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Evaluation of Nursery Container Types for Raising Radiata Pine Seedlings and Cuttings

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EXECUTIVE SUMMARY

While most planting stock is raised bare-root in New Zealand, there is an increasing use of containers to raise stock for planting outside the usual winter season and for expensive vegetatively-propagated clonal material. The important parameters to be considered when choosing a type of container are cell volume, cell shape, and surface area; basically, larger planting stock can be produced in larger containers, provided plant density is not limiting top growth. However, plants in larger cells also require a larger growing area and are therefore more expensive to grow. Cell volumes commonly range from 90-150 ml. In 2007, a survey was done of the main container-growing nurseries in New Zealand, and Horizon2 in Victoria, Australia. The BCC S/S 81 trays were the most common tray type, used in three of the nurseries, followed by the Lannen 81F and 63F trays. These all have square cells and cell volumes of 85-100 ml.

The aim of this study was to raise radiata pine seedlings and cuttings in a wide range of commercially-available containers, ranging in size from 85-220 cc, with different shapes and surface areas (15 types) and then evaluate the size and quality of planting stock produced.

Results from this nursery study showed:

Container-grown seedlings

If a yield of at least 80% out the gate is desired, then a container cell size of at least 120 ml and a growing density of 330/m^2 or less were required. Larger plants are produced in containers with higher cell volumes and lower growing densities, as well as fewer plants in smaller sizes. Seedling root collar diameter was significantly correlated with container cell volume and growing density, but total seedling dry weight was influenced more by growing density than container cell volume. Therefore, it might be possible to increase the proportion of seedlings reaching minimum size specifications by using smaller volume container cells, and leaving some cells blank to lower growing density, as is done currently in some New Zealand nurseries. However, this would need to be evaluated in nursery trials, and would still not totally compensate for the container cell volume effect on plant quality.

Container-grown cuttings

If a yield of at least 80% out the gate is desired, then a container cell size of at least 120 ml was required. All containers of 100 ml or less gave a yield of less than 70% out the gate. Cutting basal diameter was equally affected by container cell volume and growing density, and container cell depth was also significant. For root volume, container cell volume was more important than growing density. Container cell volume and growing density were equally important for total plant dry weight. Therefore, lowering growing density by leaving some container cells blank might not have such a beneficial effect on yield for cuttings as it does with seedlings.

This nursery study has shown how plant size and yield is affected by container cell volume and growing density, with improved plant size and yield with increasing container cell volume and decreasing growing density. Earlier field trials in New Zealand using bare-root seedlings have shown that larger diameter seedlings have had better survivals and growth in the field than smaller plants, and that a diameter of at least 4 mm was necessary. A study in 1983 concluded that smaller diameter seedlings should be planted on mild sites, while larger diameter seedlings should be planted on harsher sites with frost or exposure problems. Also, the research showed that within a given root-collar diameter class, seedlings grown at a lower density grew better in the field, probably reflecting a greater root volume and dry weight. Container-grown plants are smaller than bare-root plants, and therefore might be expected to have problems on harder sites. However, the minimum plant specifications for container-grown plants would need to be defined in appropriate field trials.

BACKGROUND

While most planting stock is raised bare-root in New Zealand, there is an increasing use of containers to raise stock for planting outside the usual winter season and for expensive vegetatively-propagated clonal material. There is a very wide range of containers available on the market, and more are being produced each year. The important parameters to be considered are cell volume, cell shape, and surface area; basically, larger planting stock can be produced in larger containers, provided plant density is not limiting top growth. However, plants in larger cells also require a larger growing area and are therefore more expensive to grow. Cell volumes commonly range from 90-150 ml, while common cell shapes are round or square, with or without side-slits for air pruning. Vertical ribs on the cell walls are often used to prevent or minimise root spiralling. A recent design from Sweden is a star-shaped cell, with the sharp angles preventing root spiralling.

The ideal container would produce economical plants of the required size, with no root distortion or spiralling. Cuttings require a deeper container than seedlings, to allow for the setting depth. There is no simple specification for the minimum plant size or quality required; a larger plant will be required on hard cold sites with weed and animal problems, compared with those required for warm, cultivated sites without establishment problems. However, a minimum height of 20 cm, and a minimum root collar diameter of 3 mm are often specified.

INTRODUCTION

Bare-root plant production is the main nursery production system in New Zealand. It is cost effective and produces large, high quality plants for establishment in winter. Container-growing systems have been developed for the northern latitudes of the Northern Hemisphere, where the climate is harsher, bare-root production is more risky and unpredictable, and several growing seasons may be required to produce large enough stock. Also, in tropical areas, plants do not become dormant in winter, so planting must be done in summer, during the rainy season, and containerized systems are often preferred in these areas. There have been two excellent reviews of container-growing systems in North America, including the Proceedings of the North American Containerized Forest tree Seedling Symposium, held at Denver, Colorado, USA in 1974 (Tinus *et al.* 1974), and the Proceedings of the Canadian Containerized Tree Seedling Symposium, held at Toronto, Ontario, Canada in 1981 (Scarratt *et al.* 1982). Also, there is The Container Tree Nursery Manual, produced in six volumes by the USDA Forest Service from 1995-1999, and Volume 2 covers containers and growing media (Landis *et al.*1990).

Container-grown stock is being used in New Zealand in increasing numbers.
There are both advantages and disadvantages with using container-grown planting stock. (Gutzwiler and Winjum 1974, Kinghorn 1974, 1982, Cleary *et al.* 1978, Faulds and van Dorsser 1987, Ball and Brace 1982, Mason and Jinks 1990, Menzies and Arnott 1992). Possible advantages include:

- Container systems maximise seed use of scarce seeds, since germination conditions can be closely controlled.
- Smaller cuttings can be set in containers than in bare-root nursery beds, maximising production from stoolbeds. This is because problems of soil splash and frost lift are avoided after setting.
- There are fewer weed problems in the nursery.
- There is less transplanting shock with an intact root system with a potting mix.
- The planting season can be extended beyond the winter months.
- Containerized seedlings are easier and faster to plant, especially in rocky soil or debris-covered sites, or with mechanised planters.
- Faster production of planting stock is possible, with greater control and more flexibility over growing schedules.
- Higher quality plants can be produced for some species, such as western hemlock, the true firs and the Cedros provenance of radiata pine.

However, there can also be disadvantages with containerized stock:

- Containerized planting stock can be more expensive to produce, particularly in large containers, because of the cost of containers and potting mix, and lower plant growing densities. Larger containers may also cause weight problems for planting operations, especially if the potting mix is saturated.
- Containerized planting stock will be smaller than bare-root stock, because of the higher plant growing density.
- With small containers, there can be rapid moisture loss.
- There can be problems with poor root systems, such as spiralling, which can lead to tree toppling problems.
- There can be water deficit problems if there is not good contact between the root plug and soil after planting, or if the rooting depth is too shallow after planting.
- Small containerized plants can be vulnerable to browsing animals.
- There can be a large capital cost in setting up suitable facilities, especially in harsher climates.
- There can be problems in conditioning crops for field conditions.
- Frost heaving can be a problem, especially with small containers.

- There can be a higher disease/pest risk in container nurseries, with their protected growing environment and high plant densities.

There are many different container types and sizes available around the world, and the choice is often driven by economic rather than biological concerns. Container size is one of the most important concerns, as the larger the container, the larger the plant that can be produced (Kinghorn 1974). Biological considerations include the size of the seed or cutting, the ultimate size of the crop plant, and the environmental conditions on the planting site, while economic considerations include cost and availability of the container and the amount of available growing space (Landis 1990). Common sizes used in New Zealand for production of planting stock range from 90 ml up to 150 ml, although sizes from 13-50 ml may be used for lining out stock to produce stoolbed plants or growing-on lines, and sizes up to 220 ml have been used to produce larger planting stock for harsh sites.

While container volume is often used to describe size, container depth, diameter, shape, and number of cells per m^2 are also important. The major constraint on container volume is economical, not biological, because larger containers require more growing space and more potting mix, and plants grown in larger containers require a longer time to bind the potting mix and are bulkier to handle and plant in the field (Landis 1990). Container depth is important because of its effect on the water holding properties of the growing medium (Landis 1990), and to ensure sufficient depth for root development of cuttings after setting. Cell diameter affects the spacing between cells and therefore the growing density. Plants require a certain minimum amount of growing space, which varies with species and age (Landis 1990). In general, plant quality increases with a corresponding decrease in growing density.

The individual cells within the trays may be round, square, or rectangular, with or without side-slits, and with a wide range of cell dimensions. Commonly, they will have smooth walls so the roots don't penetrate and make the plug difficult to remove, and the cavity will be tapered from top to bottom so that the plants can be easily extracted from the top (Tinus and McDonald 1979). One of the potential problems with container-grown plants is root spiralling. Root spiralling is worst in round, smooth-walled plastic containers. For this reason, containers often have vertical ridges or ribs protruding into the growing medium to train roots downwards. Side-slits are also sometimes used, to assist in air-pruning roots that pass the slits. Roots that grow down through the drainage hole at the base of the container are air-pruned in the lower humidity outside the container.

There is little information available on growth of radiata pine in different types and sizes of containers. The choice appears to be made on price and cell volume, with cell sizes of 85-128 ml being used. A survey of the main nurseries in New Zealand, and Horizon2 in Victoria, Australia, that were growing radiata pine in containers was done in 2007 (Menzies 2007). The BCC S/S 81 trays were the most common tray type, used in three of the nurseries, followed by the Lannen 81F and 63F trays (Table 1). These all have square cells and cell volumes of 85-100 ml. Two of the nurseries (P F Olsen and Southern Woods) left a blank cell beside each plant to lower the plant growing density from over 500 plants/m^2 down to around 360 plants/m^2.

The plant quality specifications used for container-grown seedlings and cuttings in the six nurseries are given in Table 2. For seedlings, the minimum height ranges from 15-22 cm, and the minimum root collar diameter ranged from 3.0-4.0 mm. Maximum height before topping was required ranged from 30-35 cm. For bare-root seedlings, typical specifications would be a minimum height of 20 cm and a minimum root collar diameter of 5 mm (Menzies *et al.* 2005). For cuttings, the minimum height ranged from 18-22 cm, and the minimum root collar diameter ranged from 3.5-4.5 mm. Maximum height before topping was required ranged from 30-35 cm. For bare-root cuttings, typical specifications would be a minimum height of 20 cm and a minimum root collar diameter of 7-8 mm (Menzies *et al.* 2005).

Table 1: Container types and numbers that are used for growing radiata pine seedlings and cuttings in six nurseries in New Zealand and Australia (Menzies 2007)

	Lannen 63F	Lannen 64F	Lannen 64FD	Lannen 81F	BCC S/S 81
LxWxH (mm)	397x294x90	385x385x73	385x385x110	385x385x73	385x385x85
No. cells	63	64	64	81	81
Layout cells/tray	9x7	8x8	8x8	9x9	9x9
Cell volume (ml)	90	115	128	85	100
Cells/m^2	539	434	434	549	546
	Thousands of trays used by nurseries for radiata pine (seedlings and cuttings)				
PF Olsen	40.0[1]				25.0[2]
Horizon2 (Te Teko)	13.5	1.0	10.5[3]	6.05	
Southern Woods	10.0[1]				
Oregon			20.0		100.0
Edendale	5.0				5.0
Horizon2 (Austr.)	0.5			54.0	
Total no. trays	69.0	1.0	30.5	60.05	130.0
Total no. cells available	4,347,000	64,000	1,952,000	4,864,050	10,530,000

[1] leave blank cell beside each plant to reduce growing density to 42/63 cells; =359/m^2
[2] leave blank cell beside each plant to reduce growing density to 54/81 cells; =364/m^2
[3] plan to increase numbers in 2008 to 32,000 trays

Table 2: Seedling and cutting quality specifications used in the six nurseries surveyed (Menzies 2007)

	Seedlings				
Nursery	Root collar diameter (mm)	Minimum height (cm)	Maximum height (cm)	Sturdiness ratio (height/diameter)	Quadrants with roots
PF Olsen	3.5	22	30		
Horizon2 (Te Teko)	3.5	22	35		
Southern Woods	4.0	20	35		
Oregon	3.5	22	35		
Edendale	3	15	35		
Horizon2 (Austr.)	3.0	20	30		
	Cuttings				
PF Olsen	3.5	22	30		
Horizon2 (Te Teko)	4-4.5[1]	20-22[1]	30-35[1]	<60	2+
Southern Woods	4.0	20	35		
Oregon	4.5	22	35	<60	2+
Edendale	4.0	18	35		
Horizon2 (Austr.)	3.5	20	30	<60	2+

[1] range allows for specifications for different clients

STUDY OBJECTIVES

The aim of this study was to raise radiata pine seedlings and cuttings in a wide range of commercially-available containers, ranging in size from 85-220 ml, with different shapes and surface areas (15 types) and then evaluate the size and quality of planting stock produced.

METHODS

Following approval for the nursery phase of the Project in 2007, containers were purchased of as many different types as practicable, covering types of 85-220 cc volume (Table 3). Fifteen different container types were obtained, but for the V150 containers with no side-slit, only sufficient containers for one treatment were available.

Conventional "stem" cuttings were collected from Te Ngae Nursery on 24-25 July 2007 and set on 26 July 2007. The cuttings were placed in a heated greenhouse for rooting and growing on.

Table 3: Container types for nursery trial

Manufacturer	Tray type	Volume	Density	Format	External dimensions	Cell shape	Sideslit?	No. trays/trt
Raptis Pax	QNT	220	278	10x5	600x300x130	Square	No	6
Panth	S120-28	120	308	5-6x5	350x260x90	Star	Yes	12
Panth	S105-56	105	378	8x7	384x384x90	Star	Yes	6
Panth	S90-33	90	440	6-7x5	350x215x90	Star	Yes	12
Lannen	49F	155	330	7x7	385x385x100	Square	Yes	9
Lannen	64FD	128	434	8x8	385x385x110	Square	Yes	6
Lannen	64F	115	434	8x8	385x385x73	Square	Yes	6
Lannen	63F	90	539	9x7	397x294x90	Square	Yes	6
Lannen	81F	85	549	9x9	385x385x73	Square	Yes	6
BCC	V150	150	316	6x4	352x216x100	Round	No	15
BCC	V150 SS	150	316	6x4	352x216x100	Round	Yes	15
BCC	V120 SS	120	526	8x5	352x216x110	Square	Yes	9
BCC	S/S81	100	546	9x9	385x385x85	Square	Yes	6
BCC	V93	93	526	8x5	352x216x87	Round	No	9
BCC	V90AB	90	526	8x5	352x216x90	Square	Yes	9

Control-pollinated seed from Te Ngae Nursery was sown on 2 October 2007, with two seed per container cell, and containers were placed in a greenhouse for germination, alongside the cuttings. Germination started on 15 October. Cells were thinned to one seedling per cell, and empty cells were transplanted with spare germinating seedlings as germination occurred.

The two treatments of seedlings and cuttings were raised adjacent to each other, so that the cuttings did not compete with the seedlings. Each treatment was divided into three replications. Within a replication, each tray type was kept together in a block to minimise edge effects. The tray types were randomly placed within each replication. The total number of plants per treatment varied from 300-486 per tray type, depending on the number of cells per tray, and trays per treatment (Table 3). This was to ensure there would be a minimum of 60 plants per treatment for each of two field trials, and 30 plants per treatment for morphological assessment.

The plants were moved to an outdoor growing area on raised frames in November 2007 for growing on. The plants were given liquid fertiliser on an "as required" basis to maintain healthy growth. The conventional stem cuttings exceeded 40 cm tall for some container types by the end of summer, and so all of these were topped to a nominal height of 30 cm in May 2008 to maintain healthy foliage to the bases of the cuttings. The seedlings were not topped.

In July 2008, the plants from each treatment and replication were deplugged and randomly selected for morphological assessment of plant quality (30 plants per container type and stock type, at least 20 cm tall and 3 mm basal diameter) and possible field planting (120 plants per container type and stock type, at least 20 cm tall and 3 mm basal diameter). All live plants were measured for height and basal diameter, using a grading board. The percentage of dead and cull trees was calculated from the number of cuttings set or seed sown for each container type (based on a minimum height of 20 cm and a minimum basal diameter of 3 mm for seedlings and 3.5 mm for cuttings). The plants for morphological assessment were washed free of potting mix, and their root volumes measured by water displacement. The plants were then divided into tops and roots, oven-dried at 70^{o}C, and then weighed to obtain top, root and total dry weights.

Bare-root seedlings and cuttings of the same genetic quality were obtained from the Timberlands Ltd Te Ngae Nursery in Rotorua in July 2008 for comparison with the container-grown plants. There were two boxes of each stock type, and the plants for the morphological study (30 of each stock type) and the two possible field trials (120 of each stock type) were randomly selected from these boxes.

RESULTS

Rooting of the cuttings was excellent and germination of the seed was also excellent. At completion of the nursery trial in July, average survival of the cuttings was 83.6% (range 76-100%), while the average survival of the seedlings was 95.3% (range 94-97%).

Analysis of the data from the morphological samples (30 seedlings and 30 cuttings) showed that all variables were significant, except for the effect of container cell type on height growth (Table 4), and this was probably caused by the topping of the cuttings in autumn reducing the height variability. On average, cuttings were significantly larger than seedlings, except for height (Table 5). There was also a significant interaction between stock type and container type for all variables, and so the results for the seedlings and cuttings will be presented separately (Table 4).

Table 4: F tests from analysis of variance for container types and both stock types

Source	Df	Height	Basal diameter	Root volume	Dry weight top	Dry weight root	Total weight
Container	14	0.47	3.64*[1]	4.66**	3.68*	3.83*	5.18**
Stock	1	10.49**	730.56***	116.03***	211.75***	247.18***	361.80***
Cont*Stock	13	33.06***	2.95***	6.19***	3.85***	3.66***	2.69***
Error	816						

[1]Where * = significant at p = 0.05, ** = significant at p = 0.01, and *** = significant at p=0.001

Table 5: Means for container-grown seedlings and cuttings

Stock type	Height (cm)	Basal diameter (mm)	Root volume (ml)	Dry weight top (g)	Dry weight root (g)	Total weight (g)
Seedlings	32.0 a[1]	4.05 b	0.36 b	3.08 b	0.81 b	3.89 b
Cuttings	29.0[2] b	5.99 a	0.79 a	5.20 a	2.23 a	7.43 a
Least Sig. Diff.	2.0	0.15	0.08	0.31	0.19	0.39

[1] For each variable, means followed by the same alphabetical letter are not significantly different (Tukey's test, P≥0.05)
[2] Cuttings were topped at a nominal height of 30 cm in May 2008

Seedlings

Survival of all the seedling treatments was over 90%, and the percentage out the gate ranged from 93.0 down to 63.7% (Table 6). There was a general trend of a higher percentage out the gate (meeting a minimum plant specification of 20 cm tall and a root collar diameter of at least 3 mm) with larger containers and lower cell densities. 93% out the gate occurred with the QNT and BCC V150 container types. There was at least 80% out the gate with a growing density of 330/m^2 or less and a cell volume of at least 120 ml. Percentage out the gate was below 70% when growing density was greater than 500/m^2.

Table 6: Percent survival and percentage out the gate for seedlings grown in different container types

Container type	Cell volume (ml)	Cell density (cells/m^2)	Survival (%)	Overall % out the gate[1]
QNT	220	278	97	93.0
Lannen 49F	155	330	96	88.5
BCC V150 S/S	150	316	97	93.0
Lannen 64FD	128	434	95	75.1
Panth S120-28	120	308	96	86.1

BCC V120 S/S	120	526	94	68.4
Lannen 64F	115	434	97	71.0
Panth S105-56	105	378	96	78.6
BCC S/S 81	100	546	94	66.5
BCC V93	93	526	94	76.0
Panth S90-33	90	440	96	80.3
BCC V90 AB	90	526	95	63.7
Lannen 63F	90	539	94	66.6
Lannen 81F	85	549	95	63.7

[1]Overall % out the gate based on the total number of cells for a container type and the number of seedlings exceeding a culling standard of 20 cm minimum height and 3.0 mm minimum basal diameter

There were highly significant differences (p≤0.001) between all seedling variables (Table 7). Seedling variable means for each container type (30 seedlings per container type) are given in Table 8. Average seedling height ranged from 28.3-33.9 cm tall, with no consistent pattern with container cell volume or density, although there was a slight trend for seedlings to be taller in larger volume containers. Average seedling diameter ranged from 3.65-4.51 mm, with a trend for a larger diameter in larger volume containers (Table 8). Seedlings grown in the PanthS120-28 container had a very good average diameter compared with plants from other similar sized containers, and this was probably caused by the low growing density of this container type. Examples of the frequency distribution for root collar diameter for four container types commonly used in New Zealand are given in Fig. 1 (the frequency distributions for root collar diameter for all container types is given in Appendix 1). Average root volume and root dry weight also tended to follow the same trend, with larger root volumes and dry weights from larger container cells (Table 8), although seedlings grown in the Lannen 49F container were smaller. Similarly, top dry weight and total dry weight tended to follow this trend. All of the container-grown seedlings were smaller than the bare-root seedlings, which could be expected, because of the growing space density and soil volume)???? Bracket??? available to the bare-root plants (typically 160/m^2).

Table 7: F tests for seedlings only from analysis of variance for container types

Source	Df	Height	Basal diameter	Root volume	Dry weight top	Dry weight root	Total weight
Container type	13	12.63***[1]	11.61***	20.53***	14.20***	15.79***	14.18***
Error	406						

[1]Where *** = significant at p=0.001

There was no consistent effect of container shape. With larger containers, three similar container types for size were the Lannen 49F (155 ml, square), the BCC V150 S/S (150 ml, round), and the Panth S120-28 (120 ml, star-shaped). The seedlings grown in the V150 S/S were significantly larger than those in the Lannen 49F for root volume, and dry weight, with the seedlings from the Panth S120-28 intermediate between the other two. However, the Lannen 49F also had a slightly higher growing density than the other two container types, and this would have had an effect on plant size. With smaller containers around 90 ml, there were three similar container types for size, with the Lannen 63F (90 ml, square), the BCC V93 (93 ml, round), and the BCC V90 AB (90 ml, square). The seedlings grown in the V90 AB had a significantly larger root volume than those from the Lannen 63F, but there were no other significant differences between the three container types, and again, the Lannen 63F also had a slightly higher growing density than the other two container types, and this would have had an effect on plant size.

The correlation coefficient matrix for containers and plant variables is given in Table 9. All seedling variables were significantly negatively correlated with cell growing density (p<0.001), and positively correlated with container cell volume (p<0.05 or better) (except for seedling top dry weight) (Table

9). Both root volume and dry weight were significantly correlated with container cell depth. As could be expected, all the plant variables were significantly correlated with each other, so that taller and fatter seedlings had larger root volumes and dry weights. A multiple regression was done on mean seedling root collar diameter (for all seedlings in the trial) for each container type, and the regression was:

Mean seedling diameter = 4.202 – 0.002*cell density + 0.00212*cell volume

$R^2 = 0.823$

This confirms the importance of both container cell growing density and container cell volume on seedling growth.

Table 8: Seedling variable means by container type, plus a bare-root seedling control (not included in the analysis). Container types have been ordered from largest to smallest. Where cell types have the same volume, the one with the lowest cell density is first.

Container type	Cell volume (cm^3)	Height (cm)	Diameter (mm)	Root volume (cm^3)	Dry weight of top (g)	Dry weight of root (g)	Total dry weight (g)
QNT	220	33.93 abc[1]	4.38 ab	0.63 a	3.72 abc	1.26 a	4.98 ab
Lannen 49F	155	32.55 abcde	4.24 abc	0.38 c	3.16 cde	0.84 cde	4.00 c
BCC V150 S/S	150	34.79 a	4.49 a	0.50 b	4.03 ab	1.16 ab	5.19 a
Lannen 64FD	128	29.59 gh	3.95 cd	0.39 bc	2.57 ef	0.90 cd	3.47 cd
Panth S120-2	120	34.70 ab	4.51 a	0.41 bc	4.30 a	0.93 bc	5.23 a
BCC V120 S/S	120	30.69 efgh	3.90 cd	0.25 d	2.61 ef	0.67 def	3.28 cd
Lannen 64F	115	29.98 fgh	3.87 cd	0.31 cd	2.69 def	0.74 cdef	3.43 cd
Panth S105-5	105	31.97 cdefg	4.10 bc	0.32 cd	3.39 bcd	0.74 cdef	4.13 bc
BCC S/S 81	100	32.15 bcdef	3.91 cd	0.30 cd	2.69 def	0.67 def	3.36 cd
BCC V93	93	33.24 abcd	4.02 bcd	0.35 cd	3.02 cde	0.81 cde	3.83 c
Panth S90-33	90	32.18 bcdef	4.00 cd	0.31 cd	2.93 de	0.66 ef	3.59 cd
BCC V90 AB	90	31.30 defg	3.69 d	0.38 c	2.90 def	0.77 cdef	3.67 cd
Lannen 63F	90	32.73 abcde	3.92 cd	0.23 d	2.94 de	0.65 ef	3.58 cd
Lannen 81F	85	28.33 h	3.65 d	0.24 d	2.16 f	0.56 f	2.72 d
Least Sig. Diff.		2.55	0.38	0.11	0.75	0.24	0.95
Bare-root		41.16	9.27	0.94	18.51	3.51	22.02

[1] For each variable, means followed by the same alphabetical letter are not significantly different (Tukey's test, P≥0.05)

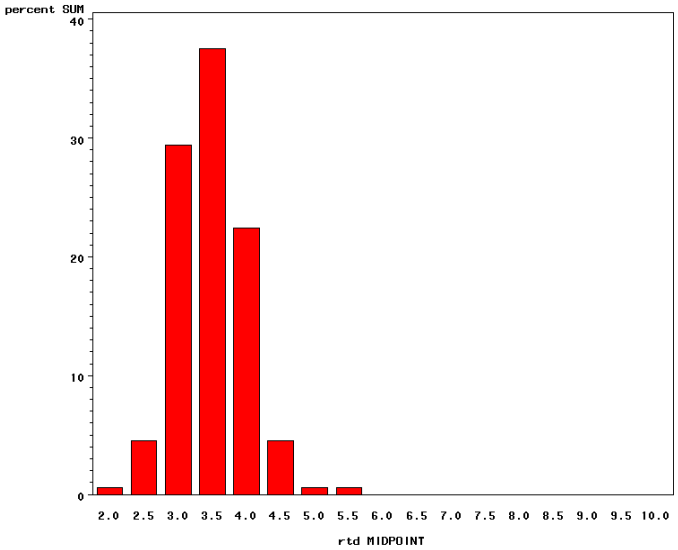
Table 9: Correlation coefficients for seedling means

		Container cell			Seedlings					
		volume	density	depth	height	diameter	root_vol	DW_top	DW_root	tot_wt
Container cell	volume	1.00	-0.77**	0.80***	0.63*	0.79***	0.85***	0.51	0.86***	0.63*
	density		1.00	-0.49	-0.83***	-0.89***	-0.78***	-0.80***	-0.79***	-0.84***
	depth			1.00	0.34	0.53	0.67**	0.35	0.69**	0.46
Seedlings	height				1.00	0.94***	0.73**	0.91***	0.75**	0.91***
	diameter					1.00	0.81***	0.81***	0.82***	0.86***
	root_vol						1.00	0.68**	0.96***	0.79***
	DW_top							1.00	0.73**	0.98***
	DW_root								1.00	0.84***
	tot_wt									1.00

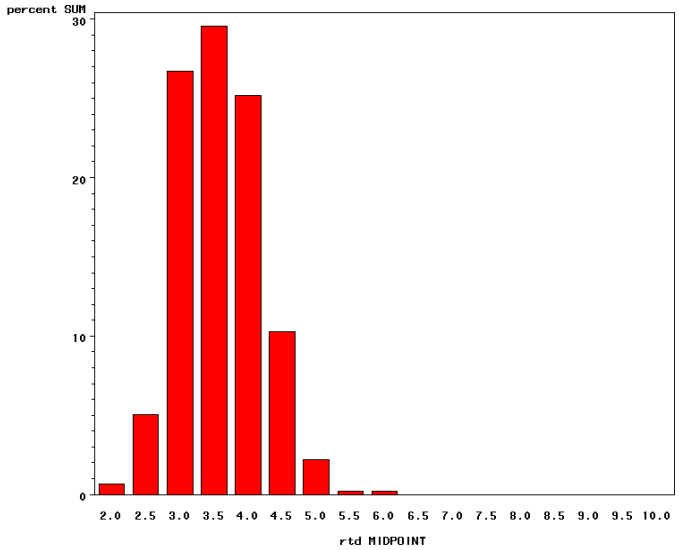
Any correlation greater than 0.55 = p< 0.05, 0.65 = p<0.01, 0.78 = p< 0.001

Figure 1: Frequency distributions for root collar diameter of seedlings for four different container types of (Lannen 63F (90ml), (2) BCC S/S81 (100ml), (3) Lannen 64FD (128mml), and (4) BCC V150 S/S (150ml)

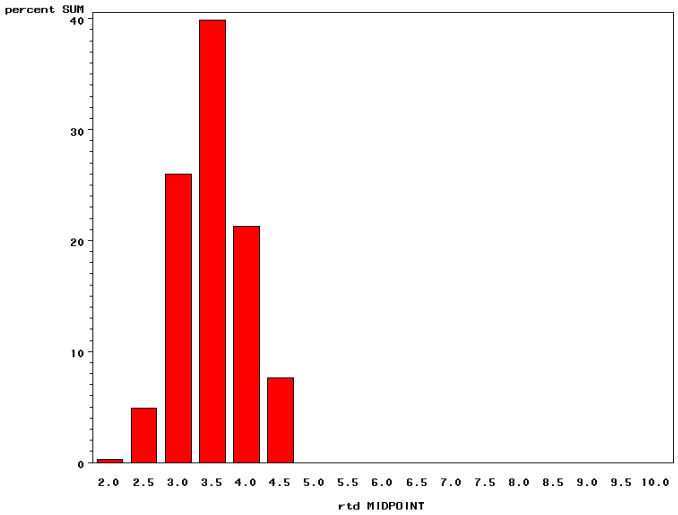
Lannen 63F (90ml)



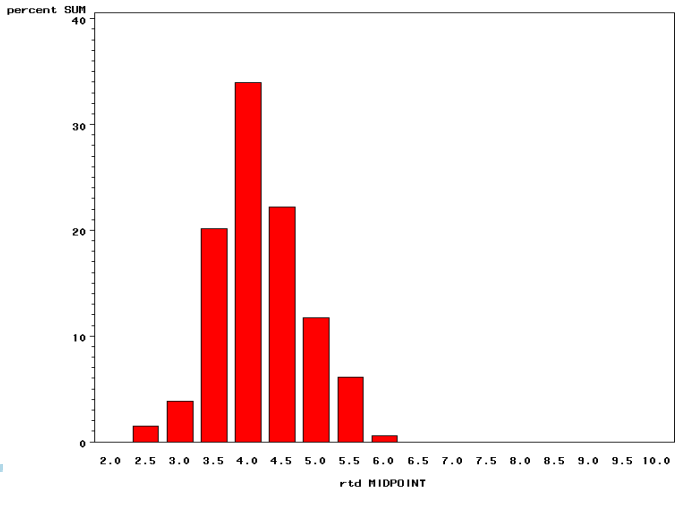
BCC S/S81 (100ml)



Lannen 64FD (128ml)



BCC V150 S/S (150ml)



Cuttings

Cutting survival was best in the larger containers (Table 10). Six container types had a volume of 100 ml or less, and of these, only the cuttings grown in the Panth S90 (with a lower cell density of 440/m^2 had survivals over 85%. Ten container types had a cell volume of 120 ml or less, and of these, only the cuttings grown in the Panth S120 and the Lannen 64F containers had survivals over 90%. To exceed 80% of cuttings out the gate, the container volume had to be at least 120 ml. Only the BCC V120 S/S container type did not meet this standard, probably because the cell density was comparatively high (526/m^2). All the container types of 100 ml or less had less than 70% out the gate, except for the Panth S90-33, which had a comparatively low cell density of 440/m^2.

Table 10: Percent survival and percentage out the gate for cuttings grown in different container types

Container type	Cell volume (ml)	Cell density (cells/m^2)	Survival (%)	Overall % out the gate[1]
QNT	220	278	100	95.3
Lannen 49F	155	330	99	88.1
BCC V150 S/S	150	316	97	84.1
BCC V150	150	316	98	87.7
Lannen 64FD	128	434	95	84.1
Panth S120-28	120	308	96	86.8
BCC V120 S/S	120	526	84	73.2
Lannen 64F	115	434	92	78.8
Panth S105-56	105	378	86	76.8
BCC S/S 81	100	546	77	65.0
BCC V93	93	526	76	65.7
Panth S90-33	90	440	86	70.8
BCC V 90 AB	90	526	76	59.1
Lannen 63F	90	539	83	67.6
Lannen 81F	85	549	79	61.6

[1]Overall % out the gate based on the total number of cuttings set in a container type and the cuttings exceeding a culling standard of 20 cm minimum height and 3.5 mm minimum basal diameter

There were highly significant differences ($p \leq 0.001$) between all cutting variables (Table 11). Cutting variable means for each container type (30 seedlings per container type) are given in Table 12. Average cutting height ranged from 24.7-32.1 cm tall. However, the cuttings were topped at a nominal height of 30 cm in May 2008. The topping was done at a fixed height above the base of the frame for all cuttings, and so cuttings growing in taller container types were topped at a lower height. Thus, final heights are more a reflection of container depth, with the cuttings in the QNT containers the shortest. Average cutting diameter ranged from 5.33-6.54 mm, with a trend for a larger diameter in larger volume containers (Table 12). Examples of the frequency distribution for root collar diameter for four container types commonly used in New Zealand are given in Fig. 2 (the frequency distributions for root collar diameter for all container types is given in Appendix 2). Average root volume and root dry weight tended to follow the same trend, with larger root volumes and dry weights from larger container cells (Table 12), although cuttiings grown in the Lannen 49F container were smaller, as occurred with the seedlings. Similarly, top dry weight and total dry weight tended to follow this trend. Bare-root cuttings were larger than all the container-grown cuttings, except for some of the root volumes and dry weights of container-grown plants in larger cells. However, the bare-root cuttings had their root systems trimmed to a plantable size after lifting. Bare-root cuttings would typically be grown at a density of around 115/m^2.

Table 11: F tests for cuttings only from analysis of variance for container types

Source	Df	Height	Basal diameter	Root volume	Dry weight top	Dry weight root	Total weight
Cell	14	56.67***[1]	5.43***	17.43***	6.87***	8.44***	6.80***
Error	410						

[1]Where *** = significant at p=0.001

Table 12: Cutting variable means by container type, plus a bare-root cutting control (not included in the analysis). Container types have been ordered from largest to smallest. Where cell types have the same volume, the one with the lowest cell density is first.

Container type	Cell volume (cm^3)	Height (cm)	Diameter (mm)	Root volume (cm^3)	Dry weight of top (g)	Dry weight of root (g)	Total dry weight (g)
QNT	220	24.71 f	6.54 a	1.37 a	5.99 ab	3.46 a	9.45 a
Lannen 49F	155	26.62 e	5.92 abcd	0.84 cd	4.91 cde	2.23 bcd	7.14 bcd
BCC V150 S/S	150	26.80 e	6.31 ab	1.14 ab	5.63 abc	2.90 ab	8.53 abc
BCC V150	150	27.92 de	6.17 abc	0.94 bc	5.46 abcd	2.50 bc	7.96 abcd
Lannen 64FD	128	30.97 ab	5.84 bcd	0.82 cde	4.73 cde	2.12 bcd	6.85 bcd
Panth S120-2	120	27.18 de	6.35 ab	0.71 cdef	6.15 a	2.44 bc	8.59 ab
BCC V120 S/S	120	29.76 bc	5.62 cd	0.70 cdef	4.37 e	2.02 cd	6.40 d
Lannen 64F	115	30.58 ab	6.30 ab	0.73 cdef	6.13 a	2.31 bcd	8.44 abc
Panth S105-5	105	27.22 de	6.08 abc	0.53 f	5.05 bcde	1.55 d	6.59 d
BCC S/S 81	100	26.58 e	5.83 bcd	0.72 cdef	4.72 cde	2.11 bcd	6.82 cd
BCC V93	93	31.91 a	5.99 abc	0.73 cdef	5.11 abcde	2.24 bcd	7.35 bcd
Panth S90-33	90	32.04 a	5.78 bcd	0.57 ef	4.88 cde	1.63 d	6.51 d
BCC V90 AB	90	30.14 b	5.96 abcd	0.64 def	5.54 abc	1.93 cd	7.47 bcd
Lannen 63F	90	32.07 a	5.33 d	0.72 cdef	4.39 de	1.98 cd	6.37 d
Lannen 81F	85	28.42 cd	5.89 bcd	0.65 def	4.97 bcde	2.02 cd	6.99 bcd
Least Sig. Diff.		1.52	0.64	0.26	1.08	0.79	1.76
Bare-root		33.82	7.71	0.84	11.84	2.74	14.57

[1] For each variable, means followed by the same alphabetical letter are not significantly different (Tukey's test, P≥0.05)

There was no consistent effect of container shape. With larger containers, three similar container types for size were the Lannen 49F (155 ml, square), the BCC V150 S/S (150 ml, round), and the Panth S120-28 (120 ml, star-shaped). The cuttings grown in the V150 S/S had a significantly higher root volume than those from the other two container types. However, the Lannen 49F also had a slightly higher growing density than the other two container types, and this would have had an effect on plant size. With smaller containers around 90 ml, there were three similar container types for size, with the Lannen 63F (90 ml, square), the BCC V93 (93 ml, round), and the BCC V90 AB (90 ml, square). The cuttiings grown in the V93 had a significantly larger diameter than those from the Lannen 63F, and again, the Lannen 63F also had a slightly higher growing density than the other two container types, and this would have had an effect on plant size. Cuttings were set in both side-slit and non-side-slit BCC V150 container types, but there were no significant differences between the plants grown in these two container types.

The correlation coefficient matrix for containers and plant variables is given in Table 13. All cutting variables (except height) were significantly negatively correlated with cell growing density ($p<0.05$ or better), and positively correlated with container cell volume ($p<0.01$ or better) (except for cutting top dry weight) (Table 12). Cutting basal diameter, root volume and root dry weight were significantly correlated with container cell depth. As could be expected, all the plant variables except height were significantly correlated with each other, so that taller and fatter seedlings had larger root volumes and dry weights, although top dry weight was not correlated with root volume.

A multiple regression was done on mean cutting diameter (for all cuttings in the trial) for each container type, and the regression was:

Mean cutting diameter = 5.701 – 0.0014*cell density + 0.00352*cell volume

$R^2 = 0.886$

As with seedlings, this confirms the importance of both container cell growing density and container cell volume on cutting growth.

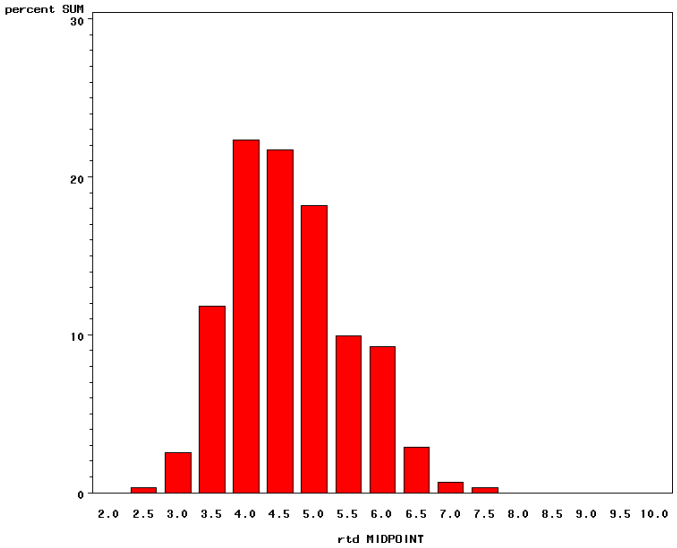
Table 13: Correlation coefficients for cutting means

		Container cell			Cuttings					
		volume	density	volume	density	volume	density	volume	density	volume
Container cell	volume	1.00	-0.78***	0.80***	-0.20	0.88***	0.90***	0.43	0.85***	0.69**
	density		1.00	-0.50	-0.08	-0.90***	-0.61*	-0.61*	-0.60*	-0.67**
	depth			1.00	-0.60*	0.66**	0.70**	0.00	0.56*	0.28
Cuttings	height				1.00	-0.08	-0.04	0.49	0.05	0.33
	diameter					1.00	0.75**	0.62*	0.73**	0.75**
	root_vol						1.00	0.41	0.95***	0.73**
	DW_top							1.00	0.60*	0.92***
	DW_root								1.00	0.87***
	tot_wt									1.00

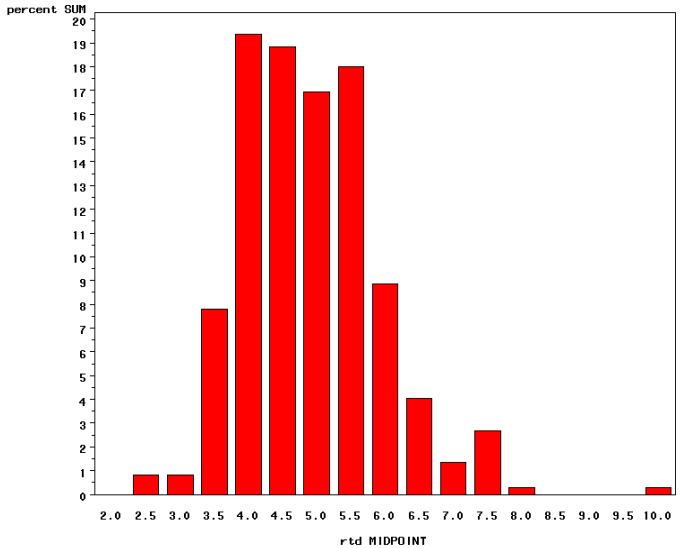
Any correlation greater than 0.55 = p< 0.05, 0.65 = p<0.01, 0.78 = p< 0.001

Figure 2: Frequency distributions for root collar diameter of cuttings for four different container types of (1) Lannen 63F (90ml), (2) BCC S/S81 (100ml), (3) Lannen 64FD (128ml), and (4) BCC V150 S/S (150ml)

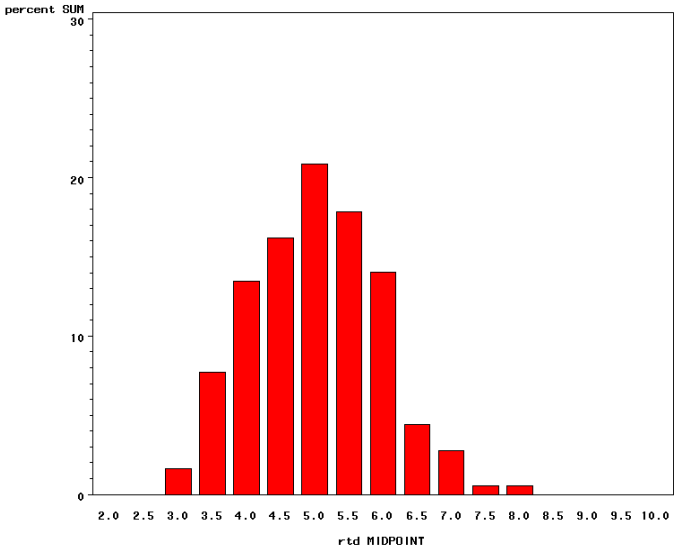
Lannen 63F (90ml)



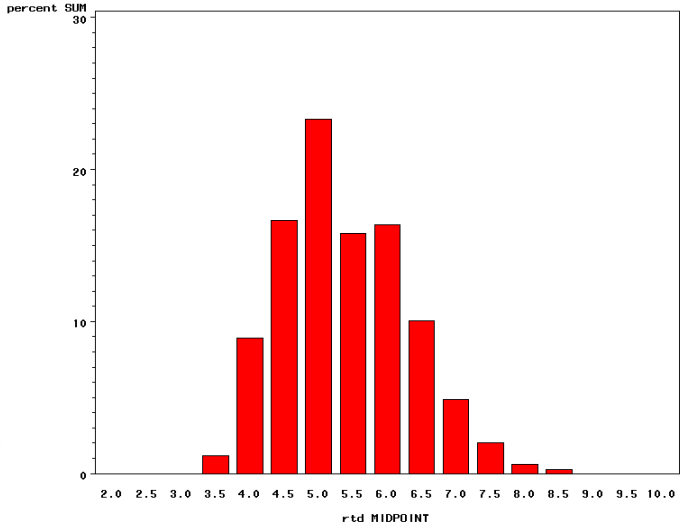
BCC S/S81 (100 ml)



Lannen 64FD (128ml)



BCC V150 S/S (150ml)



DISCUSSION

For a target yield of at least 80% of seedlings out the gate from container cells sown, a minimum container cell volume of 120 ml and a maximum growing density of 330/m^2 was required (Table 6). Also, plant size was larger under these conditions, and there were fewer plants in the smaller sizes (Table 6, Fig. 1). There was a higher percentage of plants in the 3.0-3.5 root collar diameter range in the 90-100 ml containers, compared with more in the 3.5-4.5 mm root collar diameter range with the 128-150 ml containers (Fig. 1). Both container volume and growing density were significantly correlated with root collar diameter (Table 9). The correlation coefficient for root collar diameter and growing density (-0.89) was slightly greater than that for container cell volume (0.79), while for root volume it was the other way around. Total plant dry weight was more affected by growing density than container cell volume.

Some nurseries in New Zealand are leaving some container cells blank, so that there is a blank cell beside each plant. This lowers the growing density for a given cell volume (Table 1). For the 90 ml Lannen 63F container, this lowered the growing density from 539/m^2 to 359/m^2, and for the 100 ml BCC S/S 81 container, the growing density is lowered from 546/m^2 to 364/m^2. This could be expected to increase the proportion of plants reaching minimum height and root collar diameter specifications, but wouldn't compensate for the container cell volume effect. Based on the multiple regression equation for mean seedling diameter (pg. 10), and changing the cell growing density from 539 cells/m^2 to 359 cells/m^2 for a 90 ml Lannen 63F container, predicted mean seedling root collar diameter would change from 3.26 mm to 3.64 mm, an increase of 0.38 mm. However, this benefit would need to be evaluated in a nursery trial. The closest container types in the current trial to these cell volume and growing density conditions were the Panth S105-56 (105 ml cell volume and 378 cells/m^2 density) and Panth S90-33 (90 ml cell volume and 440/m^2 density). The percentage of seedlings out the gate for these two container types was 78.6 and 80.3% respectively, which was higher than other containers with similar cell volumes (Table 6).

For the cuttings, to get a minimum of 80% of plants out the gate required the same container cell volume as for seedlings (Table 10). All the containers with a cell volume of 100 ml or less had less than 70% of plants out the gate, except for the Panth S90-33, which has a lower container cell density than the other similar sized container types. For cuttings, both container cell volume and growing density were equally important for their effect on plant basal diameter, and container cell depth was also significant, based on the correlation coefficients (Table 13). For plant root volume, container cell volume was more important than container depth, and growing density was less important, although still significant. Both container cell volume and growing density were equally important for total plant dry weight. This was a different result from what occurred with seedlings, and so lowering growing density by leaving some container cells blank might not have such a beneficial effect on yield for cuttings, compared with seedlings. Based on the multiple regression equation for mean cutting diameter (pg. 15), and changing the cell growing density from 539 cells/m^2 to 359 cells/m^2 for a 90 ml Lannen 63F container, predicted mean cutting diameter would change from 4.63 mm to 4.89 mm, an increase of 0.26 mm. As expected, this gain is less than that predicted for seedlings, and the benefit would need to be evaluated in a nursery trial. While the yield of cuttings out the gate for the two Panth container types of 90 and 105 ml was better than for the two Lannen and BCC container types of 90 and 100 ml cell volumes, the increased yield was not as good as that with the seedlings. Thus for increasing the yield of cuttings out the gate, both a higher container cell volume and a lower growing density would be required, whereas for increasing seedling yield out the gate, lowering growing density by leaving some cells blank might be sufficient.

This nursery study has shown how plant size and yield is affected by container cell volume and growing density, with improved plant size and yield with increasing container cell volume and decreasing growing density. However, it is not possible to define a minimum plant specification for seedlings or cuttings without comparing the performance of different-sized plants in the field. Field

trials have also shown that larger diameter bare-root radiata pine seedlings have had better survivals and growth in the field, and that a diameter of at least 4 mm is necessary (Prior 1969, Wilkinson 1969, Anstey 1971, Balneaves and Fredric 1983). Smaller diameter seedlings should be planted on mild sites, while larger diameter seedlings should be planted on harsher sites with frost or exposure problems (Balneaves and Fredric 1983). Also, Balneaves and Fredric (1983) found that within a given root-collar diameter class, seedlings grown at a lower density grew better in the field, probably reflecting a greater root volume and dry weight. Container-grown plants are smaller than bare-root plants (Tables 5, 8 &12), and therefore might be expected to have problems on harder sites. However, the minimum plant specifications for container-grown plants would need to be defined in appropriate field trials.

There were no consistent effects of container shape or the presence of side slits on the size of the resulting plants, although there were not many direct comparisons available. There might be differences in the way roots grow out from the container plug after field planting. There has been anecdotal evidence from Australia that there is less root spiralling from plants grown in square cells rather than round cells, but this would need to be evaluated in field trials.

CONCLUSION

This nursery study has shown how plant size and yield is affected by container cell volume and growing density, with improved plant size and yield with increasing container cell volume and decreasing growing density. However, it is not possible to define a minimum plant specification for container-grown seedlings or cuttings without comparing the performance of different-sized plants in the field. Container shape did not have a consistent significant effect on plant size. There might be differences in the way roots grow out from the container plug, but again, this would need to be evaluated in field trials.

Container-grown seedlings

If a yield of at least 80% out the gate is desired, then a container cell size of at least 120 ml and a growing density of 330/m^2 or less are required. Larger plants are produced in containers with higher cell volumes and lower growing densities, as well as fewer plants in smaller sizes. Seedling root collar diameter is significantly correlated with container cell volume and growing density, but total seedling dry weight is influenced more by growing density than container cell volume. Therefore, it might be possible to increase the proportion of seedlings reaching minimum size specifications by using smaller volume container cells, and leaving some cells blank to lower growing density, as is done currently in some New Zealand nurseries. However, this would still not totally compensate for the container cell volume effect on plant quality.

Container-grown cuttings

If a yield of at least 80% out the gate is desired, then a container cell size of at least 120 ml is required. All containers of 100 ml or less gave a yield of less than 70% out the gate. Cutting basal diameter was equally affected by container cell volume and growing density, and container cell depth was also significant. For root volume, container cell volume was more important than growing density. Container cell volume and growing density were equally important for total plant dry weight. Therefore, lowering growing density by leaving some container cells blank might not have such a beneficial effect on yield for cuttings as it would with seedlings.

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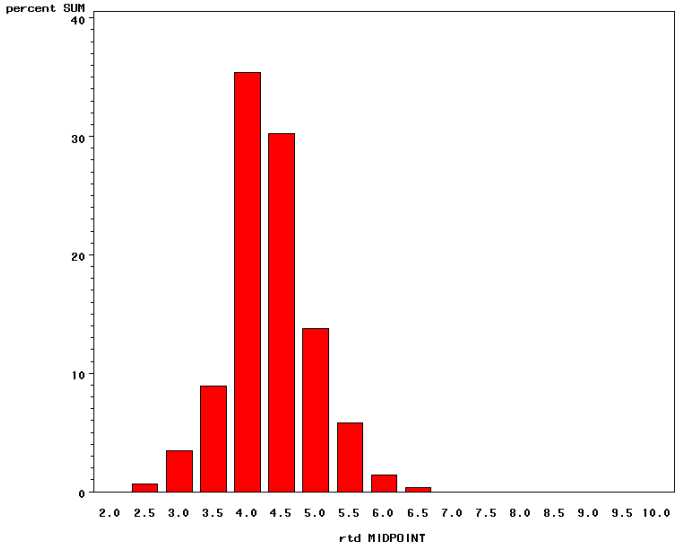
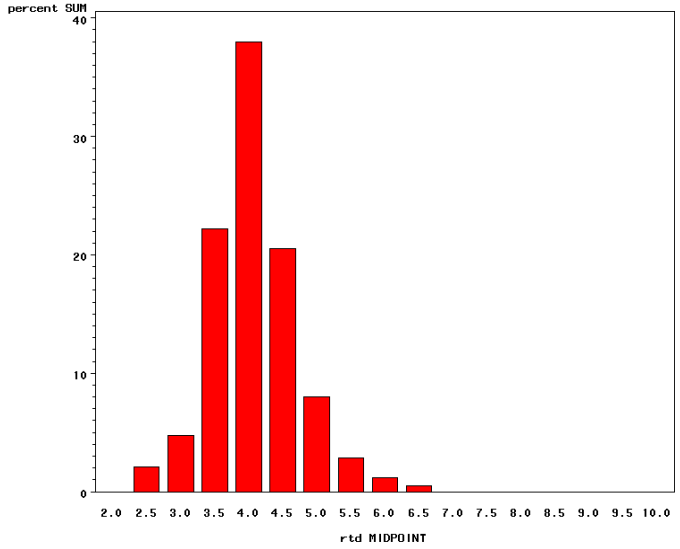
APPENDICES

Appendix 1: Frequency distributions for root collar diameter of seedlings for different container types

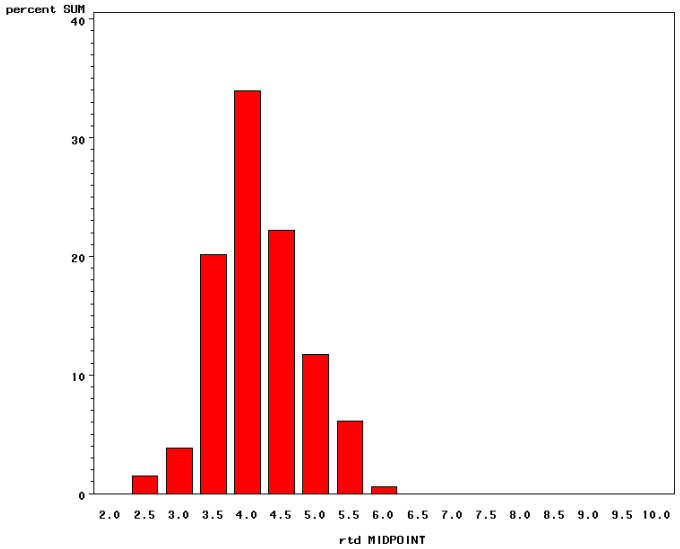
QNT (220 ml)

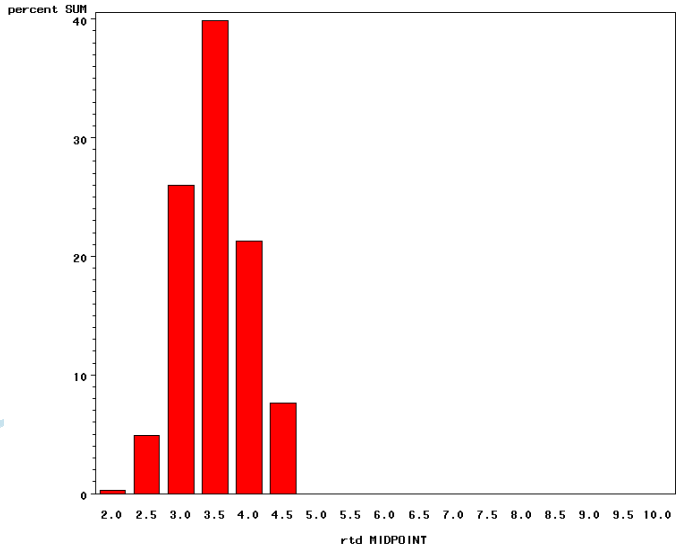


Lannen 49F (155 ml)



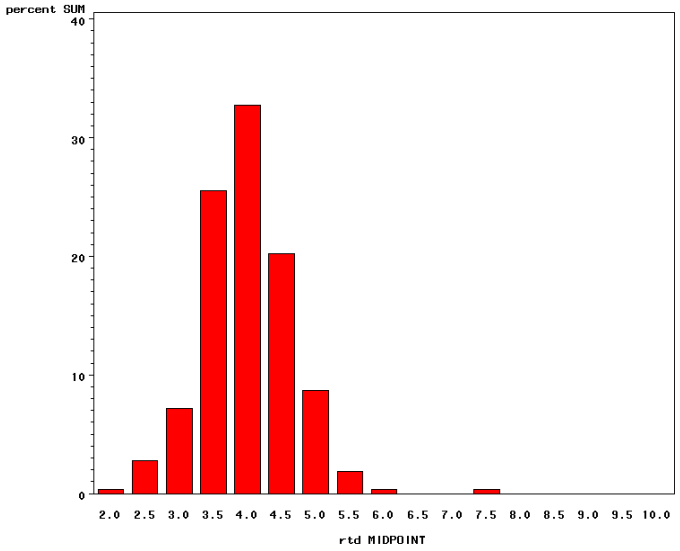
BCC V150 S/S (150 ml)



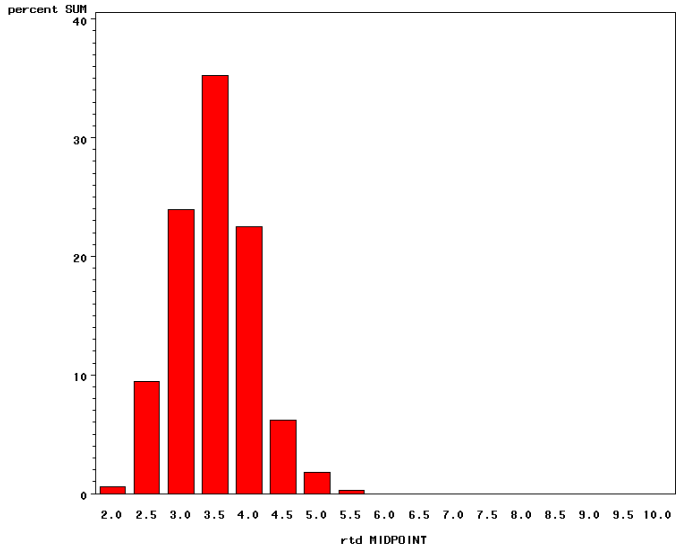


ne_G23a

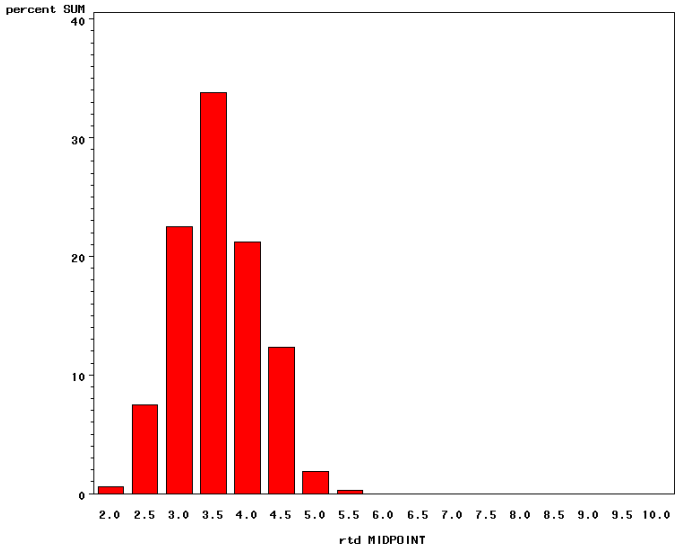
Panth S120-28 (120 ml)



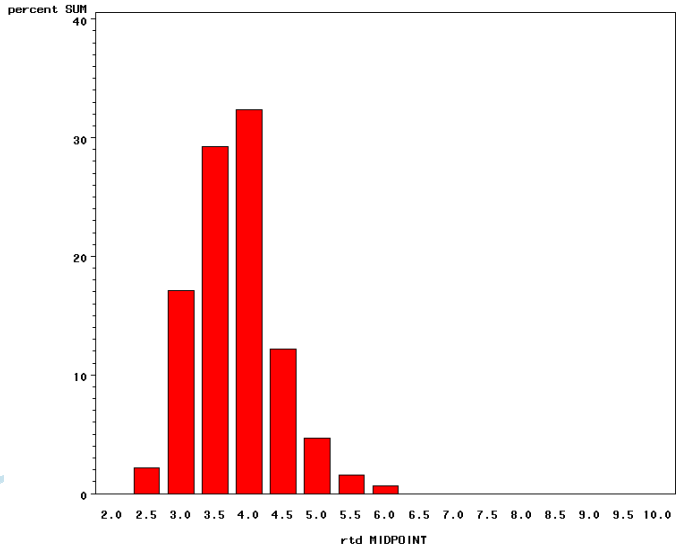
BCC V120 SS (120 ml)



Lannen 64F (115 ml)



Panth S105-56 (105 ml)



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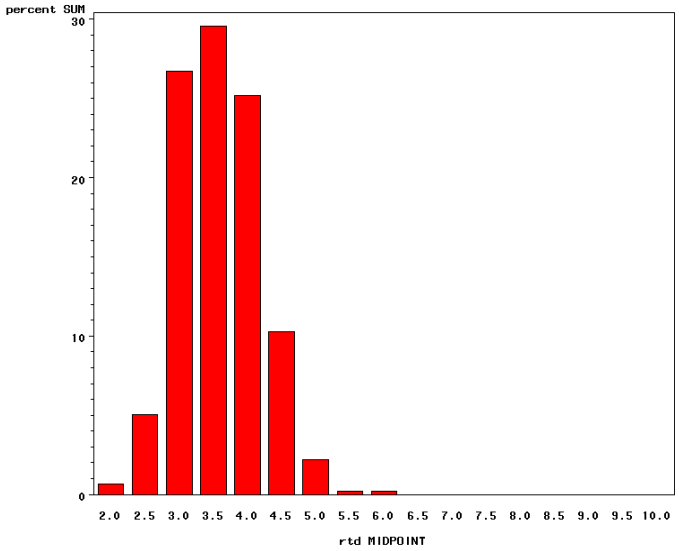
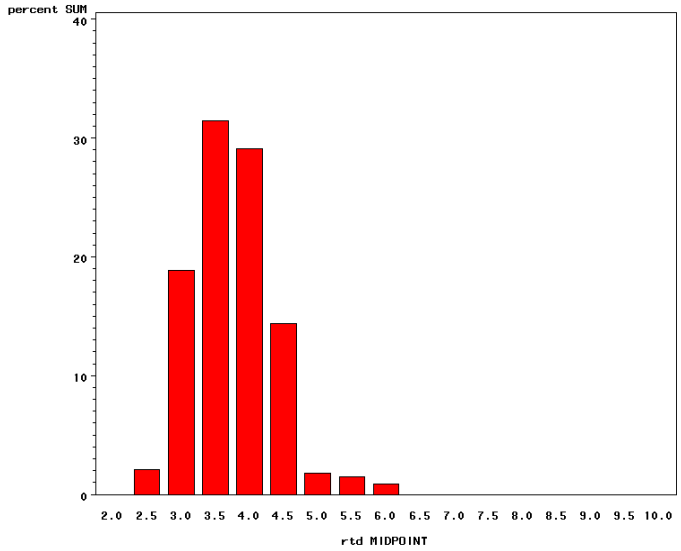
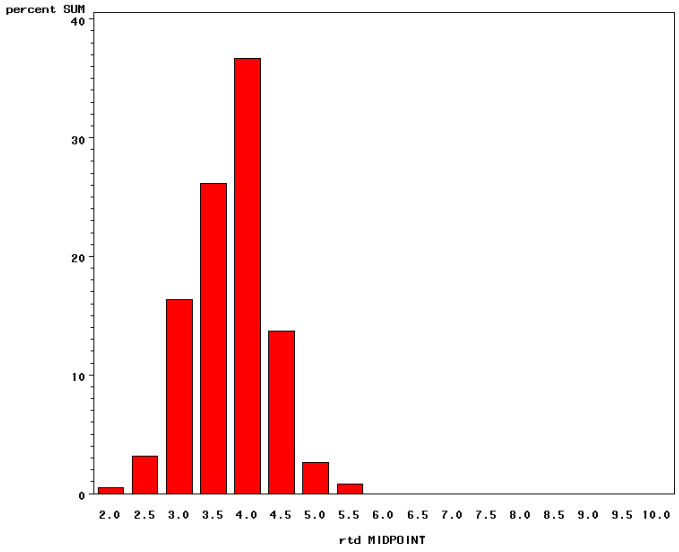
BCC S/S 81 (100 ml)



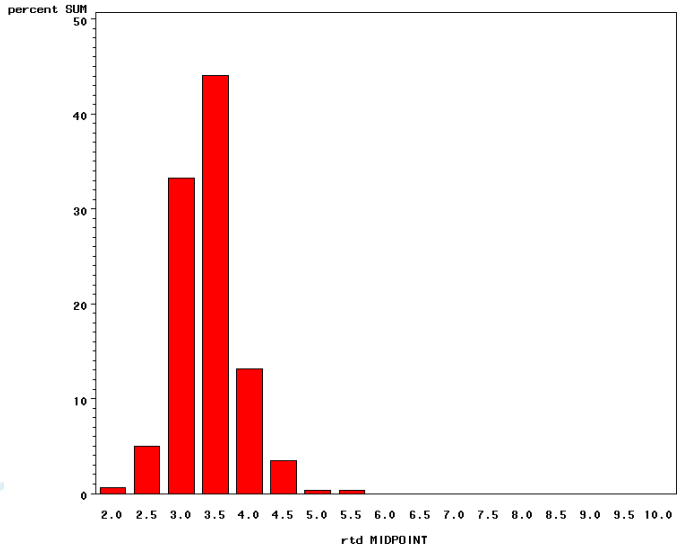
BCC V93 (93 ml)



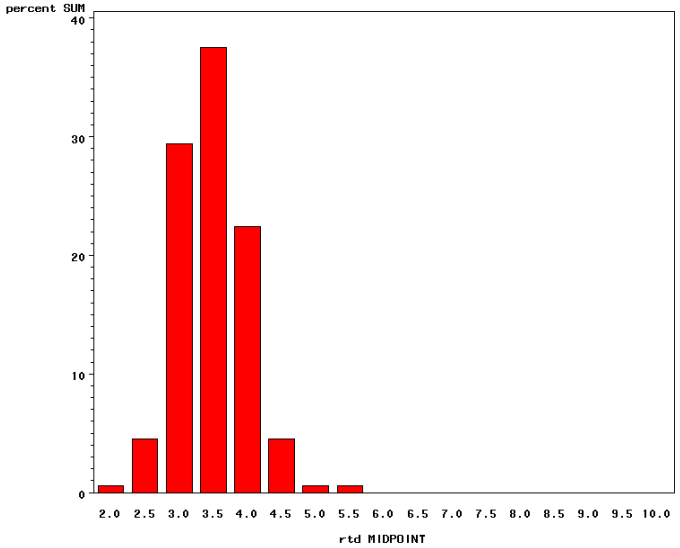
Panth S90-33 (90 ml)



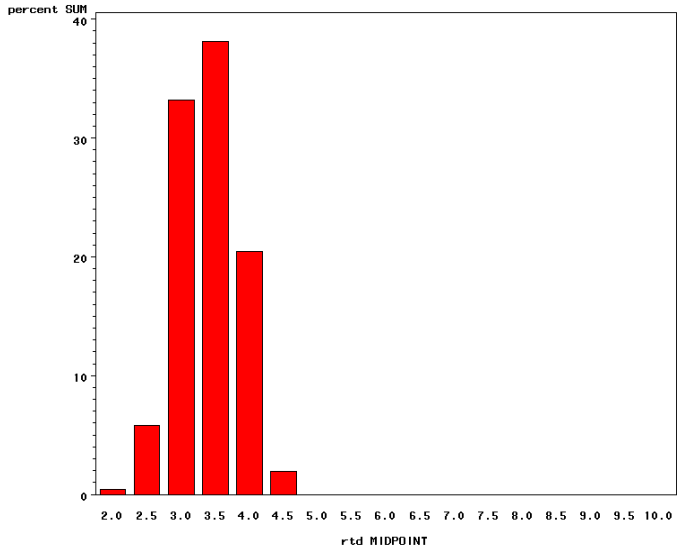
BCC V90 AB (90 ml)



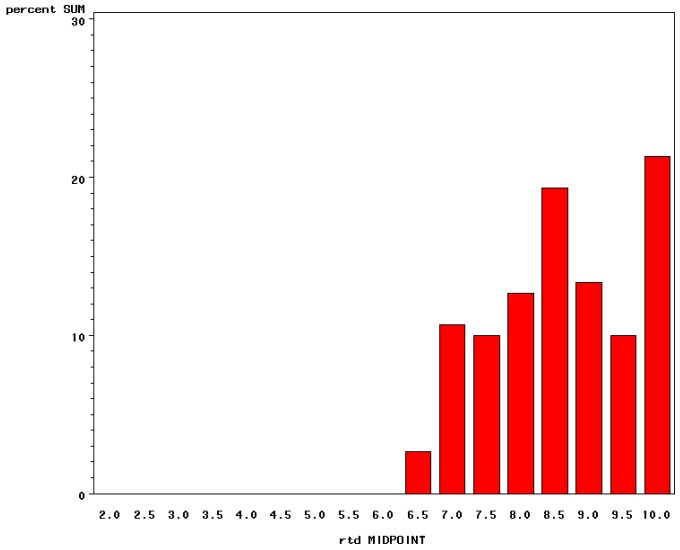
Lannen 63F (90 ml)



Lannen 81F (85 ml)

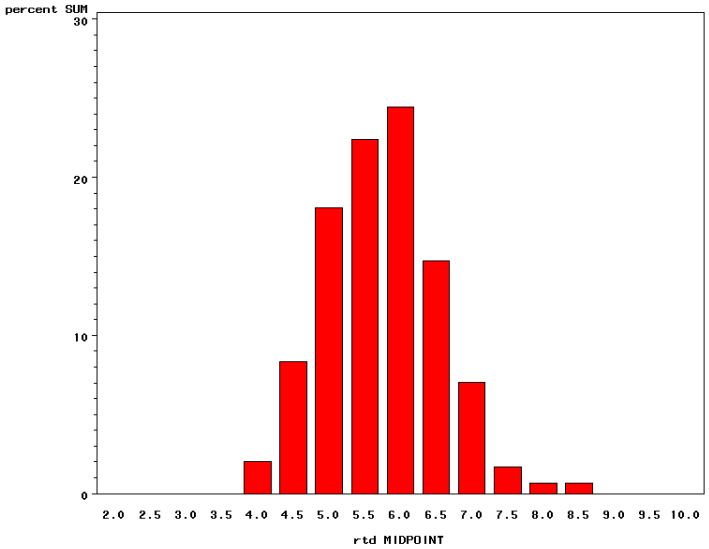


Bare-root seedlings

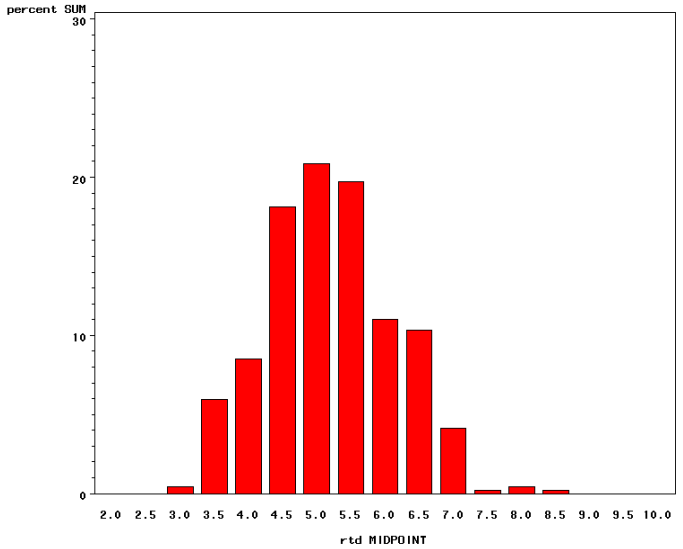


Appendix 2: Frequency distributions for root collar diameter of cuttings for different container types

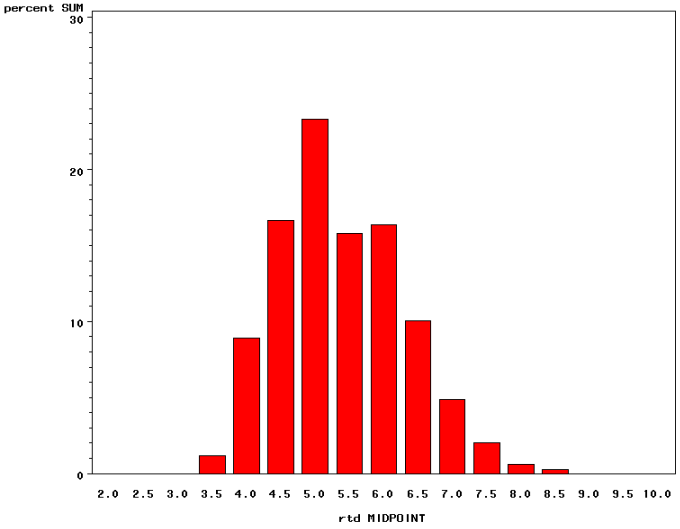
QNT (220 ml)



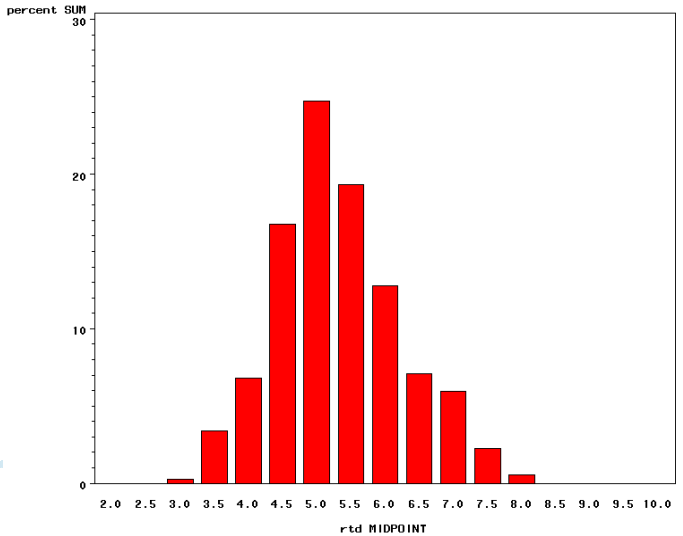
Lannen 49F (155 ml)



BCC V150 S/S (150 ml)



BCC V150 (150 ml)



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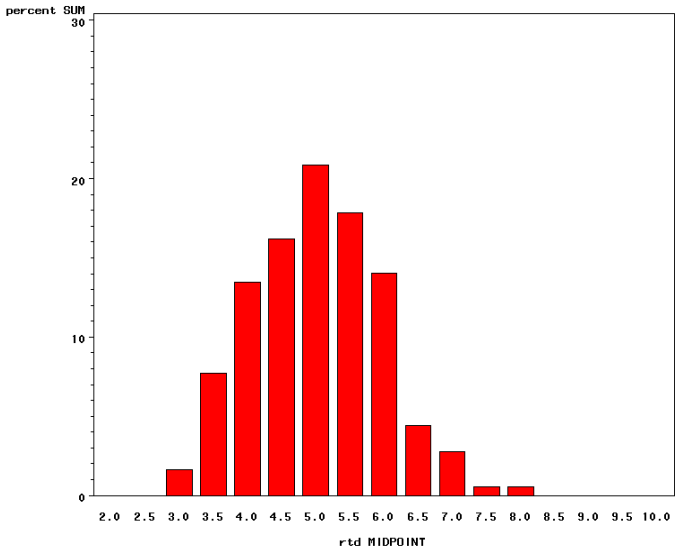
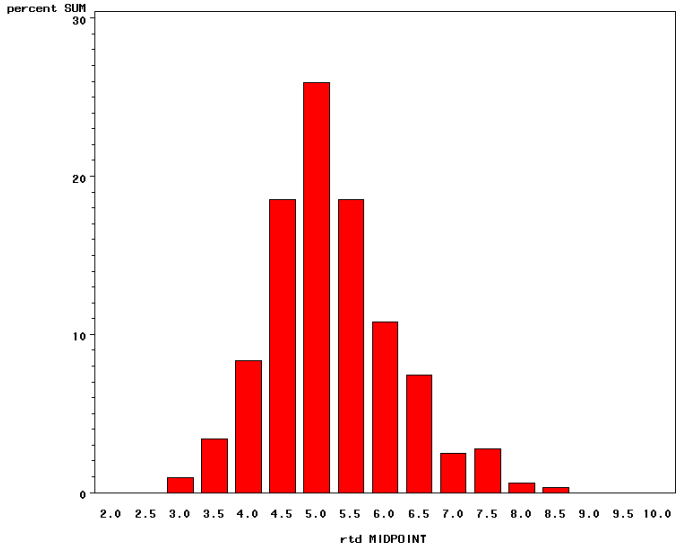
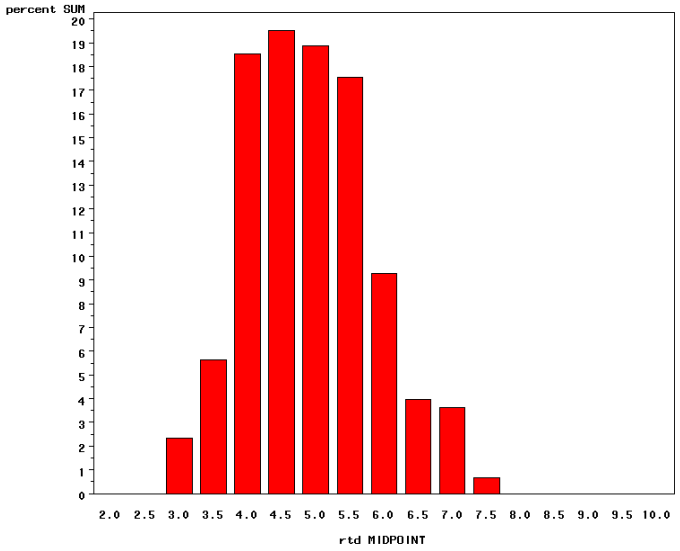
Lannen 64FD (128 ml)



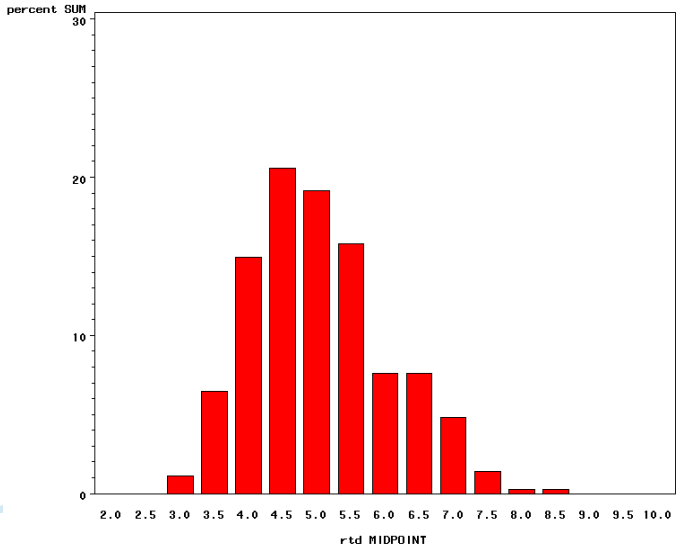
Panth S120-28



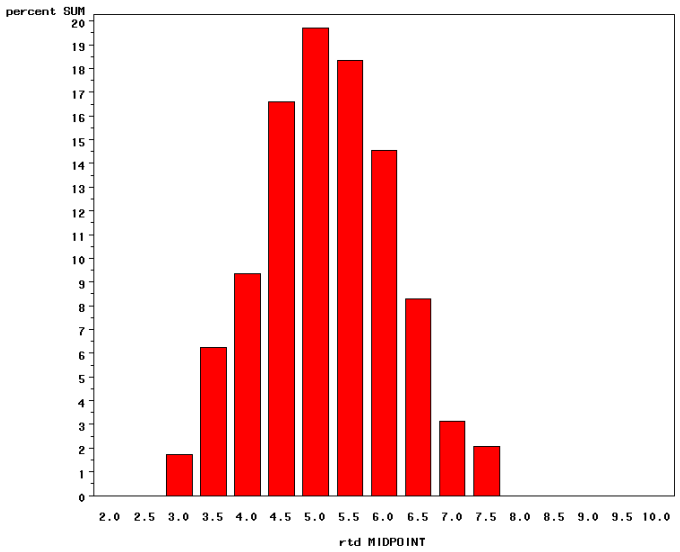
BCC V120 S/S (120 ml)



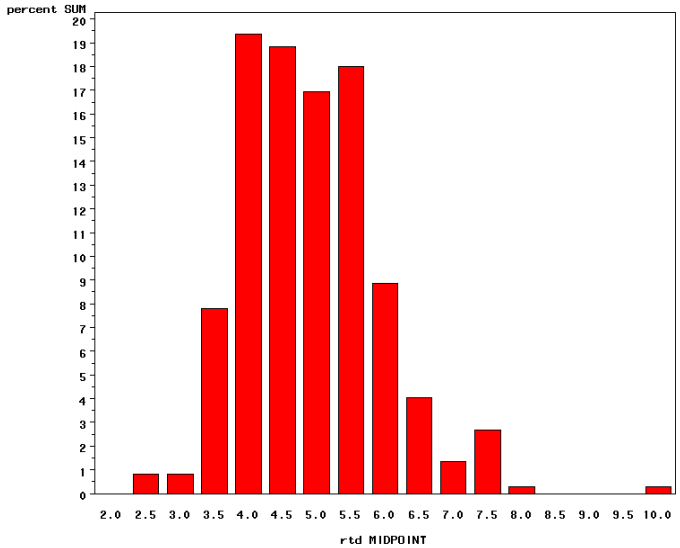
Lannen 64F (115 ml)



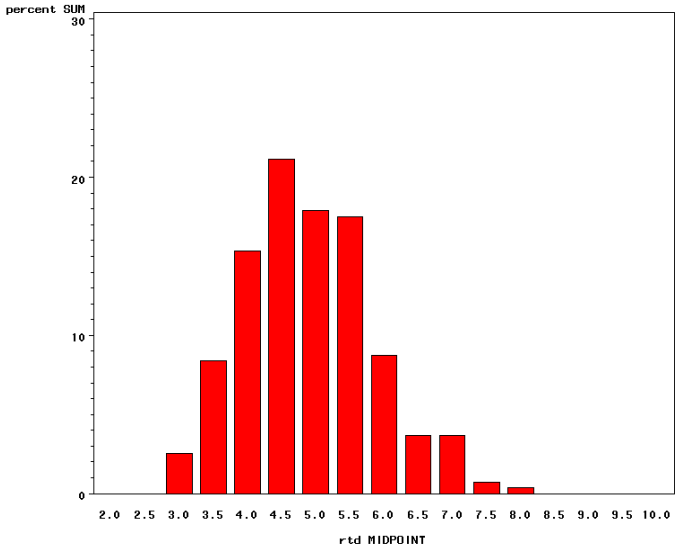
Panth S105-56 (105 ml)



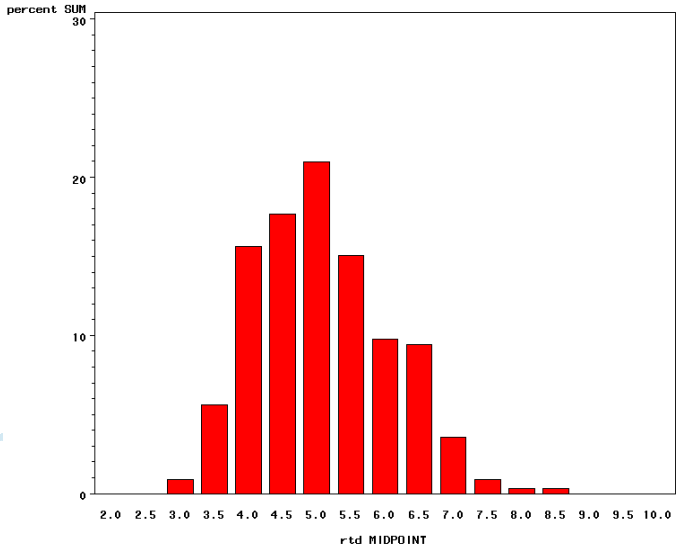
BCC S/S 81 (100 ml)



BCC V93 (93 ml)



Panth S90-33 (90 ml)



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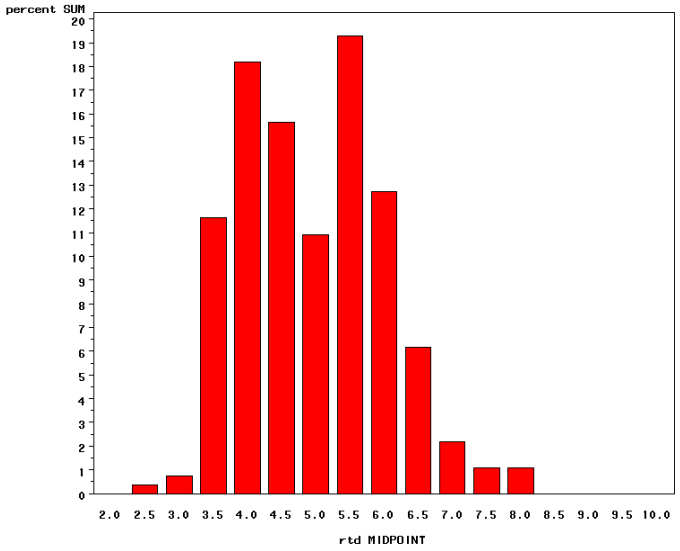
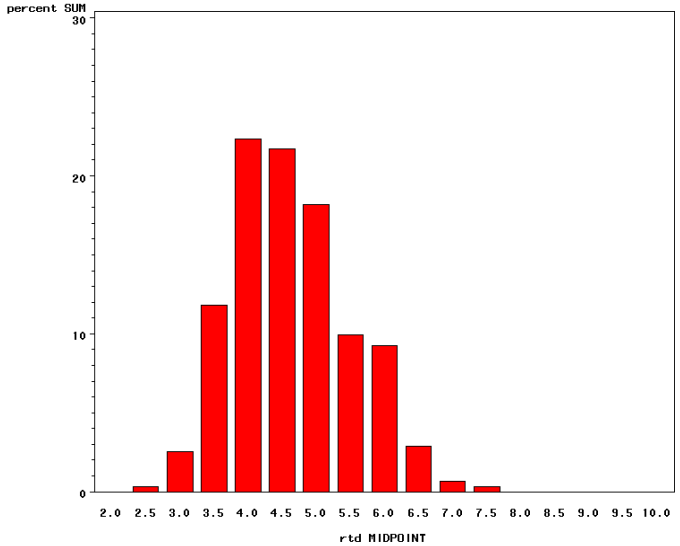
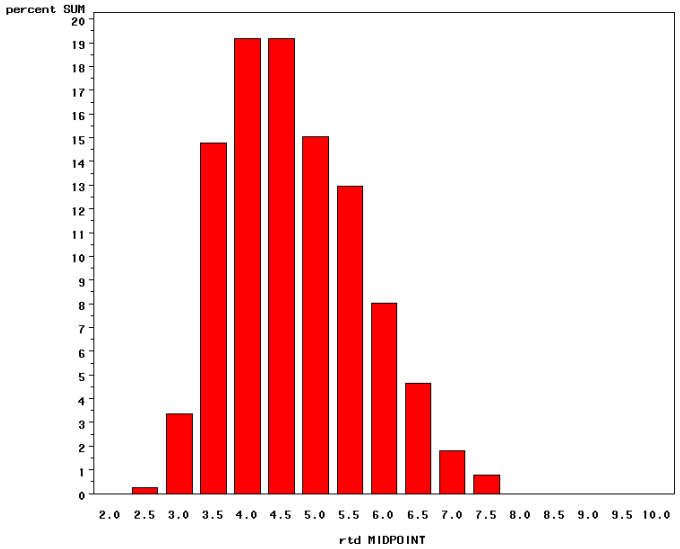
BCC V90 AB (90 ml)



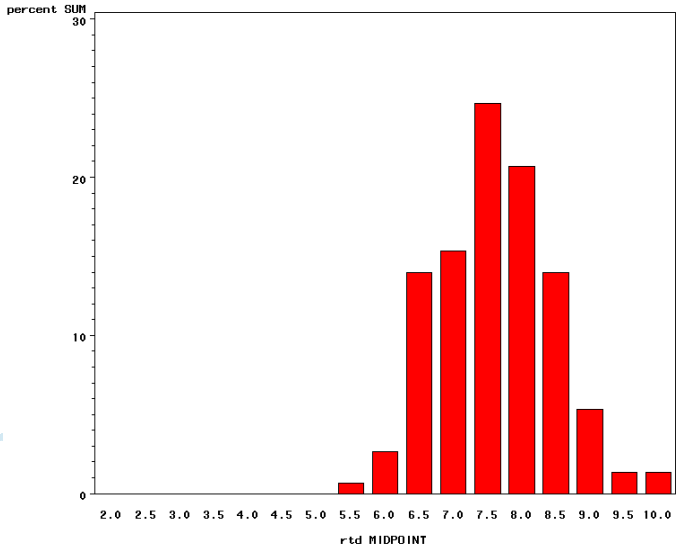
Lannen 63F (90 ml)



Lannen 81 F



Bare-root cuttings



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