Project Title	Profit optimisation through modelling and management of non-uniformity in Hardy Nursery Stock species
Project number:	HNS 136
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Location of project:	New Place Nurseries Ltd., Pulborough, West Sussex RH20 1AT & Hilliers Nurseries Ltd., Ampfield Romsey, Hampshire SO51 9PA
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Date project commenced:	1st June 2005
Date completion due:	31st May 2006
Key words:	Plant variability, waste, profit optimization, modeling, statistics.

The results and conclusions in this report are based on a series of experiments conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

[Name]
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Grower Summary

Headline

Crop uniformity, in the first year of growth, can be improved by cutting selection.

Background and expected deliverables

Hardy nursery stock (HNS) growers have identified within-crop variability as a major business problem, because waste levels, due to plant non-uniformity, frequently approach 20%. This problem clearly reduces profits and is caused by the strict plant-quality and uniformity specifications demanded by the DIY chains and garden centres, which are the main customers of many nurseries. Even in species where the variation within the crop is not immediately obvious, there can still be a 5-10% loss. This is incurred because the non-saleable plants are either discarded, or need to be retained until they reach an acceptable quality for sale. The latter approach incurs additional maintenance costs and also runs the risk that these plants may never 'catch-up' and become saleable.

Previous HDC funded research (HNS 117) addressing the issue of variability and waste, assessed 10 HNS species and 14 crops. Variability tended to increase over time, but some species were identified as being inherently more variable that others. Differences experienced by plants in water supply, competition for light and nutrients, quality of light, root development rate, pruning and potting methods, as well as timing of operations were identified as probable sources of variability. No significant amount of variability could be attributed to differences in the initial cutting material. This was an unexpected result, because previous research had shown that cutting size and type often affected both liner size and quality (Acker & Leutscher, 1993; HNS 69; Cameron *et al*., 2001).

The results of HNS 117 may possibly have been due to the environmental effects listed above being of overwhelming significance during the lifetime of the experimental crop. It is logical to assume, however, that the quality of the end product is highly likely to depend on getting the first steps in the plant production process right. The validity of the conclusion of HNS 117, therefore, merited re-assessment by additional on-nursery experimentation, which forms the main component of this project's first annual report.

One of the project's first objectives, therefore, was to set up on-nursery experiments for thirteen representative plant species, to assess the effect of cutting type on subsequent plant growth and development. For *B. thunbergii* 'Harlequin', for instance, there were six cutting types: those made from container-grown or field-grown stock plants and of three perceived qualities, 'Best', 'Standard' and 'Poor'. Measurements of stem diameter, plant height and numbers of shoots were made at periodic intervals, usually prior to pruning and survival was also recorded.

Data for the experiments described here will be used to inform future modeling activities and the building of an Excel spreadsheet-based operations management tool. The business modelling approach uses the Linear Programming technique to find the maximum profits achievable within a given set of business constraints. The word "Programming" here is used in the sense of "planning" and a preliminary analysis showed that waste as a percentage of profit can easily be more than 100%, even though waste per plant species is approximately 20%. On the positive side, significant improvements to profitability are potentially possible through improved crop uniformity, even if the cost of the stock-planting material is increased due to greater selectivity in the type of cutting used to initiate the crop.

These tools will be developed specifically to help growers make important decisions about the best mix of species grow, in what quantities, how best to utilise their nurseries' resources, how to minimise waste and increase crop quality and uniformity. At the end of the project in May 2008, these tools will be available through the HDC and should allow HNS Production and Sales Managers to assess easily and rapidly alternative options and thus provide an objective, quantitative basis for decision making that maximises the profits generated by their complex businesses.

Summary of the project and main conclusions

There were large differences in the size and physical structure of the different cutting types in eleven of the thirteen plant species examined: *Berberis thunbergii* 'Harlequin', *Camellia williamsii* 'Donation', *Choisya ternata* 'Aztec Pearl', *C. ternata* 'Sundance', *Cistus saviifolius* 'Silver Pink', *Photinia x fraseri* 'Red Robin', *Pieris floribunda* 'Forest flame', *Pittosporum tenuifolium* 'Garnettii', *Prunus incisa* 'Kojo-no-mai', *Rhamnus alaternus* 'Argenteovariegata', *Viburnum tinus* 'Eve Price'. For two other species, *Potentilla fruticosa* 'Chelsea Star' and *Weigela japonica* 'Kosteriana Variegata', a single cutting type was used and, in the former, there was a noteable amount of variation in the height, width and volume of newly established cuttings.

For all the species except *Weigela* 'Kosteriana Variegata', strong relationships were observed between cutting type and subsequent plant growth. It is probable for *Weigela* 'Kosteriana Variegata' that cutting type also affects subsequent plant growth, but that the experimental design was not suitable for picking this up. For *Potentilla* 'Chelsea Star', a clear relationship between cutting volume and the number of subsequent branches that were produced was evident.

Data collected during the early development of the plants, showed that cutting type and structure could also exert a major effect on the subsequent physical structure of the plants. This has major implications for achieving high quality liners, which have the general characteristics of being bushy, vigorous and of a pre-determined uniform height.

For certain species such as *Berberis thunbergii* 'Harlequin', the perception of the growers as to what constituted the 'best' cuttings was an accurate reflection of the subsequent initial performance of those cuttings. For others, such as *Cistus* 'Silver Pink', cuttings rated as 'poor' outperformed others rated as 'good'. It will be interesting to see whether these relationships remain consistent in the final assessment of plant quality.

For some species, such as *Berberis thunbergii* 'Harlequin', it was apparent that factors other than cutting volume were important in determining the initial vigour of the plants. For instance, when the poorest cuttings of this species, which had the smallest volumes, did produce a shoot, these were amongst the longest measured. It is probable that this effect is related to the nutrient status and 'reserves' present within the cuttings, or to rate of root establishment.

Initial work on *Berberis thunbergii* 'Harlequin' liners at Hilliers showed that 'best' and 'standard' categories had large differences in the widths of their lower stems, measured at soil level at the part of the stem that had been the original cutting. This provides a strong indication that, at least for this species, cutting width and volume has a long-term impact on the subsequent quality of the resulting plant.

The survival of the different plant species varied considerably and for some species such as *Prunus incisa* 'Kojo-no-mai', the larger cuttings had the best survival rates. For others such as *Choisya* 'Aztec Pearl', survival appeared to have been related to cutting structure, where those with the most foliage avoided their compost getting too wet and thus problems with rot. For *Berberis thunbergii* 'Harlequin', the main cause of mortality was failure of the cuttings to root. It is clear that the period prior to the cuttings forming roots is when they are highly vulnerable to adverse changes in humidity and the water content of the compost.

If, as the data in this report strongly suggest, there is a strong relationship between cutting and subsequent liner quality for the majority of the species studied, it should be possible to predict the quality of liners from the quality of the cuttings and a statistical sampling tool could be built to do this.

The experimental plants will continue to be followed this year. In addition, there are now sufficient experimental data to begin modelling potentially advantageous trade-offs, with a focus on those between the increased costs of using cutting material selectively and the potential subsequent cost savings. These could be made from increased crop uniformity, reduced waste, reduction in the need to hold back poor quality plants until they reach an acceptable standard, and reductions in the pruning, sorting and picking costs.

Financial benefits

The decisions taken and procedures followed by growers at each stage of the plant-production process, are affected by numerous constraints with associated cost implications. To date, only limited work has been done on economic analyses of the consequences of these decisions and processes, with regard both to losses due to crop variation and their effect on profits. An opportunity exists, therefore, to collect, analyse and model these data with the aim of significantly improving the competitiveness, efficiency and profitability of HNS growers' businesses.

The biological data and the preliminary model presented here are particularly encouraging, because they show that within the existing constraints, there is the potential to improve crop uniformity for many species, reduce waste and improve profitability.

Action points for growers

These results have several direct implications for management of the non-uniformity problem faced by growers, which are:

- Stock-plant management is extremely important and efforts focused on producing and utilising only the type of cutting, for each species, that produces the 'best' quality liners, should reduce non-uniformity greatly.
- In order to manage non-uniformity effectively, and still be able to produce a sufficient quantity of grade I liners cost-efficiently for sale, it is advisable to grade the cuttings at the time of planting and to keep the different batches and types separate from one another.
- Adoption of these practices should provide the following benefits, i) the numbers of plants that need to be held back until they reach an acceptable quality will be reduced, ii) 'best' material can be placed in locations within the polytunnels that are least likely to be affected by low humidities or frost and so losses of this important category of plants will be reduced, iii) cutting types that grow at different rates can be pruned at the optimum time, iv) the increased uniformity within the batches should reduce the time and costs required for sorting and picking when the liners are graded for onward distribution and sale.

Science Section

Introduction

Previous research addressing the issue of variability and waste assessed 10 HNS species and 14 crops. Variability tended to increase over time, but some species were identified as being inherently more variable that others (HNS 117).

Differences experienced by plants in water supply, competition for light and nutrients, quality of light, root development rate, pruning and potting methods, as well as timing of operations were identified as probable sources of variability (HNS 117).

No significant amount of variability could be attributed to differences in the initial cutting material (HNS 117), an unexpected result that may have been due to the environmental effects listed above being of overwhelming significance during the lifetime of the experimental crop. After discussions with growers, however, the view remains that the quality of the stock planting material and the timing of operations are key factors determining the success, or otherwise, of uniform crop production. It is logical to assume that the quality of the end product is highly likely to depend on getting the first steps in the plant production process right, and so the validity of the conclusion of HNS 117 merited re-assessment by additional on-nursery experimentation.

Materials and Methods

The experiments to re-evaluate finding of HNS 117 that measurable variation in starting material cannot be linked to variation in the final crop began at a nursery that specialises in the production of liners (New Place Nurseries Ltd.). The experiments consisted of setting up batches of stock material with different levels of starting variability. Species that were perceived to have a minimal problem with non-uniformity and waste were also selected for comparative purposes.

Planning and carrying out the work involved discussions with nursery management and staff to decide practical details such as types of cutting to use, appropriate data collection periods and variables to be measured that were considered by them to be the most important.

The experimental plants will be followed throughout the production cycle until final sale and data will be collected over the coming two years on the conditions that plants are grown in, when they are re-potted, pruned, picked and sold. Accurate data will also be collected on the costs due to plant wastage as a result of their failure to meet the quality criteria of the various customers. The quantitative biological data were analysed using the GenStat statistical package (GenStat, 2005).

The following thirteen plant species and varieties were selected for experimentation: *Berberis thunbergii* 'Harlequin', *Camellia williamsii* 'Donation', *Choisya ternata* 'Aztec Pearl', *Choisya ternata* 'Sundance', *Cistus* 'Silver Pink', *Photinia x fraseri* 'Red Robin', *Pieris* 'Forest flame', *Pittosporum tenuifolium* 'Garnettii', *Potentilla* 'Chelsea Star', *Prunus incisa* 'Kojo-no-mai', *Rhamnus alaternus* 'Argenteovariegata', *Viburnum tinus* 'Eve Price' and *Weigela* 'Kosteriana Variegata'.

Plant cuttings were prepared in the manner described below and the trays of experimental plants prepared from them were initially maintained in the mist house and, after rooting had occurred, were transferred to a polytunnel. The propagation medium used for all subjects was 70% Coir (washed), 30% Perlite no. 3 and 1kg m^{-3} P.G. mix. Plants were subjected to the standard growing practices for that particular species.

***Berberis thunbergii* 'Harlequin'**. Cuttings were prepared from either field- or container- grown stock plants and these could be of three perceived qualities, 'best', 'standard' or 'poor'. Six cutting types could therefore be differentiated and fourteen cuttings of each type were prepared and planted into 84-cell trays. Each cutting type occupied two rows of adjacent cells (14 plants) and the positions of these blocks of cuttings were randomized within trays. Cutting length and width was measured before planting. Seven trays were prepared on 20/07/05 and the performance of each cutting was followed and data collected periodically thereafter.

***Camellia williamsii* 'Donation'**. Two types of cuttings were made: those with two internodal lengths or those from stem tips. Fourty-two cuttings of each type were prepared and planted into 84-cell trays. Each cutting type occupied six adjacent rows of cells in the trays. Cutting lengths and widths were measured before planting. Three trays were prepared on 1/11/05 and the performance of each cutting was followed and data collected thereafter at periodic intervals.

***Choisya ternata* 'Aztec Pearl'**. Cuttings were prepared as either the standard two inter-nodal length cutting, shorter cuttings with a single inter-nodal length taken from the base of the stem, or from stem tips. Twenty-eight cuttings of each type were prepared and planted into 84-cell trays. Each cutting type occupied four rows of cells and the positions of these blocks were randomized within trays. Cutting length and width was measured before planting. Three trays were prepared on (31/08/05) and the performance of each cutting was followed and data collected thereafter at periodic intervals. Due to the high mortality evident in this planting, another trial was set up following the same design on 24/10/05.

***Choisya ternata* 'Sundance'**. Cuttings were available from either field- or 30 litre container-grown stock plants and these could be of two types; those with a single inter-nodal length with two leaves and those with two internodal lengths with four leaves. Four cutting types could therefore be differentiated and 21 cuttings of each type were prepared and planted into 84-cell trays. Each cutting type occupied three rows of adjacent cells and the positions of these blocks was randomized within each tray. Cutting length and width was measured before planting. Four trays were prepared on 28/07/05 and the performance of each cutting was followed and data collected thereafter at periodic intervals.

***Cistus* 'Silver Pink'**. Cuttings were prepared from either one or two-year-old container-grown stock plants and these could be of two types; 'good' or 'poor'. Four cutting types could therefore be differentiated and 21 cuttings of each type were prepared and planted into 84-cell trays. Each cutting type occupied three rows of adjacent cells and the positions of these blocks was randomized within each tray. Cutting length and width was measured before planting. Four trays were prepared on

28/02/06 and the performance of each cutting was followed and data collected thereafter at periodic intervals.

Photinia x fraseri **'Red Robin'**. Cuttings were prepared either from the tip, the middle or the bottom of stems of stock-plant material. Either 35 or 34 cuttings of each type were prepared and planted into 104-cell trays. Each cutting type occupied adjacent rows of cells and their positions were randomized within trays. Cutting length and width was measured before planting. Three trays were prepared on 6/9/05 and the performance of each cutting was followed and data collected thereafter at periodic intervals.

Pieris **'Forest flame'**. Cuttings were prepared from either soft, medium or hard stock-plant material. Twenty-eight cuttings of each type were prepared and planted into 84-cell trays. Each cutting type occupied adjacent rows of cells and their positions were randomized within trays. Cutting length and width was measured before planting. Three trays were prepared on 1/11/05 and the performance of each cutting was followed and data collected thereafter at periodic intervals.

Pittosporum tenuifolium **'Garnettii'**. Cuttings were prepared from either heels, the middle to upper part, or the lower basal end of stems. Twenty-eight cuttings of each type were prepared and planted into 84-cell trays. Each cutting type occupied adjacent rows of cells and the positions of blocks was randomized within trays. Cutting length and width was measured before planting. Three trays were prepared on 26/10/05 and the performance of each cutting was followed and data collected thereafter at periodic intervals.

Potentilla **'Chelsea Star'**. Cutting of this species were planted before the start of the experimental work in week 28 (10-14 July 05). Measurements of stem width and plant height were taken on 2/8/05 from plants in two 84-cell trays. The performance of each cutting was followed and data collected thereafter at periodic intervals, usually prior to pruning.

***Prunus incisa* 'Kojo-no-mai'**. Cuttings were prepared either from the main stem tip, the side shoots or the main stem material. Twenty-eight cuttings of each type were prepared and planted into 84-cell trays. Each cutting type occupied adjacent rows of cells and their positions were randomized within trays. Cutting length and width was measured before planting. Three trays were prepared on 6/9/05 and the performance of each cutting was followed and data collected thereafter at periodic intervals.

***Rhamnus alaternus* 'Argenteovariegata'**. Cuttings were prepared from either heels, the lower stem or from the upper end of the stem. Either 34 or 35 cuttings of each type were prepared and planted into 104-cell trays. Each cutting type occupied adjacent rows of cells and their positions were randomized within trays. Cutting length and width was measured before planting. Three trays were prepared on 26/10/05 and the performance of each cutting was followed and data collected thereafter at periodic intervals.

***Viburnum tinus* 'Eve Price'**. Cuttings were prepared from either the tops of stems (two internodes, termed 'soft'), the middle of stems (two internodes, termed 'hard') or a single internode from the base (termed 'singles'). Twenty cuttings of each type were prepared and planted into 60-cell trays. Each cutting type occupied adjacent rows of cells and their positions were randomized within trays. Cutting length and width was measured before planting. Three trays were prepared on 2/11/05 and the performance of each cutting was followed and data collected thereafter at periodic intervals.

***Weigela* 'Kosteriana Variegata'**. A single type of cutting was prepared for this species, which consisted of single internodal lengths. Stems were cut just above nodes and the leaves were trimmed to prevent them covering adjacent cuttings. Three 84-cell trays were prepared on 2/08/05 and cutting length and width was measured before planting. The performance of each cutting was followed and data collected thereafter at periodic intervals.

Results and Discussion

Berberis thunbergii 'Harlequin'

Analyses of the data allowed the following conclusions to be drawn.

Cutting length

- Container-grown 'best' and 'standard' cuttings were longer than those from field-grown material. This situation was reversed for the 'poor' material where the field-grown cuttings were much longer than those from container-grown stock plants. The cutting quality and interaction effects were both highly significant (Figure 1 and Table 1).

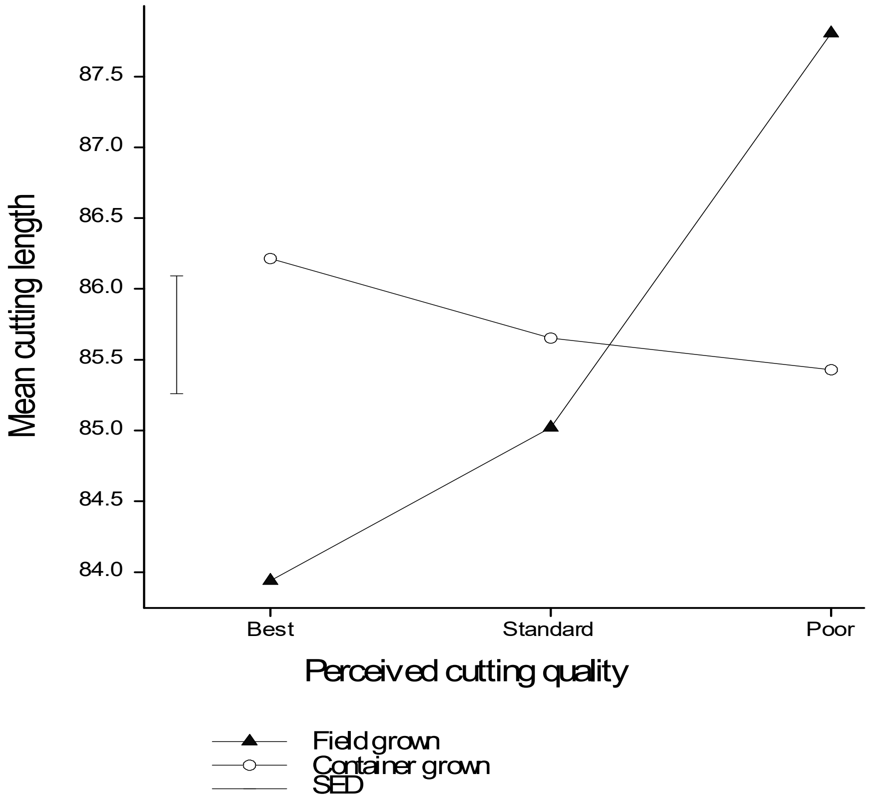

Figure 1. The mean cutting lengths of *B. thunbergii* 'Harlequin' that originated from either container-grown or field-grown stock plants and from three perceived cutting qualities.

Table 1. Analysis of variance for cutting lengths of *B. thunbergii* 'Harlequin' that originated from either container-grown or field-grown stock plants and from three perceived qualities of cutting.

Source of variation	d.f.	s.s.	m.s.	P

Stock plant type	1	4.60	4.60	0.713
Cutting quality	2	266.68	133.34	0.020
Stock plant type x cutting quality	2	545.72	272.86	<0.001

Cutting width

- The 'best' cuttings were the widest, 'standard' cuttings were of intermediate width and the 'poor' cuttings were the thinnest. This 'quality' effect was highly significant (Figure 2, Table 2).
- For 'best' and 'standard' cuttings, field- and container-grown material had similar widths; for 'poor' cuttings, field-grown material was wider (Figure 2, Table 2).

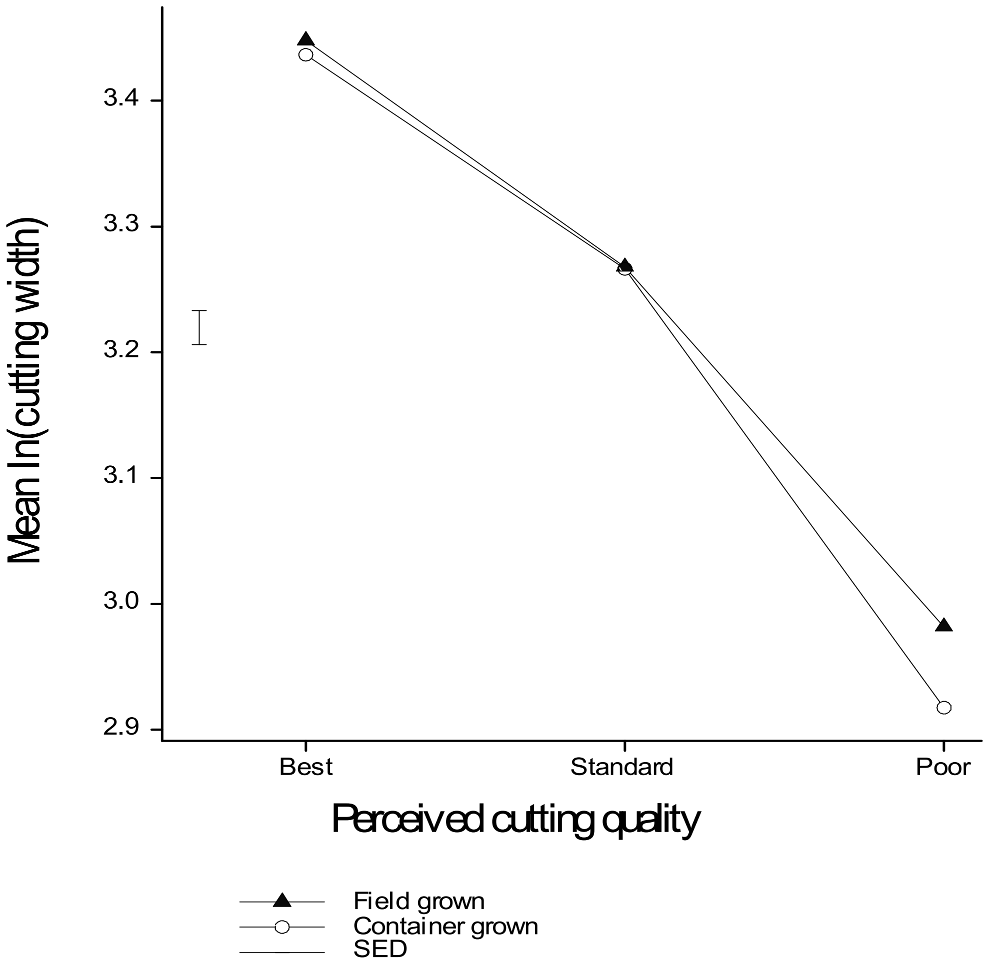

Figure 2. The mean ln(cutting width) of *B. thunbergii* 'Harlequin' that originated from either container-grown or field-grown stock plants and from three perceived qualities of cutting.

Table 2. Analysis of variance for ln(cutting width) of *B. thunbergii* 'Harlequin' that originated from either container-grown or field-grown stock plants and from three perceived qualities of cutting.

Source of variation	d.f.	s.s.	m.s.	v.r.	P
Stock plant type	1	0.09740	0.09740	2.69	0.101
Cutting quality	2	24.42820	12.21410	337.68	<.001
Stock plant type x cutting quality	2	0.11204	0.05602	1.55	0.213

Cutting volume

- The 'best' cuttings had the greatest volumes, 'standard' cuttings had intermediate volumes and 'poor' cuttings had the lowest volumes (Figure 3 and Table 3).
- In the 'poor' cutting category, cuttings from field grown material had a larger mean volume (Figure 3 and Table 3). The 'quality' effect was highly significant, while the interaction effect was just significant.

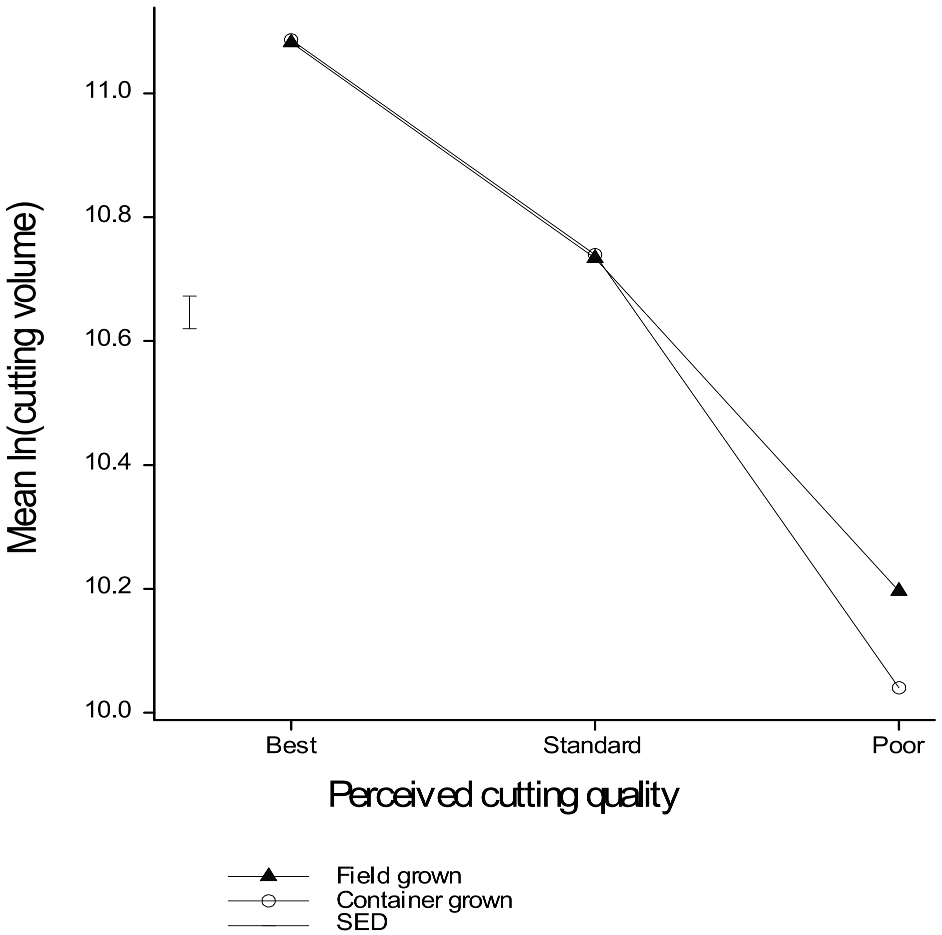

Figure 3. The mean ln(cutting volume) of *B. thunbergii* 'Harlequin' that originated from either container-grown or field-grown stock plants and from three perceived qualities of cutting.

Table 3. Analysis of variance for ln(cutting volume) of *B. thunbergii* 'Harlequin' that originated from either container-grown or field-grown stock plants and from three perceived qualities of cutting.

Source of variation	d.f.	s.s.	m.s.	v.r.	P
Stock plant type	1	0.3471	0.3471	2.53	0.112
Cutting quality	2	93.8681	46.9341	341.99	<0.001
Stock plant type x cutting quality	2	0.8504	0.4252	3.10	0.046

Number of nodes above ground

- Only the cutting quality effect was significant for the numbers of nodes above ground. The 'poor' cuttings had the greatest numbers of nodes, the 'standard' cuttings had fewer and the 'best' cuttings tended to have the least (Figure 4 and Table 4).

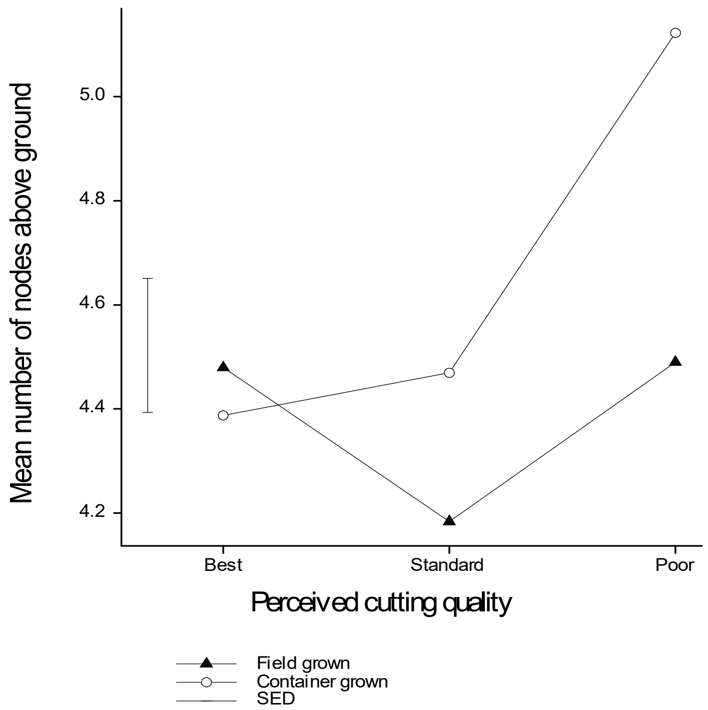

Figure 4. The mean number of nodes above ground for *B. thunbergii* 'Harlequin' that originated from either container-grown or field-grown stock plants and from three perceived qualities of cutting.

Table 4. Analysis of variance for number of nodes of *B. thunbergii* 'Harlequin' that originated from either container-grown or field-grown stock plants and from three perceived qualities of cutting.

Source of variation	d.f.	s.s.	m.s.	v.r.	P
Stock plant type	1	11.158	11.158	3.45	0.064
Cutting quality	2	24.840	12.420	3.84	0.022
Stock plant type x cutting quality	2	12.867	6.434	1.99	0.138

Number of trimmed branches (side shoots) on the cuttings

- Field cuttings had more branches than container-grown cuttings (Figure 5).
- 'Standard' field cuttings had the greatest mean number of branches, whereas container-grown 'poor' cuttings had the least (Figure 5). The stock-plant type, quality and interaction effects were all highly significant (Table 5).

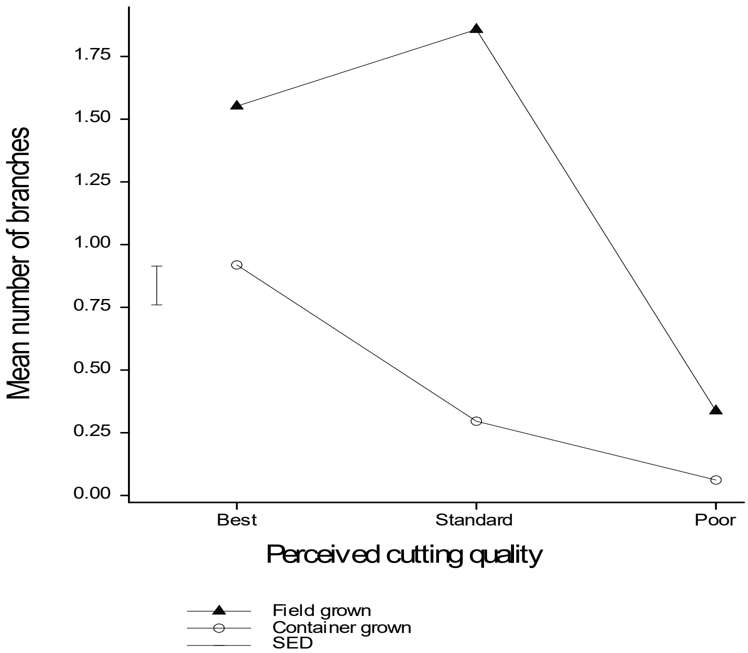

Figure 5. The mean number of branches on *B. thunbergii* 'Harlequin' that originated from either container-grown or field-grown stock plants and from three perceived qualities of cutting.

Table 5. Analysis of variance for the mean number of branches on *B. thunbergii* 'Harlequin' that originated from either container-grown or field-grown stock plants and from three perceived qualities of cutting.

Source of variation	d.f.	s.s.	m.s.	P
Stock plant type	1	99.599	99.599	<0.001
Cutting quality	2	122.031	61.015	<0.001
Stock plant type x cutting quality	2	43.167	21.583	<0.001

Production of shoots early in the season

- The ‘best’ cuttings had produced the most shoots shortly after planting (Table 6, Figure 6).
- The field-grown ‘best’ cuttings (Figure 6) and the container-grown poor cuttings produced the most and least numbers of shoots, respectively (Table 6).
- Although they produced fewer shoots, when they did so, the ‘poor’ cuttings produced the longest shoots (Table 6).

Figure 6. Vigourous shoot growth from field-grown ‘best’ cuttings.

Table 6. Numbers of plants that produced shoots early in the season (13/09/05) and the mean lengths for the different types of cutting.

Stock plant type	Perceived cutting quality					
	‘Best’		‘Standard’		‘Poor’	
	No. observed	Mean length	No. observed	Mean length	No. observed	Mean length
Field grown	32	66.50	10	40.50	6	80.00
Container grown	15	55.67	12	59.58	4	86.25

Total shoot volume

- A greater total shoot volume was produced by container-grown 'best' and 'standard' cuttings, than the field grown material. The mean total shoot volumes produced by the 'poor' cutting were similar (Figure 7).
- The effect of cutting 'quality' was highly significant, whereas the effect of stock plant type was just significant (Table 7).

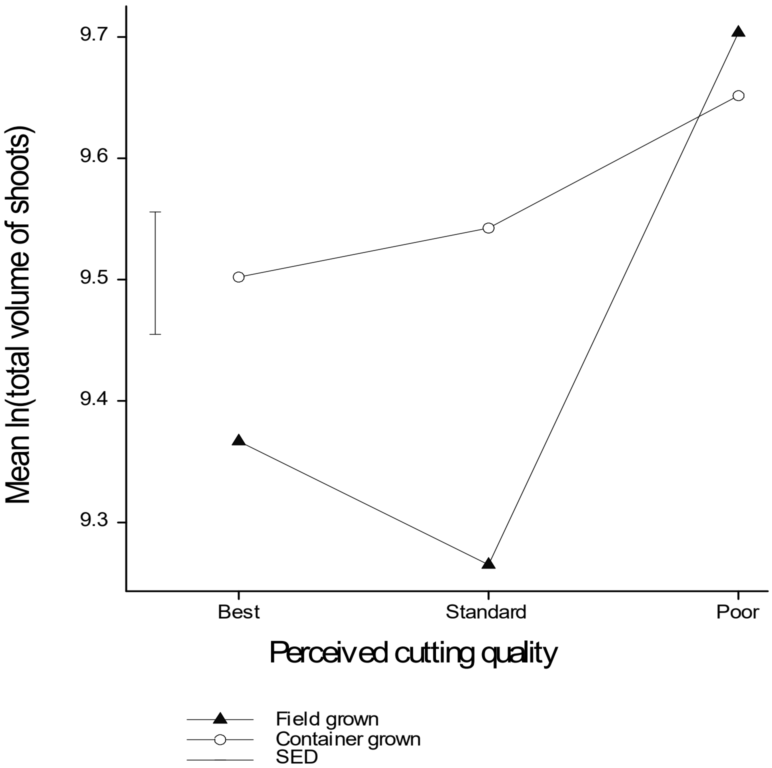

Figure 7. The mean ln(total volume of shoots) on *B. thunbergii* Harlequin cuttings that originated from either container-grown or field-grown stock plants and from three perceived qualities of cutting.

Table 7. Analysis of variance for ln(total volume of shoots) of *B. thunbergii* Harlequin later in the season (04/10/05) that originated from either container-grown or field-grown stock plants and from three perceived qualities of cutting.

Source of variation	d.f.	s.s.	m.s.	v.r.	P
Stock plant type	1	2.1237	2.1237	4.27	0.043
Cutting quality	2	8.8113	4.4056	8.86	<.001
Stock plant type x cutting quality	2	2.6737	1.3368	2.69	0.075

The relationship between cutting volume and total shoot volume produced.

- For the container- and field-grown categories of cutting, there was a slightly positive trend for a greater volume of shoot produced from the larger cuttings, although this relationship was not significant (Fig. 8).
- For the different qualities of cutting, there were also positive trends for greater shoot volume production from cuttings of greater volume, although these relationships were not significant (Fig. 9).

Plant survival until 21/2/06.

- Survival was highest for the container-grown stock-plant cuttings and all 'qualities' of these categories had a survival rate of more than 86% (Table 8).
- Survival for all field-grown categories was below 84% and the worst survival occurred in the 'standard' category of cutting (66.3%) (Table 8).
- Most mortality occurred shortly after planting and was apparently due to the plants failing to root (Fig. 10a). A possible explanation for this is that the weather was particularly hot after these cuttings had been planted and certain plants experienced low humidities and their compost sometimes dried out (Fig 10b).

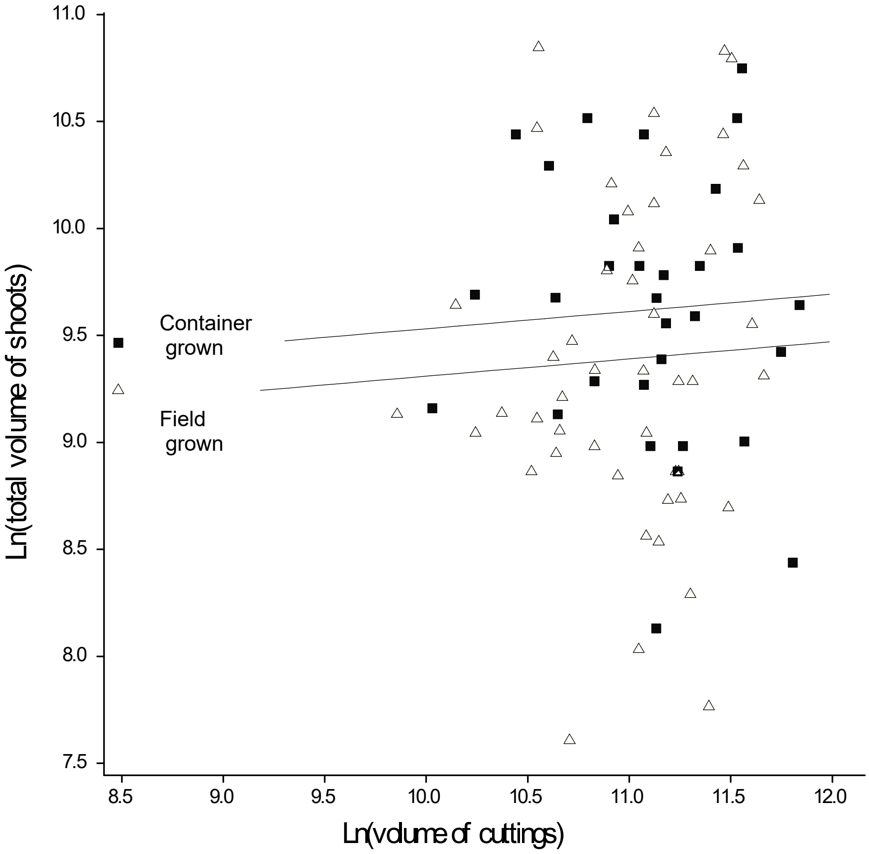

Figure 8. The mean ln(total volume of shoots) in relation to the ln(volume of cutting) late in the growing season (4/10/05), grouped according to type of stock plant. The gradients of the trend lines were positive, but not significant. Cutting material originated from either container-grown or field-grown stock plants and from three perceived qualities of cutting.

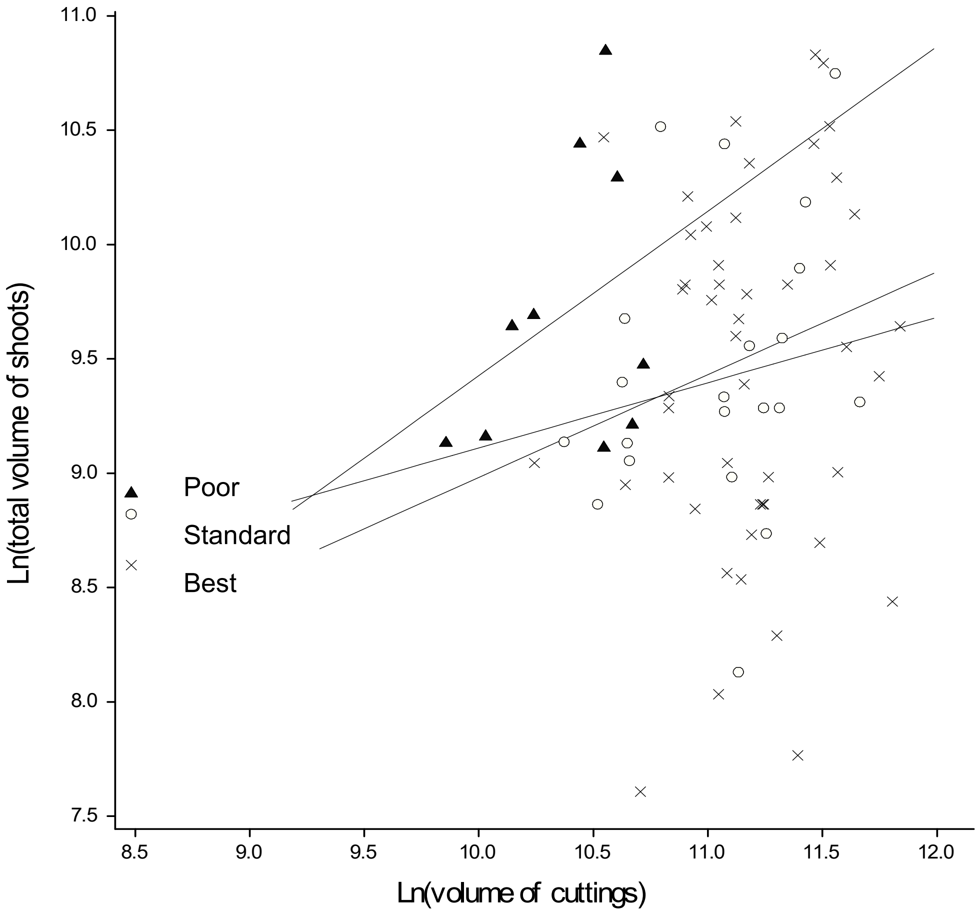

Figure 9. The mean ln(total volume of shoots) in relation to the ln(volume of cutting) late in the growing season (4/10/05), grouped according to perceived quality of cutting material. The gradients of the trend lines were positive, but not significant. Cutting material originated from either container-grown or field-grown stock plants and from three perceived qualities of cutting.

Table 8. The number and percentage survival of *B. thunbergii* Harlequin cuttings on 21/02/06. Cuttings originated from either container-grown or field-grown stock plants and from three perceived qualities.

Stock plant type	Survival					
	Best		Standard		Poor	
	No. observed	(%)	No. observed	(%)	No. observed	(%)
Field grown	83	(84.7)	65	(66.3)	82	(83.7)
Container grown	85	(86.7)	93	(94.9)	92	(93.9)

Figure 10a. Lack of rooting in almost all cases of cutting mortality.

Figure 10b. Cutting mortality was highest in areas of low humidity – top left of experimental tray.

Measurements on Berberis thunbergii 'Harlequin' liners sent to Hilliers

- Liners selected on appearance as 'best' had significantly more shoot apices and were significantly taller than those selected as 'standard' (Table 9).
- The widths of the original cutting material were significantly greater for the liners that had been selected as 'best', compared to those selected as 'standard' (Table 9).

Table 9. Measurements of cutting width, plant height and number of branches on two groups of liners (N=35 per group), selected according to perceived quality, from a batch of recently delivered liners. Data were collected on 24/03/06.

Perceived liner quality	Characteristics					
	Cutting width (mm)		No. of shoots		Plant height (mm)	
	Mean	± SEM	Median	Max, Min	Mean	± SEM
'Best'	38.9[a]	0.93	13[b]	16, 10	149.9[c]	3.19
'Standard'	26.7	0.67	5	8, 3	94.3	2.77

[a]Test statistic t = 10.67 on approximately 61.16 d.f., Probability < 0.001

[b]Mann-Whitney U (Wilcoxon rank-sum) test, Exact probability < 0.001

[c]Test statistic t = 13.17 on 68 d.f., Probability < 0.001

Summary and discussion for Berberis thunbergii 'Harlequin'

- The six cutting categories had real physical and structural differences in terms of length, width, volume, numbers of nodes, numbers of branches.
- Shortly after planting, field-grown cuttings had produced many more shoots than the container-grown cuttings.
- Shoot volume is not strongly related to cutting volume and the 'poor' cuttings with the lowest volumes produced the longest shoots. For this species, therefore, there appears to be very strong apical shoot dominance and, if a shoot is produced, the plant invests a lot of resources in it.
- The survival for the container-grown cuttings was better than that of the field-grown cuttings and is probably related to their propensity to form roots quickly.
- The 'best' liners at Hilliers Nursery had the largest stem widths, measured at the base of the stem which had been the original cutting. Provided that there is a good relationship between cutting stem width and the width of the plant stem at the same place when liners are sold, it would appear that cutting volume or width should be a reliable predictor of future liner quality.
- If the above holds true, then the current perceptions of what are the 'best', 'standard' and 'poor' cuttings is probably accurate, because these have, respectively, the greatest, intermediate and smallest widths and volumes.

- If, as currently appears, there is a strong relationship between cutting and liner quality, it should be possible to predict the quality of liners from the quality of the cuttings. A statistical sampling tool could be built to do this.
- In terms of the non-uniformity problem facing growers, these results have several implications, which are:
- Stock-plant management for this variety is extremely important and should be aimed at producing sufficient quantities of 'best' and 'standard' cuttings.
- Although important, the above measure will not, in itself, greatly reduce crop non-uniformity, as there is still a lot of variation present between 'best' and 'standard' cuttings both from the field and from containers.
- In order to manage non-uniformity, therefore, and still be able to produce a sufficient quantity of grade I liners for sale, it is necessary to grade the cuttings at the time of planting and to keep the different batches and types separate from one another.
- Adoption of this practice should provide additional benefits in that the 'best' material can be placed in locations within the polytunnels that are least likely to be affected by low humidities and therefore subject to poor survival. Also, the increased uniformity within the batches should reduce the time required subsequently when the liners are graded for onward distribution and sale.
- These trade-offs will be modelled in the next year of the project.

***Camellia williamsii* 'Donation'**

Due to the timing of planting, the data collection on this species is not as far advanced as for the *Berberis*. The following conclusions, however, can presently be drawn.

- The lengths of the two cutting types were not different, but their mean widths were significantly different (Tables 10 and 11).

Table 10. Analysis of variance for cutting lengths of two types of Donation cuttings. Mean lengths for tips and internodal cuttings, respectively, were 74.6 and 73.5 mm (SED = 0.967).

Source of variation	d.f.	s.s.	m.s.	P
Cutting type	1	67.06	67. 06	0.287
Residual	248	14619.56	58.95	

Table 11. Analysis of variance for cutting widths of two types of Donation cuttings. Mean widths for tips and internodal cuttings, respectively, were 23.35 and 26.52 mm (SED = 0.299).

Source of variation	d.f.	s.s.	m.s.	P
Cutting type	1	631.750	631.750	<0.001
Residual	248	1394.238	5.622	

Summary and discussion for Camellia williamsii 'Donation'

- The widths and therefore the sizes of these two cutting types were clearly different.

Choisya 'Aztec Pearl'

First experiment (set up on 31/08/05).

The following conclusions can currently be drawn from the available data.

- The lengths and widths of the three types of cutting were highly significantly different (Tables 12 and 13). The same conclusion can be drawn for the repeat trial data set (Tables 15 and 16).
- Survival was highest for the two internodal length cuttings, although by February 2006, this was still only around 58% (Table 14). For this trial, the tips had the best survival, although this was still only approximately 51% on 20/2/06 (Table 17).

Table 12. Analysis of variance for lengths of three types of Aztec Pearl cuttings. Mean lengths for the standard, single inter-nodal length and tips, respectively, were 83.2, 57.0 and 68.8 mm (SED = 1.98).

Source of variation	d.f.	s.s.	m.s.	P
Cutting type	2	28936.2	14468.1	<0.001

Residual	247	40735.6	164.9	

Table 13. Analysis of variance for the widths of three types of Aztec Pearl cuttings. Mean widths for the standard, single inter-nodal length and tips, respectively, were 32.7, 33.0 and 26.8mm (SED = 0.49).

Source of variation	d.f.	s.s.	m.s.	P
Cutting type	2	2059.08	1029.54	<0.001
Residual	247	2521.25	10.21	

Table 14. The number and percentage survival of Aztec Pearl cuttings on 4/10/05 and 20/2/06. The types of cutting used were the standard two inter-nodal lengths, a single inter-nodal length and tips. N = 84 initially for all cutting types. Cuttings were planted on 31/08/05.

Date	Survival					
	Two inter-nodes		Single inter-node		Tips	
	No. observed	(%)	No. observed	(%)	No. observed	(%)
4/10/05	66	(78.6)	21	(25.0)	50	(59.5)
20/2/06	49	(58.3)	19	(22.6)	26	(31.0)

Table 15. Data for the second trial. Analysis of variance for lengths of three types of Aztec Pearl cuttings. Mean lengths for the standard, single inter-nodal length and tips, respectively, were 72.8, 57.8 and 70.4 mm (SED = 1.54).

Source of variation	d.f.	s.s.	m.s.	P
Cutting type	2	10912.72	5456.36	<0.001
Residual	247	24692.94	99.97	

Table 16. Data for the second trial. Analysis of variance for the widths of three types of Aztec Pearl cuttings. Mean widths for the standard, single inter-nodal length and tips, respectively, were 34.8, 37.3 and 28.7 mm (SED = 0.44).

Source of variation	d.f.	s.s.	m.s.	P
Cutting type	2	3303.738	1651.869	<0.001
Residual	247	2012.810	8.149	

Table 17. The number and percentage survival of Aztec Pearl cuttings on 20/2/06. The types of cutting used were the standard two inter-nodal lengths, a single inter-nodal length and tips. N = 84 initially for all cutting types. Cuttings were planted on 24/10/05.

Date	Survival					
	Two inter-nodes		Single inter-node		Tips	
	No. observed	(%)	No. observed	(%)	No. observed	(%)
20/2/06	15	(17.9)	5	(6.0)	43	(51.2)

Summary and discussion for *Choisya 'Aztec Pearl'*

- The longer cuttings (standard two inter-nodal lengths and tips), had the best survival rates in the two experiments.
- The majority of mortality occurred shortly after planting and the cuttings rotted.
- The single internodal length cuttings had fewer leaves, which may have resulted in their compost becoming too moist as the water spray fell directly onto it.

- This species appears to be very sensitive to soil moisture content and the structure of the cutting appears important when a misting system is used in propagation.

Figure 11. The differential survival of the three cutting types. The tips are on the left, the single internodal lengths are in the middle and the two internodal lengths are on the right.

Choisya ternata **'Sundance'**

The following conclusions could be drawn from the experimental data for this species.

- The container-grown cuttings were longer than the ground-grown cuttings and the four leaf cuttings were longer than the two leaf cuttings (Figure 12 and Table 18).
- The pattern for cutting width was reversed with the two leaf cuttings being wider than the four leaf cuttings. The container grown cuttings were still wider than the ground grown material, but this difference was not quite significant (Figure 13 and Table 19).
- The volumes of the cuttings from the different types of stock plant differed with the container-grown material being significantly bigger (Figure 14 and Table 20).

- The total lengths of new shoots produced by the four cutting types differed significantly. The container-grown cuttings produced the longest shoots and the two leaf cuttings produced longer shoots than the four leaf cuttings (Figure 15 and Table 21).

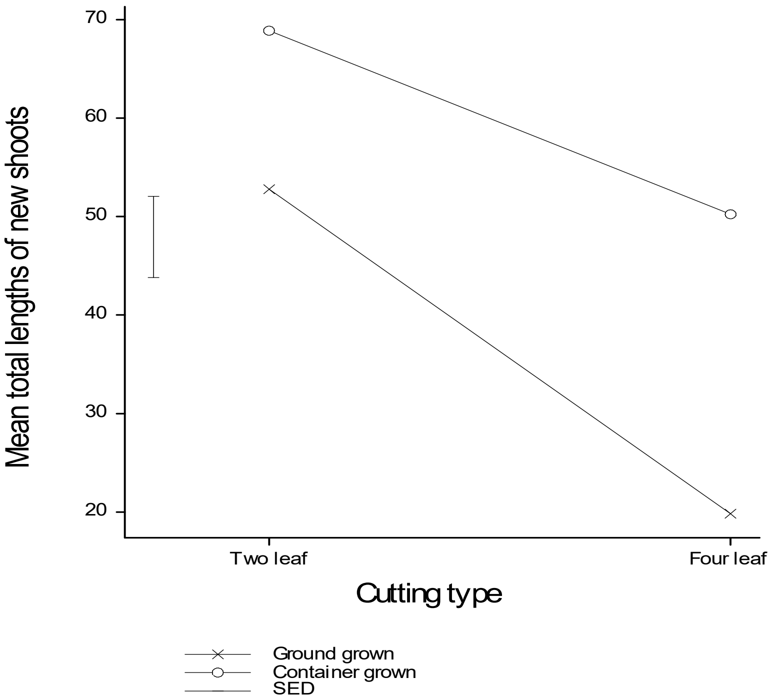

Figure 12. The mean cutting lengths of *Choisya ternata* 'Sundance' that originated from either container-grown or ground-grown stock plants and from cuttings with either two or four leaves.

Table 18. Analysis of variance for cutting lengths of *Choisya ternata* 'Sundance' that originated from either container-grown or ground-grown stock plants and from two types of cutting.

Source of variation	d.f.	s.s.	m.s.	P
Stock plant type	1	665.9	665.9	0.011
Cutting type	1	8250.7	8250.7	<0.001
Stock plant type x cutting type	1	48.0	48.0	0.495

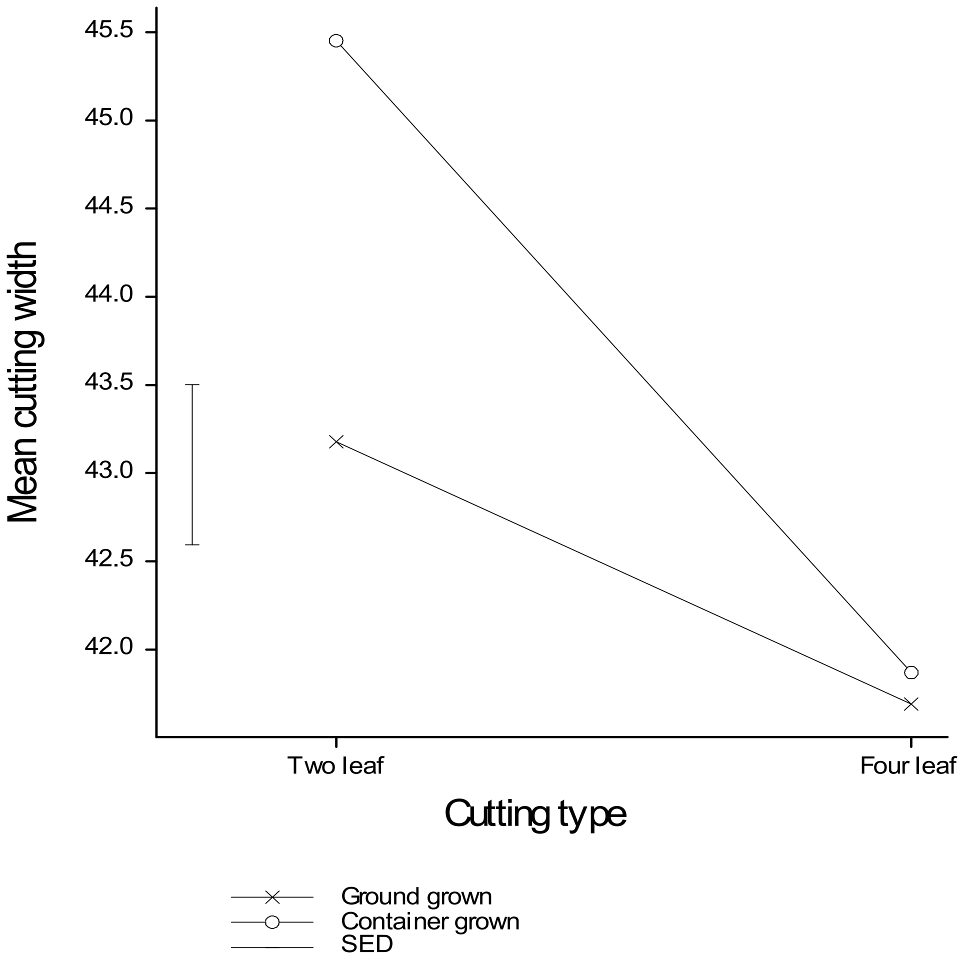

Figure 13. The mean cutting widths of *Choisya ternata* 'Sundance' that originated from either container-grown or ground-grown stock plants and from cuttings with either two or four leaves.

Table 19. Analysis of variance for cutting widths of *Choisya ternata* 'Sundance' that originated from either container-grown or ground-grown stock plants and from two types of cutting.

Source of variation	d.f.	s.s.	m.s.	P
Stock plant type	1	126.30	126.30	0.057
Cutting type	1	540.11	540.11	<.001
Stock plant type x cutting type	1	92.19	92.19	0.103

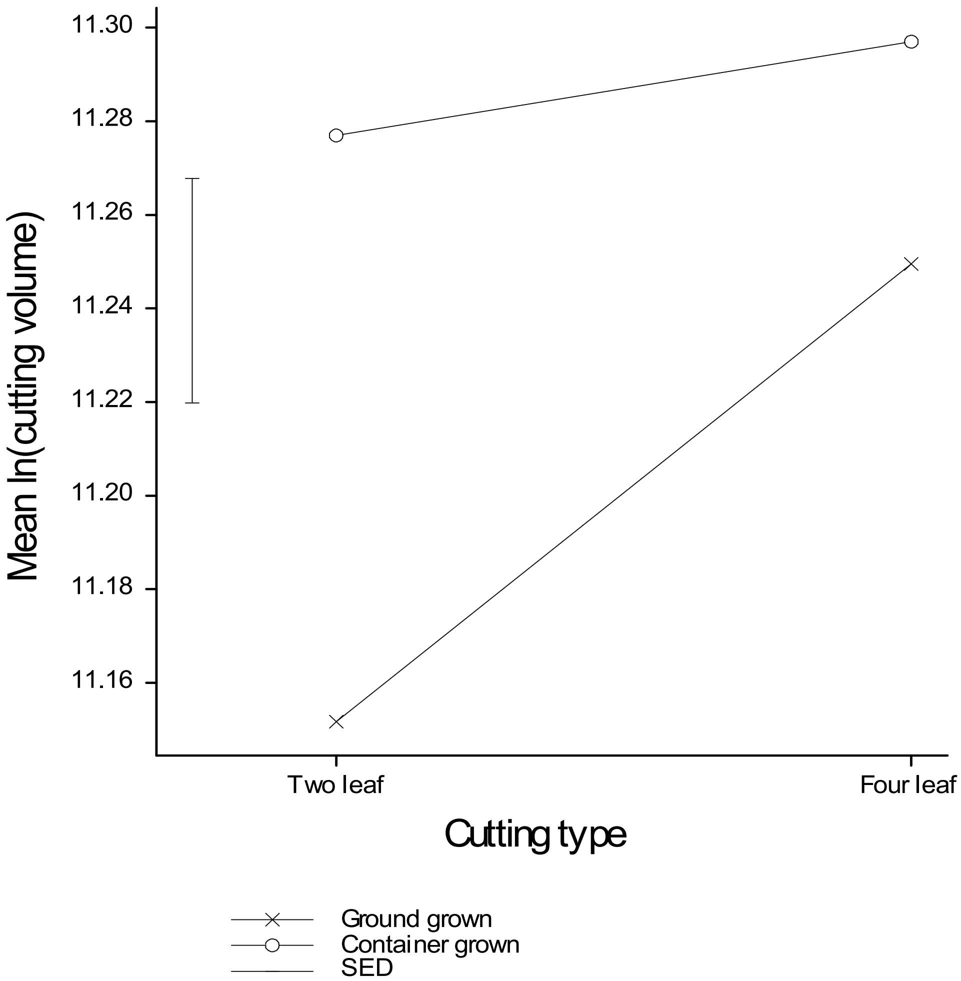

Figure 14. The mean ln(cutting volume) of *Choisya ternata* 'Sundance' that originated from either container-grown or ground-grown stock plants and from cuttings with either two or four leaves.

Table 20. Analysis of variance for ln(cutting volume) of *Choisya ternata* 'Sundance' that originated from either container-grown or ground-grown stock plants and from two types of cutting.

Source of variation	d.f.	s.s.	m.s.	P
Stock plant type	1	0.62661	0.62661	0.011
Cutting type	1	0.29180	0.29180	0.084
Stock plant type x cutting type	1	0.12696	0.12696	0.253

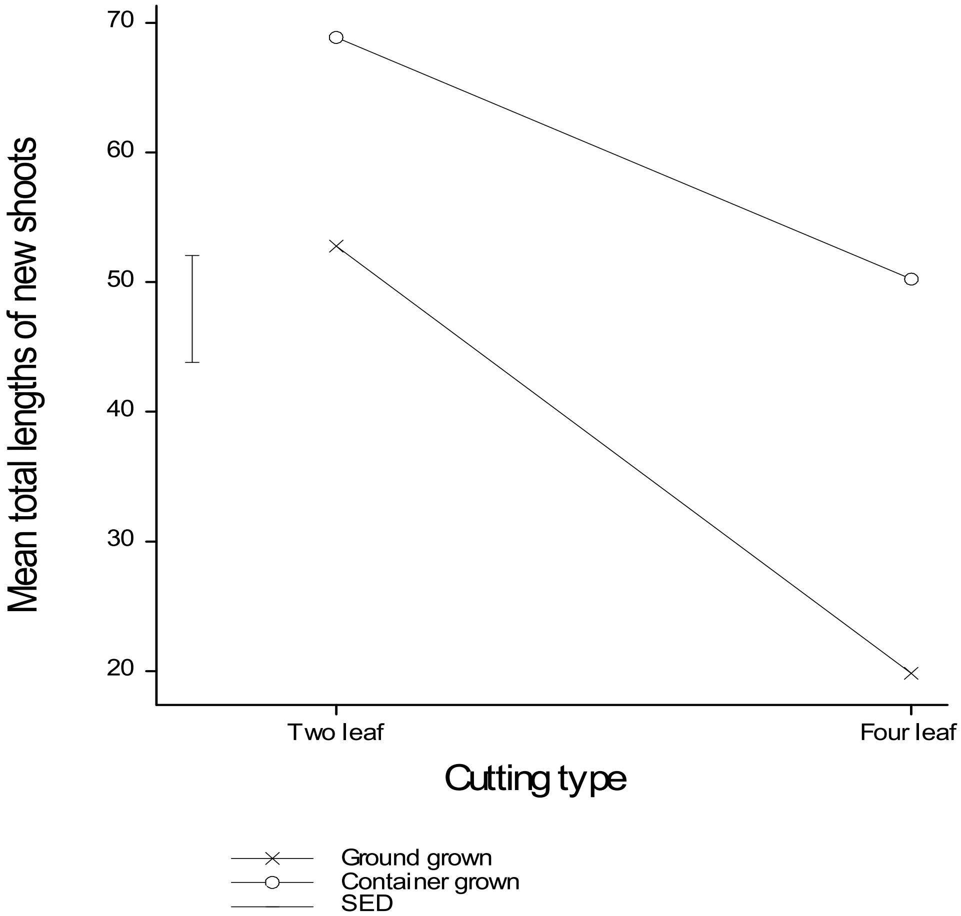

Figure 15. The mean total lengths of shoots of *Choisya ternata* 'Sundance' that originated from either container-grown or ground-grown stock plants and from cuttings with either two or four leaves.

Table 21. Analysis of variance for total lengths of shoots of *Choisya ternata* 'Sundance' that originated from either container-grown or ground-grown stock plants and from two types of cutting.

Source of variation	d.f.	s.s.	m.s.	P
Stock plant type	1	45417	45417	<0.001
Cutting type	1	55918	55918	<0.001
Stock plant type x cutting type	1	4296	4296	0.221

- The survival of the four cutting types was all greater than 83% (Table 22).

Table 22. The number and percentage survival of *Choisya ternata* 'Sundance' on 20/02/06. Cuttings originated from either container-grown or ground-grown stock plants and from two cutting types.

Stock plant type	Survival			
	Two leaf		Four leaf	
	No. observed	(%)	No. observed	(%)
Ground grown	72.00	(85.7)	76.00	(90.5)
Container grown	76.00	(90.5)	70.00	(83.3)

Summary and discussion for *Choisya ternata* 'Sundance'

- The different types of cutting had significantly different sizes and the three cutting types that had the greatest volumes, produced the longest lengths of new shoot.
- Apparently due to being covered by the leaves of adjacent plants (bottom right of Fig. 16), some buds did not produce shoots, which contributed to non-uniformity.

Figure 16. The shading effect of leaves from adjacent plants (bottom right).

- Although the container-grown two leaf cuttings produced the longest lengths of new shoots, these young plants were already not as bushy as the plants produced from four leaf cuttings. There are strong indications for this species, therefore, that the cutting type can have an immediate influence on plant structure, which was more clearly apparent when plants were transferred to the liner pots (Figure 17).

Figure 17. From left to right, young plants that grew from container-grown two leaf, container-grown four leaf, ground-grown two leaf, ground-grown four leaf cuttings.

Cistus 'Silver Pink'

Analysis of the data revealed the following conclusions.

- Both the effects of perceived quality and age of the stock plant were highly significant (Fig. 18).

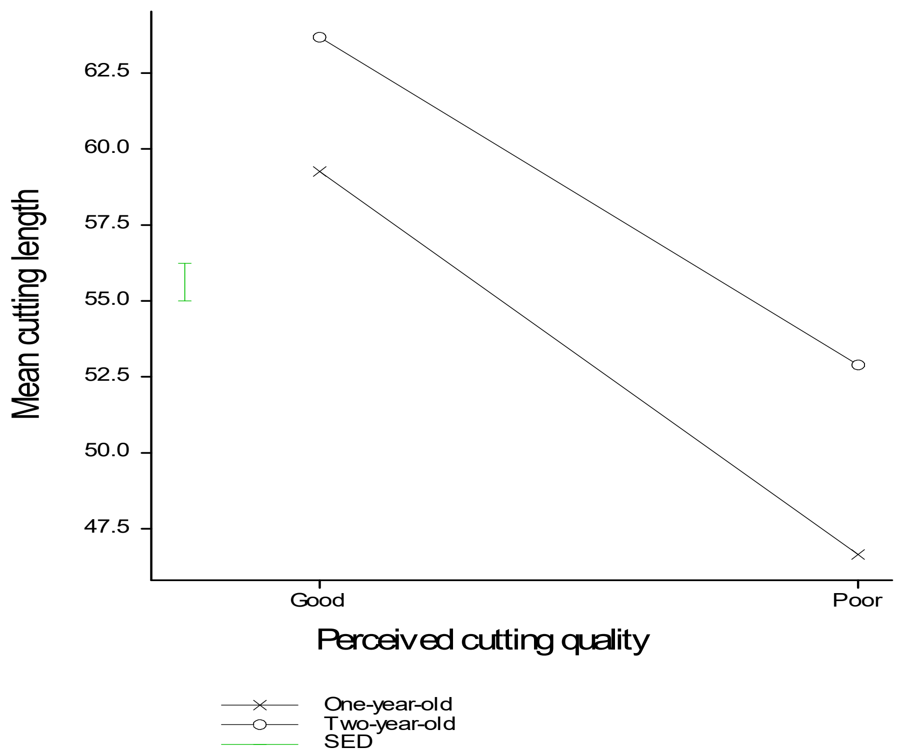

Figure 18. The mean cutting lengths of *Cistus* 'Silver Pink' that originated from one- or two-year-old container-grown stock plants and from cuttings that were considered either good or poor quality.

Table 23. Analysis of variance for cutting lengths of *Cistus* 'Silver Pink' that originated from one- or two-year-old container-grown stock plants and from cuttings that were considered either good or poor quality.

Source of variation	d.f.	s.s.	m.s.	P
Stock plant age	1	2384.00	2384.00	<.001
Cutting quality	1	11491.74	11491.74	<.001
Stock plant type x cutting quality	1	69.67	69.67	0.299

- The effects of perceived quality, age and the interaction were all significant for cutting width (Figure 19 and Table 24).

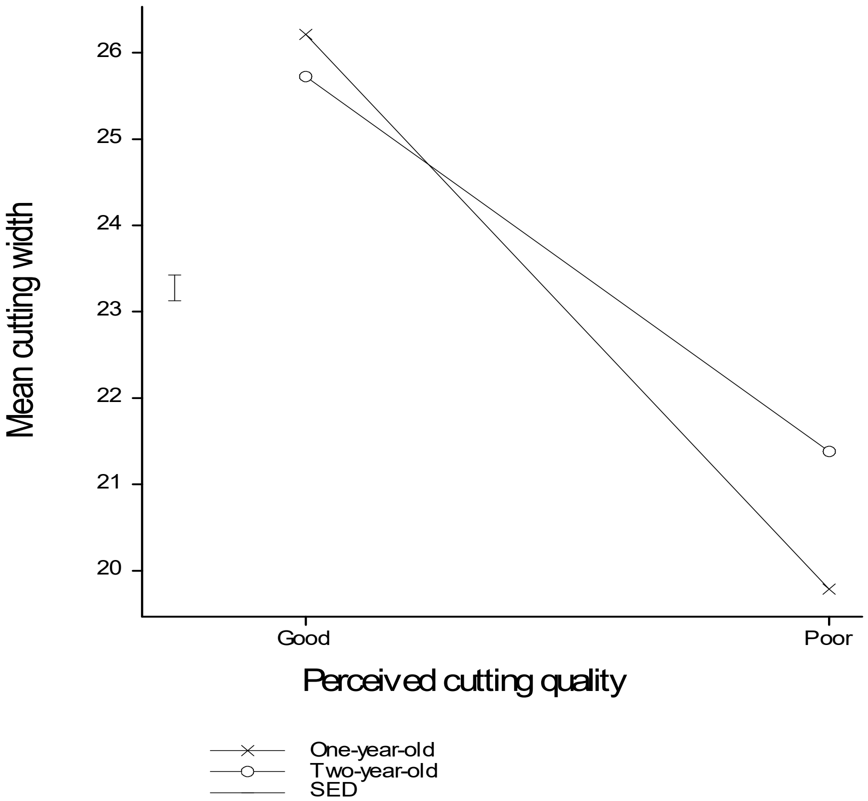

Figure 19. The mean cutting widths of *Cistus* 'Silver Pink' that originated from one- or two-year-old container-grown stock plants and from cuttings that were considered either good or poor quality.

Table 24. Analysis of variance for cutting widths of *Cistus* 'Silver Pink' that originated from one- or two-year-old container-grown stock plants and from cuttings that were considered either good or poor quality.

Source of variation	d.f.	s.s.	m.s.	P
Stock plant age	1	25.741	25.741	0.010
Cutting quality	1	2437.574	2437.574	<0.001
Stock plant type x cutting quality	1	91.146	91.146	<0.001

- The effects of perceived quality, age and the interaction were all significant for cutting volume (Figure 20 and Table 25).

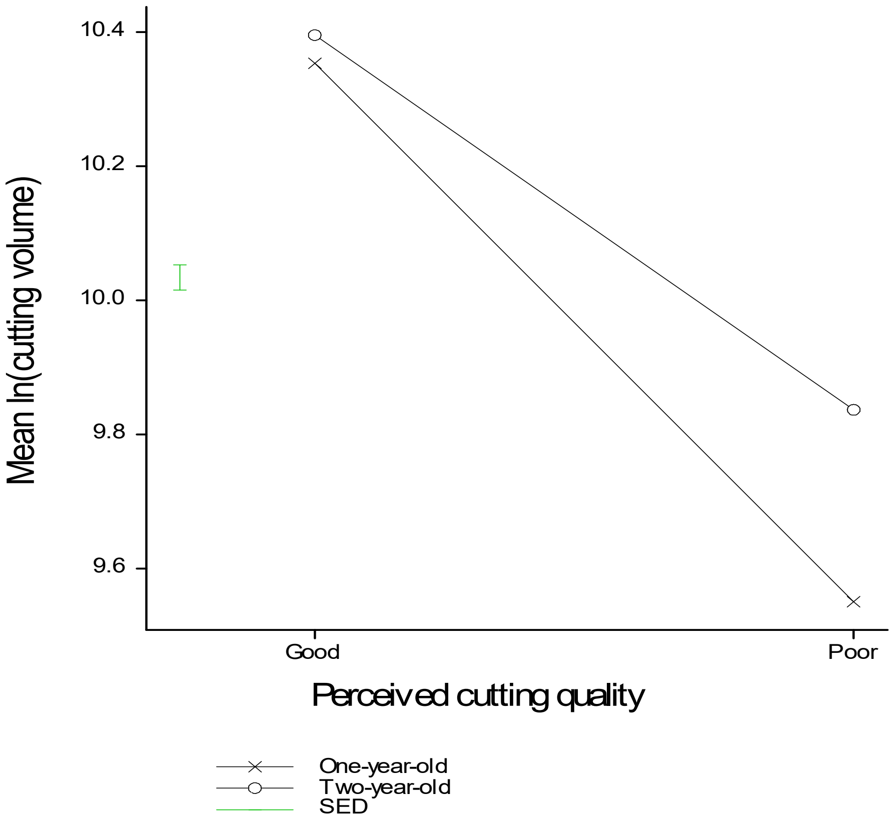

Figure 20. The mean ln(cutting volume) of *Cistus* 'Silver Pink' that originated from one- or two-year-old container-grown stock plants and from cuttings that were considered either good or poor quality.

Table 25. Analysis of variance for ln(cutting volume) of *Cistus* 'Silver Pink' that originated from one- or two-year-old container-grown stock plants and from cuttings that were considered either good or poor quality.

Source of variation	d.f.	s.s.	m.s.	P
Stock plant age	1	2.26571	0.02213	<.001
Cutting quality	1	38.96681	2.26571	<.001
Stock plant type x cutting quality	1	1.25104	38.96681	<.001

- The effects of perceived quality, age and the interaction were all significant for shoot volume (Figure 21 and Table 26). It is interesting to note that the one-year-old 'poor' cuttings, which were the smallest, produced the greatest volume of shoot.

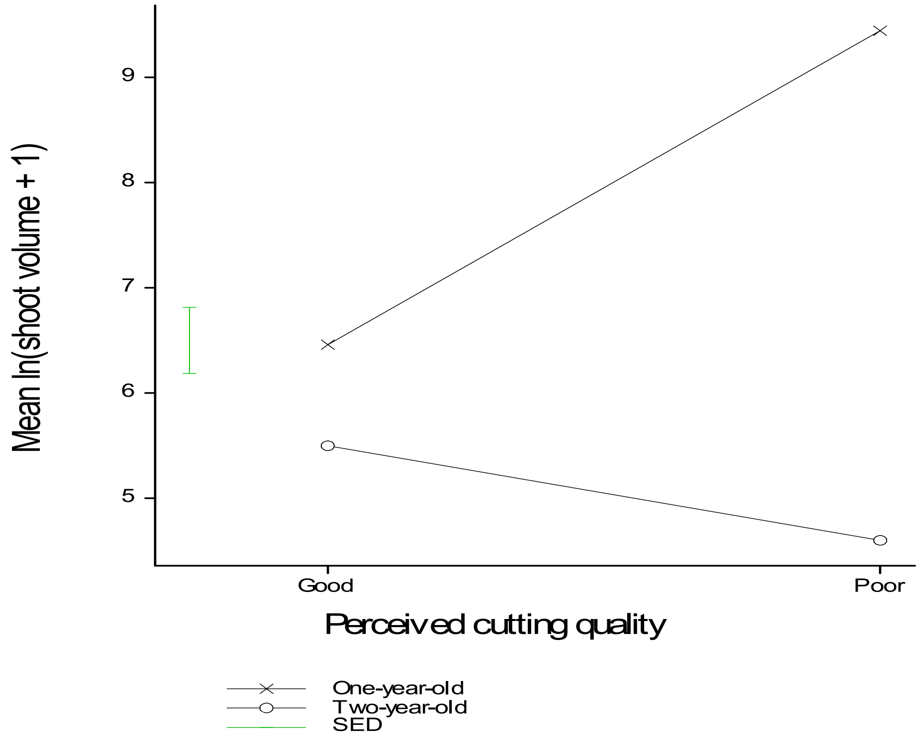

Figure 21. The mean ln(shoot volume +1) on 24/4/06 of *Cistus* 'Silver Pink' that originated from one- or two-year-old container-grown stock plants and from cuttings that were considered either good or poor quality.

Table 26. Analysis of variance for ln(shoot volume + 1) on 24/4/06 of *Cistus* 'Silver Pink' that originated from one- or two-year-old container-grown stock plants and from cuttings that were considered either good or poor quality.

Source of variation	d.f.	s.s.	m.s.	P
Stock plant age	1	707.74	707.74	<0.001
Cutting quality	1	91.27	91.27	0.019
Stock plant type x cutting quality	1	316.92	316.92	<0.001

Excellent survival = 100% in all treatments.

Summary and discussion for *Cistus 'Silver Pink'*

- The cuttings that are perceived to be the 'best' had the highest volumes.
- Cuttings from 2-yr-old plants had greater volumes than from 1-yr-old plants.

- The cuttings that were perceived to be poor from 2-yr-old plants had bigger volumes than 'poor' cuttings from the 1-yr-old plants. However, the 1-year-old 'poor' cuttings produced the greatest mean shoot volumes. This suggests that, for this species, factors other than just cutting volume play a role in determining cutting vigour.
- The survival of all categories of cutting at the time these data were collected was 100%.

***Photinia x fraseri* 'Red Robin'**

Analysis of the data revealed the following conclusions.

- The lengths, widths and volumes of the three types of cutting were all different, but this did not result in a difference in the volume of shoot produced (Table 27). Possible reasons for this include the density at which the cuttings are planted, which results in many of the buds being shaded by the leaves of adjacent cuttings (Fig. 22).
- Survival was more than 98% for all cutting categories (Table 27).

Figure 22. Shading effect of leaves on adjacent cuttings.

Table 27. Analyses of variance for cutting lengths, widths, ln(volume) and ln(total shoot volume + 1) for *Photinia x fraserii* 'Red Robin' cuttings made from different parts of stems: tips, middle stem and base of the stem.

Parameter	Cutting type			SED	P
	Tips	Middle of stem	Bottom of stem		
Mean length (mm)	74.61	81.14	96.63	1.861	<0.001
Mean width (mm)	31.23	35.49	41.27	0.479	<0.001
Mean ln(volume)	10.932	11.273	11.748	0.0341	<0.001
Mean ln(total shoot volume +1)	5.58	4.96	6.47	0.663	0.073
Percent survival on 20/2/06 (n)	100.0 (104)	98.1 (102)	99.0 (103)	-	-

Summary and discussion of results for *Photinia x fraserii* 'Red Robin'

- The physical characteristics of the three types of cutting were very different although this was not reflected in the volumes of the shoots produced.
- One important feature of this species is the relatively long length of the cuttings, particularly those taken from the base of the stem, which means that the architecture of the liner is largely predetermined. It is probable that this characteristic is incompatible with the production of compact, bushy liners.

***Pieris* 'Forest flame'**

The following conclusions could be drawn from the data.

- The mean lengths of the different cutting types were just significantly different, but their mean widths were highly significantly different (Table 27).
- The mean volumes of the different cutting types were also very different, with the soft, medium and hard cuttings having the smallest, intermediate and largest volumes, respectively (Table 27).

Table 27. Analyses of variance for cutting lengths, widths and ln(volume) for three different perceived cutting qualities (Soft, Medium and Hard) of *Pieris* 'Forest Flame' cuttings.

Parameter	Cutting type			SED	P
	Soft	Medium	Hard		
Mean length (mm)	45.16	44.50	46.29	0.716	0.043
Mean width (mm)	26.39	31.57	38.90	0.592	<0.001
Mean ln(volume)	10.101	10.446	10.890	0.0386	<0.001

Summary and conclusions for Pieris 'Forest flame'

- As with the other species described above, there were significant differences in the physical shape of the different types of cutting. Over the coming months, it should be possible to see how these relate to variability in the developing crop.

***Pittosporum tenuifolium* 'Garnettii'**

The experimental data provided the following insights into non-uniformity within this species.

- The mean lengths, widths and volumes of the three cutting types were very different.

Table 28. Analyses of variance for cutting lengths, widths and ln(volume) for three different perceived cutting qualities (Heel of side shoot, Middle stem, Upper stem 'best') of *Pittosporum tenuifolium* 'Garnettii'cuttings.

Parameter	Cutting type			SED	P
	Heel of side	Middle	Upper stem		

	shoot	stem	'best'		
Mean length (mm)	88.04	78.01	80.40	1.045	<0.001
Mean width (mm)	21.94	33.23	24.87	0.590	<0.001
Mean ln(volume)	5.903	6.747	6.161	0.0448	<0.001

Summary and conclusions for Pittosporum tenuifolium 'Garnettii'

- As with the other species described above, there were significant differences in the physical shape of the different types of cutting. Over the coming months, it should be possible to see how these relate to variability in the developing crop.

***Potentilla* 'Chelsea Star'**

The following conclusions can be drawn from the *Potentilla* 'Chelsea Star' experimental data.

- There was substantial variation in the height of the young plants and this was only reduced slightly by pruning (Table 29). The main reason for the relatively small decrease in variability after pruning was that many long stems were missed in the pruning process (Figs. 23a and 23b). Although plants are apparently treated in the same manner, this is not strictly the case and they receive varying degrees of pruning.

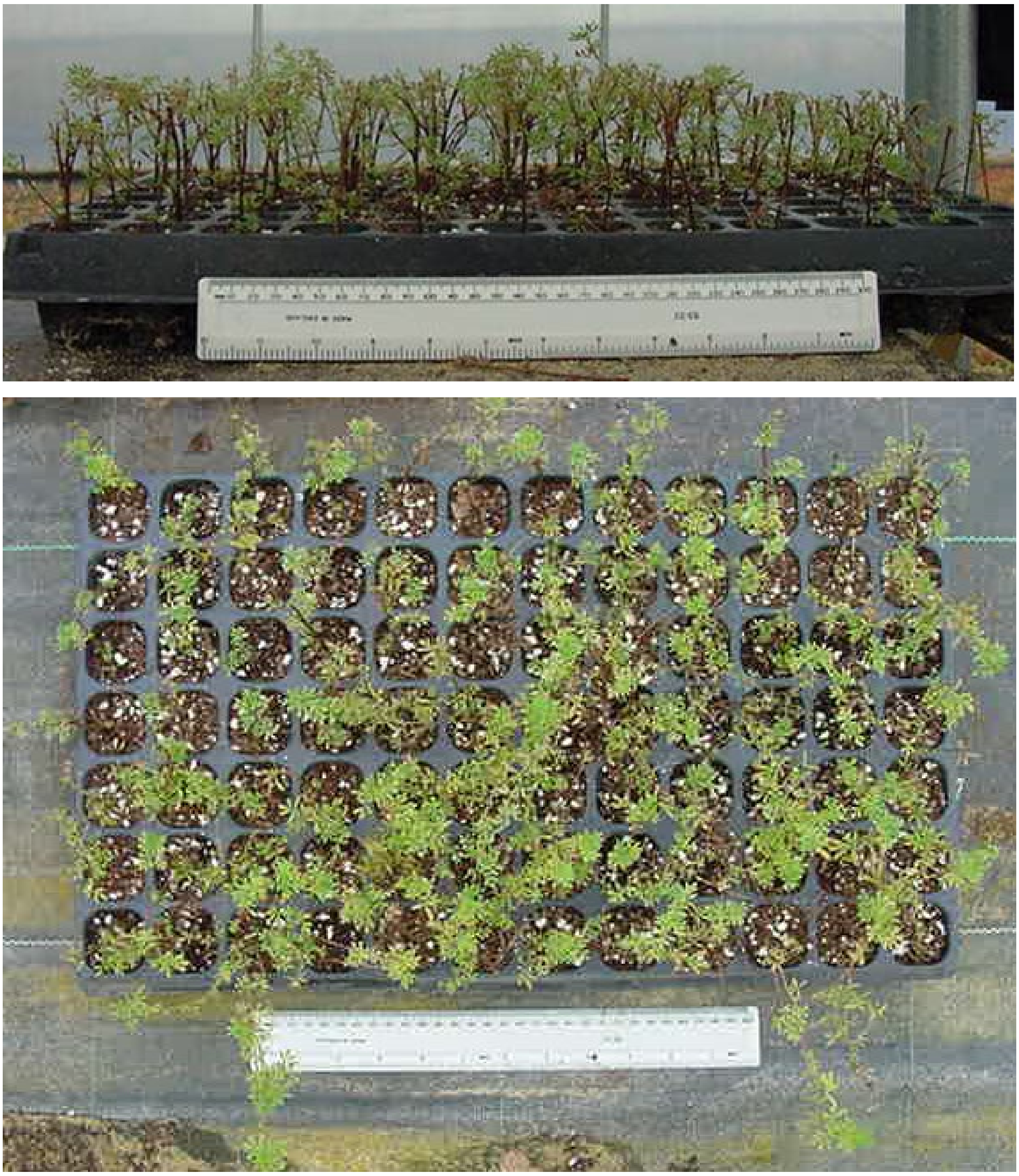

Figure 23a (top). The height of pruned plants was quite variable; Figure 23b (bottom). Top view of the same tray showing that many long stems remained after pruning.

- There was also considerable variation in the width and volumes of the young plants (Table 29).
- Survival of the young plants was high (Table 29).

Table 29. Summary statistics for the data for cuttings of *Potentilla* 'Chelsea Star'. Only one type of cutting was made and data were taken on 9/8/05 from plants that had been planted in wk 28 and had already rooted in trays.

Parameter	Single cutting type	
	Initial data collected on 9/8/05	Data collected on 4/10/06 after pruning
No. of cuttings	168	167
Mean height ± SEM (mm)	91.07 ± 2.44	62.60 ± 2.05
Mean width ± SEM (mm)	13.30 ± 0.26	-
Mean ln(volume) ± SEM	4.869± 0.040	-
Median no. of branches	3.0	3.0
Lower quartile	1.5	1.5
Upper quartile	4.0	4.0
Percent survival	100	99.4

- There was a strongly significant relationship between the above-ground stem volume and the numbers of branches on the young plants (Figure 24).

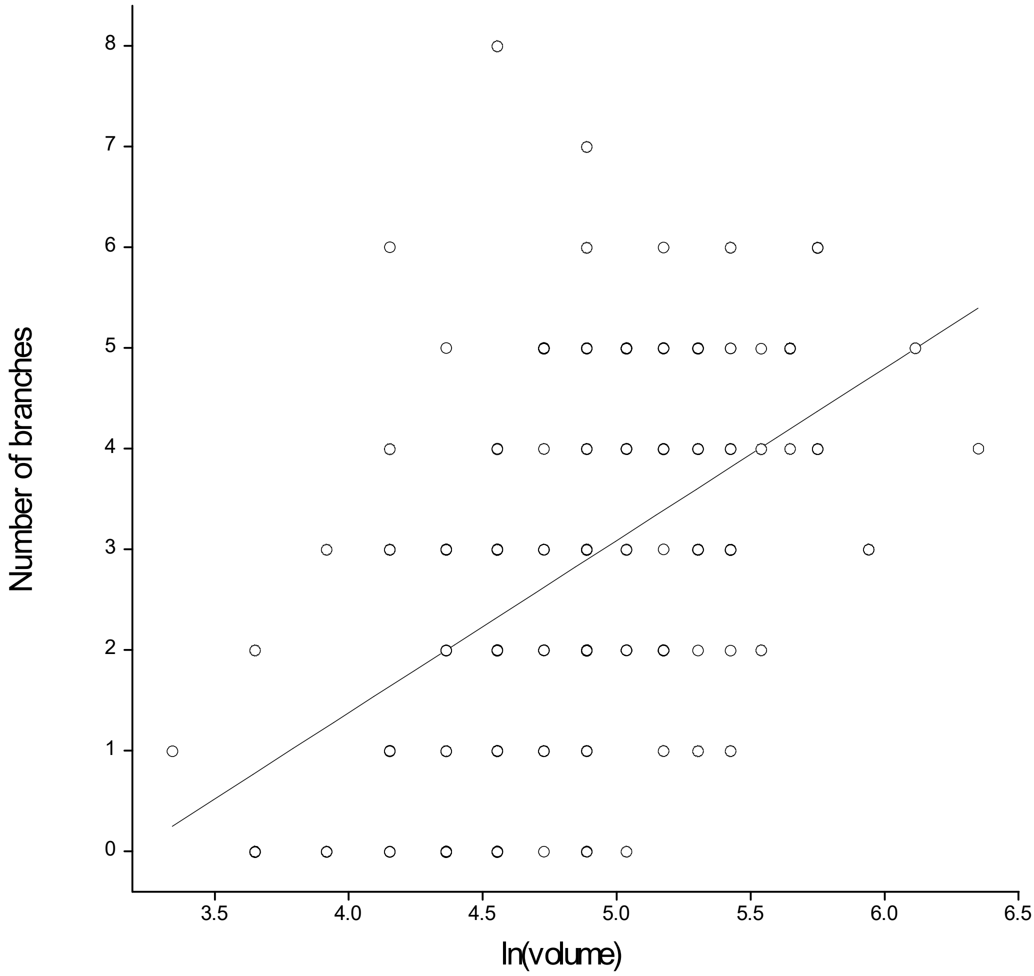

Figure 24. Regression analysis for the number of branches produced on cuttings of *Potentilla* 'Chelsea Star', in relation to their initial above-ground main stem volume. Regression analysis ($P<0.001$). Parameter estimates are: $b = 1.711 \pm 0.245$ ($P<0.001$); $c = -5.45 \pm 1.2$ ($P<0.001$).

Summary and discussion of results for Potentilla 'Chelsea Star'

- There was a relatively large amount of variation in the physical characteristics of the young plants and this was only reduced slightly by the first prune. A method of ensuring that plants are pruned more uniformly will reduce variation and probably lead to the production of more uniform plants.
- The strong relationship between the numbers of branches and above ground stem volume suggests that selectively using cuttings with a greater stem width should result in bushier plants of higher quality.

***Prunus incisa* 'Kojo-no-mai'**

The following conclusions can be drawn from the experimental data on *Prunus incisa* 'Kojo-no-mai'.

- The lengths, widths and volumes of the three cutting types were significantly different. The lower stem cuttings and the main stem tips had the greatest and smallest volumes, respectively (Table 30).
- Survival until mid winter (20/2/06) was greater than 83% for all types of cutting. Towards the end of winter, there was severe frost that probably caused the increased mortality seen when transferring the young plants into liner pots (Table 30).
- The lower stem cuttings produced plants at this stage that had the greatest mean height, had the greatest mean number of branches (Figure 25) and had the best survival (Table 30).

Figure 25. *Prunus incisa* 'Kojo-no-mai' plants that were grown from lower stem, main stem tip, and side shoot heels, from left to right, respectively.

Table 30. Analyses of variance for cutting lengths, widths and ln(volume) for three different perceived cutting qualities (Lower stem, Main stem tip, Side shoot) of *Prunus incisa* 'Kojo-no-mai'cuttings.

Parameter	Cutting type			SED	P
	Lower stem	Main stem tip	Side shoot		
Cutting data					
Mean length (mm)	84.25	60.36	75.18	1.283	<0.001
Mean width (mm)	27.54	16.92	21.76	0.380	<0.001
Mean ln(volume)	6.376	5.404	5.908	0.0335	<0.001
Percent survival on 20/2/06 (n)	97.6 (82)	92.9 (78)	83.3 (70)	-	-
Liner data[a]					
Mean plant height (mm)[b]	156.4	128.9	131.5	4.34	<0.001
Mean no. of branches per plant[c]	5.541	3.341	4.061	0.2098	<0.001
Percent survival (n)	67.9 (57)	50 (42)	38.1 (32)	-	-

[a]Data were collected on 10/5/06, before liners were first pruned.

[b]Plant height was taken as the distance from the liner-pot soil surface to the tip of the highest branch.

[c]Assessed as the total number of apices present.

- The heights of the plants in the liner pots just prior to their first prune was highly significantly related to the volume of their cuttings (Figure 26).

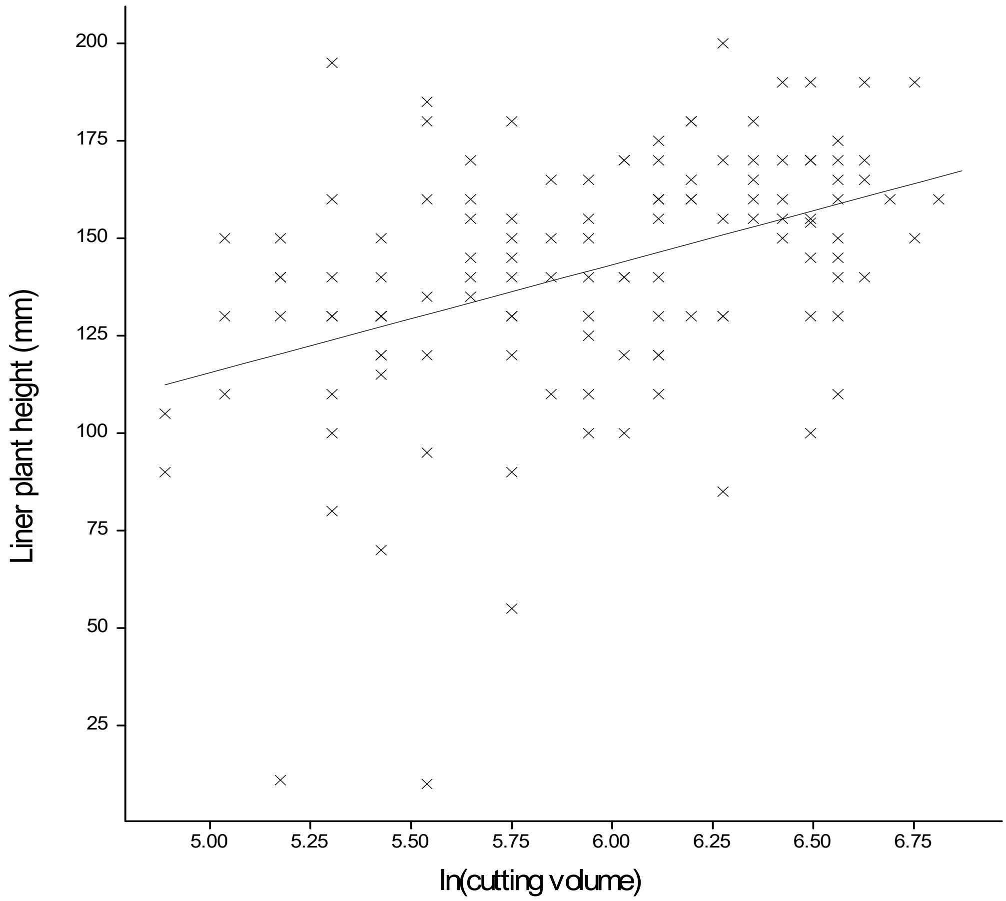

Figure 26. Regression analysis of liner height against original ln(cutting volume) (P <0.001; estimate of b = 27.72 ± 5.2, P < 0.001; estimate of c = -23.1 ± 31.0, P = 0.46).

Summary and discussion of results for *Prunus incisa* 'Kojo-no-mai'

- The physical characteristics of the types of cutting were significantly different and, at the time of writing this report, these differences can be seen to be related to the quality of the plants when transferred into liner pots. These data suggest that greater uniformity within batches of plants could be achieved by keeping the different types of cutting separate at the time of planting.
- Survival of the young plants grown from thinner cuttings was poorer over the winter period. The grading of cuttings at the beginning of the plant production process would provide the potential additional benefit of being able to provide more protection against frost for the thinner plants by placing them in the middle of the polytunnels.

***Rhamnus alaternus* ‘Argenteovariegata’**

The following conclusions can be drawn from the experimental data.

- The cutting mean lengths, widths and volumes were all significantly different for the three cutting types (Table 31).
- There had not been much measurable change in the plants when transferred into liner pots on 24/4/06.

Table 31. Analyses of variance for cutting lengths, widths and ln(volume) for three different perceived cutting qualities (Heels, Middle stem and upper stem ‘best’) of *Rhamnus alaternus* ‘Argenteovariegata’.

Parameter	Cutting type			SED	P
	Heels	Middle stem	Upper stem ‘best’		
Cutting data					
Mean length (mm)	82.13	89.90	87.33	0.934	<0.001
Mean width (mm)	21.21	41.51	30.42	0.586	<0.001
Mean ln(volume)	5.848	7.195	6.562	0.0378	<0.001

Summary and discussion of results for Rhamnus alaternus ‘Argenteovariegata’

- The different cutting types had significantly different physical attributes, but it is too early to determine what effect these may have on the quality of the liners produced from them.

***Viburnum tinus* ‘Eve Price’**

The following conclusions can be drawn from the experimental data.

- The three cutting types had significantly different lengths, widths and volumes (Table 32).

Table 32. Analyses of variance for cutting lengths, widths and ln(volume) for three different perceived cutting qualities (Top, Hard and Singles) of *Viburnum tinus* 'Eve Price' cuttings.

Parameter	Cutting type[a]			SED	P
	Top	Hard	Singles		
Cutting data					
Mean length (mm)	95.23	103.94	67.43	1.941	<0.001
Mean width (mm)	28.07	35.49	40.46	1.021	<0.001
Mean ln(volume)	6.413	6.862	7.129	0.0515	<0.001

[a]Top = softer with two internodes; Hard = from middle of stem with two internodes; Singles = from the base and a single internode.

Summary and discussion of results for Viburnum tinus 'Eve Price'

- The different cutting types had significantly different physical attributes, but it is too early to determine what effect these may have on the quality of the liners produced from them.

***Weigela* 'Kosteriana Variegata'.**

The following conclusions can be drawn from the experimental data.

- There was relatively little variation in the lengths, widths and volumes of the cuttings used (Table 33).
- Survival of these cuttings was relatively high (92%) by the middle of winter (Table 33).
- After transfer into liners, there was relatively little variation in plant height and the mean number of shoots per plant. Survival, however, had dropped to approximately 74%, which may also have been due to the severe frosts that occurred later in the winter.

Table 33. Analyses of variance for cutting lengths, widths and ln(volume) for standard *Weigela* 'Kosteriana Variegata' cuttings.

Parameter	Standard cutting
Cutting data	
Mean length (mm) ± SEM	40.1 ± 0.21
Mean width (mm) ± SEM	36.59 ± 0.29
Mean ln(volume) ± SEM	6.942 ± 0.016
Percent survival on 20/2/06 (n)	92.1 (232)
Liner data[a]	
Mean plant height (mm)[b]	114.41 ± 1.87
Mean no. of shoots per plant	3.134 ± 0.090
Percent survival (n)	73.8 (186)

[a]Data were collected on 10/5/06, before liners were first pruned.

[b]Plant height was taken as the distance from the liner-pot soil surface to the tip of the highest shoot.

- There was no clear relationship between cutting volume and plant height (Fig. 27).

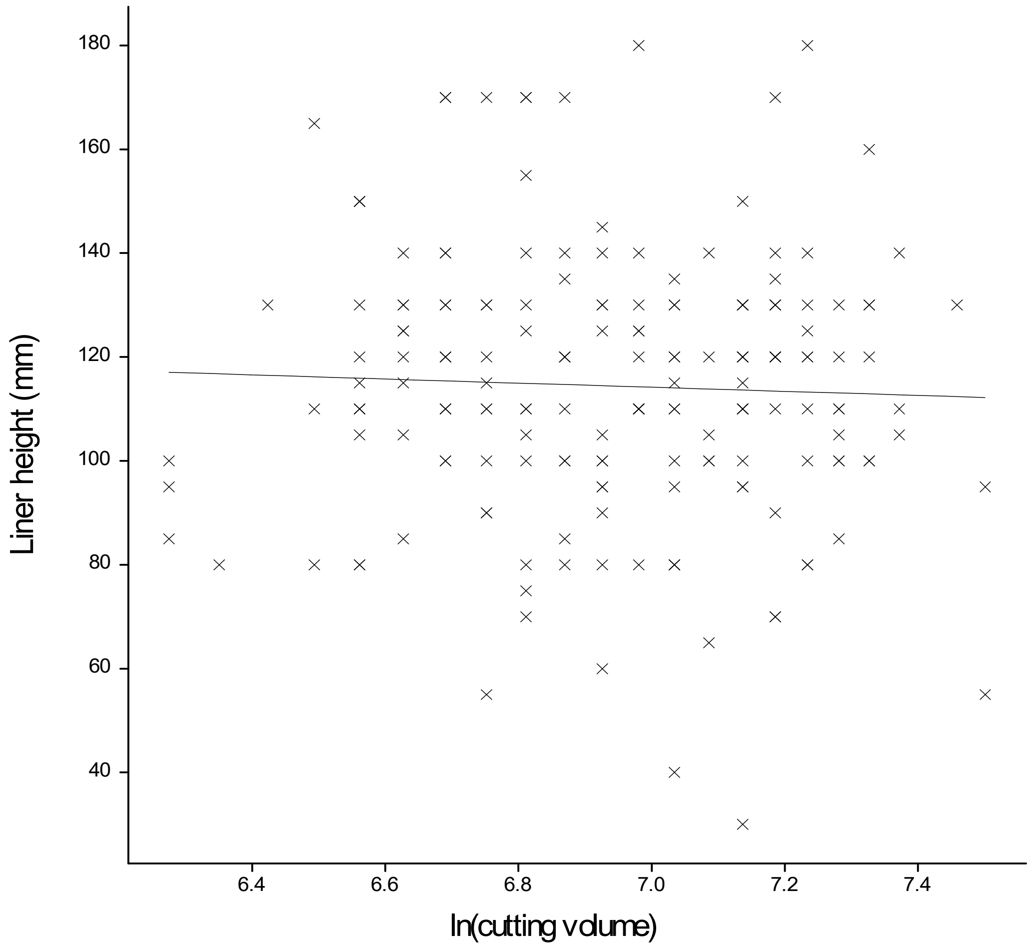

Figure 27. Regression analysis of liner height against original ln(cutting volume) (P <0.582; estimate of b = -3.95 $\pm$ 7.17, P < 0.582; estimate of c = 141.9 $\pm$ 49.8, P = 0.005).

Summary and discussion of results for Weigela 'Kosteriana Variegata'

- The cutting were relatively uniform and these produced plants in which the relationship between cutting volume and plant height was not significant.
- Although the statistics suggest that the majority of plants are relatively similar, there were still noticeable differences between plants at either end of the spectrum (Figure 28). It is probable that a contributory factor is the shading of buds that occurs from the leaves of adjacent plants in the trays used to plant the cuttings.

Figure 28. The variation present at the extreme ends of the spectrum in the young *Weigela* 'Kosteriana Variegata' plants recently transferred into liner pots.

Summary of the factors affecting non-uniformity in the experimental species

The various factors that introduced variation into the crop and the approximate time periods over which these effects could be detected are summarized in Table 34.

Table 34. The influence of the various factors that affected crop non-uniformity.

Plant species	Cutting dimensions (length & width)	Cutting structure (No. of internodes & branches)	Apical dominance	Stock-plant type (Field, container, ground, age)	Cutting survival	Spacing / lighting[a]
Berberis thunbergii 'Harlequin'	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓	-
Camellia williamsii 'Donation'	✓✓	✓✓	✓	-	✓	✓
Choisya 'Aztec Pearl'	✓✓✓	✓✓✓	✓	-	✓✓✓	✓✓✓
Choisya ternata 'Sundance'	✓✓✓	✓✓✓	✓✓	✓✓✓	✓	✓✓✓
Cistus 'Silver Pink'	✓✓✓	✓✓	✓	✓✓✓	✓	✓
Photinia x fraseri 'Red Robin'	✓✓✓	✓✓✓	✓✓✓	-	✓	✓✓✓
Pieris 'Forest flame'	✓✓✓	✓✓✓	✓✓✓	-	✓	✓✓✓
Pittosporum tenuifolium 'Garnettii'	✓✓✓	✓✓✓	✓✓	-	✓✓✓	✓
Potentilla 'Chelsea Star'	✓	✓✓	✓	-	✓	✓
Prunus incisa 'Kojo-no-mai'	✓✓✓	✓✓✓	✓	-	✓✓	✓
Rhamnus alaternus 'Argenteovariegata'	✓✓✓	✓✓✓	✓✓✓	-	✓✓✓	✓
Viburnum tinus 'Eve Price'	✓✓✓	✓✓✓	✓	-	✓✓	✓
Weigela 'Kosteriana Variegata'	✓	✓	✓	-	✓	✓✓

[a]Assessed by observation only.
✓✓✓Highly significant and lasting contribution
✓✓Intermediate significance
✓Relatively small and short term effects

Visit to the HTA to assess the usefulness to this project of their database on nurseries

- A visit was made to the HTA, who helpfully demonstrated the data stored in their data-base. Although some financial figures related to nursery losses, the proportion of losses attributable to non-uniformity could not be determined. Data had also been aggregated and no data were available for individual plant species. This database, therefore, was considered to be of little use to this project.

Modelling

- At the start of the project, a preliminary model of the plant production process was built, which was demonstrated at the HNS panel meeting at Wellesbourne. This model is set up to use the Solver in Excel to find the maximum profits within given constraints.
- A preliminary investigation of the behaviour of this model produced several interesting results. In particular, the model showed that actions to decrease waste, pruning, sorting and potting times can increase profits significantly, even if the costs of stock planting material are increased at the same time.
- In the coming year, the experimental data collected so far will be used to inform and improve the model, which has been altered to include the plant species and varieties being looked at in this study (Excel file attached). The next step in the modeling process will be to enter estimates, within sensible ranges, for the costs and examine strategies for optimizing profits. In particular, given the above experimental results and conclusions, it is intended to focus on the trade-offs between the increased costs of selectively using cutting material and the potential subsequent savings made from increased crop uniformity, reduced waste and associated decreased pruning, sorting and potting times.

Conclusions

- There were real differences in the size and physical structure of the different cutting types in eleven of the thirteen plant species examined: *Berberis thunbergii* ‘Harlequin’, *Camellia williamsii* ‘Donation’, *Choisya* ‘Aztec

Pearl', *Choisya ternata* 'Sundance', *Cistus* 'Silver Pink', *Photinia x fraseri* 'Red Robin', *Pieris* 'Forest flame', *Pittosporum tenuifolium* 'Garnettii', *Prunus incisa* 'Kojo-no-mai', *Rhamnus alaternus* 'Argenteovariegata', *Viburnum tinus* 'Eve Price'. For *Potentilla* 'Chelsea Star', there was also a noteable amount of variation in the height, width and volume of newly established plants.

- For all the species except *Weigela* 'Kosteriana Variegata' (for which there was a single cutting type) strong relationships were observed between cutting type and subsequent plant growth. It is probable for *Weigela* 'Kosteriana Variegata' that cutting type also affects subsequent plant growth, but that the experimental design was not suitable for picking this up. For *Potentilla* 'Chelsea Star', for which there was also only a single cutting type, there was a strong relationship between cutting volume and the number of subsequent branches that were produced.
- Data collected during the early development of the plants, showed that cutting type and structure could also exert an important effect on the subsequent structure of the plants. This has major implications for achieving high quality liners that, characteristically, are bushy, vigorous and of a pre-determined uniform height.
- For certain species such as *Berberis thunbergii* 'Harlequin', the perception of the growers as to what constituted the 'best' cuttings was a relatively accurate reflection of the subsequent initial performance of those cuttings. For others, such as *Cistus* 'Silver Pink', cuttings rated as 'poor' outperformed others rated as 'good'. It will be interesting to see whether these relationships remain consistent in the final assessment of plant quality.
- For some species, such as *Berberis thunbergii* 'Harlequin', it was apparent that factors other than cutting volume were important in determining the initial vigour of the plants. For instance, when the poorest cuttings of this species, which had the smallest volumes, did produce a shoot, they were amongst the longest measured. It is probable that this effect is related to the nutrient status and 'reserves' present within the cuttings.
- Initial work on liners at Hilliers showed that 'best' and 'standard' *Berberis thunbergii* 'Harlequin' had real differences in the widths of their lower stems,

which had been the original cuttings. This strongly supports the hypothesis that, at least for this species, cutting volume has a long-term impact on the subsequent quality of the resulting plant.

- The survival of the different the plant species varied considerably and for some species such as *Prunus incisa* 'Kojo-no-mai', the larger cuttings had the best survival rates. For others such as *Choisya* 'Aztec Pearl', survival appeared to have been related to cutting structure, where those with the most foliage avoided their compost getting too wet and thus problems with rot. For *Berberis thunbergii* 'Harlequin', the main cause of mortality was failure of the cuttings to root. It is clear that the period prior to the cuttings forming roots is when they are highly vulnerable to adverse changes in humidity and the water content of the compost.
- If, as the data in this report strongly suggest, there is a strong relationship between cutting and subsequent liner quality for the majority of the species studied, it should be possible to predict the quality of liners from the quality of the cuttings and a statistical sampling tool could be built to do this.
- In terms of the non-uniformity problem facing growers, these results have several implications, which are:
    - I. Stock-plant management is clearly extremely important and should be aimed at producing sufficient quantities of 'best' and 'standard' cuttings.
    - II. Although important, the above measure will not, in itself, greatly reduce crop non-uniformity, as there is still a lot of variation present between 'best' and 'standard' cuttings. Also, the type of stock plant used to make the cuttings, either container- or field-grown, introduces variation into the cuttings.
    - III. In order to manage variability, therefore, and still be able to produce a sufficient quantity of grade I liners cost-efficiently for sale, it may be advisable to grade the cuttings at the time of planting and to keep the different batches and types separate from one another.
    - IV. Adoption of this practice should provide the following benefits, i) the numbers of plants that need to be held back until they reach an acceptable quality will be reduced, ii) 'best' material can be placed in locations within the polytunnels that are least likely to be affected by low

humidities or frost and so losses of this important category of plants will be reduced, iii) the increased uniformity within the batches should reduce the time and costs required for sorting and picking when the liners are graded for onward distribution and sale.

- The experimental plants will continue to be followed this year. In addition, there are now sufficient experimental data to begin modelling potentially advantageous trade-offs, with a focus on those between the increased costs of selectively using cutting material and the potential subsequent cost savings made from increased crop uniformity, reduced waste, reduction in the need to retain grade II plants until they reach the required quality and reductions in the pruning, sorting and picking costs.

Technology transfer

The research results are not yet at a stage where technology transfer is appropriate.

Acknowledgements

I am extremely grateful to all the staff at New Place Nurseries and at Hillier Nursery, without whose consistent help, generosity and willingness to share their knowledge, this project would not have been possible.

Glossary

Cutting volume - calculated using the formula (22/7) x $(\text{stem diameter}/2)^2$

Cutting width - cutting stem diameter, measured at the middle of the cutting

Ln - natural logarithm (to the base e)

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