IDENTIFYING THE KEY FACTORS CONTROLLING HNS UNIFORMITY

R. S. Harrison-Murray & C. J. Atkinson

EAST MALLING RESEARCH

J.S. Fenlon

UNIVERSITY of WARWICK

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Project leaders	**Mr J.S. Fenlon (for Warwick HRI)** **Dr R.S. Harrison-Murray (for East Malling Research)**
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Key workers:	**Mrs W. Oakley, Mrs J. Taylor, Miss E. Reid**
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Project co-ordinator	**John Woodhead, Hilliers Nursery Ltd., Ampfield House, Romsey, Hants, SO51 9PA**
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The results and conclusions in this report are based on an investigation conducted over one year. The conditions under which the experiment was carried out and the results obtained have been reported with detail and 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.

CONTENTS

GROWER SUMMARY......6

Headline......6
Background and expected deliverables......6
Summary of the project and main conclusions......7
Uniformity & variability......7
Measures of variability......8
The limits to delivery......8
Main results from commercial nursery data collection......9
Some other importantstatistical ideas......9
The Pareto Lawy......9
The binomial distribution- how proportions work......9
Designed experiments - DIY Trials......10
Conclusions......12
Financial benefits......12
Action points for growers......13

SCIENCE SECTION......14

Introduction......14

Materials and Methods......15

Collaborating nurseries......15
Choice of crops......15
Choice of measured variables......16
Sampling and labelling......16
Statistical analysis......17
Outline of data collected......18

Results and Discussion......24

Escallonia rubra 'Crimson Spires' containers......24
Elaeagnus x *ebbingei* liners......30
Elaeagnus x *ebbingei* containers......32
Euonymus japonicus containers......33
Hypericum calycinum (cutting to liner stage)......35
Hebe albicans liners......37
Canopy area......39
Hebe albicans containers......39
Penstemon 'Port Wine' liners......41
Penstemon 'Port Wine' containers......42
Spiraea 'Arguta' cuttings / liners......44
Choisya 'Aztec Pearl'......45
Weigela florida 'Variegata' liners......46

Summary and conclusions......48

Future work......50

TECHNOLOGY TRANSFER......53

GLOSSARY : TERMS, ABBREVIATIONS AND PRODUCTS USED......54

TABLE 12 52

GROWER SUMMARY

Headlines

- Evidence from monitoring commercial crops, as part of a scoping study, suggests that most of the variability in the final size of plants is due to non-uniform environment, particularly irrigation. Little variability could be traced back to differences in the starting material.
- Growers aiming to satisfy large orders for multiples may have difficulties in meeting these orders using current stock levels simply because of the natural variability of the crop.

Background and expected deliverables

Lack of crop uniformity has been identified by growers and the HDC as a key issue threatening the profitability of the HNS industry. It creates severe wastage because a substantial proportion of crops fail to reach saleable specification and also adds greatly to labour costs.

Historically, scientific research into HNS has been directed at identifying treatments that improve the average performance of the crop, rather than limiting the variation between plants within the same treatment. Part of this report relates to the largely fruitless search for information on the uniformity problem both within the industry and the scientific literature: identification of stages of the growing process in which the opportunity for variability to occur was an important aim, as well as identifying those parts of the process where information was lacking. In anticipation of there being a limited amount of data on non-uniformity a major part of the report presents new data collected on commercial nurseries, which was designed specifically to measure changes in uniformity of HNS crops over the course of production.

At the outset, the expected deliverables were:

1. A report on the nature and size of the industry in the UK
2. A review of scientific and other literature for quantitative measures of the within-batch uniformity of HNS crops and the way that it changes over the course of the production process.

3. A ‘risk analysis’ of the above material together with the results of the study on commercial crops.
4. Presentation and discussion of findings to the grower community.

It was not expected that this short project could provide definitive answers to questions about the nature and sources of non-uniformity in HNS but rather that it would provide preliminary answers that would provide the foundation for further studies.

Summary of the project and main conclusions

A paper on the nature and size of the industry was prepared in the autumn of 2003 by Tim Briercliffe and Martin Emmet, and is attached as Appendix 2. Supplementary to that report, which provides a ‘snap-shot’ of the industry in 2003, it is worth commenting that within the whole horticultural sector, ornamental stock is the only area to show sustained growth (in terms of value) – in the order of 6% p.a. over the last 15 years. This is in marked contrast to several other commodities such as top fruit, protected vegetables and mushrooms which have exhibited a considerable decline over the same period.

Meetings with growers suggested that uniformity was more of a problem with growers delivering to ‘volume’ retailers, particularly in terms of delivering a crop to a ‘tight’ specification. For the more regular inter-nursery, garden-centre and landscape / amenity business tight specification was less of a problem, although crop uniformity was seen as a problem when preparing orders. Many growers saw ‘controlling waste’ as an important contribution to the uniformity problem, but there were several specific sources of non-uniformity that they identified as being potential culprits:

- water supply / irrigation
- cutting type / clonal status
- nutrients / compost
- drainage / potting / water status
- light / spacing / environment

A thorough search of the published literature, using bibliographic database services, failed to identify any papers on the subject of HNS uniformity, nor any published data that could be reworked to provide relevant information. Growers were not able to supplement this with much useful data – inevitably, and understandably, the majority of data maintained by growers relates to stock and sales, with a limited amount of information on losses. Unpublished data from a completed LINK project on irrigation of HNS (HNS 97) proved to be of some value but involved relatively small numbers of plants and was confined to the container stage of production. The most comprehensive data were those collected from commercial nurseries which are detailed later. The following list shows the sources of data that were identified and have been used in the preparation of this report:

- The new data collected from commercial nurseries.
- Unpublished data from a completed LINK project on irrigation of HNS (HNS 97).
- Data provided on propagation success of batches of *Clematis* spp.
- Some comprehensive data on losses on 10 species through the 'process'
- Cumulative sales data on a single species.

The studies undertaken on commercial nurseries are detailed in the Scientific section of this report. The length of the project was too short to follow any single batch of plants from cutting to finished container, so measurements were made on cuttings, liners and containers. A further report entitled 'Statistical Risk Analysis' is submitted as Appendix 1, and details findings and recommendations from the analysis of all available data.

Uniformity and variability

To achieve uniformity one must control variability. As alluded to above the approach to HNS research in the past has been directed at identifying treatments that improve the average performance of the crop, rather than limiting the variation between plants within the same treatment. Variability can essentially be considered as the converse of uniformity, although it is more helpful to distinguish between *inherent* (or 'known') *variability*, and *uncertainty*, which relates primarily to one's lack of knowledge. The latter might be thought of as *risk*. Although we know that plants are variable, growers will generally have a 'feel' for how a particular species will respond under 'good' conditions, e.g. the average rooting percentage, losses at potting on, etc. This is considered to be the inherent variability. However, these estimates are often thrown off course by bad timing, poor weather conditions, perverse buying patterns, etc., these being the *risk* or *uncertainty* factors associated with the general variability.

Measures of variability

Two measures of variability, or non-uniformity, have been emphasised in the formal measurement part of this project and used to compare different crops and to study changes in variability within each crop:

1. The **standard deviation** (abbreviated to **sd**) puts a number to the degree to which measurements on individual plants are scattered around the mean.
2. The **coefficient of variation** (abbreviated to **CV**) expresses the sd as a percentage of the mean, i.e. CV =100 × sd / mean

To get an idea of what the number means, it is useful to know that, with many types of data, 68% of the individuals making up a sample are likely to lie within one standard deviation of the mean. So, if the mean height of a batch of plants is 10 cm and the sd is 1 cm, about 70% of plants will have a height in the range 9 to 11 cm. The CV expresses the relative variability of the crop, much of which is inherent. We shall see later how it can be moderated.

The limits to delivery

Suppose we have a plant whose selling specification demands a height of between 60 and 80 cm. With an sd of 10 cm we might expect to move about 2/3rds of our crop (recall the figure of 70% above). To achieve this in the current example we need a CV as low as 14%, (≈100×10/70), whereas the average CV for the crops we measured was close to 25%. With a CV of 25% we could only expect to deliver just over 40% of the crop! **Hence, there are limits to what can be achieved with an individual crop. The natural variation of individual plants means that delivery needs to be staggered, if most of the crop is to be used.**

Main results from commercial nursery data collection

Escallonia rubra 'Crimson Spires' provides a good example of the sort of data collected.

A container crop was monitored, starting one week after plug plants had been potted into 2L pots and trimmed. Variability of plant height, in terms of both sd and CV, increased as the plants grew and was reduced each time the crop was pruned or trimmed. At the start, CV was 16% and twice rose to about 30% before being reduced by re-trimming, finally reaching 19% after autumn trimming had brought the crop to a saleable condition. To put these measures into context, the largest and smallest plants were initially 8 to 22 cm (range of 14 cm), rose to 14 to 55 (range of 41 cm) and finished at 19 and 42 cm (range of 23 cm).

There was little indication that a large plant at the start tended to produce the largest plant at the end. Only 2% of the variation in final height was explained by the correlation with the initial height. Using a model fitting procedure to look for the combined effects of many factors explained 29% of the variation (though if the height *before* the final trim was taken as the 'final' height, then this rose to 59%). The only significant component of the model was 'Location', i.e. differences between the three samples, which were almost certainly due to differences in local environmental conditions. In this case, the effect was clearly due to water from an adjacent roadway running off into the polyhouse and increasing the water supply to plants in one particular area. More generally, small differences in location can lead to large differences in crop performance. **The control, or more realistically, the management of local variability is an essential factor in achieving greater uniformity. The need for 'calibration' of stock areas is an important starting point in managing variability.**

Some other important statistical ideas

The Pareto Law (or 80/20 rule)

This is an empirical law that comes from economics and is currently very fashionable in business. Stated simply it says that performance depends disproportionately on doing few things really well. So, when we try to measure, say, what percentage of results is produced by what percentage of causes, we frequently find that the answer is often close to 80% of results from 20% of causes. Some examples might be:

- 80% of sales come from 20% of products
- 20% of customers provide 80% of business (20% of effort?)
- The majority of plants are dispatched very quickly

In fact, the analysis of one grower's sales data over a full year showed that 80% of his plants were dispatched within 10 weeks of the plants being ready (approximately 20% of the year!).

The binomial distribution – how proportions work

If we wish to estimate a production run, we would normally divide the number of plants we want by the expected proportion that survive, and that new number is the number we should start with, i.e.

- We want n plants – how many cuttings should we take?
- Suppose we take n and proportion p survive, then we only have np plants
- We need to start with x plants, so that $xp = n$, i.e. $x = n / p$

So, for example if we have a 75% success rate, then we would expect to raise 133% of the target number. But, to be sure, we need more, and the excess depends on the initial number. Thus, for 100 we would need an excess of 47%; for 250 an excess of 42%; and for 1,000 an excess of 37%. The larger the target the closer to 33% we get. These ideas are based on a concept known as the binomial distribution. The above calculation is based on the assumption that the loss factor is known (i.e. known variability). Due to the uncertainty or risk factors real systems tend to be even more variable! These ideas will be expanded in the Risk Analysis section.

In general, different loss rates occur at different stages of the growing cycle. Studies of data on staged loss (e.g. losses at propagation, rejection at the potting stage, loss as a liner, and loss as a container) supplied by one grower only emphasised the importance of considering the product of all losses. Two important lessons follow from this:

- The calculation on propagation numbers depends on all losses
- Losses at a later stage are more expensive than losses at propagation, as the 'lost' plant remains in stock longer.

Designed experiments – DIY Trials

With hundreds of species / cultivars being routinely grown there is no way in which formal trials can be run in a research environment. Nevertheless it is essential to use sound statistical principles to design trials to provide evidence on optimal growing conditions. There seems to be little alternative but for growers to run their own trials and 'share' information. A definite requirement for the future is the provision of training material on the design and conduct of such trials.

Conclusions

On the basis of this single season preliminary study, the main conclusions are as follows:

- Variation in the starting material is not generally the main cause of variation in the final crop. However, this generalisation is unlikely to hold true in all circumstances, particularly if different batches of starting material are mixed or if it is already close to final size and simply requires to become established in a larger pot to be ready for sale.
- Variation in environmental conditions is an important source of variability in the final crop, leading to differences in growth between one area and another within the crop. Sometimes such effects can be detected as clearly visible gradients on the bed but often they would not be readily detected by eye.
- Variation in water supply is probably the most important environmental factor causing non-uniformity of HNS.
- The next stage in solving the uniformity problem is to identify the source of the variation between adjacent plants Is it differences in their individual micro-environments (e.g. variation in water reaching individual plants, or competition for light amongst pot-thick plants) or is it inherent but invisible physiological differences in the starting material?
- The 'average' CV of the crops measured was 25%, and this generally refers to the variability of small batches of plants. This inherent variability of the plants has important implications for what can be delivered. If a specification is set 'too tightly' relative to the natural variability of the crop there may be a lot of wastage, as only a relatively small proportion of the crop will comply with the specification at any one time. This has very important implications for negotiating standards with large retailers.

Financial benefits

The results of this preliminary project provide the first hard data on a problem which is having huge economic impacts on the HNS industry. These data provide some strong pointers to the cause of the problem and a solid basis for deciding the future direction of research in this area. The project also suggests directions in which growers should look to reduce the problem, in advance of more detailed studies. However, it would be premature to attempt to put a financial value on the improvements in uniformity that we anticipate will come from developing more uniform delivery of irrigation and crop production protocols which maximise uniformity, thereby substantially reducing labour costs and wastage.

Action points for growers

It is too early to give firm recommendations but the results suggest that growers wishing to improve their crop uniformity should concentrate on two areas:

- Minimising environmental variation with the area occupied by a crop, paying particular attention to all aspects of water supply and drainage.
- Optimising trimming and pruning procedures to get the greatest possible long term increase in uniformity. This involves using the most appropriate equipment to achieve uniform cutting height. It also involves timing the operation to minimise the problem of missing plants (or individual shoots) which then rapidly overtake those that were pruned.

In addition the project has highlighted the dearth of data for decision-making outside the framework of stocks and sales. To reduce both the problems of non-uniformity and risk management, growers need to keep more plant-measurement records and details of plant losses through the growing process.

SCIENCE SECTION

Introduction

Lack of crop uniformity has been identified by growers and the HDC as a key issue threatening the profitability of the HNS industry. It creates severe wastage because a substantial proportion of many crops fail to meet buyers specifications or other criteria of saleability. It also adds greatly to labour costs because at every stage nursery staff need to take account of variation in the crop in making decisions about pruning and other plant manipulations.

Uniformity is not an easy property to specify, but it relates to consistency of product, particularly within a batch. The primary method of achieving uniformity at present is through pruning and grading out of weak plants at intermediate stages. At the end of the production process, the assembly of uniform batches to meet individual orders further increases the uniformity of product supplied to an individual customer. This process alone has been estimated to account for 30 - 40% of a nursery's total labour costs. More generally, it has been asserted that a 30% reduction in wastage could lead to a three-fold increase in profit margins. By identifying the sources of non-uniformity this project aimed to pave the way to reduce those costs and enable the industry to become more competitive.

Historically, scientific research into HNS has been directed at improvement in average performance, with an emphasis on differences between treatment means rather than the variation between plants within the same treatment. Therefore, there is a need to re-examine published results to see whether it is possible to extract useful information about the variability within batches of plants receiving the same treatment and the way that it changes through the production process. Part of this report relates to the largely fruitless search for relevant information in the literature. The major part of the report presents new data collected on commercial nurseries and designed specifically to measure changes in uniformity of HNS crops over the course of production. As such it provides a solid foundation to the search for the source(s) of non-uniformity and the development of ways to counteract it.

Other parts of this project have explored the HNS production process *per se*, by analogy with a manufacturing process, aiming to identify critical points within the process. This part of the project takes a more biological perspective.

It is often assumed that, if the grower could ensure that all plants received 'best practice', then variation would be eliminated but this is only likely to be true if the starting material is uniform. In practice, starting material is rarely uniform and plant growth models predict that, in an optimal environment, differences between plants will increase with time.

Materials and Methods

Collaborating nurseries

The following nurseries kindly allowed us free access to collect data for this project:

- Coblands Nurseries, Tonbridge, Kent (data collected at the Court Lane nursery, Hadlow)
- New Place Nurseries, Pulborough, West Sussex
- Palmstead Nurseries, Wye, Kent

Choice of crops

Discussion with many growers suggested that the problem of non-uniformity was not restricted to specific crops. Indeed, growers found it hard to suggest species or varieties that would be particularly suitable as models for this research. Crops were therefore selected largely on practical considerations such as availability and ease of access.

Data was collected from 10 species and 14 crops as follows:

Choisya 'Aztec Pearl' cuttings - liners	New Place
Elaeagnus x ebbingei containers	Palmstead
Elaeagnus x ebbingei liners	Palmstead
Escallonia rubra 'Crimson Spires' containers	Palmstead
Euonymus japonicus containers	Palmstead
Exochorda 'The Bride' cuttings	New Place

Hebe albicans containers	Coblands
Hebe albicans liners	Coblands
Hypericum calycinum containers	Palmstead
Hypericum calycinum cuttings-liners	Palmstead
Penstemon ‘Port Wine’ containers	Coblands
Penstemon ‘Port Wine’ liners	Coblands
Weigela florida ‘Variegata’	East Malling
Spiraea ‘Arguta’ cuttings - liners	New Place

Choice of measured variables

The choice of measured variables was a compromise between the aim of quantifying non-uniformity that is relevant to the needs of the HNS market in a representative sample of crops, the resources available for collecting data, and the desire to avoid subjective measures. The main variables measured are listed below:

Plant height (primary variable, measured on every occasion)
Stem diameter (were possible the main stem, below the lowest branch)
Number of branches (often subdivided into different categories)
Canopy area (estimated from two measurements of canopy diameter, at right angles, viewed from above)
Flowering (as appropriate)

Sampling and labelling

In each crop, three samples of approximately 20 plants were labelled at the start of the experiment so that the changes in individual plants could be monitored as the crop developed. The precise number varied between 18 and about 30, depending on the way plants were grouped and whether it was anticipated that some plants would die or their identity would be lost during potting etc. Each sample consisted of a block of adjacent plants (e.g. 5 plants in 4 adjacent rows) and, wherever possible, was surrounded on all sides by at least two pots so as to avoid edge effects.

The three samples were seperated by at least 2 m and their position was selected to encompass possible environmental variation, e.g. along the length of a polytunnel.

They are referred to a Location 1, 2, and 3. Our expectation was that differences between 'Locations' would reflect variation due to non-uniformity of environment.

Statistical analysis

The non-uniformity or variability of a set of plants, that is the dispersion of individual size measurements was quantified by calculating the standard deviation (sd), the most widely used and reliable statistic for this purpose. Since variability often increases as plants grow, we also calculated the coefficient of variation (CV), that is the standard deviation as a percentage of the mean:

$$CV = sd / mean \times 100$$

Subjective assessment of variability may correspond more closely to other measures of non-uniformity, particularly the range between the maximum and the minimum, so we also present some data in that form.

To explore how much of the variation in the final crop is related to variation present in the starting material, two statistical techniques were used. First, correlation analysis, and second, modelling by multiple linear regression. For correlation analysis, a matrix of correlation coefficients was generated which showed how closely related were all the measurements made on a particular crop. The larger the correlation coefficient between two variates (e.g. final plant height and initial stem diameter) the more closely in variation in one is paralleled by variation in the other (e.g. the thicker the liner stem the taller the final plant).

The second technique is an extension of the process linear regression used to find a line of best-fit to a scatter graph. Multiple linear regression allows the influence of more than one explanatory variate on the value of a single dependent variate to be combined into a single statistical model. For example, it allowed us to explore whether final plant height was related to the combined influence of the height and stem diameter of the starting material as well as other variables such as the number of branches. By adding terms successively to the model and measuring the decrease in residual variance (i.e. the variance not 'explained' by the model) it is possible to identify which terms are most important and to test which have a statistically significant effect.

The modelling approach also allows one to test whether the relationships defined by the model differ between particular classes of individual. For example, it allowed us to determine whether plants in the three different locations behaved differently. In this way, it provided an measure of the extent to which local environmental conditions influenced the final size of individual plants compared to the size of the starting material.

Neither of these approaches can provide evidence for a causal relationship between variates.

Outline of data collected

Listed below are the recording dates for each crop, together with information about the recording of heights at which crops had been trimmed. Rarely did visits to nurseries coincide with the monitored crops being trimmed. Instead, pruning / trimming height was measured when the crop was next recorded (Figure 1)

Figure 1. The height to which plants were trimmed was generally measured some time later, when subsequent regrowth was recorded. The arrows highlight pruning cuts on *Escallonia*, made on the 8 July but not measured until there was substantial regrowth to record, on 4 September.

Palmstead nursery				
Species / batch	**Stage**	**Date**	**Record**	**Comment**
Elaeagnus ebbingei	Liner	25/06/03	1	
		24/07/03	2	
		04/09/03	3	
		04/12/03	4	
Elaeagnus ebbingei	Liner	25/06/03	1	
		24/07/03	2	
		04/09/03	3	
		04/12/03	4	
Elaeagnus ebbingei	Container	11/06/03	1	Included height of cutting over, done around 19 May. Little new growth at this time.
		24/07/03	2	
		21/08/03	3	
Euonymus japonicus	Container	26/06/03	1	From pot rim to highest growing point (already had had one cut-over)
		24/07/03	2	Included height of cutting over on 10/07/03
		21/08/03	3	
Hypericum calicynum	Propagation	09/07/03	1	Height of cuttings in module trays measured from tray surface.
	Container (1.5 L)	04/12/03	2	First measurement after potting directly into final container
Hypericum calicynum	Container (1.5 L)	10/06/03	1	Included the height at which plants had been cut over on 25/05/03, shortly after potting
		25/06/03	2	
		09/07/03	3	

Escallonia rubra 'Crimson Spire'	Container	02/07/03	1	Included the height at which plants had been cut over on 26/6/03. (2nd trimming since propagation)
		09/07/03	2	
		23/07/03	3	
		04/09/03	4	Included height of cutting over on 28/7/03.
		27/11/03	5	

Coblands Nursery				
Species	**Stage**	**Date**	**Record**	**Comment**
Hebe albicans (Rooted cuttings from mist bed, potted off into 9 cm pots, hand watered under glass)	Cutting - Liner	30/06/03	1	
		30/07/03	2	
		09/09/03	3	Plant were top heavy and flopping over - pulled upright to measure.
		18/12/03	4	Plants had lignified, some in bent over position, so no longer possible to pull upright for measuring. Plants in location 1 were all upright.
Hebe albicans (2 L pots in a polytunnel)	Container	17/06/03	1	
		30/06/03	2	Some heights were slightly less than previous record, apparently due to wilting.
		09/09/03	3	
		18/12/03	4	Plants in location 3 had been moved outside so that the remainder could be spaced out.
Penstemon 'Port Wine' (Rooted cuttings from mist bed, potted off into 9 cm pots, hand watered under glass)	Cutting - Liner	08/07/03	1	Cuttings measured in first the propagation module tray and then again immediately after potting and pinching back to 2 visible nodes
		30/07/03	2	
		09/09/03	3	
		18/12/03	4	Included measurement of the height at which they had been cut over on 17 November.

Penstemon 'Port Wine' (2 L pots on an outside bed with sprinkler irrigation)	Containe r	19/06/03	1	Included the height at which plants were cut over during potting on 30/5/03)
		30/06/03	2	
		30/07/03	3	Height measured to top of the flower spike
		12/09/03	4	Height measured to top of the flower spike

Newplace Nursery

Species	Stage	Date	Record	Comment
Choisya 'Aztec Pearl'	Cutting - Liner	01/07/03	1	Height' was measured as the length of the entire cutting before sticking
		29/07/03	2	Number of roots visible at the base of plugs recorded. No top growth so no height measurement
		11/09/03	3	Height measured from the rim of the liner pot - both the height of the original cutting and the height of new growth
Exochorda macrantha 'The Bride'	Cutting	01/07/03	1	Height was measured as the length of the entire cutting before sticking
Spirea 'Arguta'	Cutting - Liner	01/07/03	1	Height measured from the surface of the plug compost.
		29/07/03	2	Height to the top of the original cutting and the tallest new growth measured
		11/09/03	3	Height of rooted cuttings after transfer to liner pots, measured from the pot rim. Also measured was the height of the uppermost branch on the main stem.

Results and Discussion

Escallonia rubra 'Crimson Spires' containers

Monitoring started one week after plug plants had been potted directly into 2L pots and trimmed. Variability of plant height, in terms of both sd and CV, increased as the plants grew and was reduced each time the crop was pruned or trimmed (Figure 2). At the start, CV was 16% and twice rose to about 30% before being reduced by retrimming, finally reaching 19% after autumn trimming had brought the crop to a saleable condition. To put these measures into more more familiar units, the largest and smallest plants were initially 8 to 22 cm (range of 14 cm), rose to 14 to 55 (range of 41 cm) and finished at 19 and 42 cm (range of 23 cm). These alternative measures of variability are shown graphically by the 'whiskers' of the 'box and whisker' plots in Figure 3. The same figure includes data for stem diameter and number of branches, both of which show that variability increased as the plants grew in a similar way to the variability of plant height.

In the expectation that the largest plants at the start of the experiment would tend to be the most vigorous and therefore grow most rapidly, we investigated the relationship between initial plant height and plant height later in the season. Plotting the data (Figure 4) and calculating the correlation coefficient provided little support for the prediction that a large plant at the start was tended to produce the large plant at the end. Even before the final trim, only 4% of the variation could be explained by correlation with the initial size.

Table 1 shows part of a matrix of correlation coefficients that was used to explore relationships amongst all the measurements made on the crop over the course of the season. It shows, for example, that plant height before final trimming correlated better with initial stem diameter than initial plant height. The first column of the matrix shows all the correlations with initial height (ht[1]): the correlation coefficient with the second height measurement (ht[2]) is 0.96, which indicates a very close relationship, but the coefficient decreases progressively through the successive height measurement (ht[3], ht[4] and ht[5]) indicating that the relationship became weaker over the course of the season. A complete correlation matrix, including all types of measurement made, is available in the Appendix.

A relationship of the sort we had expected can easily be obscured by interactions with other factors. We therefore used a statistical model fitting procedure to look for the combined effects of many factors. The best model explained 29% of the variation, a considerable improvement on the correlation with initial plant height alone. However, the only term in the model which explained a significant amount of variation was 'Location', i.e. differences between the three samples that were monitored (Table 2). A similar model, for the height *before* the final trimming, included a significant influence of initial stem diameter as well as Location, and explained 59% of the variation.

Figure 5 illustrates why Location was so significant. Plants in Location 3 were on average more than 50% taller than those from the Locations 1 and 2. The graphs suggest that, within each Location, the tallest plants at the start tended to be the tallest plants at the end, though the modelling results indicate that the effect was not statistically significant.

Differences between Locations are very likely to be due to differences in local environmental conditions (though without randomisation of plants between locations there are other possible explanations) . In this case, observations on the ground made it clear that the effect was due to water from an adjacent roadway running off into the polyhouse and increasing the water supply to plants in one particular area (Figure 10 and Figure 11).

A number of photographs are included to help the reader visualise the experiments and the variation to which the data refer. Figure 6 shows the appearance of representative plants at the start of the experiment and Figure 7 illustrates variability of the crop on two subsequent occasions. Figure 8 and Figure 9 trace the development of individual plants from contrasting Locations.

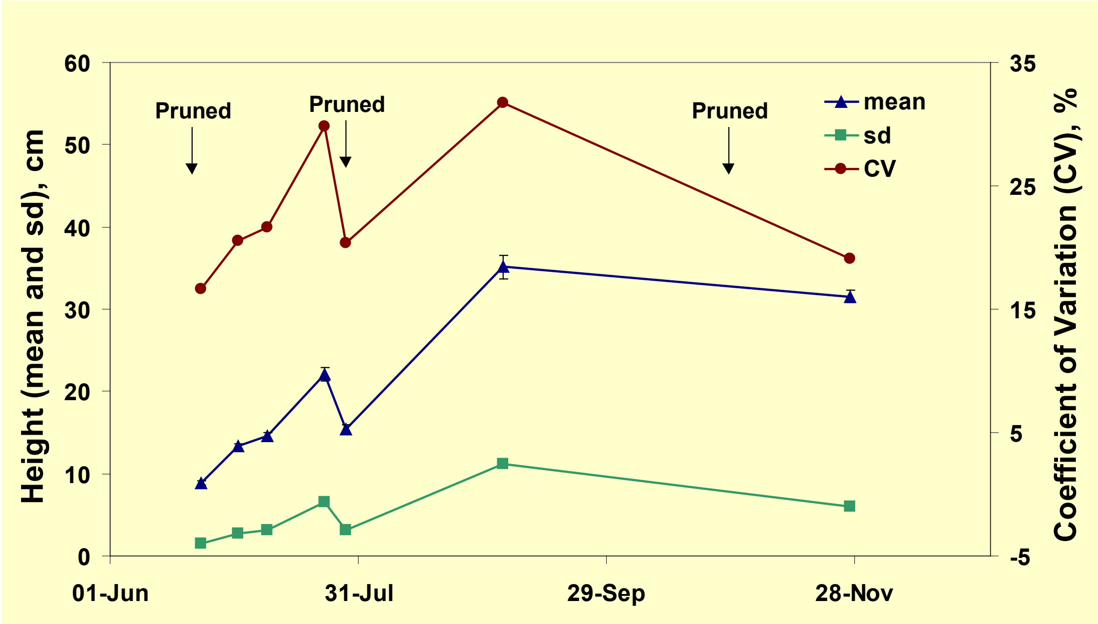


Figure 2. ***Escallonia rubra*** **'Crimson Spires': changes in the uniformity of plant height over the course of the season, as the plants grew and were repeatedly trimmed. The crop was growing a polythene twin-span house under overhead sprinkler irrigation.**

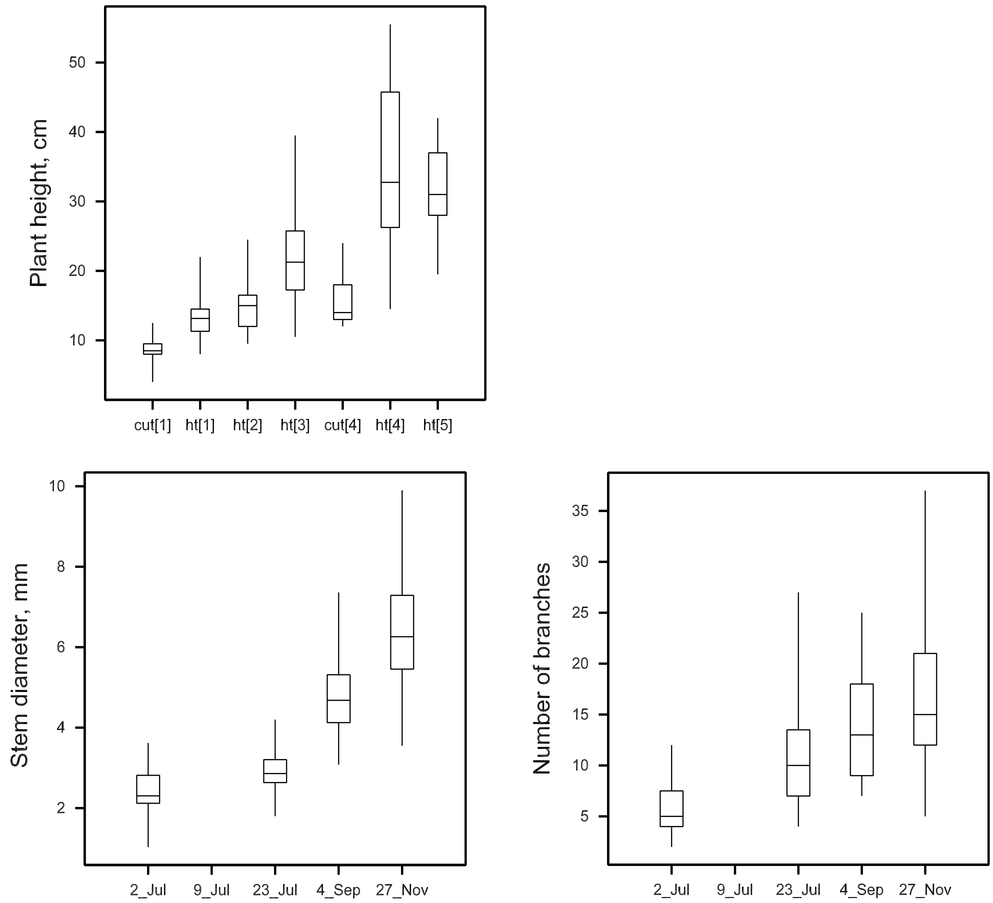


Figure 3. ***Escallonia rubra*** **'Crimson Spires': changes in the uniformity of plant height stem diameter and number of branches over the course of the season shown as 'box-and-whisker' plots. The 'whiskers' show the full range of values from the 60 plant sample, the 'box' shows the limits of the central 50% of the population, and the horizontal line indicates the median. In the upper plot, the points on the horizontal axis correspond to the seven recording dates shown in Figure 2.**

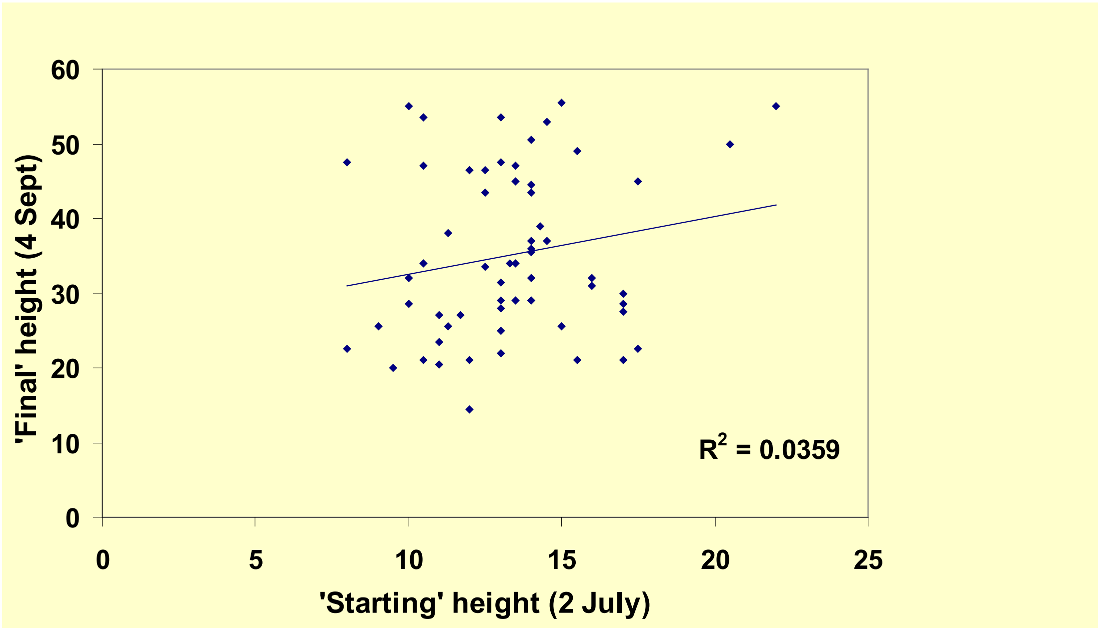


Figure 4. Relationship between plant height at the beginning and end of the container growth phase in an crop of *Escallonia* 'Crimson Spires'. For this purpose, final height has been defined as the height in September, before final trimming. Plotted points represent individual plants and the line represents the average relationship as fitted by linear regression The value of R^2 indicates that only 3.6% of the variation in final height is attributable to variation in initial height.

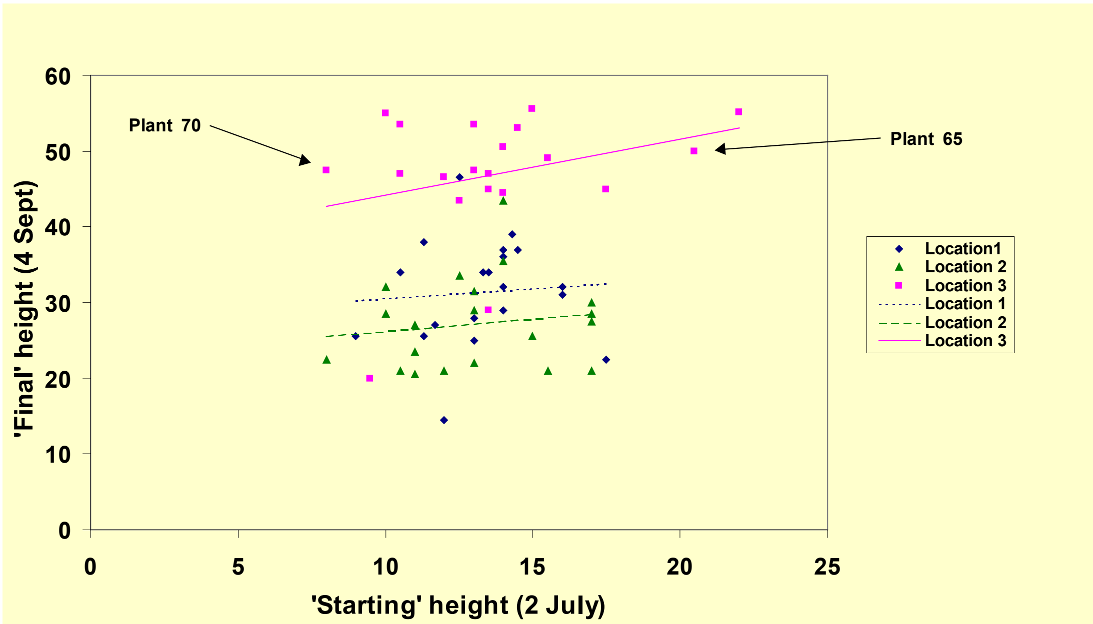


Figure 5. Effect of location on the relationship between initial and final plant height in an crop of *Escallonia* 'Crimson Spires'. 'Locations' were distinct areas within a polythene house far enough apart to make the environmental conditions different (2-5m apart). The data points are the same as those plotted in Figure 4 but different symbols have been used to distinguish the three locations and separate regression lines have been fitted to each. Plants in Location 3 received

more water than the others due to runoff from an adjacent roadway. The data points corresponding to the photographs in Figure 8 (i.e. plants 65 and 70) are arrowed.

Table 1. A matrix of correlation coefficients amongst selected variables from a crop of *Escallonia* 'Crimson Spires'. Correlations with plant height before final trimming (i.e. ht[4]) are shaded, and the larger values (i.e. >0.3) are in bold type. Key: ht = plant height; st_diam = stem diameter; n_brnch = number of branches; missed = missed previous pruning. Number in brackets identifies the measurement date: 1 = 2 July ; 2 = 9 July ; 3 = 23 July; 4 = 4 September; 5 = 27 November.

ht[1]	1.00							
ht[2]	0.96	1.00						
ht[3]	0.83	0.91	1.00					
ht[4]	0.29	0.21	0.28	1.00				
ht[5]	0.15	0.15	0.13	**0.46**	1.00			
st_diam[1]	0.45	0.35	0.32	**0.35**	-0.03	1.00		
n_brnch[1]	0.38	0.24	0.13	0.19	0.05	0.67	1.00	
missed[1]	-0.15	-0.05	0.06	0.07	-0.04	-0.49	-0.80	1.00
	ht[1]	ht[2]	ht[3]	ht[4]	ht[5]	st_diam[1]	n_brnch[1]	missed[1]

Table 2. Statistical significance of adding various terms to a linear regression model relating final height of *Escallonia* 'Crimson Spires' (*after* final trimming) to initial measurements on the same individual plants. The model explained 28.6% of the variation in final plant height. This table indicates that the only term with a significant effect was 'Location' (i.e. three different areas within the crop where data were collected). A similar model for plant height on 4 September, before final trimming, explained 59% of the variation and showed an additional significant affect due to stem diameter (*P* = 0.035).

Model term	*P* (significance level)
Location	**<0.001**
Initial stem diameter (st_diam[1])	0.263
Initial height (ht[1])	0.955
Initial number of branches (n_brnch[1])	0.932
Location x st_diam[1]	0.152
Location x ht[1]	0.672
Missed the first trim (missed[1])	0.487

Figure 6. *Escallonia rubra* 'Crimson Spires': representative plants on 2 July, when first recorded 1 week after potting from plugs into 2 L pots.

Figure 7. ***Escallonia rubra*** **'Crimson Spires' crop, viewed from above to emphasise the variability in leaf area and ground cover by plants in the same 'Location' and the large difference in growth between 'Locations'. Upper row: 4 weeks after potting (25 July); lower row: 10 weeks after potting (4 September). Left column: 'Location' 2; right column: 'Location' 3.**

Figure 8. ***Escallonia rubra*** **'Crimson Spires': photographs tracing the growth and development of the tallest and shortest plant in Location 3 (plant 65, left and plant 70, right). In this case, the final size reflects the difference in initial size but this was not consistently the case.**

Figure 9. ***Escallonia rubra*** **'Crimson Spires': photographs showing the growth and development of two plants in Location 2 (plant 49, left and plant 47, right). Plant 49 was initially the larger but was pruned much harder when plants were tidied up in October. It is clear that this differential pruning broke the correlation between current size and earlier size and produced very dissimilar final plants. This is an example of the way that pruning can sometimes fail to increase the uniformity of a crop**

Figure 10. Overall view of the ***Escallonia*** **crop on 4 September, showing the position of the three 'Locations'. Growth was much more vigorous in the bed at the far left hand end (Location 3). There was also a decline in plant height across the main bed which is visible in this picture (from right to left).**

Figure 11. ***Escallonia rubra*** **'Crimson Spires', at the time of the first record on 2 July. The uneven colour of the medium suggests uneven irrigation.**

Elaeagnus x *ebbingei* liners

Starting with rooted cuttings which had been potted into 9 cm liner pots a few weeks earlier, variability was intially high, mainly because cuttings had started to grow at different times. Over the season, CV declined from 33% to 27% and then remained constant (Figure 12). There was no pruning so that this small decline in CV indicates that, relative to their size, the smaller cuttings grew faster than the larger ones, probably by drawing on carbohydrate reserves.

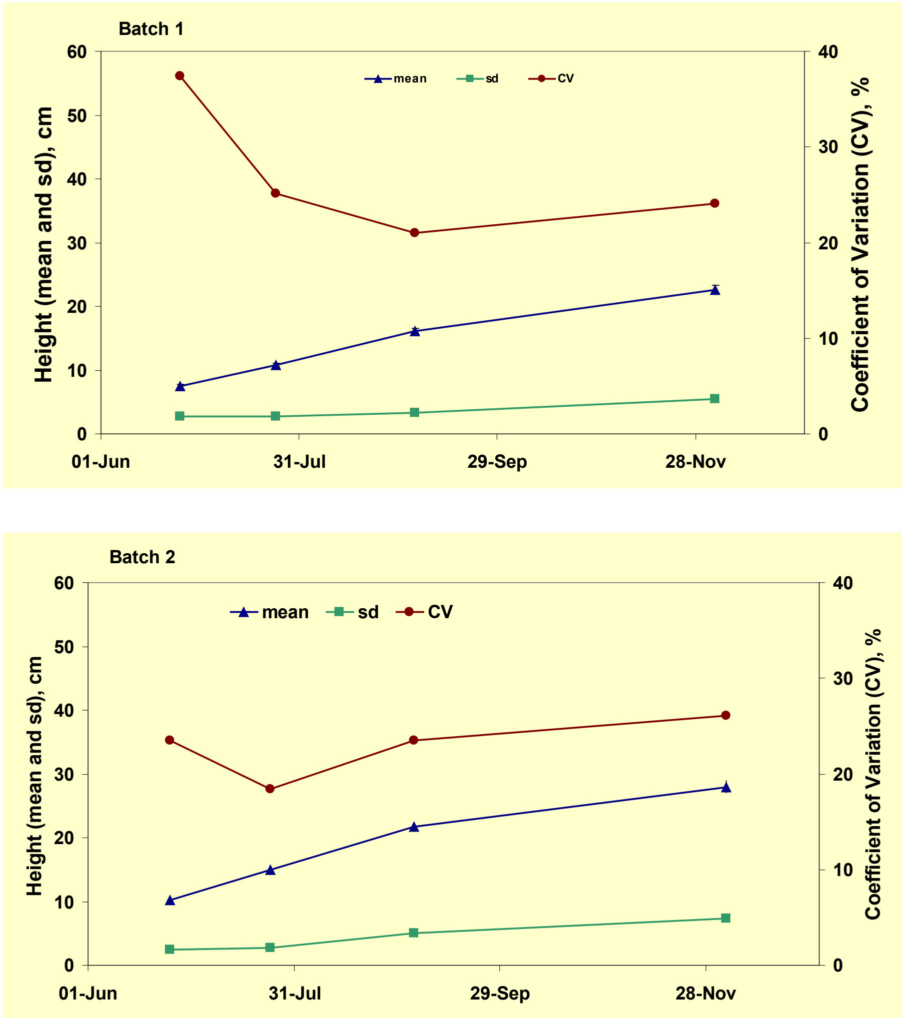


Figure 12. *Elaeagnus* x *ebbingei* liner crop: changes in uniformity as plant height increased over the course of the season. The crop originated from two separate batches of cuttings, the first being propagated in December 2002 (upper graph), the second in January 2003 (lower graph). The batches were grown side by side in a multibay polythene house.

The liner crop being studied actually came from two batches of cuttings. Statistical modelling of final height showed that the difference between these batches was the only significant factor relating final size to the starting material (Table 3). There was no effect of large scale environmental variation (i.e. 'Location' effect). However, marked variation in water content of adjacent pots was observed, despite fine and apparently uniform overhead irrigation, and seems likely to have contributed to pot to pot variability.

For the number of branches on the final liners, modelling indicated significant effects of batch, initial height, initial stem diameter and whether the plant flowered or not, but there was no significant effect of the initial number of branches.

Table 3. *Elaeagnus x ebbingei* liners: statistical significance of adding various terms to a linear regression model relating final height to initial measurements on the same individual plants. The model explains 24.0% of the variation in final plant height.

Model term	*P* (significance level)
Location (loc)	0.403
Batch (batch)	**<0.001**
Initial stem diameter (st_diam[1])	0.449
Initial height (ht[1])	0.108
Initial number of branches (n_brnch[1])	**0.013**
Flowers present on 24 July (flwrng[2])	**0.004**
st_diam[1] x batch	0.250
ht[1] x batch	0.223

Elaeagnus x *ebbingei* containers

In parallel with the liners, a separate container crop was monitored. Initial variability (CV = 16%) was smaller than final variability of the liners (CV = 27%), probably due to a recent trim with a hedge clipper. As the plants grew, sd increased but the increase kept roughly in line with plant growth so that CV was almost constant (Figure 13). There were no good correlations between final height and initial measurements and a statistical model explained only 1% of the variation in final height (Table 4).

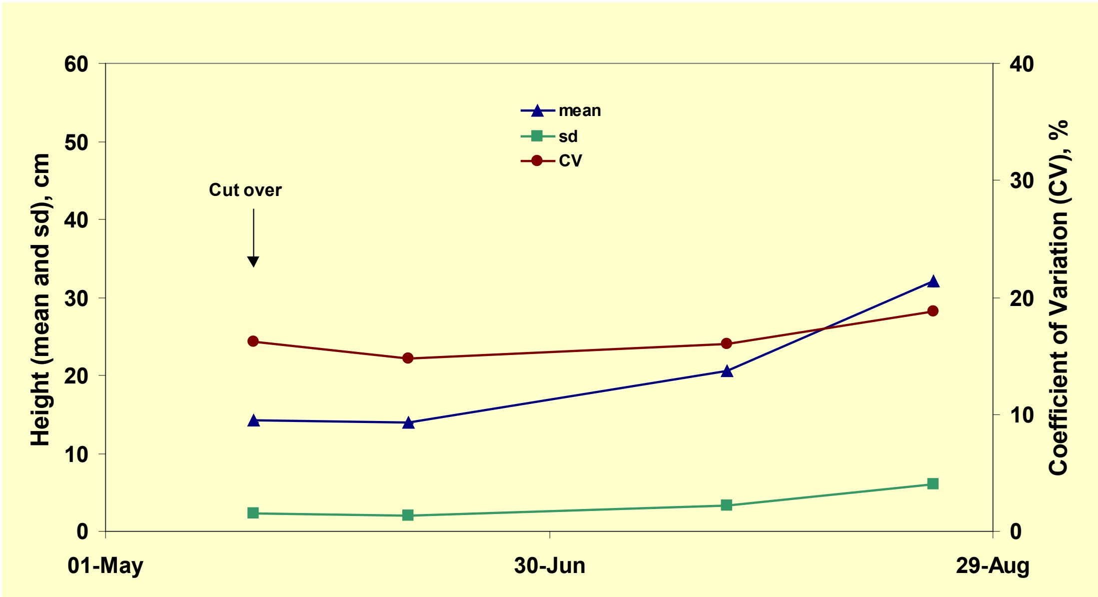


Figure 13. *Elaeagnus* x *ebbingei* containers: changes in uniformity as plant height increased over the season. Plants were in 3 L pots on an outside bed under overhead sprinkler irrigation.

Table 4. *Elaeagnus x ebbingei* containers: statistical significance of adding various terms to a linear regression model relating final height to initial measurements on the same individual plants. The model explains 1.3% of the variation in final plant height.

Model term	*P* (significance level)
Location (loc)	0.782
Initial stem diameter (st_diam[1])	0.736
Initial height (ht[1])	0.877
Initial number of primary branches (n_brnch[1])	0.092
Type of cutting	0.070

Euonymus japonicus containers

Starting with material that had recently been potted from plugs into 2 L pots, variability was intitially high. Before potting, the material had been cut over, mainly to provide cutting material for a new batch. As the plants grew, sd increased more slowly than average height so that CV fell progressively over the first 6 weeks before starting to rise again (Figure 14).

Model fitting explained almost half the variation in final height. The effect of 'Location' was again the most significant component of the model but there were also significant effect of initial stem thickness (Table 5). The effect of stem thickness showed a significant interaction with 'Location' and including the number of secondary branches also significantly improved the model. The latter term was not strictly a measure of the starting material because secondary branches were not present at the time of the first records.

The strong 'Location' effect was probably attributable to variation in water supply to the three samples because there was evidence run-off from the adjacent roadway similar to that seen with the *Escallonia* crop.

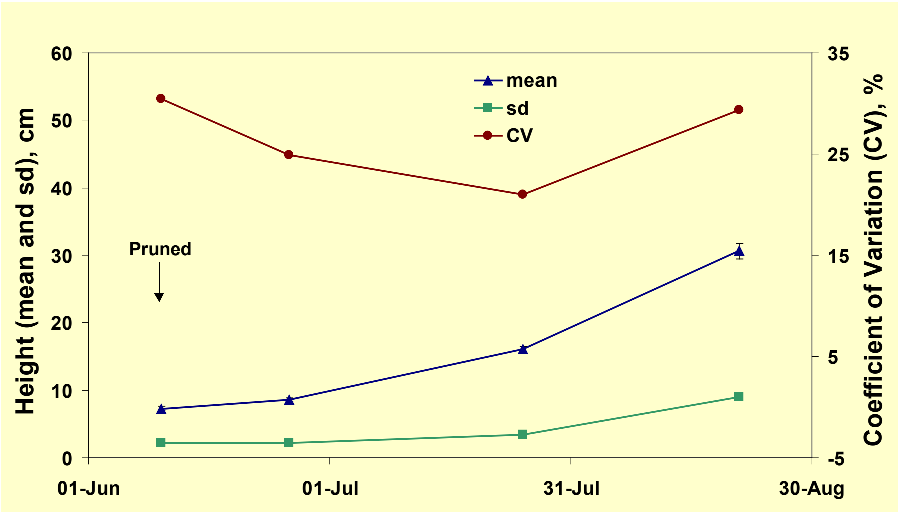


Figure 14. *Euonymus japonicus* containers: changes in uniformity as plant height increased over the season. Plants were in 2 L pots in a polytunnel. The first measurement, on 10 June, refers to the height of pruning cuts present on the starting material (plugs) when potted.

Table 5. *Euonymus japonicus* containers: statistical significance of adding various terms to a linear regression model relating final height to initial measurements on the same individual plants. The model explains 47.6% of the variation in final plant height.

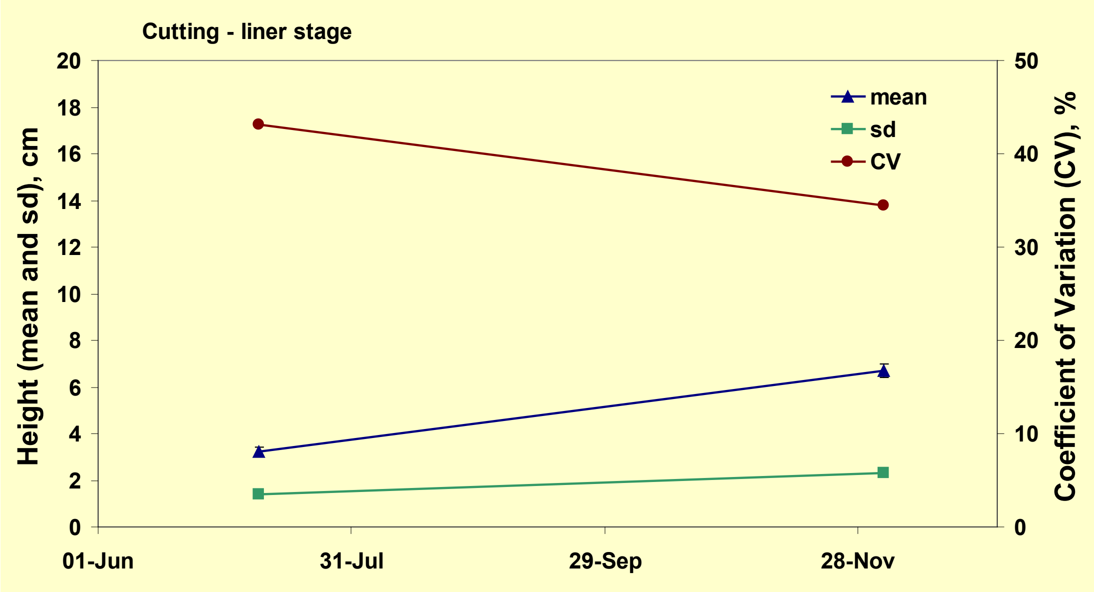
Model term	*P* (significance level)
Location (loc)	**< 0.001**
Initial stem diameter (st_diam[1])	**0.040**
Initial height (ht[1])	0.070
Initial number of primary branches (n_brnch[1])	0.153
Number of secondary branches present on 25 July (n_brnch[2])	**< 0.001**
ht[1] x loc	0.178
st_diam[1] x loc	**0.036**

***Hypericum calycinum* (cutting to liner stage)**

By the time cuttings could first be measured, at the end of weaning, they were very variable (CV = 43%, see upper graph in Figure 15). When first observed as recently stuck cuttings being propagated under fog they appeared very uniform. The variability in the rooted cuttings presumably refects slight differences in the time they took to root and thus for buds to break and new shoots to start growing. This was somewhat reduced (CV = 35%) after the rooted cuttings had been potted into 1.5 L pots, perhaps partly through rejection of some of the weakest cuttings during potting.

We also monitored a separate container crop. The starting material was rather more advanced plug plants than those described in the previous paragraph. The plants had already been cut over to collect cutting material so that CV was substantially lower at 21%. However, shoots that were missed in that trimming operation rapidly emerged increasing CV to 31% (Figure 15, lower graph). With further growth, there was some decline in variability. This can probably be attributed to flowering because, as flowers formed they effectively prevented further growth of individual shoots and eventually the whole plant. This allowed some time for other plants to 'catch up' before they too switched from vegetative growth to flowering.

In many species there is little growth after flowering and the control of flowering is partly dependent on the plant having reached a certain minimum size. *Hypericum calycinum* appears to belong to this group. For such plants, the genetic control on the flowering process imposes a natural tendency to reduced variability at the time of flowering, at least in terms of plant height. However, other aspects of plant appearance such as the shape and the number of flowers will not necessarily benefit in this way. To fully understand the control of variability in individual crops there will be a need to investigate specific aspects of plant size and horticultural quality relevant to each crop.



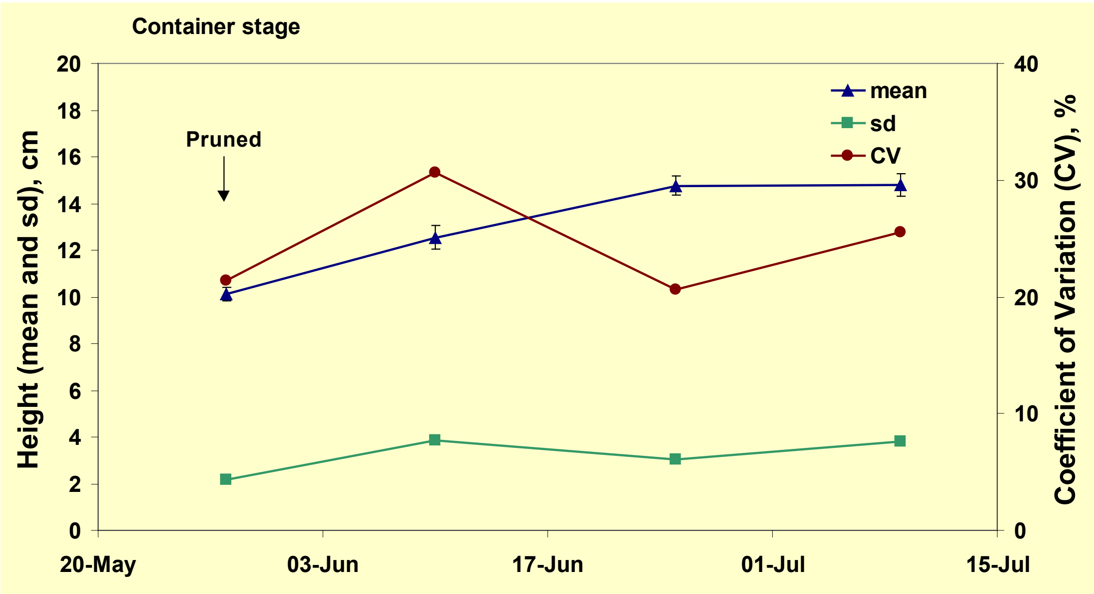


Figure 15. ***Hypericum calycinum*****: changes in uniformity over the course of two production stages. The upper graph refers to a batch of cuttings propagated in early June 2003 and measured at the start of weaning and after potting. The lower graph refers to growth of a separate batch of plants, propagated in early 2003, and the plugs potted directly into 1.5L pots on around 26 May.**

Table 6. *Hypericum calycinum* containers: statistical significance of adding various terms to a linear regression model relating final height to initial measurements on the same individual plants. The model explains 58.2% of the variation in final plant height. Modelling the cutting - liner stage, showed a significant influence of 'Location' only, associated with visible differences between the trays at the end of weaning.

Model term	*P* (significance level)
Location (loc)	**< 0.001**
Initial height (ht[1])	**< 0.001**
Initial stem diameter (st_diam[1])	0.095
Number of main stems (n_stems[1])	0.697
Initial number of branches (n_brnch[1])	0.799
Whether missed during pruning on 28 May (missed[1])	**< 0.013**
st_diam[1] x loc	0.345
ht[1] x loc	0.330
n_stems[1] x loc	0.466
n_brnch[1] x loc	0.661
missed[1] x loc	0.002

***Hebe albicans* liners**

The starting material for this crop was a batch of cuttings rooted under mist which had been thoroughly weaned but were still in the module tray in which they were rooted. They appeared to be quite variable, some bearing flowers, others with multiple breaks near the top of the cutting and others still single stemmed. The first record was made after they had been potted into 9 cm pots and transferred to a large greenhouse for growing on. The crop was placed in a corner of the greenhouse where shading was uneven. A capillary irrigation system (seephose and matting) was no longer functional so that irrigation was by hand from a lance.

At the time of the first record there was already evidence of uneven watering, with some plants wilting. One month later, a third of the plants in Location 3 were dead. Despite this variable environment, as the plants grew to nearly twice their original height there was little increase in sd so that CV dropped from 28% to 14% in September(Figure 16). After that there was some increase in variability as some plants stopped growing while others continued to grow. Physical damage to some plants and dieback of others also contributed to the rise in variability over the autumn.

Additional plant losses in August raised the total losses from the crop as a whole to 17%. This time they were in Location 1, but again appeared to be due to insufficient irrigation.

Model fitting explained only 23 % of the variation in final height, with a significant effect of Location alone (Table 7). With hand watering, the pattern of uneven watering is often inconsistent so that there is less chance that its adverse effect will be spotted in terms of poor plant performance in particular locations.

These results suggest that growth and development is under strong genetic control in *Hebe albicans* so that the crop naturally tends to become more uniform. It is not clear how this control operates but for CV to have decreased over time, initially weak plants must have grown in height relatively fast compared to the initially larger plants. The increase in CV over the autumn period, associated with dieback that was probably caused by water stress, shows that, even for species whose growth is tightly 'programmed', environmental variation can introduce non-uniformity into crops.

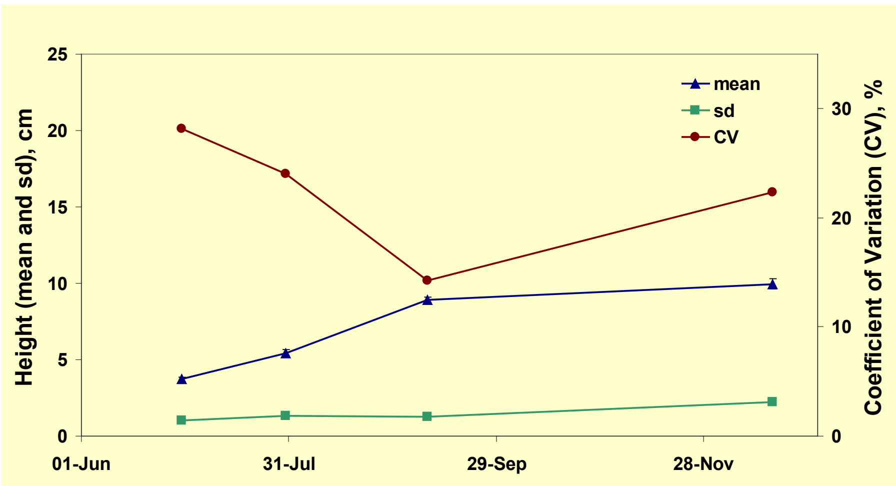


Figure 16. *Hebe albicans* liner crop: changes in uniformity as plant height increased over the course of the season. The crop was grown under glass and was hand watered.

Table 7. *Hebe albicans* liners: statistical significance of adding various terms to a linear regression model relating final height to earlier measurements on the same

individual plants. The model explains 23.1% of the variation in final plant height.

Model term	*P* (significance level)
Location (loc)	**< 0.001**
Initial stem diameter (st_diam[1])	0.285
Initial height (ht[1])	0.399
Number of growing points on the cutting (ng_points[1])	0.777
Number of flower heads on the cutting (n_flws[1])	0.411
Number of branches on 30 July (n_brnch[2])	0.830
st_diam[1] x loc	0.567
ht[1] x loc	0.672
n_brnch[1] x loc	0.285

Canopy area

Canopy area, based on two measurements of the diameter of the leaf canopy when viewed from above, is an important measure of size for a plant like *Hebe albicans*. Final canopy area correlated significantly with final plant height (r = 0.376) but more strongly with the final number of basal branches (r = 0.603). Correlations with earlier measurements were all very weak and the best fitting model explained only 3% of the variation. Weak correlation with initial shape and size is consistent with strong genetic control of growth and development.

Hebe albicans containers

Initial height (~11 cm)and variability (CV=19%) was very similar to that seen in the last measurements on the liner crop, even though they were completely different batches of plants. The second measurement of height showed a *decrease* in height which appeared to be due to slight wilting. Thereafter, there was a slow increase in height to 18 cm with only a slight increase in sd, so that CV decreased to 15% (Figure 17. This data coincides well with the subjective impression of a crop that was reasonably uniform at the start and became more uniform with time.

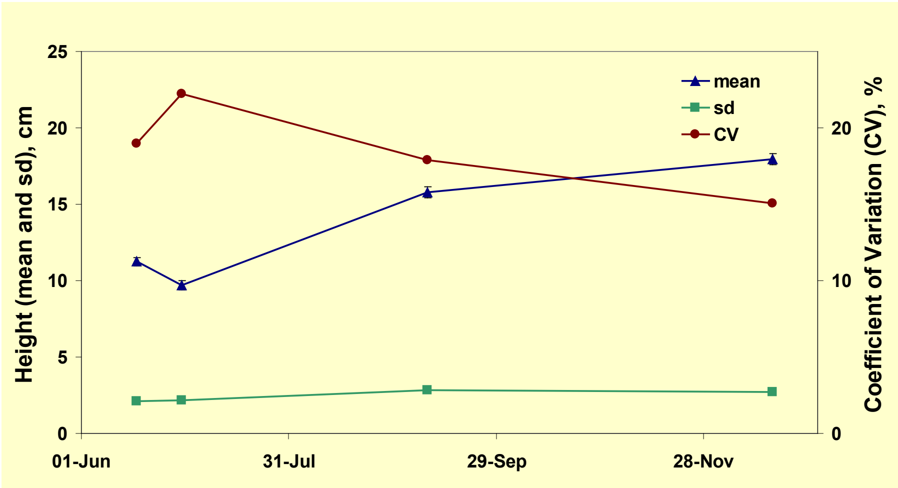


Figure 17. *Hebe albicans* container crop: changes in uniformity as plant height increased over the course of the season. The crop was grown in a twin span polythene house with overhead sprinkler irrigation.

Model fitting explained 51% of the variation in final height, with again a significant effect of 'Location' as well as three attributes of initial size (Table 8).

A similar model for final canopy area explained 41% of the variation. The significant terms were the canopy area and height of the liners used as starting material. In this case there was no significant effect of 'Location'.

Table 8. *Hebe albicans* containers: statistical significance of adding various terms to a linear regression model relating final height to earlier measurements on the same individual plants. The model explains 51.3% of the variation in final plant height.

Model term	*P* (significance level)
Location (loc)	**< 0.001**
Initial stem diameter (st_diam[1])	**0.009**
Initial height (ht[1])	**< 0.001**
Initial number of basal branches (n_brnch[1])	**0.043**
Initial canopy area (cnpyarea[1])	0.590
st_diam[1] x loc	0.604
ht[1] x loc	0.374
cnpyarea[1] x loc	0.546
n_brnch[1] x loc	0.940

Penstemon 'Port Wine' liners

The starting material was rooted cuttings which had been held over longer than ideal and were showing huge variation in height associated with position in the mist bed. Average height of the cuttings at this stage was 11.7 cm with a sd. of 7.8 cm (giving a CV of 66%) and some of the cuttings were starting to flower. During potting into 9 cm liner pots the plants were pinched back to two or three nodes, which removed much of the variation in height: the sd dropped to 1.1 cm and CV to 27% (Figure 18).

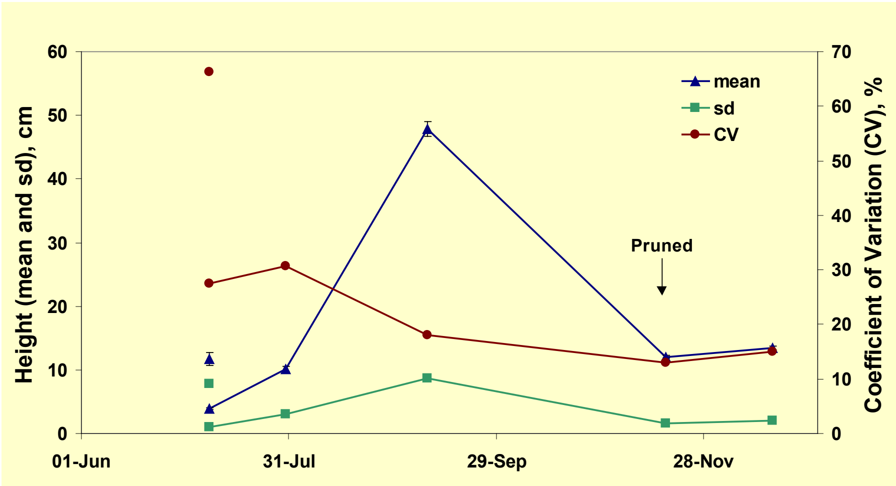


Figure 18. *Penstemon* 'Port Wine' liner crop: changes in uniformity as plant height changed due to growth and pruning. The disconnected points refer to measurements made on the rooted cuttings in their trays immediately prior to pruning and potting on 8 July. The crop was grown under glass and was hand watered.

As the plants regrew over the first 3 weeks after pinching, sd and CV increased. However, thereafter sd increased more slowly than average height so that CV fell to 18% (Figure 18). This was probably due to the tallest plants starting to initiate flowers so that their growth slowed down compared to shorter plants. The liners were then cut back, later than intended, reducing sd but with little further reduction in CV.

Model fitting explained only 16% of the variation in height before the final cutting back, the effects of 'Location' and initial stem diameter almost being significant. By comparison, 41% of the variation in the final number of branches, an important aspect of liner quality, was explained by a similar model (Table 9). The model included significant effects of 'Location' and initial stem diameter but there was no significant influence of initial number of branches (i.e. branches on the cuttings before pinching and potting).

In summary, pruning very variable cuttings at potting was reasonably effective in removing variability but it is likely to have been a carry-over from the propagation stage that explains the effect of 'Location' on final branch number.

Table 9. *Penstemon* 'Port Wine' liners: modelling final branch number. The table shows the statistical significance of adding various terms to a regression model relating final number of branches to measurements made on the rooted cuttings before potting. The model explains 32.7% of the variation in the number of branches on the finished liners. A similar model for plant height on 30 July, before severe trimming, explained much less of the variation (15.8%). While none of the terms was significant at P = 0.05, the effects of 'Location' and initial stem diameter came close to significance (P = 0.064 and P = 0.052 respectively).

Model term	*P* (significance level)
Location (loc)	**0.028**
Initial number of branches (n_brnch[1])	0.228
Initial stem diameter (st_diam[1])	**0.037**
Initial height (ht[1])	0.674
Flowers present on cutting (flwng[1])	0.945
Number of leaves retained at potting (n_lvs[2])	**0.002**
st_diam[1] x loc	0.384
ht[1] x loc	0.117
n_lvs[1] x loc	**0.023**

***Penstemon* 'Port Wine' containers**

The starting material for this crop was a batch of liners which had been allowed to grow too tall before cutting back, just as happened to the crop described above. As a result height was initially very uniform (CV = 12%). However, this masked variation in the number of viable leaves, many of the lower leaves had been shaded out, and there were few intact lateral shoots ready to resume growth immediately. As lateral buds started into growth, height was measured to the tallest growing point rather than the height to which the crop had been cut. There was therefore a slight decrease in average height, along with an increase in sd (Figure 19). This increased CV, which then continued to increase as the plants grew until shoots switch to flower production in July. As referred to earlier, flowering had the effect of reducing variation in height and in the finished crop the CV of plant height was only 12%.

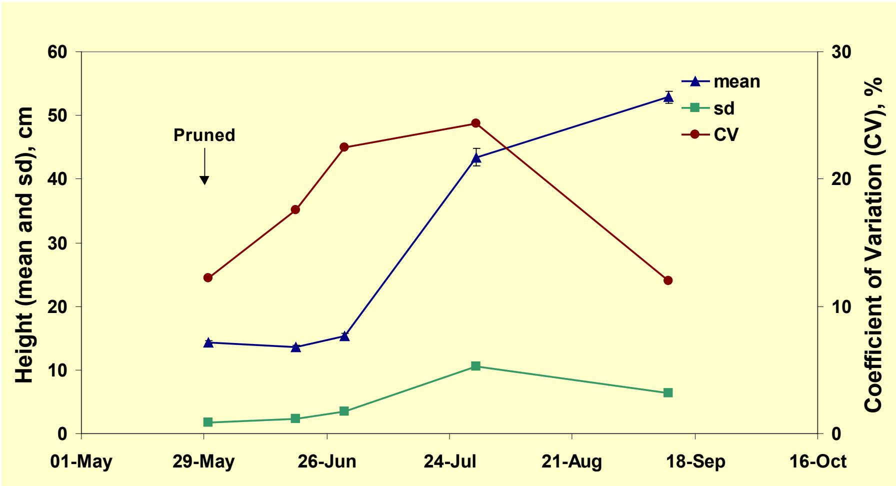


Figure 19. *Penstemon* 'Port Wine' container crop: changes in uniformity as plant increased over the course of the season. The crop was grown on an outside bed with overhead sprinkler irrigation.

Not surprisingly in view of the strong influence of flowering and the severe pruning just before the first height measurement, model fitting explained only 10% of variation in final height, the only significant component being 'Location'. However, quality of the finished plant depended more on the number of flowering branches than plant height. The CV for this variable was 47%. Fitting a model accounted for 46% of the variation with significant effects from 'Location', the number of main stems and new growing buds (Table 10).

The effects of 'Location' may well have been related to water supply. Plants were irrigated by manually controlled overhead irrigation nozzles. The amount and distribution was such that 28% of plants were lost over the course of the experiment, excessive water stress apparently being the major cause of losses.

Table 10. *Penstemon* 'Port Wine' containers: modelling the final number of flowering stems. The table shows the significance of adding various terms to a model relating number of flowering shoots on the finished plant to initial measurements on the same individual plants. The model explains 45.9% of the variation in final plant height.

Model term	*P* (significance level)
Location (loc)	**0.013**
Initial height (ht[1])	**0.047**
Initial average stem diameter (st_diam[1])	0.531
Initial number of stems (n_stems[1])	**< 0.001**
Initial number of growing shoots (n_growbs[1])	**0.008**
Initial canopy area (cnpyarea[1])	0.055
Height liners cut to before potting (cut_ht[1])	0.123
st_diam[1] x loc	0.606
ht[1] x loc	0.559
n_stems[1] x loc	0.422
cnpyarea[1] x loc	0.279
n_growbs[1] x loc	0.353

***Spiraea* 'Arguta' cuttings / liners**

This crop was monitored from the unrooted cutting stage, the first measurements being made a few days after sticking. The results in Figure 20 show that the height of the cuttings was relatively uniform, the CV being just 8%, but rapidly increased as growth of new laterals added to plant height during rooting and weaning. Although there was a further increase in CV after potting, it is not possible to attribute that increase to the effect of potting *per se*. The increase was modest and it seems likely it would have occurred if the cuttings had been left in the rooting trays, where they would have been more susceptible to variable shortage of water or nutrients and to competition for light.

Since it was not possible to monitor the crop through to the finished liner stage, modelling the sources of variation was not attempted.

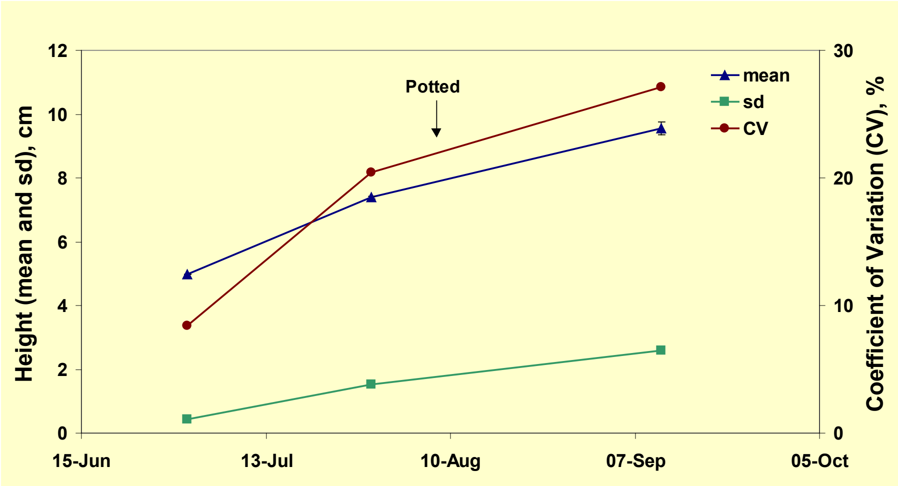


Figure 20. ***Spiraea*** **'Arguta' liner crop: changes in uniformity during rooting and early stages of liner production. The first measurement was on freshly stuck cuttings under mist, the second on rooted cuttings during weaning in the mist house, and the third was on the linersat about 4 weeks after potting and transfer to a polythene tunnel under overhead sprinkler irrigation.**

Choisya 'Aztec Pearl'

A limited amount of data was collected on this crop, starting with the entire length of the cuttings as prepared. The data in Figure 21 show that cuttings were cut to a fairly uniform length (sd of 1 cm, CV of 13%). The variability in height of visible cutting after sticking was similar in absolute terms but this was a much greater proportion of the small length of cutting exposed so the CV increased to 3%. This reflects the weakness of plant height as a measure of size for cuttings, especially non-apical cuttings. It was clear that cuttings of similar height and thickness could differ considerably in leaf area and in the extent of shading from other cuttings.

By the time that the rooted cuttings were potted on into 9 cm pots about 10 weeks later, average plant height had more than doubled. The sd also increased over this period but by slightly less than two times so that the CV decreased to about 30%. Unfortunately, it was not possible to monitor this crop through the subsequent trimming and regrowth and overwintering to the finished liner.

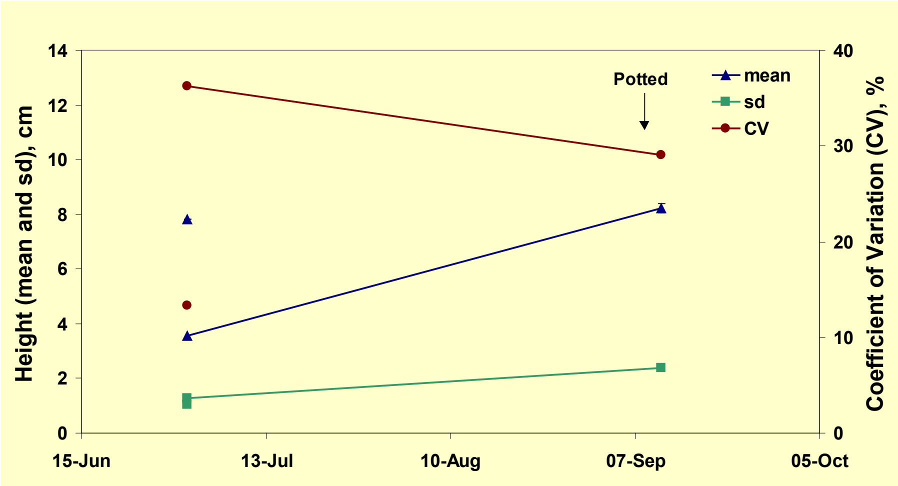


Figure 21. *Choisya* 'Aztec Pearl' liner crop: changes in uniformity of plant height during rooting and early stages of liner production. The disconnected points refer to the length of the entire cutting before sticking.

***Weigela florida* 'Variegata' liners**

This crop was studied at East Malling where it was easier to test for carry-over effects from the stock plant. Cuttings were collected from two distinct types of shoot on the hedge. 'Upper' shoots were those from the top of the framework, which tend to be strongly growing thick vertical shoots; 'Lower' shoots were those from lateral positions lower on the framework, which tend to be weaker growing and thinner shoots growing at a small angle away from the vertical. The aim was to select from these two sources cuttings which looked essentially the same and test to see whether there any variability in the finished liners that reflected the 'invisible' difference in their origin.

We collected the weakest 'Upper' shoots and the 'Strongest' lower shoots and then graded them on the bench to achieve as close a match in appearance as possible. Based on a sample of 20 shoots of each type, Upper shoots averaged 85.8 ±1.3 cm compared with 71.0 ± 1.2 cm (mean ± standard error). Apical cuttings prepared from these sources were extremely similar in all visible respects. For example the length of the prepared cuttings was 7.58 ±0.297 from Upper shoots and 8.24 ± 0.337 from Lower shoots. Stem diameters were 2.79 ± 0.058 and 2.50 ± 0.056 respectively. Dry weight, leaf area, leaf number and leaf area per unit leaf dry weight were all closely similar.

Keeping the identity of each individual cutting, these two types were then handled together, in 4 closely adjacent 'Locations', starting with rooting in fog.

The CV of cutting length, as prepared on the bench, was 18.2%. After sticking, the sd of the height above the surface of the tray was similar to that of cutting length but, since the exposed part of the cutting was much shorter than the entire length, CV was much greater at 30% (Figure 22). Cuttings grew during rooting and the increase in sd was smaller than the increase in height so that CV decreased slightly. An initial pruning to two visible nodes further reduced sd as well as height, with a small decrease in CV. Little change in CV occurred during the flush of regrowth following this pruning. More severe pruning, to just one visible node, reduced sd to < 1 cm but average height was then so small that CV *increased*. This was partly an artefact of using plant height as a measure of plant size and partly because the cut was made to a node rather than to a specific height. As plants regrew, CV fell to 16%, which is almost certainly lower than it would have been if the second pruning had been omitted.

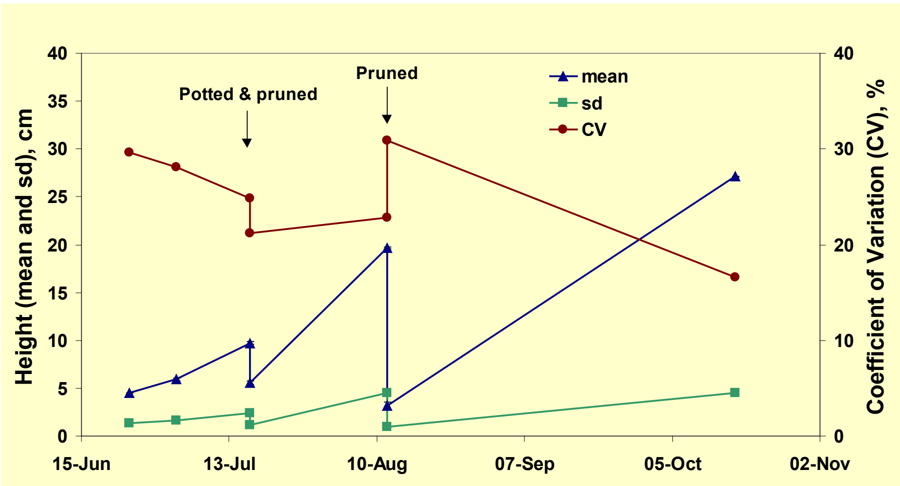


Figure 22. *Weigela florida* 'Variegata' liner crop: changes in uniformity during rooting of cuttings and early growth of liners in small scale facilities at East Malling. The first measurement was on freshly stuck cuttings in fog, the second at the start of weaning, the third and forth before and after potting. After potting, plants were cut back to 2 nodes and placed on a sandbed in a polytunnel. The liners were handwatered as required.

As in the trials on commercial nurseries, correlations between initial and later height measurements were weak. Model fitting for the variation in height on 10 August, before the second pruning, explained 22% of the variation, with significant effects of cutting type and the height of the previous cutting over (Table 11). For the final height, and for growth following the second pruning, model fitting explained only 7 to 8% of the variability and, anomalously, attributed a significant effect to the initial height of the cuttings. Occasional anomalies of this sort are inevitable when fitting a large number of alternative models and it seems extremely unlikely that the result would be repeatable.

In summary, it seems that any effect of earlier size or growth in an earlier phase is weak in this species. An carry-over effect of cutting source was detected but it was not a major factor determining variability and had no significant effect after the second pruning. Either the observed plant to plant variability must be due to slight variations in the micro-environment, or to other aspects of 'invisible' variation between plants. One possibility is that potential growth rate depends on factors that differ greatly between individual buds within a single plant. In that case, pruning, by replacing one set of shoots with shoots from a new set of buds, may tend to break any correlation between final size and size or growth rate in the early stages.

Table 11. *Weigela florida* 'Variegata' liners: modelling plant height after the first growth flush (i.e. over the 4 weeks between 1st and 2nd pruning) The table shows the statistical significance of adding various terms to a regression model. The model explains 21.6% of the variation in the in plant height on 12 August.

Model term	*P* (significance level)
Location (loc)	0.067
Type of cutting (from high or low on the hedge (c_type)	**0.010**
Initial stem diameter (st_diam[1])	0.791
Initial height (ht[1])	0.556
Root score at potting (r_score[3]	0.176
Height after potting & pruning (cut_ht[3])	**<0.001**
st_diam[1] x c_type	0.924
ht[1] x c_type	0.244

Summary and conclusions

- In terms of sd, variability almost always increased as the crops grew and only decreased when they were trimmed or pruned.

- In some crops (e.g. the Escallonia crop described above), sd increased faster than the rate of plant growth so that CV increased also. For such crops, it appears that their shape and size are not tightly controlled genetically. Rather, they are programmed as 'opportunists' growing as fast as conditions allow. For such crops, trimming is essential to maintain a reasonable level of uniformity and to create a well-balanced shape.
- In other crops, e.g. Hebe, sd increased more slowly than the plants grew so that CV decreased. In such crops it appears that the shape and size is under relatively strong genetic control. Nonetheless, adverse environmental conditions can distort the genetically programmed growth pattern so non-uniform environmental conditions remain a major source of variability.
- The tightness of genetic control can vary with stage of growth. For example, Penstemon was very variable as a rooted cutting and during liner growth but became much more uniform, at least in terms of plant height, as shoots switched from vegetative growth to flower production.
- Averaged over all crops studied, there was a tendancy for CV to increase slightly over the course of production.
- Pruning always reduced sd but, when cuttings or liners were cut back hard in the early stages of production, the reduction in height was sometimes greater than the reduction in sd so that CV actually increased. However, this was essentially an artefact of relying on height as a measure of plant size and CV dropped rapidly as the plants regrew from axillary buds.
- The reduction in variability from pruning could be short-lived, particularly if some shoots were missed because, at the time of pruning, they were not long enough.
- There was some evidence that variability increased most rapidly during rooting and weaning, probably because cuttings and the rooting process are particularly sensitive to environment and it is hard to create a uniform propagation environment. There was no evidence of a sharp increase in variability following potting or any other production process.
- There was remarkably little correlation between final plant height and size of starting material, whether the starting material was cuttings for a liner crop or

liners for a container crop. The same applied to other measures of plant size such as the number of branches, the canopy area or stem thickness.

- Using a statistical modelling procedure to investigate the combined effects of many influences, e.g. to account for the effect of stem thickness as well as height of the starting material, we still found that little of the variability in the final crop could be attributed to the size of individual plants at the start.
- The most consistently significant source of variability in the final crop was variation in growth between different parts of the crop, i.e. between the 'Locations' of our three samples, which were usually as little as 2-5 m apart. This strongly suggests that non-uniform environment was the major source of variability in the final crop.
- In some cases (e.g. the Escallonia container crop and the Hebe liner crop), this 'Location' effect was clearly attributable to variation in water supply. In other, no cause could be identified.
- Variation in the starting material is not generally the main cause of variation in the final crop. However, this generalisation is unlikely to hold true in all circumestances, particularly if different batches of starting material are mixed or if it is already close to final size and simply requires to become established in a larger pot to be ready for sale.
- Variation in environmental conditions is an important source of variability in the final crop, leading to differences in growth between one area and another within the crop. Sometimes such effects can be detected as clearly visible gradients on the bed but often they would not be readily detected by eye.
- Variation in water supply is probably the most important environmental factor causing non-uniformity of HNS.

Future work

The project has highlighted the importance of enviromental variation over distances of 1 to 5 m within the growing area of a crop. It has failed to identify the source of the variation between adjacent plants and this must be the next step in solving the uniformity problem. Is it differences in their individual micro-environments (e.g. variation in water reaching individual plants, or competition for light amongst pot-thick plants) or is it inherent but invisible physiological differences in the starting material?

There is also a need to extend the sort of nursery trials described here to collect simple environmental measurements such as soil moisture content and to involve nurseries more in making this sort of measurement. In the long run, improvement will depend on attention to detail in all aspects of the crop production process and this will require nursery staff to become sensitive to the factors that introduce variability and probably to do there own trials to optimise protocols to suit their own facilities, crops and markets.

Improving the uniformity of water delivery is clearly important and requires research but any additional effort in this area will need to be carefully coordinated with the LINK project and HDC demonstration project which should be starting shortly.

In the longer term, it is very likely that reliable data on the economic costs and benefits of achieving greater uniformity will be required so that individual businesses can make rational decisions on how much effort to invest in eliminating variability.

As understanding of the nature of the problem improves there will be an increasing need for in-depth studies of particular crops identified as representative of important sub-sectors. This should be co-ordinated with providing nurseries with guidance or even training in how to conduct trials to optimise their own systems of production.

Pruning is clearly an important tool in the nurseryman's armoury and current methods appear to be an unhappy compromise between doing a precise job and keeping the lid on the labour costs involved. In an age when some pot plants are being visually scanned and pruned robotically, there is a need to identify the sort of equipment that could improve practice in the HNS industry in a cost-effective way.

The question of improved equipment for pruning cannot be separated entirely from the need for greater understanding of the ways that HNS respond to pruning. This is a complex problem from the physiological viewpoint because the factors controlling which buds start to grow and which remain dormant, with and without pruning, are poorly understood. What is required is a combination of a systematic study of reponses to pruning at the practical level in a number of important crops, together with more stategic physiological studies such as those envisaged for the studentship on the control of branching in HNS.

TECHNOLOGY TRANSFER

There have been no specific technology transfer events but the project has involved a good deal of two way exchange of knowledge between researchers, advisers and nurserymen in the course of gathering the required information.

GLOSSARY : terms, abbreviations and products used

CV - coefficient of variation - a measure of variability of a particular measurement, such as plant height, over a population of individual, expressed relative to the average size of the measurement. It is defined as the standard deviation / mean and is usually expressed as a percentage. (CV% = (sd ÷ mean) x 100)

***P* -** probability, expressed as a fraction. E.g. $P = 0.5$ is the same as a 50% probability.

($P < 0.05$, $P < 0.01$, or $P < 0.001$) - a statement of the statistical probability (*P*) that the observed differences could have been due to chance. The smaller the value of *P*, the more certain we can be that the result is 'real'. A value of 0.05 is conventionally taken as the threshold for accepting the result, i.e. that an effect is 'statistically significant'.

sd - standard deviation - a measure of the variability of a set of values, i.e. the dispersion of the individual values around the mean. It provides a measure of how far, on average, individual values differ from the mean.

TABLE 12

Table 12. Correlation matrix for Escallonia 'Crimson Spires'.

Key: ht = plant height; std = stem diameter; nb = number of branches; miss = missed previous pruning; growth = increase in height over the preceding interval. Number in brackets identifies the measurement date: 1 = 2 July ; 2 = 9 July ; 3 = 23 July; 4 = 4 September; 5 = 27 November.

ht[1]	1.00												
ht[2]	0.65	1.00											
ht[3]	0.49	0.68	1.00										
ht[4]	0.21	0.44	0.68	1.00									
ht[5]	0.09	0.26	0.39	0.60	1.00								
std[1]	0.26	0.14	0.05	0.26	0.17	1.00							
std[3]	0.34	0.30	0.46	0.51	0.38	0.63	1.00						
std[4]	0.21	0.29	0.38	0.62	0.58	0.44	0.64	1.00					
nb[1]	0.25	0.08	-0.02	0.14	0.14	0.47	0.36	0.35	1.00				
nb[3]	0.27	0.34	0.71	0.52	0.48	0.25	0.55	0.39	0.27	1.00			
nb[4]	0.17	0.34	0.51	0.60	0.41	0.22	0.32	0.57	0.10	0.37	1.00		
nb[5]	0.01	0.05	-0.20	-0.20	0.29	-0.07	-0.30	-0.13	0.02	-0.12	-0.07	1.00	
miss[1]	-0.01	0.11	0.41	0.30	0.04	-0.39	0.00	0.09	-0.40	0.23	0.21	-0.25	1
	ht[1]	ht[2]	ht[3]	ht[4]	ht[5]	std[1]	std[3]	std[4]	nb[1]	nb[3]	nb[4]	nb[5]	miss[1]

Photographs for HNS 117 final report (EMR part)

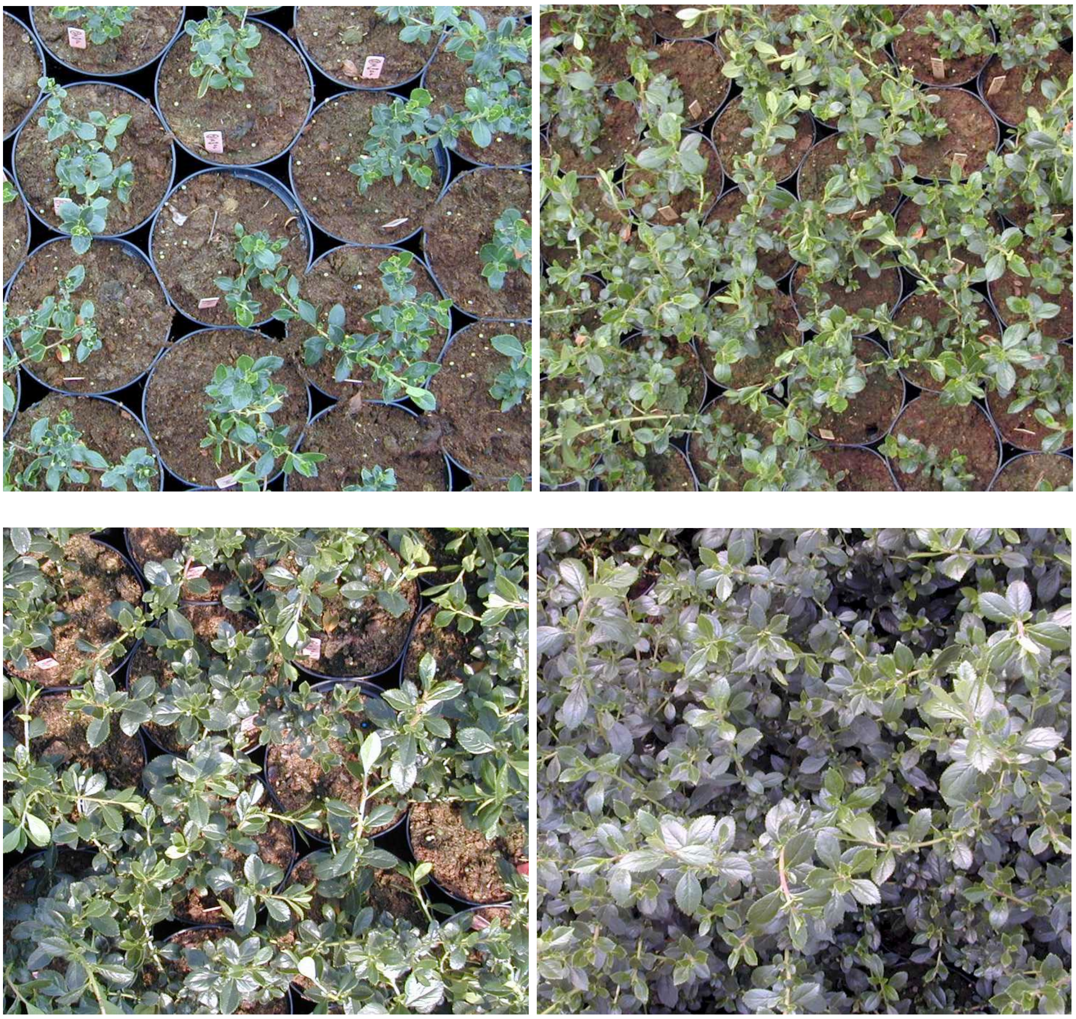


Figure 7. *Escallonia rubra* 'Crimson Spires' crop, viewed from above to emphasise the variability in leaf area and ground cover by plants in the same 'Location' and the large difference in growth between 'Locations'. Upper row: 4 weeks after potting (25 July); lower row: 10 weeks after potting (4 September). Left column: 'Location' 2; right column: 'Location' 3.

4 weeks after potting (25 July)

10 weeks after potting (4 September)

22 weeks after potting (27 November)

Figure 8 ***Escallonia rubra*** **'Crimson Spires': photographs tracing the growth and development of the tallest and shortest plant in Location 3 (plant 65, left and plant 70, right). In this case, the final size reflects the difference in initial size but this was not consistently the case.**

4 weeks after potting (25 July)

10 weeks after potting (4 September)

22 weeks after potting (27 November)

Figure 9. ***Escallonia rubra*** **'Crimson Spires': photographs showing the growth and development of two plants in Location 2 (plant 49, left and plant 47, right). Plant 49 was initially the larger but was pruned much harder when plants were tidied up in October. It is clear that this differential pruning broke the correlation between current size and earlier size and produced very dissimilar final plants. This is an example of the way that pruning can sometimes fail to increase the uniformity of a crop**

Photographs for HNS 117 final report (EMR part)

Figure 10. Overall view of the ***Escallonia*** **crop on 4 September, showing the position of the three 'Locations'. Growth was much more vigorous in the bed at the far left hand end (Location 3). There was also a decline in plant height across the main bed which is visible in this picture (from right to left).**

(This picture missing)

Figure 11. ***Escallonia rubra*** **'Crimson Spires', at the time of the first record on 2 July. The uneven colour of the medium suggests uneven irrigation.**

Appendix 1

STATISTICAL RISK ANALYSIS

Introduction

Lack of crop uniformity has been identified by growers and the HDC as a key issue threatening the profitability of the HNS industry. It creates severe wastage because a substantial proportion of many crops fail to meet buyers' specifications or other criteria of saleability. It also adds greatly to labour costs because at every stage nursery staff need to take account of variation in the crop in order to make decisions about pruning and other methods of plant manipulation.

Uniformity is not an easy property to specify, but it relates to consistency of product, particularly within a batch. The primary method of achieving uniformity at present is through pruning, and the removal of weak plants at intermediate stages. At the end of the production process, the assembly of uniform batches to meet individual orders further increases the uniformity of product supplied to an individual customer. This process alone has been estimated to account for 30 - 40% of a nursery's total labour costs. More generally, it has been asserted that a 30% reduction in wastage could lead to a three-fold increase in profit margins. By identifying the sources of non-uniformity this project aimed to pave the way to reducing those costs, thus enabling the industry to become more competitive.

Historically, scientific research into HNS has been directed at identifying treatments that improve the average performance of the crop, rather than limiting the variation between plants within the same treatment. Therefore, there is a need to re-examine published results to see whether it is possible to extract useful information about the variability within batches of plants receiving the same treatment and the way that it changes through the production process. Part of this report relates to the largely fruitless search for information on the uniformity problem both within the industry and the scientific literature: identification of stages of the growing process in which the opportunity for variability to occur was an important aim, as well as identifying those parts of the process where information was lacking. In anticipation of there being a limited amount of data on non-uniformity a major part of the report presents new data collected on commercial nurseries, which was designed specifically to measure changes in uniformity of HNS crops over the course of production. That specific exercise is reported on separately in the Scientific Report section. In this report we shall look more generally at other sources of information.

How much of a problem is uniformity?

As part of this project meetings were arranged with growers and nurseries visited so that we could see the nature of the problem, the logistics involved, and get some idea of the different perceptions of growers of the problem. Some 10 nurseries (of varying sizes) were visited, and extra discussions were had with growers and advisers. Meetings with growers suggested that uniformity was more of a problem with those delivering to 'volume' retailers, particularly in terms of delivering a crop to a 'tight' specification. For the more regular inter-nursery, garden-centre and landscape / amenity business tight specification was less of a problem, although crop uniformity was seen as a problem when preparing orders. These general comments are in accord with the findings of Tim Briercliffe and Martin Emmett in Section 5 of their report 'Defining the Size of the Industry and the Most Important Products' which accompanies this document as a further Appendix. Briercliffe and Emmett note that the industry is changing, and they attribute this primarily to the increasing volume of plant material now being sold through multiple retail outlets such as DIY superstores, major garden centre chains and supermarkets. The impacts of these changes are affecting the industry both directly, in terms of the pressure on margins to growers who supply these outlets, but also indirectly, as the major growers become involved in category management. This frequently leads to specialisation within the supply chain, with inter-dependence of growers through sub-contracting of processes or plant-supply. It is worth emphasising some of Briercliffe and Emmett's comments:

> "The dynamics of this sector are changing. An increasing volume of plant material is now sold through multiple retailing outlets, such as DIY Superstores, major garden centre chains and supermarkets. With this shift comes greater pressure to reduce cost and improve quality/uniformity. Wastage can no longer be tolerated by growers as

the pressure on margins means that disposing of waste usually means disposing of profit. Uniformity is therefore an essential requirement for long term sustainability of businesses supplying retailers.

Higher standards of uniformity are increasingly demanded by multiple retail customers showing little flexibility against the specifications set. Failure to meet these specifications leads to increased wastage and handling inefficiencies within the supplying nursery. Uniformity is of lower importance for nurseries supplying the amenity sector where cost is a stronger driving force.

It is likely that most growth in recent years has been in 'Trade Sales'. This growth emphasises the increasing specialisation within the industry as different links in the supply chain become more distinct. Many of the larger nurseries are reducing the volumes of plants that they propagate themselves and some do not propagate at all. This means an increased reliance on other businesses supplying propagated (liner) material. The industry of 'young plant production' has rapidly expanded over the last decade and looks set to continue to do so. These specialist propagating nurseries are able to invest in a more focused way and concentrate on improving uniformity. Growers buying liners have a much higher quality expectation from liner suppliers than if they were growing liners themselves. In addition to this, increased mechanisation means that uniform liners are even more important. This trend has been most clearly seen in the bedding plant sector where uniform seedlings are essential for automatic transplanters to work efficiently."

Many growers saw 'controlling waste' as an important contribution to the uniformity problem, but there were several specific sources of non-uniformity that they identified as potential culprits:

- water supply / irrigation
- light / spacing / environment

- cutting type / clonal status
- nutrients / compost
- drainage / potting / water status

The results of Richard Harrison-Murray's investigations in the earlier part of this report would tend to confirm that the first two factors are certainly important sources of lack of uniformity, but also suggests that cutting type and clonal status can also have a marked effect on subsequent crop growth.

Published literature

A thorough search of the published literature, using bibliographic database services, failed to identify any papers on the subject of HNS uniformity, nor any published data that could be reworked to provide relevant information. Growers were not able to supplement this with much useful data – inevitably, and understandably, the majority of data maintained by growers relates to stock and sales, with a limited amount of information on losses. Unpublished data from a completed LINK project on irrigation of HNS (HNS 97) proved to be of some value but involved relatively small numbers of plants and was confined to the container stage of production. The most comprehensive data were those collected from commercial nurseries which are detailed elsewhere.

The CAB abstracts from 1973 to the present were searched systematically in an attempt to identify papers that might contain useful data. Individual key-words generally identified too many 'hits', e.g. the word 'growth' was picked up over half a million times! 21 genera were identified as important, and between them they generated some 11,000 hits, individual genera varying from a couple of dozen hits to several thousand. Selective use of 'key genera' with other terms such as 'pot grown' and 'nursery', or restriction to CPIPPS publications provided some 50 'hits' that looked potentially promising. A dozen of these were chosen randomly and the full papers found and read. In all cases, where a statistical analysis had been done it conformed to the standard analysis of variance method, which assumes that variation between treatments or cultivars is consistent. In practice this assumption is rarely checked, but it is not possible to re-analyse the results because source data are never published. Given the result of this survey it was concluded that we would not find anything of value in a fuller literature search.

Other data sources

The following list shows the sources of data that were identified and have been used in the preparation of this report:

- The new data collected from commercial nurseries.
- Unpublished data from a completed LINK project on irrigation of HNS (HNS 97).
- Data provided on germination success of batches of *Clematis* spp.
- Some comprehensive data on losses on 10 species through the 'process'
- Cumulative sales data on a single species.

The studies undertaken on commercial nurseries are detailed in the Scientific section of this report. That section (prepared by Richardson Harrison-Murray) detailed the results from 14 distinct crops grown on three commercial nurseries as well as a crop of *Weigela florida* grown at East Malling Research Station. This report looks at some wider statistical issues that emerge from those data, and also considers some of the results based on the other commercial data that we were given access to.

1. Some basic statistical ideas

Uniformity and variability

To achieve uniformity one must control variability. As alluded to above the approach to HNS research in the past has been directed at identifying treatments that improve the average performance of the crop, rather than limiting the variation between plants within the same treatment. Variability can essentially be considered as the converse of uniformity, although it is more helpful to distinguish between *inherent* (or 'known') *variability*, and *uncertainty*, which relates primarily to one's lack of knowledge. The latter might be thought of as *risk*. Although we know that plants are variable, growers will generally have a 'feel' for how a particular species will respond under 'good' conditions, e.g. the average rooting percentage, losses at potting on, etc. This is considered to be the inherent variability. However, these estimates are often thrown off course by bad timing, poor weather conditions, perverse buying patterns, etc., these being the *risk* or *uncertainty* factors associated with the general variability. An important aspect of good quality control is to gain information on the *inherent variability* factors, but also to decrease the uncertainty due to the *risk* factors. Both of these are most effectively tackled by effective recording and data analysis.

Measures of variability

Two measures of variability, or non-uniformity, have been emphasised in the formal measurement part of this project and used to compare different crops and to study changes in variability within each crop:

3. The **standard deviation** (abbreviated to **sd**) is a measure of the variability of individual plants about the mean.
4. The **coefficient of variation** (abbreviated to **CV**) expresses the sd as a percentage of the mean, i.e. CV =100 × sd / mean

To get an idea of what the numbers mean, it is useful to know that, with many types of data, 68% of the individuals making up a sample are likely to lie within one standard deviation of the mean. So, if the mean height of a batch of plants is 10 cm and the sd is 1 cm, approximately 7 plants out of 10 will have a height between 9 and 11 cm. The CV expresses the relative variability of the crop, much of which will be inherent. We shall see later how it can be moderated.

Variation in variability

To illustrate the case being made above, the following two figures illustrate some of the variation in measured CVs encountered in the nursery trials. In Figure 1 there is a simple scatter-plot of the coefficients of variation of the measured species over time, and it can be seen that in only a few cases did the CV fall below 15%.

Figure 1: Coefficients of variation of 12 crops through 2003

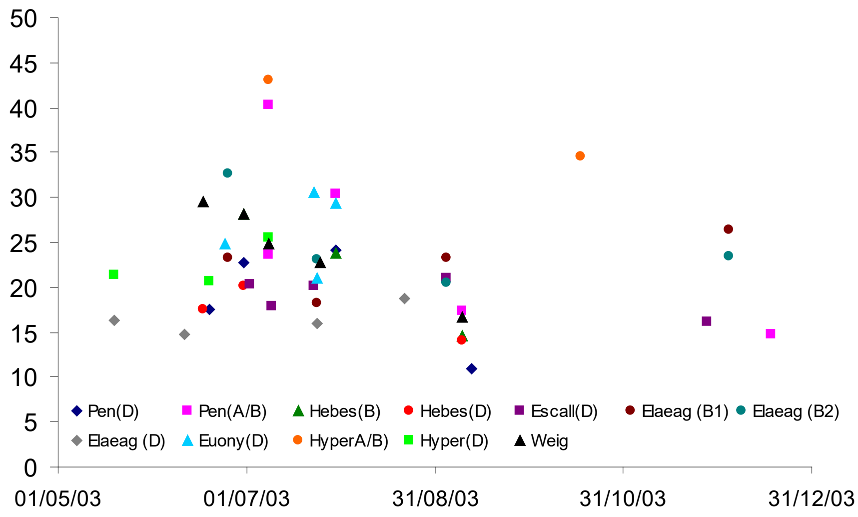
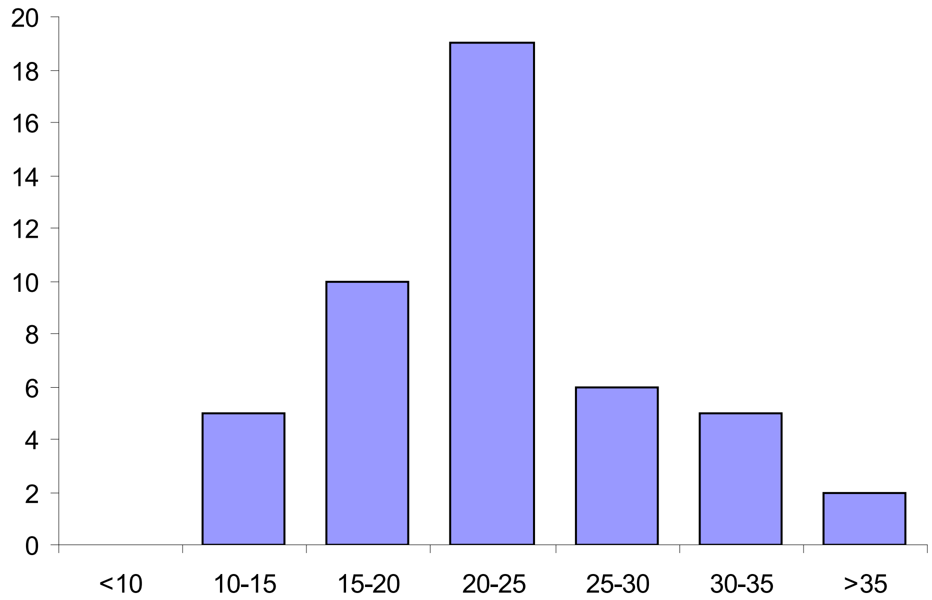


Figure 2 presents the same data as a histogram. The average CV for the 47 samples is 22.9%, but note that from Figure 1 some species do appear to have inherently larger or smaller CVs than the average.

Suppose we have a plant whose selling specification demands a height of between 60 and 80 cm. Let us say that the crop we have has an sd of 10. Then we might expect to move about 2/3rds of our crop (recall the figure of 68% above). To achieve this in the example here we need a CV as low as 14%, ($\approx 100 \times 10/70$), which is very low compared with the average CV for the crops we measured which was close to 25%. A CV of 25% would only deliver just over 40% of the crop!

Figure 2: Data from Figure 1 expressed as a histogram



The following table (Table 1) shows the impact of CV on crop acceptability:

Table 1: The impact of different CVs on the proportion of the crop that would comply in the above example

CV	'max' %age of crop acceptable
10	85
15	66
20	52
25	43
30	37
35	32
40	28
45	25
50	22

This is an extremely important point: different crops will have inherently different CVs; this implies that the proportion of one crop complying with a set specification will generally be different from another. Depending on the strictness of the specification only a proportion of a crop will be within target at any one time. The largest proportion will be ready when the average of the crop is within the specification. To sell more of the crop, a fraction will have to be harvested early and a fraction later. Some of this is self-evident and practically quite useful in that no retailer would want all the crop at the same time, but it is also important to challenge a 'tight' specification if it is too costly in terms of waste.

Hence, there are limits to what can be achieved with an individual crop, and a very important lesson is that natural variation means that delivery needs to be staggered, if most of the crop is to be used. Measurement is essential to establish the natural variation of a crop, so that an effective estimate of the saleable proportion of a crop can be calculated.

Correlation over time

In the scientific report on the data collected on commercial nurseries, Richard Harrison-Murray reported that "there was remarkably little correlation between final plant height and size of starting material". One can qualify that quite substantially, and note that

a. correlation declines over time;

b. the rate of decline is different with different crops;

c. the rate of decline is likely to vary between the same crop at different stages, and even between different batches of a crop at the same stage.

Figure 3: Plots of the correlation coefficient of successive height measurements *v.* the time between observations for *Hebe*s in liners (B) and containers (D) [see text for more details].

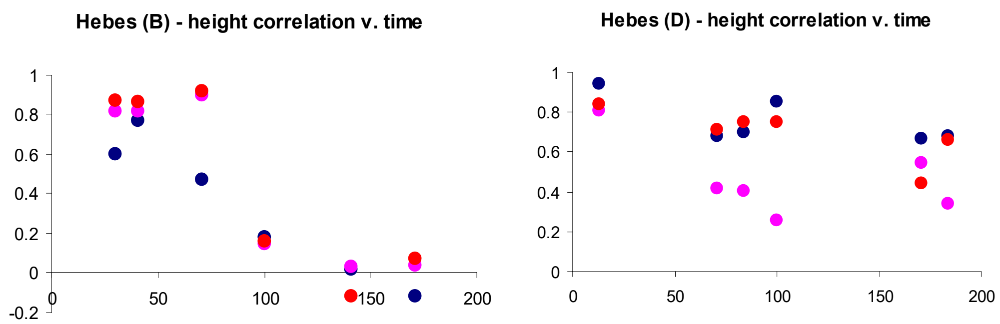
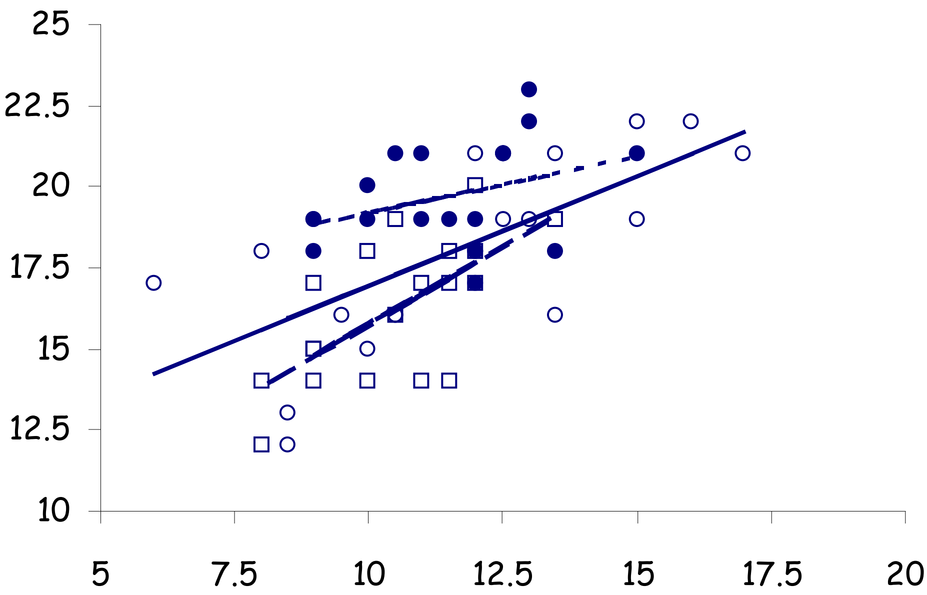


Figure 3 illustrates two of these features. The Figure shows the correlations between successive batches of two crops of *Hebe albicans*, one as liners and the other as containers. In the liner crop the correlation between successive measurements has virtually dropped to zero after about 120 days, whereas for the containers the correlation is still of the order of 0.5 – 0.6 six months after the first measurement. This may not be as surprising as it first seems inasmuch as the liners are much smaller plants, so that competition between individuals may not be very severe, whereas the more established container plants certainly show a much greater capacity for ‘memory’.

In Figure 3, there are three points corresponding to each time, and these represent the three batches that were measured at any one time. Recall that these batches were sometimes close together, although they were ‘selected’ in an effort to encompass possible environmental variation. For the liner data the three batches appear to be quite consistent, with the exception of one of the batches measured some 71 days apart. On the other hand, the container data seems to show much more variability between batches. As an illustration of this, the actual sample data for the three batches measured 184 days apart (17 June to 18 December) are presented in Figure 4. The solid symbols represent one of the batches which had a correlation coefficient of 0.341 (15 df; $p>0.05$), i.e. there was no significant relationship between initial and final height. The other two batches, however, showed

Figure 4: Scatter plot of measured plant heights in December 2003 relative to June 2003 for three batches of container-grown *Hebe*

albicans.



correlations of 0.681 (18 df) and 0.661 (17 df) both of which are significant at *p<0.01*. Note that the slopes of the three batches on Figure 4 are quite different, and these actually reflect the variability in finishing heights. In the batch with low correlation the plant heights seem to converge at the end of the measurement period, whereas in one of the other batches (that represented by the open squares) they possibly diverge. There is no obvious explanation for this behaviour, but the most likely cause is a quite marked difference in local environment.

One particularly interesting (and perhaps counter-intuitive) lesson from these data is the following: despite the differences that may be occurring from batch to batch it is generally better to leave batches of plants together rather than to sort (or grade) them at an intermediate stage. As a very simple example, suppose we had re-graded the above *Hebe*s at the outset into small, medium and large plants. Table 2 shows that the variability (as expressed by the sd) would have been much smaller initially. However, by the time the plants were re-measured in December, the variation in heights would have been much the same, and the change considerably greater. What would appear to be the case is that the average change in plant height has been evened out (through re-grading) but the variation has increased. Leaving the plants in their original groups suggests more marked differences in the averages but less variation within the groups.

Table 2: The effect of grading at the wrong time

	Sample 1		Sample 4		Change 1-4	
	mean	**sd**	**mean**	**sd**	**mean**	**sd**
A	11.63	2.924	18.05	2.892	6.43	2.324
B	11.65	1.540	19.76	1.640	8.15	1.869
C	10.45	1.477	16.21	2.200	5.74	1.653
lower	8.98	0.993	16.05	2.505	7.13	2.466
middle	11.25	0.618	17.78	2.130	6.53	2.132
upper	13.50	1.395	20.00	1.886	6.47	2.189

The above suggests the following important point: that the environmental history of a plant is quite important, at least over a short period, and that therefore 'local' groups of plants should generally be kept together through their nursery life. Indeed, the mixing of plants grown in different environments (e.g. different glasshouses or standing areas) would seem inadvisable, but these results suggest that even local variation is important, so that even smaller batches should be kept together through their nursery life. This accords with the practice of classical experimental design which uses local variation as a basis for blocking. My own experience with designing experiments over many years in glasshouse and outdoor trials at Littlehampton, Efford and Stockbridge House has shown me that local variation can be hugely significant.

Some other important statistical ideas

The Pareto Law (or 80/20 rule)

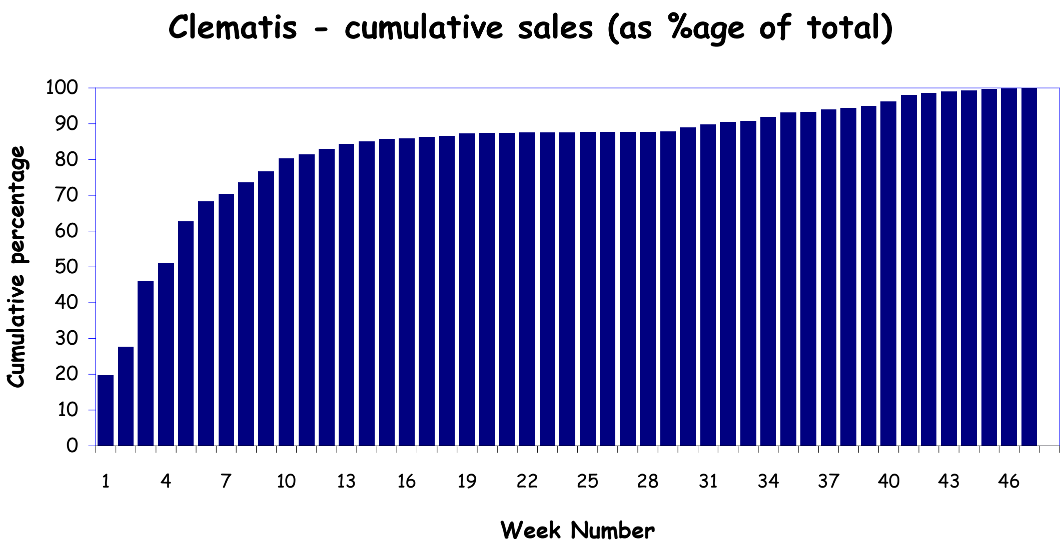
This is an empirical law that comes from economics and is currently very fashionable in business. Stated simply it says that performance depends disproportionately on doing few things really well. So, when we try to measure, say, what percentage of results is produced by what percentage of causes, we frequently find that the answer is often close to 80% of results from 20% of causes. Some examples might be:

- 80% of sales come from 20% of products
- 20% of customers provide 80% of business (20% of effort?)
- The majority of plants are dispatched very quickly

In fact, the analysis of one grower's sales data over a full year showed that 80% of his plants were dispatched within 10 weeks of the plants being ready (for approximately

20% of the year!). This is illustrated in Figure 5. The significance of this example is simply the focus on what is important. Much will depend on the philosophy of a business, but if one

Figure 5: Plot of cumulative sales of clematis over a 12-month period



builds costs into the equation, then the cost of holding and caring for a small proportion of stock would need to be weighed against the alternative opportunity cost.

The binomial distribution – how proportions work

If we wish to estimate a production run, we would normally divide the number of plants we want by the expected proportion that survive, and that new number is the number we should start with, i.e.

- We want n plants – how many cuttings should we take?
- Suppose we take n and a proportion p survive, then we only have np plants
- We need to start with x plants, so that $xp = n$, i.e. $x = n / p$

So, for example if we have a 75% success rate, then we would expect to raise 133% of target. But, to be sure, we need more, and the excess depends on the initial number.

GUARANTEEING THE OUTCOME

If our success rate was 50%, then our problem would be much the same as tossing a coin and asking that we have a fixed number of 'heads'.

Suppose we toss a coin ten times – how many heads will we get?

> In fact, we only get 5 heads about 25% of the time;
> 40% of the time we will get 4 or 6 heads;
> and some 20% 3 heads or 7 heads.

So, if we wanted to guarantee 5 heads (and by guarantee we mean get fewer than 5 heads only 5% of the time) we would have to toss the coin 16 times, which is not 200% of the target (given by the *n / p* formula above) but 320%!

On the other hand, if we are looking for 50 heads, then the number we need is 117, which is only 234%. For 500 heads we need approximately 1,050 throws, and excess of 210%

Thus, for 100 we would need an excess of 47%, for 250 an excess of 42%, and for 1,000 an excess of 37%. The larger the target the closer to 33% we get. These ideas are based on a concept known as the binomial distribution.

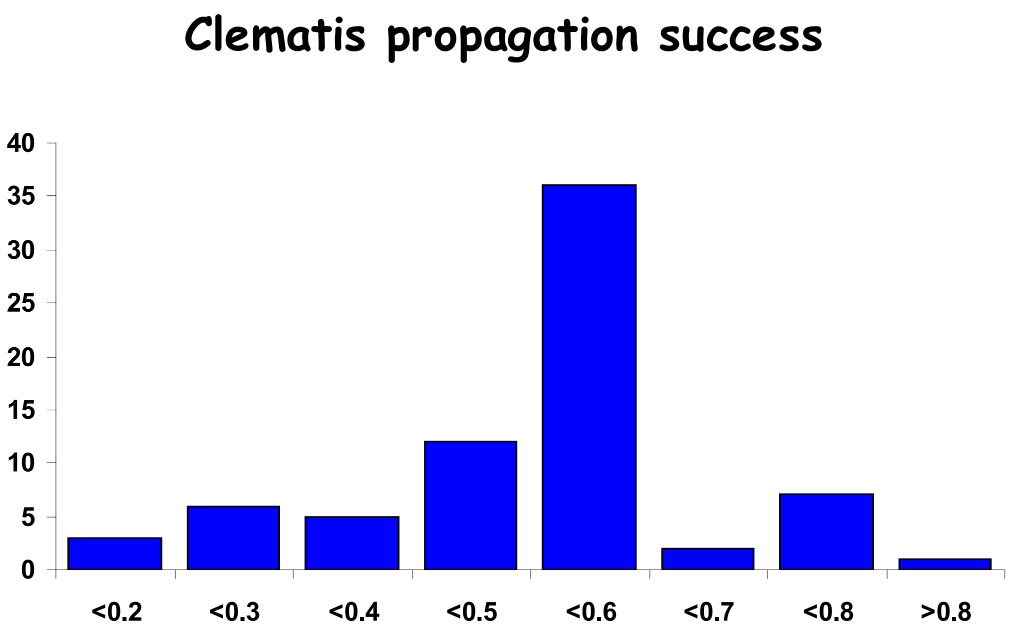
The above calculation is based on the assumption that the loss factor is known (i.e. known variability). Due to the uncertainty or risk factors real systems tend to be even more variable! Thus, for example we might expect that the average survival rate is, say 75% and adjust our numbers accordingly. However, we might find that in a good year we might expect up to 85% survival, whilst in a bad year losses may be as high as 50%. Some idea of that variation is helpful in ascertaining what strategy to use: a cautious strategy would assume high losses and over-protect, but that could be costly in terms of excess stock, whereas a higher risk strategy would work to a low excess with a stand-by of buying in if stocks fell low. An interesting example is provided by the following propagation record of a particular species from one nursery:

The data are based on 71 records of propagation success for Clematis with batch sizes ranging from 100 to over 2,000. Some simple statistics of the data are the following:

- Overall success rate = 0.562
- Batch average = 0.545 (range 0.05-0.88)

Figure 6 shows a histogram of the propagation success rates of individual batches.

Figure 6: Clematis propagation success



Some 67% of the batches lie within the range 0.5 to 0.7, whereas 80% of the individual cuttings do, which suggests that large batches tend to have higher propagation rates. In fact, this is borne out by the data with 11 out of the 14 batches with success rates lower than 0.5 coming from batches of less than 500 cuttings. Although there is no direct evidence to support this, it seems likely that propagation success might well improve over the period of propagation, so that longer propagation runs would be likely to enhance the average – effectively an improvement due to settling in, or learning.

Losses through the 'process'

One of the potentially important features of the propagation process is that failures are realised quickly so that measures can be taken early to counter any shortfalls. However, the converse should also be considered: that holding on to excess rooted cuttings can be costly if there is no planned use for them!

The next set of data (provided by a commercial nursery) show the losses through the process for ten crops. Each number represents a percentage, and is conditional on the previous stage, so, for example, the percentage lost as liners gives the number of liners (accepted at the potting stage) that survive through to potting on as containers.

Table 3: Survival rates for ten commercial HNS crops at different stages of the growing process.

Crop	propagn	rejected as liner	lost as liner	lost as container	overall
Acanthus 'Sum. Beauty'	93.5	94.5	97.2	98.5	84.5
Choisya ternata	96.7	99.4	90.2	97.0	84.0
Convovulus cneorum	89.9	93.0	98.5	98.7	81.3
Cotinus 'Velvet Cloak'	87.9	74.2	74.6	99.3	48.4
Philadelphus 'Belle Etoile'	80.3	81.2	77.1	97.0	48.8
Photinia 'Red Robin'	98.8	91.4	70.5	99.1	63.1
Spiraea arguta	98.3	94.3	99.8	97.0	89.7
Syringa 'Red Pixie'	98.6	98.2	99.7	99.8	96.4
Tadescantia 'Sweet Kate'	90.0	77.2	64.5	97.0	43.5
Viburnum tinus 'Spirit'	100.0	96.9	84.6	97.0	79.6

The overall survival is simply the product of the survival at different stages, and that would generally be the survival percentage that one would want to use in any initial calculation for propagation numbers, as described above. There appear to be some obvious 'winners' and 'losers' in this table, with *Syringa* performing particularly well, but *Cotinus*, *Philadelphus* and *Tadescantia* showing survival rates of less than 50%. In general, different loss rates occur at different stages of the growing cycle, but losses at a later stage are more expensive than losses at propagation, as the 'lost' plant remains in stock longer.

As a simple example of this, let us suppose that all the above plants could be sold for £2 (i.e. 200p) and that the cost of losing them at the four stages is respectively 20p, 30p, 30p and 50p – the real cost at any stage being the cumulative cost up to that stage. The next table (Table 5) now shows how the return on propagating 1,000 plants changes according to the position of the proportions. The return is made up of two components:

a. Sale of final containers (net return)
b. Losses through the process

but ignores fixed costs and the cost associated with making up numbers (or lost sales).

Table 5: Margins for different plant loss profiles

Crop	sales	losses	net
Acanthus 'Sum. Beauty'	592	-75	517
Choisya ternata	589	-119	470
Convovulus cneorum	569	-76	493
Cotinus 'Velvet Cloak'	338	-275	64
Philadelphus 'Belle Etoile'	341	-254	87
Photinia 'Red Robin'	442	-265	176
Spiraea arguta	628	-69	559
Syringa 'Red Pixie'	674	-17	658
Tadescantia 'Sweet Kate'	304	-337	-33
Viburnum tinus 'Spirit'	557	-167	390

Although *Convolvulus* and *Viburnum* have very similar overall loss rates, the return for the latter is much lower because the losses occur later therefore incurring greater costs; a similar situation occurs with *Acanthus* and *Choisya*. Note also that the small difference in return between *Choisya* and *Convolvulus* is not reflected in the three percentage point difference in overall survival. Again this is primarily due to a different loss profile. In Table 5 the individual species are unimportant, the example is intended to demonstrate the impact of different loss profiles, which can just as well occur with the same plant species at different locations or between years.

As noted earlier (with the clematis propagation data), figures on survival will vary both between batches, and potentially more so between seasons, so that recording of these data is important

a. in order to make 'good' decisions, but also
b. for benchmarking purposes.

Whilst benchmarking is important for individual growers, there is value in considering the sharing of bench-marking information – this does not necessarily give away any 'trade secrets', but it sets standards and helps the whole industry to develop. It also helps to identify universal problem areas.

Designed experiments – DIY Trials

With hundreds of species / cultivars being routinely grown there is no way in which formal trials can be run in a research environment. Nevertheless it is essential to use sound statistical principles to design trials to provide evidence on optimal growing conditions. There seems to be little alternative but for growers to run their own trials and 'share' information. A definite requirement for the future is the provision of training material on the design and conduct of such trials.

The theory of experimental design arose from the study of agricultural field trials in England in the first half of the twentieth century. It was based on the very simple principle that differences between imposed treatments (or varieties) would tend to be consistent despite any underlying environmental factors, such as weather or climatic factors, soil, shading, etc. It led to the idea of making comparisons between treatments in so-called 'blocks', i.e. areas of land that were deemed reasonably uniform, and this quickly led to the classical design of experiments. This became the paradigm for agricultural and horticultural research through the post-war years and proved immensely successful in advancing agriculture and horticulture, improving yields, and controlling pests and diseases.

In fact the ideas were so successful that they spread to industry and medicine. Medicine was like agriculture in that individual subjects were susceptible to huge natural variation, whereas industry, particularly engineering, was much more concerned with finding the conditions that would optimise yield, output, strength or some other measure. Many of the recent advances in engineering precision have been based on a different approach to quality control pioneered by Taguchi. The method is a holistic one encompassing initial design and end-use, as well as considering the impact of what are termed intrinsic and extrinsic variables. This latter is no more than efficient classical industrial experimental design. Whilst 'designer' plants are not likely to be considered in HNS, this methodology is being considered in the pot-plant industry (see the report on PC152 'Robust Product Design' in the July 2004 issue of HDC News).

The very success of the statistical design of experiments in agriculture created changes in the requirements for crops, particularly in the case of horticulture. Over the last twenty-five years or so the market has become much more demanding in terms of quality – essentially a shift from a supply-led system to a demand-led one – and, certainly in the case of edible crops, the large retailers have gained control of the supply chain, and are forcing changes in the way growers run their businesses. Today it is estimated that around 80% of fresh horticultural produce is traded through the supermarkets. Until recently, ornamental nursery stock was fairly immune to this, but the large retail chains are beginning to impose stricter standards on the industry.

What can experimental design show us? Over many years various empirical laws were developed, looking at such things as the variability associated with plant growth, in terms of both the size of the plant and in terms of its physical location. In particular it was quickly realised that making comparisons between plants set close together, on the assumption that the conditions were likely to be more nearly uniform locally, led to considerable gains in precision. Some simple rules of design carry through to production:

- Start with uniform material
- Block for planned uniformity
- Relative variation is fairly constant, so larger plants will 'vary' more than smaller ones

However, another couple of rules are important for proper experimentation:

- Replication: repetition of treatments, to insure against 'false positive' results which will occur by chance

- Randomisation: which both prevents bias but also ensures that the basis for inference (or decision-making) is statistically sound.

With the HNS sector growing literally hundreds of species / cultivars it will be necessary to run trials and 'share' information. Where little is known, simple 'factorial' designs can yield much information. Suppose, for example, that one wants to set up a 'simple' experiment looking at:

2 cutting types x
2 composts x
2 levels of irrigation x
2 nutrient levels x
2 pot sizes x
2 environments

= 64 combinations!

This can be reduced to 16 runs by employing a 'trick' called fractional replication, so that a carefully chosen subset can yield important information on main effects, 2-factor interactions and some 3-factor ones. Thinking in terms of the Pareto rule, these trials need to be focused on important species. Experimental design is a complex subject, and although there are many textbooks on it there are none to my knowledge addressed to the particular concerns of the HNS sector. Development of an appropriate training course for technical staff is something that should be considered by the HDC.

Conclusions

"Benchmarking, monitoring and recording all sounds dull but needs doing, and needs constant reviewing to look at what happened – what was achieved and what was not, and to set realistic targets." *- David Gilchrist*

- Different crops have different levels of inherent variation (most easily characterised by the CV). This means that the proportion of a crop that will meet a given specification will vary. Two obvious implications follow from this:
    - a specification that is set ‘too tight’ for the natural variation of the crop will lead to undue (and costly) wastage
    - to comply with a given specification growers need to stage dispatch – it is highly unlikely that the whole of a crop will hit the target at a given time
- Local variation in plants can be quite marked due to small-scale environmental variation\; effects of lighting or shading, differential irrigation, complex air currents, local variation in temperature, etc. This suggests that managing plants in batches is likely to reduce the general scale of variation. It also suggests that sorting or re-grading individual plants could be counter-productive.

- Estimating the numbers of plants necessary to ‘guarantee’ a final saleable quantity involves dividing the required number of plants by the expected proportion of survivors. Other modifications can be made according to what risk factors need to be considered.

- There appears to be a general lack of good data relating to crop performance through the growing process (in terms of both variability and losses) outside the framework of stocks and sales. To enable good decision-making and reduce the problems of non-uniformity and risk-management, growers need to keep more plant measurement records. Such data is also important for good ‘benchmarking’.

- Whilst benchmarking is important for individual growers, there is value in considering the sharing of bench-marking information – this does not necessarily give away any ‘trade secrets’, but it sets standards and helps the whole industry to develop. It also helps to identify universal problem areas.

- There seems to be little alternative but for growers to run their own trials and ‘share’ information. A definite requirement for the future is the provision of training material on the design and conduct of such trials.

HDC Nursery Stock Uniformity Project (HNS 117)

Defining the Size of the Industry and the Most Important Products

1. Objectives

This report was commissioned as part of HDC Project HNS 117. In order to fulfil the following objective:

Define the Industry.

In order to understand the nature and scale of the problem some general statistics on the size and shape of the industry will be collated. These will be taken from official sources (where available) and from direct discussion with growers and consultants. Important factors to be considered are (i) the approximate number of growers and their size distribution, together with any specialisations, e.g. liner production only; (ii) the nature of the market, i.e who purchases from the growers; (iii) the major plant species in production together with any noticeable trends. Although the British industry has its own focus this may need to be framed within a more general European context. The study should identify those crops that are regarded as 'key' within the industry.

2. Methodology

Data was collated from the following official sources:

1. Horticultural Census and Survey Data (Defra)

2. The Garden Industry Monitor (Horticultural Trades Association)

3. European Industry Data (University of Hannover)

In order to fulfill the objective it was necessary to determine the "key" crops (according to economic and strategic criteria). This required some original research on the market for nursery stock products. A number of growers and retailers were interviewed and a meeting of ADAS consultants was convened on 24 July 2003 at Warwick University to discuss relevant issues. Due to commercial sensitivity, much of the information gathered was anecdotal.

One outcome of the discussions and data analysis, was the recognition of the importance of systems of product categorization in defining "key" crops. A possible system of categorization was consequently developed.

3. Basic Data on The Nursery Stock Industry in the UK

General Horticultural Census Data

In the 2001 census data the key statistics for Hardy Ornamental Nursery Stock (HONS) Production in the **UK** were:

Total area of HONS Production (field and container grown)	**9040 ha**
Number of Containerised HONS	**238 million**
Value of HONS Product	**£ 392 million**

This general census also identifies that a wholesale value of £374 million (95%) is produced in England and Wales.

Nursery Stock Census Data

Since 2000 an additional and more specific survey of the HONS Sector has been carried out only in **England and Wales**. In 2002 the key statistics were:

Total area of **field grown** HONS Production **2566 ha**
(Trees = 1669 ha, Roses = 300 ha, Climbers and Shrubs = 170 ha, Perennials = 154 ha)

Total Number of HONS containers **127 million**
(Trees = 13.8 mil, Roses = 6.3 mil, Climbers and Shrubs = 47.5 mil, Perennials = 38.4 mil)

NB: There is a discrepancy between the data in the two forms of census. The Nursery Stock census only accounts for 53% of the number of containers described in the general census. This may be due in part to the relatively low response rate (60%) of the Nursery Stock Census.

The 2002 HONS survey yielded some interesting statistics about selection of containers:

Final containers of between 2 – 4 litres were the most popular selection for Roses (74.7% of crop), Climbers (83.9%) and Shrubs (71.3%).

Final containers of less than 2 litres were the most popular selection for Herbaceous Perennials (47.4%) and other smaller plants.

The number of Holdings Producing Nursery Stock Crops in the UK

Defra Census data is collected from those horticultural enterprises operating from sites with a "holding number". Historic census data suggests that the number of holdings growing nursery stock as a business is around **1000**.

The census does generate data on the size of HONS holdings and the basic mix of products that they grow, however, this information is not published by Defra.

Not all of the enterprises producing nursery stock have holding numbers. The RHS Plant Finder 2003-2004 lists about 800 nurseries, but many of these are based within private gardens.

NB: The income, area and production of nurseries based within private gardens is probably generally unaccounted for in the statistics used elsewhere in this report.

4. Impact of the Global Market on Nursery Stock Supply

Data on the global trade in nursery stock products are collated and published annually by the University of Hanover. Their report utilises the best sources of national statistics across the European Union and other major ornamental crop production nations.

Statistics of this type are collated in different timescales by different countries, so the results are not perfectly in phase, but they give a clear impression of the relative scale of import and export activity.

In 2001 the UK imported about **£52 million**[1] of nursery stock products[2] per annum. Most imports came from the Netherlands (£35 million), they supply a similar range of products to those produced by the UK Industry. The next most important exporter is Italy (£6.5 million). There is a general belief in the UK trade that the value of Italian imports is significantly increasing. Further evidence of this is the prominence of Italian exporters at UK trade shows in recent years.

In 2001 UK exports of nursery stock products totalled less than **£4 million**[3] , this represents about 1% of total UK production.

1 Based on €1 = £0.66p
2 For this context: data for “nursery stocks” and “hardy perennials”, as defined in the University of Hannover Report, has been combined.
3 This excludes the value of dry bulb exports

5. UK Nursery Stock Supply Chain

There are two independent sources of data on the destination of HONS product in the UK. The results of the Defra Nursery Stock census 2002 and the study of consumer activity in the Garden Industry Monitor 2003 are given below (Tables 1 & 2).

Table 1: Destination of Saleable Production (Defra 2002)

Outlet	% of Saleable Production
Amenity Sector (i.e. Landscaping Projects)	18.3%
Retail Sector (e.g. Garden Centres, Supermarkets)	37.8%
Trade Sales (e.g. Other Nurseries)	33.7%
Direct to Public sales (including Mail Order)	10.2%

Based on 570 census returns

This level of information has only been collected in recent years, however, it is likely that most growth has been in 'Trade Sales'. This growth emphasises the increasing specialisation within the industry as different links in the supply chain become more distinct. Many of the larger nurseries are reducing the volumes of plants that they propagate themselves and some do not propagate at all. This means an increased reliance on other businesses supplying propagated (liner) material. The industry of 'young plant production' has rapidly expanded over the last decade and looks set to continue to do so. These specialist propagating nurseries are able to invest in a more focused way and concentrate on improving uniformity. Growers buying liners have a much higher quality expectation from liner suppliers than if they were growing liners themselves. In addition to this increased mechanisation means that uniform liners are even more important. This trend has been most clearly seen in the bedding plant sector where uniform seedlings are essential for automatic transplanters to work efficiently.

Higher standards of uniformity are increasingly demanded by multiple retail customers showing little flexibility against the specifications set. Failure to meet these specifications leads to increased wastage and handling inefficiencies within the supplying nursery.

Uniformity is of lower importance for nurseries supplying the amenity sector where cost is a stronger driving force.

Table 2: Market Share of HONS by Retail Distribution Channel (GIM 2003)

Retail Outlet	Market Share (%)
Garden Centres and Retail Nurseries	54%
DIY Superstores	16%
Other Major Retail Stores	6%
Other Named Outlets	8%
Mail Order	10%
Other Outlets	6%
Not Identified	1%

Based on data from around 6000 households

The dynamics of this sector are changing. An increasing volume of plant material is now sold through multiple retailing outlets, such as DIY Superstores, major garden centre chains and supermarkets. With this shift comes greater pressure to reduce cost and improve quality/uniformity. Wastage can no longer be tolerated by growers as the pressure on margins means that disposing of waste usually means disposing of profit. Uniformity is therefore an essential requirement for long term sustainability of businesses supplying retailers.

6. Survey of the Retail Sector

The Garden Industry Monitor (GIM)

The Horticultural Trades Association publishes an annual review of the trade known as the Garden Industry Monitor. The report contains data on consumer spending and is based on the spending of around 6,000 households selected as being a representative cross section of the GB (Great Britain, i.e. excluding Northern Ireland) population. The 2003 report is based on the year ending June 2002, key facts include:

- 49% of households purchase HONS products each year
- Of those households purchasing HONS products; the average spend per household is £90
- About 40% of the sales of garden products occur in the period April – June
- The retail value of HONS sales was £721 million (c.f. bedding plants £611 million)

The GIM categorises nursery stock and from the data presented by the 6000 households, extrapolates the value of GB sales, the results are given in Table 3.

Table 3: Retail Value of Sales of HONS Products in Great Britain (July 2001 – June 2003)

Product Category	**Value of Sales (£)**	**Percentage of Sales (%)**
Herbs	£26m	4%
Alpines	£50m	7%
Fruit Trees and plants	£23m	3%
Conifers	£28m	4%
Other Trees	£62m	9%
Christmas Trees	£23m	3%
Roses	£59m	8%
Climbers	£41m	6%
Rhododendrons and Azaleas	£30m	4%
Outdoor Ferns and Ornamental Grasses	£37m	5%
Heathers	£25m	4%
Herbaceous	£143m	20%
Other shrubs in pots up to 4 litres	£121m	17%
Other shrubs in pots over 4 litres	£42m	6%
Total	**£710m**	**100%**

Source: GIM 2003

Direct Consultation with Retailers

As part of this study, a number of Garden Centre groups were contacted for information on the most important genera in the retail market. Understandably, most declined to supply any detailed information. In the limited discussion that did take place, the following genera emerged as being of particular importance with respect to volume of sales:

- *Clematis*
- *Cordyline*
- *Hebe*
- *Lavendula*
- *Lillium*
- *Lonicera*
- *Rosa*

The primary source for most of these genera is the UK industry. However, Italy was specifically identified as an increasingly important source of *Lavendula* and other Mediterranean species.

Conifers are an important group of products, but several retailers commented on these being sourced increasingly from the Netherlands (from large scale specialist nurseries).

Two retailers were prepared to disclose more detailed information. The Author is indebted to them for the following information.

B&Q plc

B&Q plc are prominent in the horticultural sector, with 300 plus stores offering gardening products and plants. The plant offer is segmented into over 20 merchandise groups based largely on customer perception of the product.

Shrubs account for the largest proportion of sales (in excess of 20%), whilst herbaceous plants and grasses have the next largest sales participation. Other important categories include Conifers, Roses and Alpines each accounting for 5-10% of sales. There has been a marked increase in demand for heathers in recent years after a period of decline in customer interest in this group. Planted arrangements in containers and baskets continue to be popular reflecting the consumer trend for the 'instant solution'.

(Source: Ian Howell - Plant Buyer)

The Wisley Plant Centre (RHS)

The Wisley Plant Centre's customers include local people and visitors to the RHS Gardens at Wisley. The top selling genera in the Herbaceous and Shrubs categories are:

Herbaceous

1. Geranium
2. Helleborus
3. Penstemon
4. Heuchera
5= Euphorbia
5= Digitalis

Shrubs

1. Lavendula
2. Hebe
3. Fuchsia (Hardy)
4. Hydrangea
5. Cistus / Halimiocistus

(Source: Malcolm Berry – Plant Area Manager)

7. The Landscape Sector

A number of UK growers specialise in supplying the landscape sector. Traditionally, this sector utilises a lot of field grown stock, but an increasing proportion of product is now container grown.

This study did not attempt to identify the key genera specifically for landscape use, apart from reference to trade catalogues.

The landscape industry utilises a considerable amount of hedging species, along with conifers and genera with thorns such as *Rosa, Berberis, Ilex* and *Pyracantha.*

Other key species include *Cotinus, Cotoneaster, Euonymus, Lonicera (evergreen spp.) Potentilla, Viburnum, Spiraea, Symphoricarpus* and *Hedera*.

Categorisation

The HONS industry grows a diverse range of crops ranging from alpine plants to trees, in production systems ranging from field production to highly intensive protected containerised systems.

Analysis of available data is hampered by a lack of clarity and consistency in the way which products are categorised. It partly depends on the perspective of the user, viz:

- Growers might categorise crops according to the type of production system they require. Eg. “1 litre Protected Crops”
- Retailers might categorise crops according to consumer perception. Eg. “Exotics”
- Gardeners may categorise plants by their use in the garden. Eg. “Border Plants”
- Scientists might categorise by plant family or genera

Categories used in the main Defra census include “Trees”, “Roses”, Shrubs and “Herbaceous Perennials”. The more detailed Nursery Stock census contains additional categories such as “Alpines” but gives no definitions. Hence some crops (such as *Sedum sp.*) might be classed as either a “Herbaceous Perennial” or an “Alpine”.

A form of categorisation that would be beneficial to projects of this type is suggested in Appendix A.

Conclusions

Where would improvements in uniformity have the biggest impact?

In the light of a changing supply chain, it seems that growers supplying multiple retailers would gain the most from improvements in uniformity. This would include growers throughout the retail supply chain from liner producers to ‘growing on’ nurseries to packers (in the case of supermarket suppliers).

Which species should be focused on?

For the industry as a whole, it would be beneficial to focus uniformity improvement work on species sold in large volumes through multiple retailers. These should also be species grown by a wide range of growers at both liner and end product steps in the supply chain. Examples of these 'key' crops for consideration and wider industry consultation would be:

- **Lavendula**
- **Hebe**
- *Berberis*
- *Hydrangea*
- *Elaeagnus*
- *Buddleia*
- *Cotoneaster*
- *Ilex*
- *Cornus alba cvs*
- *Cotinus*
- *Forsythia*
- *Penstemon*
- *Photinia*
- *Garrya*
- *Ornamental cherry varieties*
- *Skimmia (though frequently now imported)*

Geranium, Anemone japonica cvs for herbaceous perennials.

Published References

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Defra, *Basic Horticultural Statistics 2002*, National Statistics, 2002
Horticultural Trades Association, *Garden Industry Monitor 2003 (3 Vols.),* HTA, 2003
Royal Horticultural Society, *RHS Plant Finder 2003-2004***,** Dorling Kindersley,2003
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Appendix A: Categorisation and Descriptions of Nursery Stock Production

Background

The following suggested categorisations and descriptions are based on the diverse systems of categorisation already in existence.

The categorisations are based upon:

1. Similarities in production requirements.
2. Generally recognised product groups.

Although "Bedding Plants" are generally not considered as Nursery Stock items they are included here in order to distinguish them from the "Patio Plant" category.

The Categories

1. *Bedding Plants**
2. Patio Plants*
3. Alpines*
4. Herbs
5. Heathers
6. Small Non-Herbaceous Perennials and Shrubs (including short-lived perennials and sub-shrubs) *
7. Herbaceous Perennials and Grasses (Except Bulbs and Corms)*
8. Ferns
9. Bulbs and Corms*
10. Ericaceous shrubs (eg. Rhododendron, Azalea, Pieris)
11. Climbers (except climbing roses) / wall shrubs
12. Roses
13. Larger Shrubs
14. Trees (including fruit trees, excluding Christmas trees)
15. Christmas Trees
16. Fruit Plants
17. Conifers

* Examples of specification sheets have been produced for these items.

Discussion

1. The proposed system is not perfect; plants such as hardy palms and *Yucca sp.* do not fall easily into any of the above categories

2. There is a risk of over-categorisation with the adverse consequence of making questionnaires and census forms too exacting and difficult to complete

3. If the production and retail industry plus the government could identify a uniform system of categorisation it would significantly improve the quality of market intelligence. This has partly been developed through the GIM but perhaps needs to develop with the changing industry.

Example Category Descriptions

The following examples of category descriptions have been presented in a format that gives a basic specification for the category and some basic information to assist those doing research.

Category Description Guide

Title	*From list of categories*
Description	*Typical features of category*
Ornamental Use	*Garden and landscape use*
Examples	*Well known examples (not specifically 'key' crops)*
Typical Propagation Techniques	*Listed in an estimated hierarchy (most commonly used = 1)*
Typical Production Systems	*Comments on use of protected structures and containerisation*
Markets and Formats	Landscape: Retail:
Basis for large production batches	*Explanation of the circumstances that would cause a single variety to be grown in relatively large batches*
Example Schedule 1	Product: *The product on which the example is based*
Example Schedule 2	Product: *The product on which the example is based* *NB: A second example is not always given*
Degree of Specialism	*Indication of the range of growers involved with this category*
Special Considerations	
Related Categories	*From list of categories*

Notes

1. Intermediate potting stages – these are not always detailed in the typical production schedules.

2. Some nurseries may employ specialist techniques, such as seed priming and photoperiodism, to reduce programme times.

Category Descriptions

Title	***Bedding Plants***
Description	Annuals or half-hardy perennials with attractive flowers or foliage
Ornamental Use	Used in groups in borders and containers, discarded when foliage or flowering display is over
Examples	Pansies, Salvia, cultivated Primrose (grown as an annual)
Typical Propagation Techniques	1. Seed (in plugs) A few high-value species may be raised from cuttings
Typical Production Systems	Protected structures (increasingly mechanised) always in containers.
Markets and Formats	Landscape: Similar to retail Retail: Sold in plugs, cell trays and pots (rarely larger than 1 L)
Basis for large production batches	New and established varieties are all grown in very large volumes. Retailers demand a continuity of supply during the spring, this requires successive production batches.
Example Schedule 1	*Product: 9c Pansy (late Spring sales)* Sown in plug trays on specialist propagator nursery – Jan / Feb Potted into 9c pot – April Sold in bud - May
Degree of Specialism	High degree of mechanisation is resulting in large, very efficient, specialist growers.
Special Considerations	Generally short programmes. Intensive use of plant growth regulators. Some production utilises heating and DIF / DROP regimes
Related Categories	Patio Plants

Title	**Patio Plants**
Description	Vigorous species that create a strong visual impact. May be frost tender
Ornamental Use	Placed on patios and near to homes, generally suitable for containers.
Examples	Chrysanthemums, *Osteospermum*, *Diascia*
Typical Propagation Techniques	1. Softwood Cuttings 2. Seed
Typical Production Systems	Protected structures, always in containers.
Markets and Formats	Landscape: Not a typical product. When used may be sourced from retail suppliers. Retail: Often given prime sales area in stores. Range of formats from plugs to large decorative containers.
Basis for large production batches	New introductions are promoted worldwide by large specialist propagator nurseries and seed houses. Often occur as ranges with selected colours etc – all grown on similar schedules.
Example Schedule 1	*Product: 11cm Half-Hardy Fuchsia* Cutting propagated in plug tray on specialist prop. nursery – Feb Potted into 11cm pot in heated green house - Mar Sold in bud – Apr / May
Degree of Specialism	A growing market that has a large worldwide specialist propagation industry. Production of finished plants
Special Considerations	Many new introductions have plant breeders rights and/or exclusivity arrangements.
Related Categories	Bedding Plants, Small Non-Herbaceous Perennials

Title	Alpines
Description	Small species typically associated with mountainous areas, may require special environments.
Ornamental Use	Usually displayed in small groups or collections in protected or sheltered environments
Examples	Saxifrages, Sempervivum, Aubretia, Phlox, Helianthemum, smaller Primulas, Thymes
Typical Propagation Techniques	1. Seed 2. Softwood Cuttings 3. Divisions, Bulbs
Typical Production Systems	Use of protected structures (with some frost protection), generally grown in containers.
Markets and Formats	Landscape: Rarely used Retail: Specialist area. Sold in pots 7cm – 2Litre
Basis for large production batches	A few varieties have mass-market appeal when in flower and may be sold as promotions to garden centres
Example Schedule 1	*Product: Saxifraga (Kabschia type)* Propagated from cuttings/offsets into plug trays – Spring Year 1 Potted on (9c/1L pot) – Autumn Year 1 Sold in bud and flower – Spring Year 2
Example Schedule 2	*Product: Alpine Primula Species* Seed sown in seed trays (left outside for stratification) – Autumn Year 1 Pricked out into plugs – Spring Year 2 Potted (9c/1L pot) – Summer Year 2 Sold in bud and flower – Spring Year 3
Degree of Specialism	Some specialist nurseries, the most popular varieties are in general production
Special Considerations	Seed germination will often require pre-treatments. May have exacting irrigation requirements. Some products have very long production times (relative to pot size) whilst others are short.
Related Categories	Patio Plants, Small Non-Herbaceous Perennials and Shrubs, Bulbs and Corms

Title	**Small Non-Herbaceous Perennials and Shrubs**
Description	Low growing woody or evergreen species
Ornamental Use	Various: containers, front of established borders
Examples	Dwarf *Hebe sp.*,Hardy Fuchsia, Lavendula, Dianthus, *Gaultheria*
Typical Propagation Techniques	Semi-ripe cuttings under mist or polythene tunnels on heated floors
Typical Production Systems	Outdoor irrigated beds, low cost protected structures. Smaller pot sizes often grown as single season products (spring potted).
Markets and Formats	Landscape: Mainly container grown (1 Litre) – limited bare root Retail: 9cm – 2 litre pots
Basis for large production batches	Some products have strong impulse appeal and can be grown in large volumes eg, hardy Fuchsia.
Example Schedule	*Product: 1L Helianthemums* Semi-ripe cutting propagated in plug tray - Jun Potted to 1L - Feb Sold in Flower – Apr / May
Degree of Specialism	Conifers and Heathers tend to be grown on specialist nurseries. Other subjects widely grown
Special Considerations	Slow growing subjects may take much longer than a year to produce
Related Categories	Larger Shrubs

Title	**Herbaceous Perennials and Grasses(Except Bulbs and Corms)**
Description	Non-woody perennials, generally die-back in winter
Ornamental Use	Herbaceous beds and borders, spot planting, some used in containers
Examples	*Helleborus sp., Digitalis sp., Hosta sp, Delphinium, Lupin, Hardy Geranium spp, Carex sp., Festuca, Stipa, Bamboo spp.*
Typical Propagation Techniques	1. Seed 2. Softwood Cuttings 3. Division 4. Root Cuttings 5. Micropropagation
Typical Production Systems	1. Container grown outdoors or under basic protection 2. Field grown and sold as bare root 3. Field grown and containerised prior to sale
Markets and Formats	Landscape: bare root and containerised, often sold in dormant state Retail: As above. Typical container sizes 1 Litre – 2 Litre
Basis for large production batches	Many species/cultivars with impulse appeal in Autumn and Spring are required in large volumes
Example Schedule 1	*Product: Carex comans "Bronze"* Seed sown in trays – Jan Pricked out into large plugs – Mar Potted in to 2l pot – Jul Sold – Apr
Example Schedule 2	*Product: Hosta sp.* Bare root transplant (from field crop) potted to 2L pot – spring/autumn Sold in leaf – Apr onwards
Degree of Specialism	Widely grown,. Some nurseries may specialise in a single genera
Special Considerations	A very diverse range. Vine weevil can be an issue with herbaceous perennials, some spp more than others (eg, Hosta, Bergenia, Sedum)
Related Categories	Bulbs and corms

Title	Bulbs and Corms
Description	Perennial plants may die-back in winter or summer, some are only active above ground for a short period each year.
Ornamental Use	Containers, planting in beds, borders and lawns
Examples	*Narcissus., Tulipa, Crocus, Cyclamen sp.*
Typical Propagation Techniques	1. Off sets (division of) 2. Scaling
Typical Production Systems	All require a field grown phase. Lifted bulbs/corms may be grown in containers
Markets and Formats	Landscape: Purchased as dry bulbs / corms Retail: dry bulbs/corms, containerised specimens
Basis for large production batches	Many products are required in large volumes
Example Schedule	*Product: 1 litre Anemone De Caen* Corms (from specialist grower) potted into 1 litre pot – Dec/Jan Sold in flower - May
Degree of Specialism	Field crops and storage: always specialist producers Containerised crops: Non-specialist
Special Considerations	Many species have specific storage requirements post-lifting. Storage environments can influence flowering times post-planting. Many crops grown for cut-flower rather than garden sales
Related Categories	Herbaceous perennials