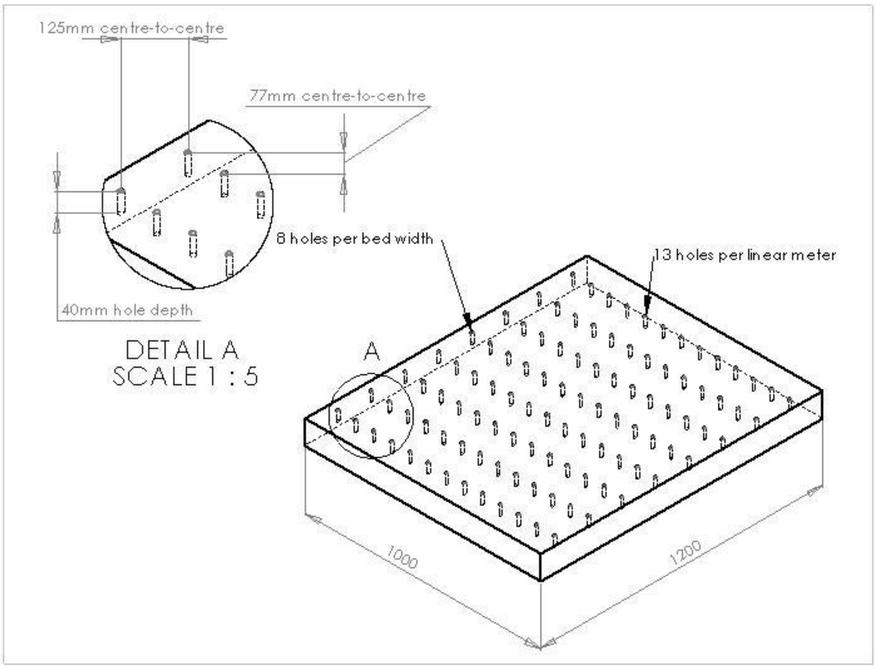

Figure 2 Radiata Pine - 40mm deep x ø10mm holes positioned per linear metre

The process of making the holes is called dibbling. Dibbling has become a major problem that has resulted in an estimated 400,000 rejections per year. An investigation of the dibbling process identified the following problems:

- Existing human dibbling methods too slow and unreliable
- Machine methods produce low quality holes that lead to mis-planted seedlings
- Lack of flexibility of existing, methods with regard to hole size and spacing
- Current methods compact the soil hindering root growth so hole drilling is preferred
- Currently, dibbling must be done on the day of planting due to the deterioration of the bed surface

Dibbling Methods

One method used for dibbling is to manually press the holes in the planting beds as shown by figure.3 and figure.4. There is a large staff turnover and because of this, workers are often undertrained. This can lead to inconsistency in dibbling in terms of hole depth, and spacing as shown in figure 5. Poorly dibbled holes often lead to seedlings with bent stems that are then rejected by the forestry industry.

Figure 3 Hand operated devices used for dibbling by the nursery staff

Figure 4 Manual dibbling process

Figure 5 Hole inconsistencies due to placement and cracking of the planter bed surface

The existing tractor pulled dibbling machine used is also inadequate with respect to producing holes of acceptable quality. The machine consists of a large cylinder with pins protruding from it as shown in figure 6. As the cylinder rolls along the ground, holes are pressed into the bed. The primary problem with this method is variation in the depth of the holes, non-round holes due to tearing and disruptions to a pesticide layer (figure 7 and 8). The non-round holes lead to incorrectly planted seedlings who's roots then grow at an angle which results in rejection. This ultimately leads to approximately 600,000 rejects.

A new design of dibbling machine was required to address the problems and the research to find a solution was undertaken by the Waikato AgriTech Group (WAG) at the University of Waikato.

Figure 6 Current machinery used to dibble the planter beds with tearing visible

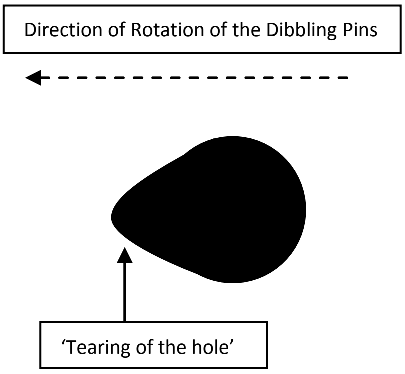

Figure 7 Plan view of the holes produced from the current dibbling machine

Figure 8 Example of holes that show signs of tearing

Development Plan

Firstly a detailed investigation of dibbling and associated issues was undertaken in close collaboration with the ArborGen nursery managers. This included extensive laboratory experiments to determine best drilling speeds, drill types and power. The requirements of the process and machine were then written as a Design Specification (Appendix 1). The key Design Specification requirements of the new dibbling machine were:

- Drilled holes not punched
- Holes to be vertical, correct depth and spacing
- 6 month for design, manufacture and commissioning
- 8 holes to be drilled in a line at set distances
- Towed by existing tractor
- Budget $80k
- Variable hole spacing and hole diameters essential
- Dibble 120,000 holes per day (minimum of 6 million during planting season)
- Minimal possibility of breakdowns during season

- Easy repair with off the shelf components or ‘cut weld’ techniques
- Must withstand the nursery environment and weather
- Must dibbler in most conditions, dry soil, muddy and frosty
- Operated by tractor driver
- Easy to move the dibbler from shed to bed and bed to bed.
- Must not damage the pesticide sprayed surface
- Ideally a self-contained machine that can be easily coupled and decoupled from a tractor
- Must count the number of holes dibbled
- Ideally will enable holes to be dibbled a few days before planting

Concept Generation

A number of concepts that met could meet most of the Design Specification requirements were generated as shown in Fig 9,10,11,12.

Figure 9 Caterpillar tracked dibbler mock-up

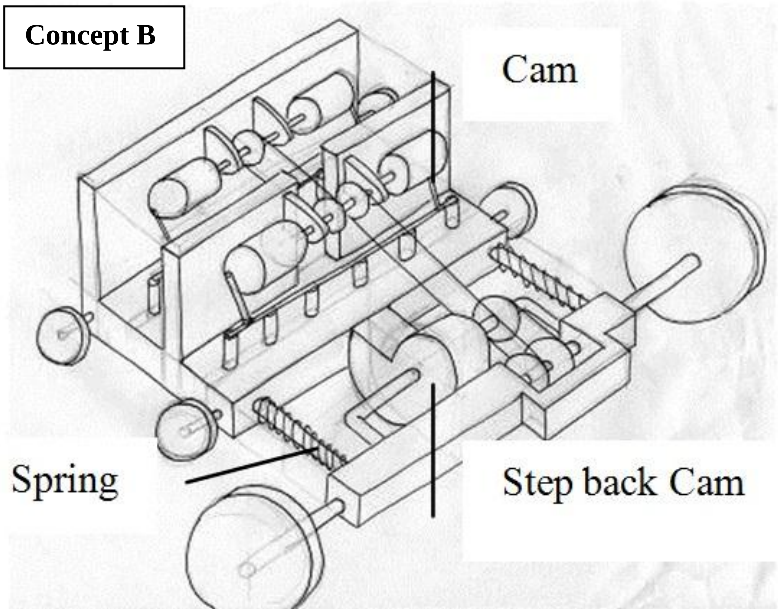

Figure 10 Cam dibbler

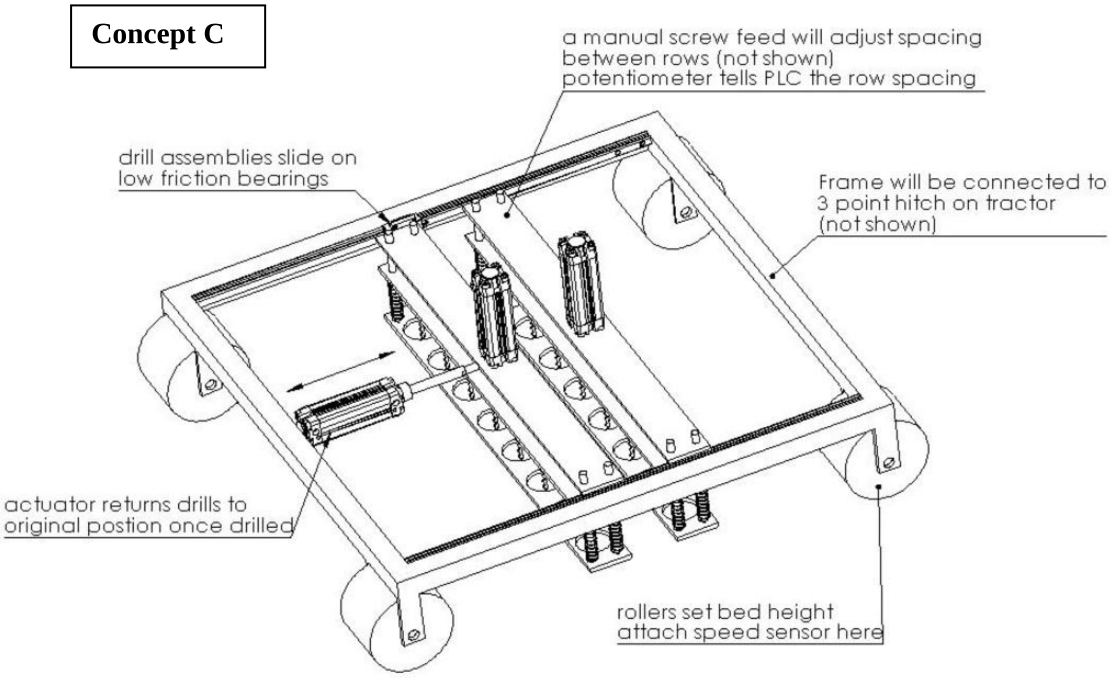

Figure 11 Pneumatics, PLC Control, rollers on bed and compressor on tractor

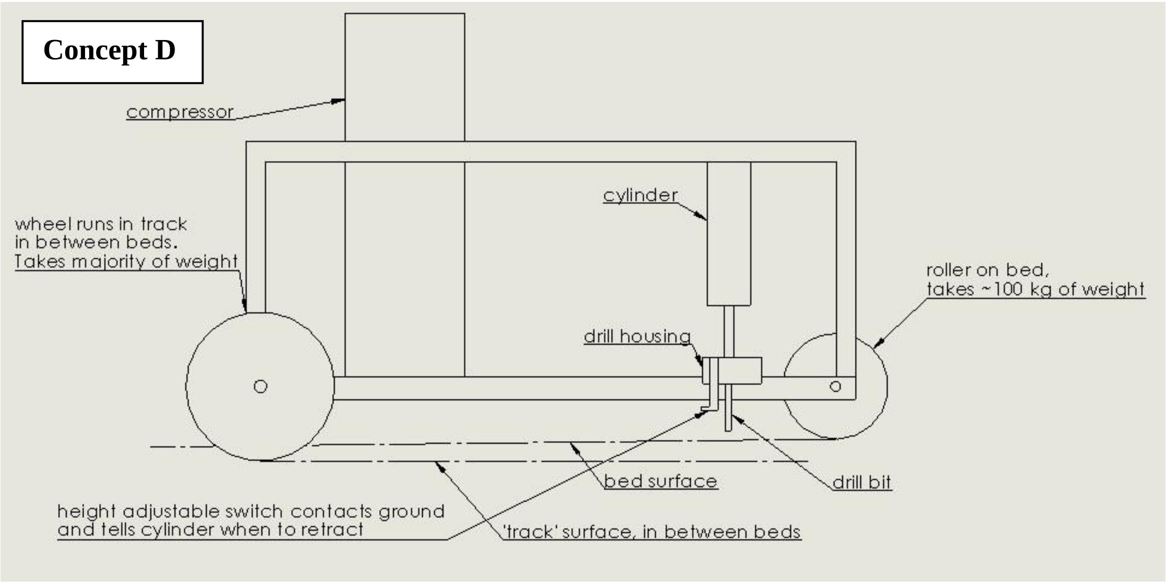

Figure 12 Pneumatics, PLC control, compressor on tractor, rear wheels off bed

Concept Selection

Each concept had advantages and disadvantages. The tracked dibbler, concept A, appeared to have several advantages over the other types so a ½ scale mock-up was built as shown in Fig. 9. Even though the mock-up worked well it had a number of limitations including; needing many internal drilling heads, and limited flexibility regarding hole sizes and spacing. Therefore this concept was rejected. The cam concept B was considered too inflexible and concept C had all rollers on the bed and did not have an integrated compressor, so both were rejected.

The concepts including their advantages and disadvantages were presented to the nursery manager at a milestone meeting. After consultation, concept D, figure 12, was selected for development into a fully operational machine as it meets all the requirements of the Design Specification. The main advantages of concept B are:

- Pneumatic ram speed control using a PLC and encoder on the roller ensures drilling matches the speed of tractor and thus straight holes are produced
- As tractor speed varies, the PLC automatically adjusts dibbling speed to maintain spacing and vertical holes
- 16 drilling heads reduce the speed of oscillation of the pneumatics, minimising forces and making operation smooth.
- Standard petrol air compressor mounted on the dibbler provides power for pneumatics, rear mounted so that minimal load is transferred to the planting bed by the front roller
- Pneumatics has proven long term reliability and ease of control using off the shelf system with easily programmable PLC
- Wheels at back of the dibbler follow tractor wheels ensuring dibbled holes are not disturbed by the machine
- Pivot at rear of dibbler ensure main chassis remains horizontal, minimising hole misalignment
- Simple magnetic sensor linked to plunger sends signal to PLC for correct depth and reverses pneumatic rams at the correct speed.
- Control panel in tractor cab gives operator control of spacing and speed with simple adjustment knobs that are linked to the PLC
- Hydraulic motors using standard tractor hydraulics and chains provide robust and reliable method for powering the drilling heads
- Roller smooth’s and improves the planting bed before dibbling and enables dibbling to occur days ahead of the old system
- Counts the dibbled holes and displays to operator

Dibbler Development

To develop the machine to the required specification including strict time lines, the following development plan was implemented:

- Industrial programmable logic controller (PLC) was used to control the dibbler as this gave the flexibility and accuracy required.
- 3D CAD was used so that a virtual machine could be designed quickly and to ensure all components and systems integrated correctly.
- Finite Element Analysis (FEA) was used to analyse the stresses in the dibbler and modifications were made as required.

- All componentry was supplied by leading manufacturers such as SKF and Norgren so that quality and reliability could be guaranteed. It also ensured spare parts will be available for the foreseeable future.
- All chassis parts and brackets were laser cut directly from the 3D CAD model ensuring rapid manufacture, accuracy and ease of assembly.
- All shafts were CNC machined from the 3D CAD model, after conversion to CAM files, ensuring rapid manufacture, accuracy and ease of assembly.
- Concurrent engineering was used so that several operations were being undertaken simultaneously to speed up the development process.

The above methods resulted in a 3D CAD model ensuring rapid manufacture, accuracy and ease of assembly as shown in Figure 13.

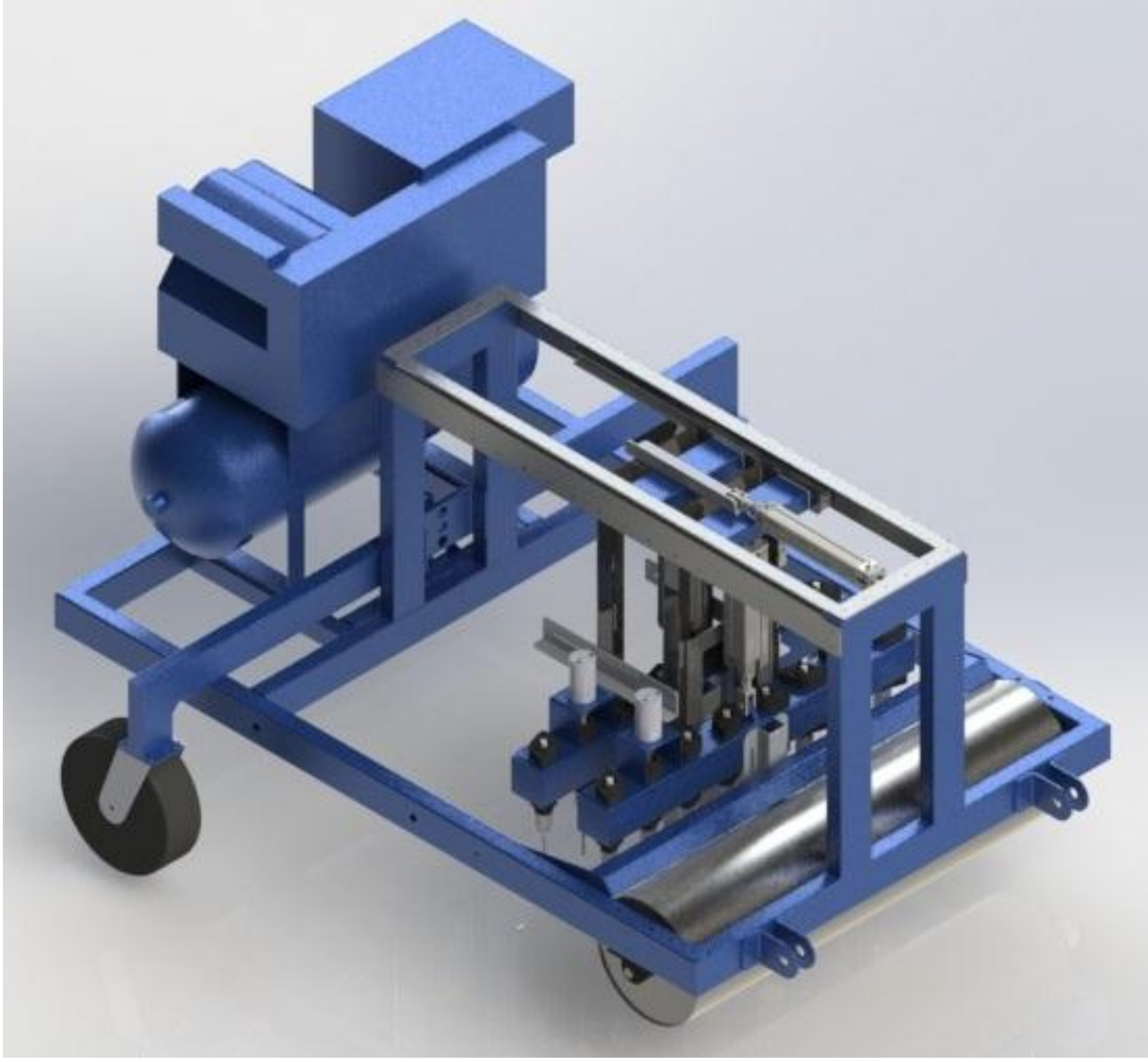

Figure 13 Final 3D CAD model of Dibbler

Testing and Results

The finished dibbler was tested on site at Tokoroa. The machine worked as expected and dibbled straight holes to the required depth and angle. It was found that after a few days the wheels on the rear of the dibbler were failing due to the harsh terrain and so were upgraded to a more robust type. The sensor for depth was prone to occasional sticking and could be replaced with a pneumatic plunger with built in sensor. The return stroke of the drilling head caused sharp impulse forces that jolted the tractor. To overcome this, the PLC was programmed to soften the return stroke, but it is suggested that a mechanical damper also be incorporated to remove the kinetic energy. Nonetheless the current dibbler has worked reliably and consistently, easily achieving the 120,000 holes per day over the entire dibbling season. The finished dibbler in operation is shown in figures 14 and 15.

Figure 14 Finished machine dibbling holes at the nursery

Figure 15 New dibbler and tractor

By visual inspection, the dibbled beds appeared to meet all the requirements i.e. vertical and correctly spaced holes as shown in Figure 16.

Figure 16 Planting bed with holes dibbled using the new machine

To check the depth and angle of the holes a simple test rig was developed as shown in figure 17.

Figure 17 Hole measuring equipment

It was clear that the dibbling method of towing a spiked wheel behind the tractor was producing very poor quality holes as shown in figure 18. The elongated hole caused by tearing of the spike as it rotates results in an unacceptably large angle, well in excess of the 3 degrees maximum angle preferred by the nursery. No further testing of these holes was undertaken as by inspection they were all outside the required angle and depth.

Figure 18 Measuring depth and angle of hole made by spiked wheel dibbler

For the new dibbling machine, a sample of 100 holes was used to determine the consistency of the depth and angle. The scales of the measuring system could at best be read to +/- 1mm and +/- 0.5 degrees. Furthermore it was found that the uneven surface of the planting bed would undoubtedly cause the new dibbler to have varying hole depth and angle as the depth sensors are located in only one place on the bed whereas there 16 holes each in different places.. It is highly unlikely that the level of the bed would be the same at all 16 points. By observation it was estimated that +/-3mm hole depth could be attributed to the uneven surface.

The results of the 100 sample holes is shown in figure 19. The basic requirement is that the holes for Pine Radiata are 40mm +/- 3mm deep and +/- 3 degree angle from the vertical. Due to the lack of resolution of the measurement method, many of the 100 measurements had the same value.

It can be seen that the even with the uneven planting bed, the dibbler achieved 76% of holes within the +/- 3mm tolerance. Only 2% of holes are outside the required +/- 3 degree angle. The average hole depth was 39.7 mm and angle 1.3 degrees with standard deviations of 3.3mm and 1.1 degrees respectively. With regard to the angle this is at least an order of magnitude better than the spiked wheel dibbler and the nursery managers are confident that even the 24 holes outside the depth tolerance will produce saleable seedlings, suggesting that the +/-3mm tolerance of the Design Specification could be increased to +/-5mm. When the uneven surface of the planting bed is considered, which is very difficult for an automated machine to compensate for at all 16 drilling points, increasing the hole depth tolerance appears the logical decision.

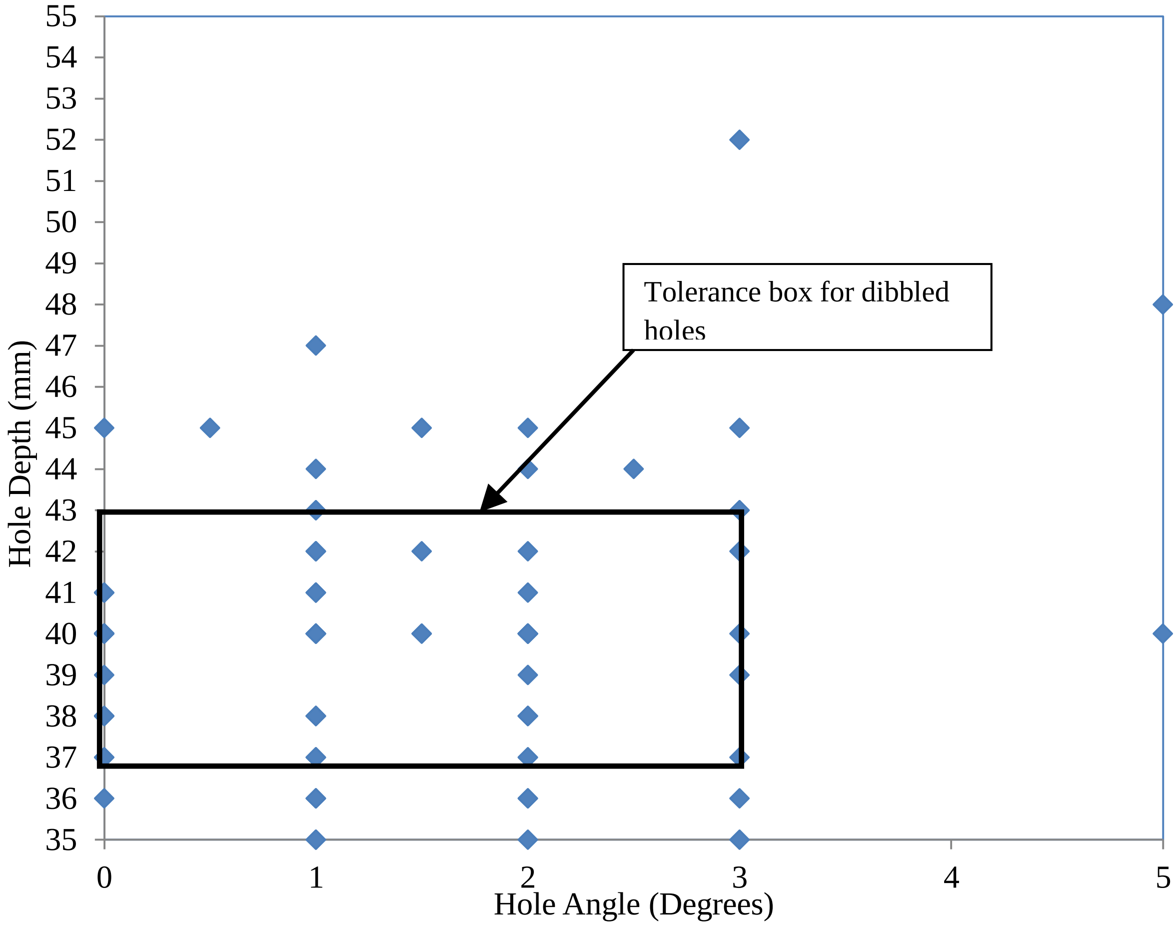

Figure 19 Depth of hole versus angle from vertical

Conclusion

A Tokoroa nursery was suffering over 7% seedling rejection (approximately 700,000 per year) due to poorly dibbled holes. A research and development project under taken by the University of Waikato was undertaken to develop a new automatic dibbling machine that could produce good quality holes at the required rate and be flexible with regard to spacing and hole sizes. The design used as many high quality off the shelf components as possible to ensure reliability and ease of replacement. 3D CAD was used to ensure the design fitted together and stress analysis was undertaken using FEA. All non bought in parts were either laser cut or CNC machines direct from the 3D CAD files ensuring speed of manufacture, accuracy and maintaining the integrity of the design. The latest PLC controlled pneumatic rams were used to provide accurate control and flexibility.

The completed machine was tested at the Tokoroa nursey and performed as expected, producing 98% holes at the required angle and 76% at the required depth. All the holes were considered good quality by the nursery manager suggesting that the current depth tolerances should be increased to +/- 5mm, especially when considering the uneven surface of the planting bed. The machine is now fully commissioned and dibbling holes on a daily basis at the nursery.

Appendix 1

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Dibbling Machine

DESIGN SPECIFICATION

1. Performance

1.1 The dibbler should be easily adjustable to allow dibbling of different diameters, depths, and spacing, and shouldn't take more than 30 mins to reconfigure

1.2 The specifications of the holes required for different types of trees currently planted at are summarised in Table 1.

Table 1 – Specifications of trees to be planted

Tree Type	Diameter (mm)	Depth (mm)	Intra-row spacing (mm)	Flat bottomed hole
Pinus radiata	10	40 ± 3	77	Yes
Douglas-fir	42 (top) 25 (bottom) (tapered)	95 ± 3	120	Yes
Plug plus	20	45 ± 3	85	Yes

1.3 There should be 104 Pinus radiata per lineal metre.

1.4 Hole to be vertical +/- 3 degrees

1.5 A tolerance of one row is allowable over 5 lineal metres.

1.6 There is the possibility of changing to different trees in future, therefore the dibbler should be infinitely adjustable within a desired range–to a depth of between 30-100 mm,and intra-row spacing between 70-120 mm

1.7 Inter-row spacing is fixed at 125 mm for all tree types.

1.8 Speed must be sufficient to dibble 120,000 Pinus radiata /shift, (80,000 Douglas-fir). A shift is approximately 2.5 to 3 hours.

1.9 Planting beds are 1200 mm wide and between 160 – 340 m long

1.10 Holes must by cylindrical and vertical with flat bottoms

1.11 Holes should be drilled rather than punched. Ideally the cuttings (*Pinus radiata*) holes should have the functionality to be either rotary bored or punched

1.12 The forming of the holes must not break the herbicide film previously sprayed on the beds

1.13 Dibbler must not clog up to the extent at which it hinders performance - in particular the hole integrity needs to be maintained

1.14 Dibbler must not adversely affect the surface of the beds in as much as leaving grooves or tracks on the bed surface

1.15 If drilled, the bits must not be clogged up by old roots and debris which are present in the beds

1.16 The dibbler should deposit the removed soil at the edge of the formed hole

2. Driving power

2.1 The dibbler may be self-driven, or it may be pulled behind a tractor currently owned by the nursery.

2.2 Available tractor specifications:

Tractor type	**PTO max output (540 rpm)**	**Electrical**	**Hydraulic**	**Forward speed (1st gear)**
Massey Ferguson 135 (1)	37 hp	12 V	2800 psi, 17 lpm	1.85 km/h (1700 erpm)
Massey Ferguson 135 (2)	37 hp	12 V	2800 psi, 17 lpm	1.85 km/h (1700 erpm)
Ford 4600	52 hp	12 V	2500 psi	2.0 km/h (1800 erpm)
Ford 6600	70 hp	12 V	2500 psi, 34 lpm	2.2 km/h (1700 erpm)

2.3 If tractor driven:
- Dibbler must be able to be disengaged when required by the tractor operator
- Dibbler must be able to be disengaged and lifted from the ground when in transit

2.4 If self-driven, must have a range of at least 4.0 km (2 km return trip to dibbling bed, ~1.2 km to dibble 120,000 holes, plus a bit extra)

2.5 If self-driven, must be capable of travelling at walking speed if the operator has to walk or faster in the case of operator being carried

3. Environment

3.1 Dibbler must operate under typical New Zealand weather between the months of May and July, including:

- Sleet on the planting beds
- Frozen ground
- Muddy ground
- Dry hard ground
- Saturated ground

3.2 The Dibbler will be stored in a shed when not in use

3.3 Dibbling time is between 8.30 am – 12.30 pm, however actual dibbling needs to be done within 2-3 hours, preferably closer to 2.

3.4 Temperature Ranges: -5 Degree Celsius to 33 Degrees Celsius

3.5 The dibbler will experience humid and wet conditions

3.6 Any noise emitted from the machine must not exceed that deemed safe under New Zealand regulation

3.7 If self-driven, dibbler must be able to drive 1 km at walking pace, and must be able to navigate muddy, uneven terrain

3.8 Dibbler must be robust enough to withstand rough handling typical in an agricultural environment

4. Life in Service

4.1 Final product must be able to be used, with correct maintenance and service, for 3 hours a day, every day, for 3 months of the year, for 20 years

5. Target Cost

5.1 $31,000-80,000 for a fully operational, commissioned machine (depending on funding)

6. Quantity

6.1 One prototype will initially be built

6.2 Further machines may be built after verification of design, however beyond scope of this part of the project

7. Maintenance

7.1 Dibbler must undergo regular maintenance as prescribed by the manufacturer

Operational

Dirt and other foreign objects must be removed from the dibbler at the end of each day with high pressure water jets

Seasonal

An annual maintenance check done by nursery staff will be carried out at the start of the dibbling season

7.2 Parts requiring regular maintenance or adjusting e.g. lubrication should be readily accessible

7.3 Parts which are likely to need replacing over the course of the machine's life should be readily available off the shelf components

8. Size & Weight Restrictions

8.1 Must fit inside a storage shed for protection from the weather

8.2 Width must not exceed that at which interferes with the neighbouring beds - beds are spaced at1800 mm

8.3 Track width should be 1800 mm to fit between the beds

8.4 Weight on bed must not adversely affect the bed surface

9. Manufacturing

9.1 Where possible the prototype should be manufactured using the resources available at the University of Waikato

9.2 Work beyond the capabilities of the university will be outsourced

9.3 Where possible, all material and components used should be readily available off the shelf

10. Aesthetics

10.1 Form is not important to the design, follows function

11. Ergonomics

11.1 One semi-skilled person should be able to set up and operate the machine

11.2 All controls needed during dibbling should be situated in an accessible position i.e. to one side of the machine

11.3 Motions required by operator must be consistent with accepted ergonomic practice

12. Quality & Reliability

12.1 Dibbler should not fail over the course of its service life

12.2 Hole placement should remain accurate for the lifespan of the dibbler

13. Safety

- 13.1 Moving parts should be guarded where feasible
- 13.2 No Dibbler should catastrophically fail under normal operating conditions
- 13.3 Must follow regulations outlined in the Health & Safety document “Guidelines for Guarding Principals and General Safety for Machinery”
- 13.4 Minimum Safety Factor of 3

14. Testing

- 14.1 Functional testing will be carried out
- 14.2 Time required to reconfigure machine to different tree types
- 14.3 Statistical analysis of hole depths and spacing

15. Commissioning

16. Commissioning will involve on site testing until a satisfactory level of operation is reached and signed off by nursery manager.

17. Documentation

- 17.1 User manual covering operation and maintenance will be supplied with Dibbler
- 17.2 Appropriate drawings and calculations will be provided

18. Disposal

- 18.1 Where possible parts should be recyclable

19. Transport

- 19.1 The dibbler needs to be transported safely from Hamilton to Tokoroa once the build is completed and be easily transportable between sites.