Project Title	Profit optimisation through modelling and management of non-uniformity in Hardy Nursery Stock species
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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.

Disclaimer. The varieties/species of plants in the trial were specifically selected for their production difficulties and non-uniformity and, as a result, the results of the project in no way reflect on general liner production at New Place Nurseries or finished plant production at Hillier Nurseries.

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.

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Grower Summary

Headline

The solution to the non-uniformity problem in some hardy ornamental species appears to lie partly in the selective use of cutting types, as well as in the use, or development, of objective, more quantitative methods for assessing liner quality.

Background and expected deliverables

Finished-plant Hardy nursery stock growers consider that within-crop variability is a major business problem, because waste levels due to plant non-uniformity frequently reach 20% (and have occasionally reached 60%) for particular 'problem' species/varieties. This problem reduces profits and occurs as a result of the strict plant-quality and uniformity specifications demanded by the DIY chains and garden centres, which are the main customers for many nurseries.

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).

No significant amount of variability, however, could be attributed to differences in the initial cutting material (HNS 117). It was logical to assume, however, that the quality of the end product would be dependent on getting the first steps in the plant production process right, and so it was decided to re-assess the validity of the conclusion of HNS 117, by further on-nursery experimentation.

The majority of experimental varieties/species of plant described here were chosen specifically for their production difficulties and non-uniformity. Two species/varieties were also included as examples where production and non-uniformity difficulties were usually absent.

The data from the nursery experiments informed the modeling activities of this project and the initial framework for an Excel spreadsheet-based operations management tool. In the second year of the project, after discussion with New Place Nurseries and the HDC technical manager, it was decided to show the progress in this area to other liner producers, in order to canvass their opinions on its usefulness and to obtain any additional feedback. Visits took place to other liner-producers and tools have been built that allow the rapid and accurate financial assessment of alternative options related to the non-uniformity problem. Businesses can therefore facilitate an objective and financial basis for decision making, which can help managers to maximize profits and minimize waste.

Summary of the project and main conclusions

In the first year, large differences were found in the size and physical structure of the different cutting types in 11 of the 13 experimental plant species: *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'. These clear differences, described in the 2006 annual report, continued to be apparent in 12 of the 13 plant species a year later. Data collected during the development of the plants in liner pots, also showed that cutting type and structure exerted an obvious effect on the subsequent structure, or 'architecture' 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 most of the species, the perception of the growers as to what constituted the 'best' cuttings continued to be an accurate reflection of the subsequent performance of the plants that grew from them. For the *Cistus* 'Silver Pink', which was mentioned in the previous report, the 'Good / yr1' cuttings also eventually produced the bushiest plants. The growth of plants from 'poor' cuttings, for example of *Berberis thunbergii* 'Harlequin', was much less predictable and consequently was an additional source of variation in the experimental crop.

In the time available before the relevant sale date, the best *Cistus* 'Silver Pink' and *Berberis thunbergii* 'Harlequin' liners also produced the best finished plants and the

differences between the comparative groups were unequivocal. **For these species, it can be concluded that although most plants may eventually become saleable, there was no evidence to suggest either that batches become more uniform with time or that the poor quality plants ever 'catch-up' with the best performing ones.**

A possible way of introducing greater uniformity into batches of plants at several points in the production process is to grade plants. For all the species examined, however, it was not possible to see a clear relationship between the physical measurements and the resulting categories of First (saleable) and Second (not saleable) liner plants. There are several reasons why this occurred, which include;

i. The plant specification used was not applied rigorously or was not current.
ii. The assessment was rapid and not quantitative.

As a result of the grading procedure, liner categories that were clearly significantly different were mixed together, with the result that there was an increase in the variability or non-uniformity of the new category, which was called Firsts.

The quantitative data showed that there was a very strong relationship between the number of branch apices or 'bushiness' of liners and those of the same finished plants, i.e. bushy liners produced bushy finished plants and non-bushy liners produce non-bushy finished plants. In addition, the quantitative data showed that the subsequent growth of less bushy and less vigorous plants at the liner stage is highly unpredictable and that they don't 'catch-up' with the best quality plants. If anything, the variation between high and low quality plants increased with time and so accentuated the non-uniformity in the experimental batches of finished plants.

Strong effects of cutting type at propagation stage were still clearly apparent in the finished plants and this potentially provides part of the solution to the non-uniformity problem. Where plants are being produced to meet an order by a finished plant producer, who requires a definite liner specification, it is vital to use only the particular type of cutting that produces the highest percentage of liners that will meet the desired specification. For some of the plant species, more than one cutting type will be able to do this, but these will almost certainly require different pruning regimes to achieve the

desired effect. If numbers of cuttings of the right type are limited, it may still be possible to generate the desired number of uniform plants by using different cutting types and keeping the plant batches separate, so that they can be pruned and managed appropriately.

The experimental data show clearly that the decisions and cutting material used at the beginning of the plant production process have permanent effects on crop variability. If insufficient care is taken at the beginning of the liner production process, the inevitable result will be a batch of liners that may have an unacceptably large number of Seconds present, if the grading specifications were to be strictly and objectively adhered to. For the more woody species, such as *Photinia x fraseri* 'Red Robin', for example, liners that fail the criterion of requiring more than a particular number of breaks in the lower portion of their stem will almost certainly never become Firsts. Unless another market for these plants can be found by the liner producer, such as the landscape market where uniformity is not such an issue, they effectively become waste, which will have major effects on the profitability, or otherwise, of this species.

The experimental research into the plant production process clearly highlights the financial importance to the finished-plant nurseries of purchasing only batches of highly uniform liners. In the experiments carried out on *Photinia x fraseri* 'Red Robin', for example, only 19 (52.8%) out of 36 plants, graded as Firsts by nursery staff at the liner stage, were ready for sale by the finished plant nursery, at the appropriate time. A further nine (25%) plants were considered to have the potential to become saleable at a later date and eight (22.2%) were so variable and of poor quality that they were considered non-saleable or waste. Plants at the end of the production cycle have already incurred the greatest possible financial investment and so the loss of more than 22% of the crop at this stage probably makes this species unprofitable to produce.

Due to the subjective way that grading at both experimental nurseries was carried out, no relationship could be found between liner and finished-plant assessments for any of the species, i.e. the liner grade was an extremely poor predictor of the 'sale quality' of the finished plant. The subjective methods used by nursery staff for grading liners have several clear drawbacks. They are very labour-intensive, insufficiently objective

and, consequently, inaccurate. A possible solution to this problem may lie in the development of an automated, computer-assisted, plant-grading system for hardy nursery stock liners. Technology such as this would provide clear benefits both to the liner producers, who would be able to certify the quality and uniformity of their liner crops with confidence, and to the finished-plant producers who would immediately experience much lower losses due to waste at the end of the plant production cycle.

Modeling activities

As part of the modeling activities of this project, visits were undertaken to other liner producers and the model, which is described in the previous report (2007), was turned into a tool. The experimental data and modeling analyses show that it is most cost-effective to tackle the non-uniformity problem at the beginning of the plant-production process. Once the liners are due to be sold to the finished plant producer, the only realistic option available for generating increased uniformity in the crop is to increase the objectivity and to use metrics in the grading process. The modeling analyses shows that the rejection of a significant proportion of the liner crop at this stage, on top of the other production losses, however, could easily make the production of the most difficult species uneconomic for the liner producer. The tools that have been built from the model, therefore, are targeted at providing the liner producer with a way of costing production easily and accurately, as well as optimizing profits in relation to non-uniformity in the crop. The tools generate sale prices for each species, based on production costs. A profit maximization facility and information on the financial cost of waste is also provided.

Although considerable progress has been made in understanding the non-uniformity problem and in discovering possible solutions, the model tools and solutions have yet to be fully validated. This could be achieved by running experimental batches of a few 'problem' species through the production process, based on the project's recommendations and by using the tools to assess accurately the financial implications and benefits. If successful, these plant batches could also be used to provide a demonstration of improved production methods to other nurserymen.

Financial benefits

In addition to the financial benefits detailed in previous reports, the following information and conclusions can provide financial benefits to hardy nursery stock growers;

- Strong effects of cutting type were still clearly apparent in the finished plants and this potentially provides part of the solution to the non-uniformity problem.

- There were also very strong relationships between the quality characteristics of liners and those of the same finished plants, e.g. bushy liners produced bushy finished plants and non-bushy liners produce non-bushy finished plants.

- This research, therefore, underlines the financial importance to the finished-plant nurseries of accurate and objective grading of liners, as well as of only purchasing batches of highly uniform plants.

- The profitability of a nursery is made up from the individual profits, or losses, incurred on the different component species sold. The Excel-based tools developed in this project, allow the identification and focus on the least profitable species, as well as the capability to determine rapidly whether or not their profitability can be improved. They have the potential, therefore, to have a big impact on overall nursery profitability.

Action points for growers

- Stock-plant management is extremely important and should clearly focus on reducing non-uniformity at the cutting stage. Growers should only produce and use the type of cutting that will produce the highest survival and percentage of saleable plants by the expected date of sale.

- If it is not possible to generate enough uniform 'best' quality cuttings, it is advisable to grade cuttings at the time of planting and to keep the different batches and types separate from one another.

- Due to the subjective way that grading at both experimental nurseries was carried out, no relationship could be found between liner and finished-plant quality assessments for any of the species, i.e. the liner grade was consistently an extremely poor predictor of the 'sale quality' of the finished plant. This finding underlines the need to develop an improved liner grading protocol, which will help both liner producers to maintain the uniformity and quality of their products, as well as reduce the losses suffered later in the production chain by the finished plant producers.

- The need to invest resources, or direct research, towards generating a cost-effective liner grading mechanism applies, to various degrees, to all of the experimental species. It will have its greatest impact, however, on those species that consistently create a large loss due to variation in the finished crop.

- The profitability of a nursery is made up of the individual profits, or losses, contributed by the different component species sold. The easy and rapid identification of the least profitable species should enable appropriate management and plant-production decisions to be made and so potentially have a big impact on overall nursery profitability. The tools generated by this project are designed to facilitate this process.

Science Section

Introduction

Within-crop variability of many Hardy Nursery Stock species frequently results in a proportion of plants failing to meet the required quality specification by the time they are due to be sold. The percentage of plants that are wasted due to being unsaleable, therefore, can often be higher than 20% and, in extreme cases, can be over 60%. This effect occurs at the end of the plant production process when a significant investment has already been made in the production of each plant. It has a clearly negative impact on the profitability of the worst affected varieties. The problem is currently felt most acutely by those finished-plant nurseries whose businesses aim to produce plants for DIY chains and garden centres by a particular date, as these customers enforce strict plant-quality and uniformity specifications.

The project's first objective, was to set up on-nursery experiments for 13 representative plant species, to assess the effect of cutting variability and 'quality' on subsequent plant growth and development.

After the first year of the project, several conclusions could already be drawn from the experimental data. There were large and significant differences in the size and physical structure of the different cutting types that could be used to propagate 11 of the 13 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'. In addition, for all the species except *Weigela* 'Kosteriana Variegata', strong relationships were observed between cutting type and subsequent plant growth.

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 uniform, high-quality liners, which have the general characteristics of being 'well-formed', bushy with breaks at the base of the stem, vigorous and of a specified 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'. Initial work on *Berberis thunbergii* 'Harlequin' liners at Hillier Nurseries (HN) 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 provided 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 was 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.

In the project's final year, additional data were collected on the survival, physical structure and percentage of plants that were graded as either 'Saleable', 'Saleable later' or 'Non-saleable' (waste) by the finished-plant producer and it was attempted to relate their final grade to their categorisation as liners.

The experimental data were used to inform the modelling activity and two tools were developed from the model after visits to other liner growers. These visits were arranged by introductions from Mr Mike Norris, New Place Nurseries (NPN), and were undertaken to visit Northern Liners (NL) and Fairweather Nursery (FN) to obtain additional feedback on the usefulness, or otherwise, of the modelling activities. The 'tools', which have been built following the wider consultation process can be considered as a 'work-in-progress' and a package that potentially can be improved or added to, depending on the interest and responses received from growers after its release by the HDC.

Materials and Methods

Summary of years 1 & 2. The experiments designed to re-evaluate the main conclusion of HNS 117, that measurable variation in starting material could not be linked to variation in the final crop, were carried out at NPN. (HNS 136 Annual Report, 2006, 2007). The experiments consisted of setting up batches of stock material with different levels of initial variability. Representative species that were perceived to have a minimal problem with non-uniformity and waste were also selected for comparative purposes.

The following thirteen plant species and varieties were selected for experimentation: *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' and *Weigela* 'Kosteriana Variegata'.

In Year 2, the experimental plants were subjected to the standard growing practices for that particular species. Data were collected at appropriate intervals on stem diameter, plant height and number of branches, as well as any mortality that had occurred since the previous measurements were collected. Prior to their transportation to their new location at the finished plant nurseries, plants were graded by staff at NPN into First and Second quality plants and any additional data were collected that related to the liner specification supplied for them.

In the current and final year of the project, plants were re-potted and allowed to 'grow-on' at the finished plant nursery. At the relevant date of sale, for each of the species, the plants were graded individually by staff of HN, Romsey. The grading procedure used at HN, Romsey also did not involve any physical measurements or quantitative analyses of the finished plants. Plants were assessed visually and subjectively and then allocated into either of three categories: saleable now, saleable later (potentially) and never saleable.

The quantitative biological data were analysed using the GenStat statistical package (GenStat 9th edition, 2007).

***Berberis thunbergii* 'Harlequin'**. *Year 1 & 2 summary*. Cuttings were prepared originally from either field- or container- grown stock plants and these were of three perceived qualities, 'best', 'standard' or 'poor'. Data collected during the first year of the project, showed that there were clear statistical differences between the different types of cutting and the field-grown cuttings, for instance, produced many more shoots than the container-grown cuttings shortly after planting. Surviving plants of the six cutting types were re-potted into 9 cm diameter liner pots, which were transferred to a poly tunnel situated on the NPN, Pulborough. Plants were positioned in the middle of the *B. thunbergii* 'Harlequin' crop and they received the standard crop management and pruning practices.

Measurements were also carried out on a sub-sample of *B. thunbergii* 'Harlequin' liners selected from the crop at HN, Romsey. Liners selected on appearance as 'best' had significantly more apices and were significantly taller than those selected as 'standard'. The widths of the original cutting material were also significantly greater for the liners that had been selected as 'best', compared to those selected as 'standard'.

Measurements were taken from the liners at NPN, Pulborough on 12/07/06 and on 5/12/06. On both occasions the clear differences in the numbers of apices and basal stem diameters between the groups was still apparent. They were then graded into First and Second quality plants on 23/01/07 by a member of NPN staff. As a result of this process, almost all the variation in the crop was retained.

A sub-sample of 32 First and 40 Second grade plants was transferred to HN, Romsey and re-potted into 3 litre pots on 27/02/07. The results of this experiment are presented below.

Measurements were also taken from the mature *B. thunbergii* 'Harlequin' plants at HN, Romsey at the end of the season on 28/11/06. These data suggested strongly that although the poorest category plants of this variety do show some evidence of 'catching up' with the other categories, at least for the stem diameter trait, the effect is not great enough to eliminate the clear differences still apparent, for instance in the numbers of apices, between the different categories of plants within the summer growing season.

***Camellia williamsii* 'Donation'**. *Year 1 & 2 summary*. Plants were grown from two types of cutting: those with two internodal lengths or those from stem tips. Forty-two cuttings of each type were prepared and planted into 84-cell trays. In Year 2, the stem diameter, plant height and the number of apices of all surviving plants was recorded on 18/09/06. The two types of cutting produced liner plants that were clearly different in their number of apices, height and stem diameter.

***Choisya* 'Aztec Pearl'**. *Year 1 & 2 summary*. The cutting types used were 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. Due to the high mortality evident in the first planting, another trial was set up following the same design. In Year 2, the stem diameter, plant height, number of apices and the number of breaks in the lowest five cm of the stem for all surviving plants was recorded on 06/03/07, prior to grading into Firsts and Seconds by staff at NPN, Sidlesham. Apart from plant height, the statistics for the other measurements were significantly different, showing that cutting type still had a major effect on liner dimensions more than 1.5 years after planting and at the first expected time of sale. In addition, the developmental structure or 'plant architecture' produced by liners from the different cutting types was clearly different and liners originating from each cutting type could be recognised easily without reference to the liner-pot label.

After grading by NPN staff, and due to the relatively high percentage of plants from each of the three types that were classified as Firsts, there was no discernable association between plant type and grading category.

A subset consisting of Firsts and Seconds from each cutting category, were then transferred to HN, Romsey.

***Choisya ternata* 'Sundance'**. *Year 1 & 2 summary*. Cuttings were taken 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. In Year 2, the stem diameter, plant

height, number of apices and the number of breaks in the lowest five cm of the stem for all surviving plants was recorded on 04/03/07, prior to grading into Firsts and Seconds by staff at NPN, Sidlesham. There were still significant physical differences between the liners originating from the different cutting types. After grading, however, there was no discernable association between plant type and grading category, because of the high percentage of plants from each of the four types that were classified as Firsts.

A subset consisting of Firsts and Seconds from each cutting category were transferred to HN, Romsey and the results are presented in the results and discussion section.

***Cistus* 'Silver Pink'**. *Year 1 & 2 summary*. 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 each 84-cell tray. Analysis of the physical dimensions of the different cutting types showed that those that are perceived to be the 'best' had the highest volumes and cuttings from 2-yr-old plants had greater volumes than those from 1-yr-old plants. In Year 2, the performance of each cutting continued to be followed and data collected at periodic intervals. Plants were measured on 28/06/06, prior to grading into Firsts and Seconds by staff at NPN, Sidlesham, on 12/07/06. A subset, consisting of Firsts and Seconds from each cutting category were then transferred to Glovers Stourbank Nursery, Wimbourne, Dorset, where they were re-potted into three litre containers. At the time of sale, the effects of cutting type were still apparent in the different groups. However, the majority plants from all categories were classed as Firsts and so no clear relationship between liner grade and either the number of apices present or the original cutting stem diameter could be discerned.

Due to a mix-up with the experimental plants, the experiment was re-started and sub-sets of First and Second class liners were selected and the experiment continued to see whether or not differences at the beginning of the finished-plant stage were still apparent at the point of expected sale. Thirty-three (82.5%) of the liners chosen as Firsts were considered ready for sale on 22/04/07, whereas only ten (25%) of the Seconds had reached an acceptable standard. Sales of this variety occur mainly in March/April/May and due to their value, the plants were released for sale and so no further data could be collected from them.

***Photinia x fraseri* 'Red Robin'**. *Year 1 & 2 summary*. 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 each 104-cell tray. In Year 2, the stem diameter, plant height, number of apices and the number of breaks in the lowest 5cm of the stem for all surviving plants was recorded on 20/04/07, prior to grading into Firsts and Seconds by staff at NPN, Sidlesham. Although the liners generated from the different cutting types were easily identifiable, this was not reflected in the grading data. Liner specification provided by HN was '15 cm tall with a minimum of four breaks within 3 cm of the base'. There was no clear differentiation between the First and Second categories, however, in terms of the number of breaks in the lower part of the stem.

A subset consisting of Firsts and Seconds from each cutting category, were transferred to HN, Romsey and the results appear in the results and discussion section.

***Pieris* 'Forest flame'**. *Year 1 & 2 summary*. 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. By the end of Year 2, very few plants remained alive and so meaningful statistical analysis was not possible.

***Pittosporum tenuifolium* 'Garnettii'**. *Years 1 & 2 summary*. Cuttings were prepared either from 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. In Year 2, survival of this variety was very low and on 30/10/06 there were only 48 remaining plants. An additional problem arose in that some of the pot labels were damaged, probably by slugs, and so these were re-numbered. The few remaining experimental plants then disappeared and could not be found.

***Potentilla* 'Chelsea Star'**. *Years 1 & 2 summary*. Cuttings of this species were planted before the start of the experimental work and so measurements of stem width and plant height were taken from plants growing in two 84-cell trays. The performance of each plant was followed and data collected thereafter at periodic intervals, usually prior to pruning. In Year 2, the number of stems and plant height was recorded on 03/07/06 for surviving plants. Cuttings with a greater stem width resulted in bushier plants of higher

quality. Plants were measured again, prior to grading into Firsts and Seconds by staff at NPN, Sidlesham. A sub-set of First and Second class liners were transferred to HN, Romsey, to continue the experiment.

***Prunus incisa* 'Kojo-no-mai'**. *Years 1 & 2 summary*. 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. In Year 2, the stem diameter, plant height and number of apices was recorded on 12/12/06 and on 02/04/07, prior to grading into Firsts and Seconds by staff at NPN, Sidlesham. Liners from the different cutting types were still clearly different, but all but four plants were categorized as Firsts in the grading process. A subset consisting of Firsts and Seconds from each cutting category were transferred to HN, Romsey, and the continuation data appear in the results and discussion section.

***Rhamnus alaternus* 'Argenteovariegata'**. *Years 1 & 2 summary*. 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. In Year 2, survival of this variety continued to be poor. The number of shoots and their length was measured on 03/07/06, but due to low numbers surviving, no significant differences between groups was apparent. The surviving plants were measured again and graded into Firsts and Seconds by staff at NPN, Sidlesham. Plants were transferred to HN, Romsey and the data collected from the continuation of the experiment appear in the results and discussion section.

***Viburnum tinus* 'Eve Price'**. *Years 1 & 2 summary*. 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. In Year 2, the stem diameter, plant height, number of apices and the number of breaks in the lowest five cm of the stem for all surviving plants was recorded on 03/04/07, prior to grading into Firsts and Seconds by staff at NPN, Sidlesham. Although there were clear physical differences between the liners grown from the different cutting types, after grading there was no clear separation into First and Second category plants, based on their height, number of breaks or number of breaks in the bottom 5 cm of the stem. A subset

consisting of Firsts and Seconds from each cutting category were transferred to HN, Romsey and the data from the continuation of the experiment appear in the results and discussion section.

***Weigela* 'Kosteriana Variegata'**. *Years 1 & 2 summary*. 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. In Year 2, the plant height, number of apices and the number of breaks from soil level was recorded on 20/04/07, prior to grading into Firsts and Seconds by staff at NPN, Sidlesham. Of 133 (53%) surviving plants, 14 (10.5%) were classified as Seconds. As far as possible, due to the low number of plants in the Seconds category, subsets of Firsts and Seconds were transferred to Hillier Nursery, Romsey. The continuation data appear in the results and discussion section below.

Results and Discussion

***Berberis thunbergii* 'Harlequin'.** The mean numbers of apices for selected First and Second class liners were different and were 10.7 $\pm$ (SEM) 0.32 and 5.78 $\pm$ 0.32, respectively (t-test, $P < 0.001$). The difference between the mean numbers of apices in the two groups was still apparent when the crop was due for sale on 26/02/08. The mean numbers of apices for finished plants grown from First and Second class liners were 35.77 $\pm$ (SEM) 1.27 and 24.97 $\pm$ 1.09, respectively (t-test, $P < 0.001$). As reported in Year 2, for a different group of experimental plants, the quantitative differences between the two groups of plants were maintained in the period from the liners' arrival at the finished-plant nursery and their sale date.

Staff at HN, Romsey graded the finished plants and, although clear quantitative differences were still present between the two groups and between plants grown from different cutting types, i.e. there was considerable variation still present, they were all categorized as saleable (Figure 1).

Figure 1. An example of the variation in bushiness present in experimental *Berberis thunbergii* 'Harlequin' finished plants. The LHS and RHS plants were grown from a 'Field-Best' and 'Container-Poor' cutting types, respectively. At the liner grading, the LHS plant was graded a First and the RHS plant a Second. They were then both classified as saleable (on 26/02/08), for the 2008 sale period, at the finished-plant producer's nursery.

Historical data from HN, Romsey on *Berberis thunbergii* 'Harlequin' at the end of the season show relatively little waste due to unsold plants. A possible explanation for this is that greater variation in plant batches may be acceptable for this species as this species is classed as a two-year crop by HN, Romsey.

***Camellia williamsii* 'Donation'**. This species was not sent to the finished-plant nursery, because it is not grown by HN, Romsey and so there was no HN liner specification. The experimental plants were graded by NPN staff and only 18 out of 215 plants (8.4%) were classified as Seconds. As the group of Firsts contained large numbers of both tip and two-internode cuttings, it was not possible to relate the quantitative differences between the plants grown from the two cutting types to liner grade. No finished plant data were collected on these plants.

Choisya 'Aztec Pearl'. In order to determine whether or not the effects of cutting type were still apparent in the finished plants, similar numbers of representatives from each cutting type were selected (Table 1) for transfer to HN, Romsey. Some categories, such

as the standard two node Seconds, had very few plants and so randomization and allotting equal numbers to each group was impossible. Thirty-six Firsts and 36 Seconds were transferred, after which they were repotted and managed by HN, Romsey, staff according to the standard nursery practices.

Table 1. The composition of the groups of experimental transfer *Choisya* 'Aztec Pearl' plants, divided by cutting type and liner grading quality, which were transferred to HN, Romsey.

Cutting type	Number of liners	
	Firsts	Seconds
Standard two node	12	4
Tip	12	28
One node, two leaves	12	4

In the period that the experimental plants were growing at the finished plant nursery, the 'architecture' of the plants did not change noticeably and so the physical structure of the cutting still had a major impact on the 'quality' of the finished plants. There was still a highly significant relationship, for example, between the number of breaks below 5 cm that a plant arrived with and the number at the point of sale ($c = 1.878 \pm$ (SE) 0.499, $P < 0.001$; $b = 1.134 \pm 0.165$, $P < 0.001$).

There was also a good relationship between the number of apices that a liner had when it arrived at HN, Romsey and the number when the appropriate sale date was reached ($c = 10.01 \pm$ (SE) 1.30, $P < 0.01$; $b = 0.602 \pm 0.185$, $P < 0.002$).

On 26/02/08, staff at HN, Romsey graded the plants into three categories: those that were saleable immediately; those that were considered to have the potential to become saleable at a later date; and those that would never become saleable (Figure 2). Analysis of the data for this species was problematic due to the low survival of plants grown from some of the cutting types.

Figure 2. The variation in experimental finished *Choisya* 'Aztec Pearl' plants, which were grown from a single-node cutting with two leaves (LHS), a standard two-node cutting (Middle) and a tip cutting (RHS) and graded as First, First and Second class liners, respectively. The 'Y'-shaped architecture of the lower stem in the LHS plant is still clearly present. These plants were classified as saleable (LHS), saleable later (Middle) and never saleable (RHS) for the 2008 sale period at the finished-plant producer's nursery.

All three of the cutting types produced approximately the same number of saleable plants. This result can be explained by the HN liner grading specification, which was '10 cm tall, 5 breaks', which did not specify where the breaks must appear. Individual plants of this species, which had very different 'architectures', were apparently acceptable for sale when present in the same batch, i.e. uniformity was not apparent in the batch of saleable plants.

Finished plants grown from tip cuttings produced the highest number of saleable plants and of the 'saleable later' category. They also produced the highest number of plants that would never become saleable. One reason for this is that tip cuttings had a very high relative survival during the liner stage and so were over-represented in the transfer plants. Another possible reason is that tip cuttings require pruning at the right time to avoid them developing a 'tree-like' architecture. This may have happened to large numbers of tip cuttings and so caused a low number of breaks per plant in this category (Table 2). Tip cuttings, when pruned at the right times, however, probably have the greatest potential to produce bushy plants. Twenty-nine out of 68 plants (42.6%) would never be saleable. When combined with the low survival of some cutting types, these

data suggest that this species would be unprofitable to produce unless cutting types are used selectively and managed appropriately.

Table 2. The composition of the groups of experimental transfer *Choisya* 'Aztec Pearl' plants, divided by cutting type and liner grading quality, which were transferred to HN, Romsey.

Cutting type	**Number of finished plants**		
	Saleable	**Saleable later**	**Never saleable**
Standard two node	3	5	8
Tip	7	15	15
One node, two leaves	5	4	6

A greater number of plants that were classified as Firsts, than those classified as Seconds at NP, Sidlesham became saleable from the finished-plant nursery at the due date of sale. Also, a higher number of Firsts than Seconds were considered to have the potential to become saleable later. The ratios were reversed in the 'Never saleable' category where more Seconds than Firsts were rejected. These data indicate that the liner grading process did differentiate plants to some extent and provided a general guide to their future potential for sale (Table 3).

Table 3. The composition of the groups of experimental transfer *Choisya* 'Aztec Pearl' plants divided by liner grade and suitability for sale as finished plants from HN, Romsey.

Grading quality	**Number of finished plants**		
	Saleable	**Saleable later**	**Never saleable**
First	10	14	11
Second	5	10	18

Almost half of the plants classified as Seconds ended up being either Saleable or Saleable later and this type of result may have given rise to the idea that poorer plants can 'catch up'. The quantitative data do not support the 'catch-up' hypothesis, however, and so a more probable explanation for the lack of a predictive relationship is the subjectivity of the plant-grading processes.

Strong and predictive relationships were present in the quantitative data collected from plants when they arrived and left the finished plant nursery and so, if a more quantitative methodology was applied to the grading processes, it would almost certainly produce a much better 'fit' between the grading quality of liners and the quality of the finished plants. This is a species where the amount of waste can sometimes be very high (up to 66%) and so improved accuracy in grading could reduce fluctuations in profitability.

***Choisya ternata* 'Sundance'**. In order to determine whether or not the effects of cutting type were still apparent in the finished plants, similar numbers of representatives from each cutting type were selected (Table 4) for transfer to HN, Romsey (some categories had very few plants and so randomization and allotting equal numbers to each group was not possible). Thirty-five Firsts and 36 Seconds were transferred, after which they were repotted and managed by HN, Romsey staff according to their standard nursery practices.

Table 4. The composition of the groups of experimental transfer *Choisya ternata* 'Sundance' plants, split by cutting type and liner grading quality, which were transferred to HN, Romsey and grown on.

Cutting type	Number of liners	
	Firsts	Seconds
Planted, 2 leaf	9	12
Planted, 4 leaf	9	11
Potted, 2 leaf	9	4
Potted, 4 leaf	8	9

In the period that the experimental plants were growing at the finished plant nursery, the 'architecture of the plants did not change noticeably and so physical structure of the cutting still had a major impact on the 'quality' of the plants. There was still a highly significant relationship, for example, between the number of breaks below 5 cm that a plant arrived with and the number at the point of sale ($c = 3.744 \pm$ (SE) 0.667, $P < 0.01$; $b = 0.741 \pm 0.203$, $P < 0.001$).

There was also a good relationship between the number of apices that a liner had when it arrived at HN, Romsey and the number when the appropriate sale date was reached (c = 7.64 ± (SE) 1.31, $P < 0.001$; b = 0.509 ± 0.175, $P < 0.005$).

On 26/02/08, staff at HN, Romsey graded the plants into three categories: those that were saleable immediately; those that were considered to have the potential to become saleable at a later date; and those that would never become saleable (Figure 3). All four of the cutting types produced approximately the same number of saleable plants. This result can be explained by the HN liner grading specification, which was "10 cm tall, 5 breaks" and did not specify where the breaks must appear. Plants with quite different 'architecture' were acceptable for sale from the finished-plant nursery. Finished plants grown from 'planted' cuttings produced the highest numbers that would never become saleable, although this conclusion cannot be tested statistically due to the small numbers of plants present in each category (Table 5).

Figure 3. The variation in experimental finished *Choisya ternata* 'Sundance' plants, which were grown from a planted-2-leaf cutting (LHS), a potted-4-leaf cutting (Middle) and a planted-4-leaf cutting (RHS), which were graded as First, Second and Second class liners, respectively. They were then classified as saleable (LHS), saleable later (Middle) and never saleable (RHS) for the 2008 sale period at the finished-plant producer's nursery.

Table 5. The composition of the groups of experimental transfer *Choisya ternata* 'Sundance' plants, divided by cutting type and suitability for sale from the finished plant nursery.

Cutting type	Number of finished plants		
	Saleable	Saleable later	Never saleable
Planted, 2 leaf	14	0	5
Planted, 4 leaf	12	1	7
Potted, 2 leaf	8	2	3
Potted, 4 leaf	11	2	2

A greater number of plants that were classified as Firsts than those classified as Seconds at NP, Sidlesham became saleable at the due date of sale. Also, more Seconds than Firsts ended up being 'never saleable', indicating that the liner grading process did differentiate plants to some extent and provide some indication as to their future salability (Table 6).

Table 6. The composition of the groups of experimental transfer *Choisya ternata* 'Sundance' plants divided by liner grade and suitability for sale as finished plants from HN, Romsey.

Grading quality	Number of finished plants		
	Saleable	Saleable later	Never saleable
First	28	1	5
Second	17	4	12

Although strong relationships were present in the quantitative data collected from plants when they arrived and left the finished plant nursery, the most probable reason for the lack of any clear relationship between the liner grade and the subsequent quality of the same finished plants is the subjectivity of the plant-grading methods used at both nurseries. This is a species where losses have sometimes been high (approximately 25%) and so improved grading accuracy would have a big effect on profitability.

***Cistus* 'Silver Pink'**. This experiment ended in Year 2 and the conclusions were that cutting type and quality had a clear effect on the liners, which carried through to the finished plants.

***Photinia x fraseri* 'Red Robin'**. In order to determine whether or not the effects of cutting type could still be seen in the finished plants, as far as was possible, similar numbers of representatives from each cutting type were selected (Table 7) for transfer to HN, Romsey. Thirty-six Firsts and 36 Seconds were transferred, after which they were repotted and managed by HN, Romsey staff according to their standard nursery practices.

Table 7. The composition of the groups of experimental transfer *Photinia x fraseri* 'Red Robin' plants, split by cutting type and liner grading quality, which were transferred to HN, Romsey and grown on.

Cutting type	Number of liners	
	Firsts	Seconds
Tip	12	9
Middle	12	15
Bottom	12	12

At the beginning of the period on the finished plant nursery, evidence that the physical structure of the cutting still had a major impact on the 'quality' of the plants was apparent. There was still a highly significant relationship, for example, between the length of a cutting and the number of stem breaks in the lowest 5 cm of the stem, i.e. shorter cuttings produced liners and plants at the beginning of their period at the finished-plant nursery with more breaks in the bottom 5 cm of the stem (c = 5.309 + (SE) 0.886, $P < 0.01$; b = -0.0401 + 0.0106, $P < 0.001$).

There was also a good correlation between the number of apices that a liner had when it arrived at HN, Romsey and the number when the appropriate sale date was reached. Figure 4 shows the clear relationship between the number of apices that the experimental plants had at the beginning and end of the experimental period at Romsey. On the 26/02/08, HN staff graded the plants into three categories: those that were saleable immediately; those that were considered to have the potential to become saleable at a later date; and those that would never become saleable.

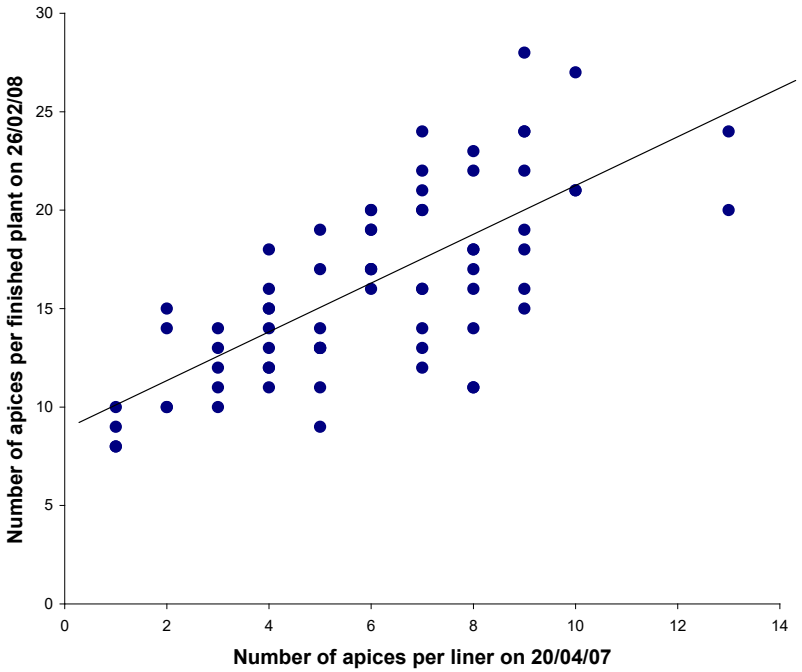

Figure 4. The relationship between the numbers of apices per *Photinia x fraseri* 'Red Robin' plant during the period that they were grown at HN, Romsey.

Even at the end of their period as finished plants, the effect of cutting type on the physical characteristics of the finished plants were still apparent. Plants originating from tip and middle-stem cuttings produced the 'bushiest' finished plants with the greatest number of breaks close to ground level (Table 8) and Figure 5.

Table 8. The effect of cutting type on the physical characteristics of the finished *Photinia x fraseri* 'Red Robin' plants.

Cutting type	Physical characteristics of the finished plants			
	Mean breaks below 7 cm	± SE	Mean number of apices per plant	± SE
Tip	4.267	± 0.4793	18.43	± 0.8863
Middle	4.625	± 0.7296	16.62	± 0.7465
Bottom	3.560	± 0.4902	13.00	± 0.7234

Figure 5. The marked variation present in experimental Photinia x fraseri 'Red Robin' finished plants. These were grown from a stem tip (LHS), a stem middle (Centre) and a stem bottom (RHS) cutting type and graded as a liner First, Second and Second, respectively, at the end of the liner stage. They were then classified as saleable, saleable later and non-saleable (waste) respectively, for the 2008 sale period at the finished-plant producer's nursery.

No clear relationship could be found, however, between the type of cutting that the plant originated from and the subjective assessment of whether or not it was saleable now, later or never. Twenty-one out of 71 remaining plants (35.2%) were effectively classed as 'never saleable', i.e. waste (Table 9).

Table 9. The grading results of the finished *Photinia x fraseri* 'Red Robin' plants with respect to the cutting type that they produced from.

Cutting type	Number of finished plants		
	Saleable	Saleable later	Never saleable
Tip	4	8	9
Middle	15	3	9
Bottom	11	5	7

With respect to the grading classification of the liners when they arrived at HN, Romsey, there was a slight bias towards the Firsts being saleable and Seconds being never saleable. Eight out of 36 (22.2%) Firsts, were categorised as never saleable and 17 out of 36 Seconds were also classed never saleable. It is also of note that 52.8% of plants

classified as liner Seconds became potentially saleable as finished plants. Approximately equal numbers of Firsts and Seconds required more time to become saleable (Table 10).

Table 10. The division of experimental plants into liner grades and the final grades of the same finished *Photinia x fraseri* 'Red Robin' plants.

Grading quality	Number of finished plants		
	Saleable	Saleable later	Never saleable
First	19	9	8
Second	11	7	17

The most probable explanation for the lack of any relationship between the liner grade at NPN, Sidlesham and the subsequent 'saleability' of plants at HN, Romsey, is the inaccuracies and subjectivity of the plant-grading procedures. Historical data on waste due to non-uniformity show that up to 35% of plants can sometimes remain at the end of the season, which is similar to the figure of 35.2% obtained from the experimental plants. This situation and profitability could be improved by implementing a more quantitative approach to the liner grading process.

***Potentilla* 'Chelsea Star'**. Seventeen First and Second category plants were transferred to HN, Romsey and repotted into finished-plant pots on 28/06/07. No difference was apparent in the number of apices present on First and Second grade plants in the two groups, which had means of 26.18 $\pm$ (SEM) 1.37 and 24.06 $\pm$ 1.5 (t-test, $P = 0.31$).

At the grading date at the finished-plant nursery (12/02/08) there were still no quantitative differences between the groups of plants, e.g. mean number of stems at the base of the plants were 15.88 $\pm$ (SEM) 1.57 and 19.53 $\pm$ 1.5 (t-test, $P = 0.106$), for Firsts and Seconds respectively. Plants were then classified as saleable, saleable later or never saleable by HN, Romsey staff. No relationship was evident between the liner quality and the finished-plant grades (Table 11).

Table 11. The relationship between liner grade and the final grade of the same *Potentilla* 'Chelsea Star' finished plants.

Grading quality	Number of finished plants		
	Saleable	Saleable later	Never saleable
First	11	6	0
Second	11	6	0

This species of plant is traditionally seen as not presenting a non-uniformity problem and most plants grown at the finished-plant nursery eventually get sold. However, there were clear differences visible in the experimental plants (Figure 6) and six out of 17 First grade liners were not yet saleable at the due date. This would increase the costs of producing this species for the finished-plant producer.

Figure 6. Examples of the variation present in experimental *Potentilla* 'Chelsea Star' finished plants. They were classified as a First (LHS) and a Second (RHS) as liners and as saleable (LHS) and saleable later (RHS) respectively, for the 2008 sale period at the finished-plant producer's nursery. The non-symmetrical shape of the plant on the RHS was present as a liner and is still clearly present in the finished plant.

The most probable explanation for the lack of any relationship between the liner grade at NPN, Sidlesham and the subsequent 'saleability' of plants at HN, Romsey is the subjectivity of the plant-grading procedures. Waste due to non-uniformity in this species is normally very low (approximately 0.5%) but, even for this species, the quality of the

finished-plant crop could be improved by a more objective and quantitative approach to grading.

***Prunus incisa* 'Kojo-no-mai'.** In the grading process, all but four liners were classified as Firsts. In order to still be able to continue the experiment to some degree, 14 liners that had been called Firsts, but had the HN specifications of Seconds, were re-assigned correctly as Seconds. As far as was possible, similar numbers of representatives from each cutting type were then selected (Table 12) for transfer to HN, Romsey. Thirty-six Firsts and 18 Seconds were transferred, after which they were repotted and managed by HN, Romsey staff according to their standard nursery practices.

Table 12. The composition of the groups of experimental transfer *Prunus incisa* 'Kojo-no-mai' plants, split by cutting type and liner grading quality, which were transferred to HN, Romsey and grown on.

Cutting type	Number of liners	
	Firsts	Seconds
Lower stem	13	1
Main stem	11	8
Side shoots	12	9

While on the HN, Romsey site certain important characteristics of the plants did not alter much, eg. there was a significant relationship between the number of breaks a liner had in the lowest 5 cm of the stem and the number as a finished plant (c = 5.57 + (SE) 1.32, $P < 0.01$; b = 0.85 + 0.26, $P < 0.002$).

On the 26/02/08, HN staff graded the plants into two categories: those that were saleable immediately and those that would miss the sale period and never become saleable. For this species, the period of sale coincided with the time of flowering.

No clear relationship could be found, however, between the type of cutting that the plant originated from and the subjective assessment of whether or not it was saleable now or

never. Eleven out of 54 plants (20.4%) were effectively classed as 'never saleable', i.e. waste (Table 13).

Table 13. The grading results of the finished *Prunus incisa* 'Kojo-no-mai' plants with respect to the cutting type that they were grown from.

Cutting type	Number of finished plants	
	Saleable	Never saleable
Lower stem	10	4
Main stem	16	3
Side shoots	17	4

With respect to the grading classification of the liners when they arrived at HN, Romsey, there was a strong bias towards the Firsts being saleable and, in this case, many of the Seconds were also saleable. It may be that for this species the presence or absence of flowers at the right time is an over-riding factor in whether or not it is saleable. This characteristic could not be included in the specification and measurements at the liner-grading stage (Table 14, Figure 7).

Table 14. The relationship between liner grade and the final grade of the same finished *Prunus incisa* 'Kojo-no-mai' plants.

Grading quality	Number of finished plants	
	Saleable	Never saleable
First	29	7
Second	14	4

Figure 7. Examples of the variation present in experimental *Prunus incisa* 'Kojo-no-mai' finished plants. These were grown from a side-shoot cutting (LHS) and a main-stem tip cutting (RHS) and graded as a liner First (LHS) and Second (RHS) respectively, at the end of the liner stage. They were then classified as saleable (LHS) and non-saleable (RHS) respectively, for the 2008 sale period at the finished-plant producer's nursery.

As mentioned at the beginning of this section on *Prunus incisa* 'Kojo-no-mai', the liner grading process was very subjective and a more quantitative approach would have greatly improved the fit between the liner and finished-plant grades. The historical losses due to non-uniformity at the finished plant nursery for this species can be as high as 13%. This figure could be reduced by greater objectivity and quantification in the grading process.

***Rhamnus alaternus* 'Argenteovariegata'**. Survival of this species was poor and so 18 plants each of those categorized as Firsts and Seconds were transferred to HN, Romsey. The Firsts mainly consisted of plants that had been grown from heel cuttings, whereas Seconds were mainly from the lower stem cuttings (Table 15). There was considerable variation still present in the experimental plants (Figure 8).

Table 15. The composition of the groups of experimental transfer *Rhamnus alaternus* 'Argenteovariegata' plants, split by cutting type and liner grading quality, which were transferred to HN, Romsey, and grown on.

Cutting type	Number of liners	
	Firsts	Seconds
Heel	16	4
Stem lower	2	9
Stem upper	0	5

Plants grown from heels survived well and produced a high proportion of saleable finished plants (Table 16).

Table 16. The grading results of the finished *Rhamnus alaternus* 'Argenteovariegata' plants with respect to the cutting type that they were grown from.

Cutting type	Number of finished plants		
	Saleable	Saleable later	Never saleable
Heel	15	2	1
Stem lower	7	2	1
Stem upper	3	0	2

With respect to the grading classification of the liners when they arrived at HN, Romsey, there was a slight bias towards the Firsts being saleable more saleable than Seconds. Equal numbers of Firsts and Seconds required more time to become saleable (Table 17).

Table 17. The relationship between liner grade and the final grade of the same finished *Rhamnus alaternus* 'Argenteovariegata' plants.

Grading quality	Number of finished plants		
	Saleable	Saleable later	Never saleable
First	14	2	0
Second	11	2	4

Figure 8. The marked variation present in experimental *Rhamnus alaternus* 'Argenteovariegata' finished plants. These were all grown from heel side-shoots, which show clearly the considerable variation present within cutting type for this species. They were graded as a First (LHS), First (Centre) and Second (RHS), respectively, at the end of the liner stage. They were then classified as saleable, saleable later and non-saleable (waste) respectively, for the 2008 sale period at the finished-plant producer's nursery.

As is the case for the other experimental species, the most probable explanation for the lack of any reliable relationship between the liner grade at NPN, Sidlesham and the subsequent 'saleability' of plants at HN, Romsey, is the subjectivity of the plant-grading procedures.

The historical levels of waste due to non-uniformity for this species at the finished plant stage can reach 18%. These losses could be reduced by greater objectivity and quantification of the grading processes.

***Viburnum tinus* 'Eve Price'**. Survival of this species was relatively good and so 36 plants each of those categorized as Firsts and Seconds were transferred to HN, Romsey. Effects of cutting type were still clearly visible in the architecture of the liners and this was reflected to some extent in the quality grading into Firsts and Seconds. The Firsts mainly consisted of plants that had been grown from the two internode cuttings (Top and Hard) heel cuttings, whereas Seconds could be from any cutting type, but the largest number came from the Singles cutting type (Table 18).

Table 18. The composition of the groups of experimental transfer *Viburnum tinus* 'Eve Price' plants, split by cutting type and liner grading quality, which were transferred to HN, Romsey and grown on.

Cutting t	Number of liners	
	Firsts	**Seconds**
Top (2 internodes)	15	9
Hard (2 internodes)	17	11
Singles (1 internode)	3	15

Plants of all cutting types produced approximately equal numbers of saleable plants by the due date of sale (Table 19).

Table 19. The grading results of the finished *Viburnum tinus* 'Eve Price' plants with respect to the cutting type that they were grown from.

Cutting type	**Number of finished plants**		
	Saleable	**Saleable later**	**Never saleable**
Top (2 internodes)	12	6	6
Hard (2 internodes)	16	7	4
Singles (1 internode)	10	4	2

First and Second class liners produced approximately equal numbers of the three categories of plant at the due sale date (Table 20, Figure 9).

Table 20. The relationship between liner grade and the final grade of the same finished *Viburnum tinus* 'Eve Price' plants.

Grading quality	Number of finished plants		
	Saleable	Saleable later	Never saleable
First	21	7	7
Second	18	10	5

Figure 9. Examples of the variation in experimental finished *Viburnum tinus* 'Eve Price' plants, which were grown from a hard-2-internode (LHS), a single-1-internode (Middle) and a single-1-internode (RHS) cutting type and graded as First, Second and Second class liners, respectively. The 'Y'-shaped architecture of the lower stem in the Middle and RHS plants were still present and is clearly visible in the RHS plant. These plants were then classified as saleable, saleable later and never saleable for the 2008 sale period at the finished-plant producer's nursery.

As for the other experimental species, the most probable explanation for the lack of any reliable relationship between the liner grade at NPN, Sidlesham and the subsequent 'saleability' of plants at HN, Romsey is the subjectivity of the plant-grading procedures i.e. the similar numbers of Firsts and Seconds in each sale category is what one would expect if the liner quality categorization was being assigned randomly.

The waste due to non-uniformity for this species is historically low and represents approximately 2% of production. This may be because the criterion for being in flower may have over-riding importance in the finished-plant grading process.

***Weigela* 'Kosteriana Variegata'**. When plants were graded on 20/04/07 at NPN, Sidlesham, there were 133 (53%) surviving plants. Of these, only 14 (10.5%) were classified as Seconds. Some of the Firsts did not meet the HN specification for this species which was, "5-10 cm tall with a minimum of four breaks from soil level". In order to continue the experiment, 13 Firsts that had been wrongly assigned were re-classified as Seconds and so 27 liner of each category were able to be transferred to HN, Romsey.

With respect to the grading classification of the liners, there was a slight bias towards Seconds being saleable and Firsts being never saleable. It was of note that the biggest category of plants for both Firsts and Seconds was the 'Saleable later' group (Table 21, Figure 10).

Table 21. The relationship between liner grade and the final grade of the same finished *Weigela* 'Kosteriana Variegata' plants.

Grading quality	Number of finished plants		
	Saleable	Saleable later	Never saleable
First	7	16	4
Second	9	15	3

Figure 10. Examples of the variation in experimental finished *Weigela* 'Kosteriana Variegata' plants, which were graded as First (LHS), First (Middle) and Second (RHS) class liners, respectively. They were then classified as saleable, saleable later and never saleable for the 2008 sale period at the finished-plant producer's nursery. The

situation for this species was complicated because many of the plants (such as those above) suffered rabbit damage.

As for the other experimental species, the most probable explanation for the lack of any reliable relationship between the liner grade at NPN, Sidlesham and the subsequent 'saleability' of plants at HN, Romsey is the subjectivity of the plant-grading procedures.

The waste due to non-uniformity for this species is historically low and approximately 3% of production. This may be due to the ability of this species to produce new ground shoots and so most plants can eventually be sold.

The 'tools' developed from the modeling activities that were undertaken to understand the non-uniformity problem

Model and tool description

The model, which is described in the previous report (2007), combines biological data on the survival and uniformity of plants with financial data on the costs and constraints of production to work out the Net Profit or Loss incurred when producing a particular nursery stock species. The model generates sale prices for each species, based on production costs, has a profit maximisation facility and provides information on the financial cost of the waste.

The experimental data and modeling analyses show that it is most cost-effective to tackle the non-uniformity problem at the beginning of the plant-production process. Once the liners are due to be sold to the finished plant producer, the only realistic option available for generating increased uniformity in the crop is to increase the objectivity and to use accurate metrics in the grading process. The modeling analyses shows that the rejection of a significant proportion of the liner crop at this stage, on top of the other production losses however, could easily make the production of the most difficult species uneconomic. The 'tools' that have been built from the model therefore are targeted at providing the liner producer with a way of costing production and optimizing profits in relation to non-uniformity in the crop.

The tools are available in the Excel file ProGro2008.xls

Conclusions

- The clear differences in the size and physical structure of plants grown from different cutting types continued to be clearly apparent right to the end of the plant production process.
- Data collected during the development of the plants in liner pots showed that cutting type and structure could also exert an obvious effect on the subsequent structure or 'architecture' of the plants. This has major implications for achieving high quality liners that, characteristically, are bushy, vigorous and of a pre-determined uniform height.
- Another way of introducing greater uniformity into batches of plants at points in the production process is to grade plants objectively. For all the species examined at the liner stage however, it was not possible to see a clear relationship between the physical measurements and the resulting categories of First (saleable) and Second (not saleable) plants.

- As a result of the liner grading procedure, categories that were clearly different were mixed together with the result that there was an increase in the variability or non-uniformity of the new category, which was called Firsts.
- Strong effects of cutting type were still clearly apparent in the finished plants and this potentially provides part of the solution to the non-uniformity problem.
- There were also very strong relationships between the quality characteristics of liners and those of the same finished plants, e.g. bushy liners produced bushy finished plants and non-bushy liners produce non-bushy finished plants.
- Due to the subjective way that grading at both nurseries was carried out however, no relationship could be found between liner and finished-plant assessments for any of the species, i.e. the liner grade was an extremely poor predictor of the 'saleability' of the finished plant.
- The research carried out this year therefore, underscores the need for greater accuracy in the grading process and the considerable financial importance to finished-plant nurseries of being able to purchase only batches of highly uniform liners.
- The profitability of a nursery is made up from the individual profits or losses incurred on the different component species sold. The Excel-based tools allow

the identification and focus on the least profitable species, to determine whether or not their profitability can be improved. They have the potential therefore, to have a big impact on overall nursery profitability.

Technology transfer

Active technology transfer activities are now appropriate with the release and dissemination of the modeling tools. If validation activities are carried out for the project's recommendations and modeling tools, then the resulting batches of plant and financial assessments could provide useful demonstrations for increasing technology transfer and uptake.

References

GenStat Release (2008) Lawes Agricultural Trust.

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