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# WEANING AND ITS INTERACTION WITH OTHER FACTORS INFLUENCING CUTTING SURVIVAL AND LINER QUALITY

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# RELEVANCE TO NURSERYMEN AND PRACTICAL APPLICATION

## Application

The practical objective was to develop guidelines for the management of cuttings after they have rooted, to enable nurserymen to increase profitability by improving quality or by shortening production times. Based mainly on experiments with *Cotinus coggygria* 'Royal Purple', a plant that is in demand but difficult to grow to high standard, some important principles were established.

Nurserymen should not hesitate to use very supportive rooting environments (e.g. fog or polythene-enclosed-mist) to achieve good rooting because, far from making weaning more difficult, losses during weaning will often be reduced as a consequence of better root development. Weaning should ideally be rapid but progressive so that normal growth is resumed as quickly as possible while minimising losses. A short period at high humidity without leaf wetting (e.g. under a polythene tent) will often suffice, but progressive increase in stress, particularly if under evapostat control, is safer.

Winter survival, and the ability to develop a good branch framework in response to pruning, depend on accumulation of reserves after rooting. To maximise reserves, growers should aim to propagate early, preserve as many of the original leaves as possible, and restrict any attempt at shaping to early pinching of weak new shoots. Extending the season under glass can compensate for late propagation to some extent. For *Cotinus*, thickness of the main stem provides a more reliable guide to liner quality than the size or number of branches, being more closely related to the quality of the resulting container plant one year later. Using the principles described, a high proportion of *Cotinus* cuttings make saleable container plants by the end of the season following rooting.

In contrast to *Cotinus*, the leaves of some subjects (e.g. *Acer palmatum* 'Aureum') tend to deteriorate under the conditions that are best for rooting so that emphasis must be given to reducing leaf wetting to ensure a seamless progression from rooting to growing.

## Summary

A comprehensive analysis was made of the conditions and protocols required to manage the transition of *Cotinus coggygria* 'Royal Purple' from the newly rooted cutting to a liner and on into the container stage. *Cotinus* was used as an example of those plants that are in demand but in which high quality is difficult to achieve.

The objective was to understand the processes involved, particularly 'weaning' the cutting from the highly supportive rooting environment to more stressful growing conditions, and thereby develop guidelines for maximising success rate and plant quality while minimising production time. The container stage was included only in so far as necessary to determine realistic criteria for assessing liner quality. Comparisons were made with a number of other species of which *Acer palmatum* 'Aureum' provided a useful contrast.

The picture revealed is complex and not entirely consistent. Nonetheless, a number of important principles emerge which are likely to apply to many difficult subjects.

Principles

(i) Effect of rooting environment

Use of highly supportive rooting environments, such as wet fog, does not increase the need for careful weaning and often decreases it, probably by producing a better developed root system.

(ii) Importance of the original leaves

The original leaves are generally important to survival. Even where they appear to be in poor condition after a long period of leaf wetting during rooting, they are usually able to photosynthesise.

(iii) Shoot growth during rooting and weaning

New shoots that develop during rooting and weaning often fail to survive because of the atypical conditions in which they have grown. Furthermore, in contrast to the original leaves, such shoots are initially net consumers of plant resources. Rapid weaning minimises this problem.

(iv) Root disturbance

The effect of root disturbance was less than expected, but, if cuttings are rooted in trays, it is essential that potting-off is done well before the final transfer to the growing environment so as to avoid reducing the plant's ability to take up water just when its water requirements are abruptly increasing.

(v) Weaning environments and protocols

Experiments were designed to test whether successful weaning depended on any one feature of the post-rooting environment (i.e. shade, wetting or humidity). In general, high humidity environments with relatively little shade achieve higher survival rates than drier environments with extra shade, but temperatures should not be so high as to encourage soft new growth. Weaning under mist works well, particularly if controlled by our new 'evapostat'.

More important than the type of environment used for weaning is the length of time allowed for both rooting and weaning stages. It is generally best to extend the rooting period to achieve good rooting and then restrict the weaning period to about a week. This does not apply where, as with *Acer palmatum* 'Aureum', leaves on the cuttings deteriorate before full rooting has been achieved, so that the cuttings benefit from earlier transition to a drier, but still supportive, high humidity environment.

(vi) Spacing during establishment

Rooted cuttings must not become overcrowded once they resume growth because accumulation of reserves and the development of well placed branches is essential and depends of adequate illumination of all leaves. This must be taken into account when deciding between conventional trays, module trays, and direct-sticking.

(vii) Pruning

For plants such as *Cotinus coggygria*, pruning is essential to create the best possible shape, but the results of many experiments demonstrated that the ill-timed or over-severe pruning could be counterproductive. Pinching new growth on cuttings propagated early in the season helps to keep liners compact but rarely establishes a balanced branch framework. Pruning later in the rooting year, as plants become well established, stimulates uselessly weak growth and depletes plants resources leading to overwinter losses. It is generally better to allow the cuttings to grow freely in the first year, accumulating resources in the form of a thicker stem and larger root system, because this enables the plant to respond well to light pruning early in the second year. Even then one shoot easily becomes dominant and later pruning or pinching could be useful to maintain balance, though it would be at the expense of final size.

(viii) Time of propagation

The quality of plants after one year in a container correlated better with stem diameter than any other measure of liner quality, pointing to the need to build up the plant's resources after rooting. Thus, while *Cotinus* cuttings can be rooted from May to August, early propagation carries a clear benefit in terms of liner quality because it provides the longest period for the rooted cuttings to accumulate these resources.

The disadvantage of late propagation can be partly offset by extending the growing season under heated glass, with supplementary illumination. However, it can be difficult to effectively harden-off such material, making it necessary to maintain some degree of protection throughout the winter.

## Practice

These principles will enable nurserymen to manage the weaning and establishment period more positively, rather than seeing it as a period of transition, uncertainty, and delay. They will need to consider the logistics of applying them to their own circumstances and their own plants. The most important point is to optimise the rooting environment first, otherwise identifying an appropriate weaning protocol becomes confused with allowing unrooted or poorly-rooted cuttings to catch up. Once well rooted, most cuttings can **survive** direct transfer to a normal growing environment, but any steps that can be taken to make the change progressive will usually reduce losses and enhance subsequent growth. A single intermediate environment, such as a simple polythene tent or even contact polythene laid over the cuttings for a few days, will be of some value but less reliable than a multi-stage protocol. In particular, a simple system is vulnerable to a period of hot sunny weather occurring during weaning, exposing the plants to a sudden increase in water stress and temperature.

On the other hand, if the cuttings can stay in the propagation unit for an extra week or so, the more desirable progressive change in environment can readily be achieved. Timing of the transition can take account of any leaf deterioration as well as root development. The benefit of progressive removal of environmental support is very easily and reliably achieved where the propagation system, whether fog or mist, is under evapostat control. By gradually raising the set point, there will be a progressive increase in evaporative demand on the plant, irrespective of any sudden changes in the weather. Even with more conventional controllers, some sort of stepwise reduction in environmental support, albeit less reproducible, can usually be arranged (e.g. by altering timers, or changing the location of the 'wet leaf' sensor).

Rates of rooting success that can now be achieved with subjects considered as difficult-to-root as *Cotinus coggygria* 'Royal Purple' are easily high enough to justify direct-sticking. The results obtained in the current project show that by combining direct-sticking with the use of larger cuttings, retaining as many leaves as possible, rapid and progressive weaning, and early spacing-out, it will often be possible to produce a saleable plant up to a year earlier and to improve quality. In the case of *Cotinus*, it appears that quality may ultimately be limited by internal mechanisms that control the number of major branches that can remain active on a young plant in a container. It is likely that this relates to the balance between root and shoot, limiting the number of active shoot apices in line with the size of the root system. As such, it reinforces the need to concentrate effort on building up the resources of the plant below ground in the early stages of production.

# EXPERIMENTAL SECTION

## Introduction

The majority of container plants derive from leafy cuttings, which is the most important propagation system employed by HNS producers, with an estimated 200 million cuttings per year propagated in the UK. The first approach to HDC work in this crucial area was to understand and improve the rooting environment (Harrison-Murray et al. 1993a). This project shifts attention further towards the market place by understanding how to exploit, and not lose, the advantages of improved propagation in the later stages of production.

### Weaning and establishment of leafy cuttings

The processes involved in transforming a newly rooted cutting into a fully competent plant, capable of tolerating the stresses of a normal growing environment and of resuming rapid growth, have never before been subjected to systematic study. The project initially focused on the process of 'weaning' plants from the moist propagation environment to a normal environment, in which their survival depends on roots being able to take up and transport water to replace substantial amounts lost from the leaves by transpiration. Later, other factors were introduced, such as the nature of the post-weaning environment and timing of pruning, which could interact with weaning.

### Experimental approach

In consultation with industry representatives, *Cotinus coggygria* 'Royal Purple' was selected as a difficult-to-propagate and difficult-to-grow subject for which there is a substantial market. A comprehensive analysis was undertaken of the effects of cutting and environment related factors on the quality of the plants at the end of the first year. Such plants are referred to here as 'liners', with the implied aim that they should be capable of growing into a saleable container plant the following year, one year earlier than the industry norm for *Cotinus*. The factors included cutting source, size, preparation (e.g. removing tips), dark preconditioning, rooting environments, weaning environments, subsequent growing environments, and a number of aspects of timing and pruning. Each experiment included more than one factor, increasing their efficiency and testing for important interactions between treatments.

Since liner quality must ultimately be judged in terms of their ability to grow into a good quality container plant, criteria for assessing liners were examined by growing on for one year in a container. This also provided a useful test of practical progress in shortening production times.

Other subjects were examined in much less detail, and, of these, *Acer palmatum* 'Aureum' provided the most useful contrast and is therefore included in this report.

# Materials and methods

This section describes methods and facilities used in the majority of experiments but further details of those used in specific experiments are provided in the Appendix.

**Rooting environments**

Two basic systems provided contrasting levels of environmental support (i.e. transpiration suppression). Both were shaded externally with reflective shade cloth (OLS60) reducing light to 20% of that outside. Drainage was provided by 7.5 cm of fine sand which also incorporated heating cables to keep the rooting medium to a minimum of 20 °C. Alterations of these basic systems, made for certain experiments, are described with the results.

1. Fog

This was a 'ventilated wet fog' system. A combination of humidification and wetting was provided by a modified version of the Agritech spinning nozzle fogger operating in a 7x19.5 m tunnel. This type of fogger has a high output (about 150 l/h) so that one minute was sufficient to reduce visibility to a few metres, and some of this fog was visible at the end of the 15 minute interval before it fogged again. It also ran to humidify incoming air whenever the exhaust fan operated. In this way it was possible to maintain a very high humidity without excessive heat build up (< 35 °C).

2. Open mist

A totally conventional mist system operated on a 'wet leaf' sensor, positioned to ensure that cuttings were wet at all times. The house was generously ventilated but beds were surrounded by a 1m high polythene curtain to avoid strong drafts and retain some humidity around the cuttings.

**Weaning environments**

In all experiments cuttings were transferred from the rooting environment (either fog or mist or both, depending on experiment) to one or more of the following types of environment:-

<u>Mist</u>

A mist bed, operated on a 'wet leaf' sensor, was converted for weaning by enclosing half of the bed loosely in polythene, within which the sensor was positioned in a relatively wet spot. Cuttings in other locations thus received light wetting, while the partial enclosure with polythene retained some of the humidity (Environment A). The other half of the same bed operated on the same controller, but without any polythene enclosure, so that humidity was lower and water evaporated more quickly: here the leaves dried more frequently (Environment B). Even in the non-enclosed part, a polythene curtain, about 1m high, surrounded the bed to prevent dry air blowing directly onto cuttings.

Polythene tents

Lightweight tubular metal 'Melbourne' frames were used to support polythene enclosures covering an area approximately 1.8 m square. These frames have a ridged roof and, by extending the legs, the height was increased to about 1 m. A range of light intensities was achieved as follows:

Thin clear polythene (about 80% light transmission)
Thin white polythene (about 50% light transmission)
Thick white polythene + 50% black Netlon shade (about 14% transmission)
Thin clear polythene suspended below 50% black Netlon shade + reflective shade cloth, Ludvig Svenson OLS70, (about 16% transmission).

When used within a single-skinned polytunnel or glasshouse, overall light transmission at plant level was as shown in Table 1.

Shade tents

The same frames were used to support freely ventilated shade enclosures using both reflective shade materials (70% shade, Ludvig Svenson OLS70) and conventional green shade material (50% shade).

Table 1. List of the main post-rooting environments, together with an indication of how conditions in them compared.

| Code | Comparative conditions* | | | Brief description of protection provided | Type of house in which used | Light transmission, % |
|---|---|---|---|---|---|---|
| | Light | Temperature | Humidity | | | |
| (A) | M | M | M | Partially enclosed mist | Shaded glass | 20 |
| (B) | M | L | L | Open mist | Shaded glass | 20 |
| (C) | L | H | H | White polythene tent + black Netlon | Unshaded poly | 10 |
| (D) | L | L | L | OLS70 Shade tent | Unshaded poly | 10 |
| (E) | L...H | M....H | H | Contact polythene + progressively reduced shade | Unshaded poly | - |
| (F) | M | H | H | Clear polythene tent in shaded house | Shaded glass | 20 |
| (G) | VH | L | L | 40% shade cloth (green) | Unshaded poly | 40 |
| (H) | H | VH | H | White polythene tent | Unshaded poly | 34 |
| (J) | L | H | H | Clear polythene + separately supported OLS70 | Unshaded poly | 11 |
| (K) | M | L | L | 2 layers of 40% shade cloth | Unshaded poly | 20 |

* L=low; M=medium; H=high; and VH=very high

## Growing environment

Environment G was also used as the standard growing environment to which plants were moved after their designated weaning treatment. A number of other growing environments were used in Experiment 5 and full details are provided in the methods section for that experiment.

## Handling and treatment of cuttings

Cuttings were generally collected before 10:00 hours and prepared immediately in a cool damp room. They were dipped or sprayed with water if they showed signs of wilting. The standard auxin treatment was a 5 second dip in 1250 ppm IBA (i.e. 1.25 grams per litre of indolyl butyric acid) in a 50:50 mixture of acetone and water. The dip was allowed to dry on the cutting before they were handled further. The tops of all cuttings were dipped in Benlate (2 g/l). During rooting and weaning the cuttings also received a routine spray programme consisting of twice weekly Benlate alternated with Rovral, both at 2 g/l. The rooting medium was a 50:50 mixture of peat (Irish medium grade) and pine bark (Cambark fine grade) with 1kg $m^{-3}$ Ficote 140 day 16-10-10 controlled release fertiliser.

## Experimental units and design

Many experiments involved factorial combinations of treatments applied to different stages in the production process (e.g. more than one rooting environment combined with a number of weaning protocols). Because experimental units needed to be moved independently, 11 cm square pots were generally used instead of conventional propagation trays. This does not imply that all the material was 'direct-stuck': in some cases cuttings were removed from these pots and then repotted to simulate the root disturbance involved in potting-up from conventional trays. These small rooting units also had advantages with respect to the efficiency of the experimental design.

Four cuttings were usually inserted in each pot, close to the corners. Each pot, represented an experimental unit in a randomised block design. The blocks were used to absorb any variation associated with handling factors, such as might occur, for example, between the first and last batches to be stuck.

## Statistical analysis

Where appropriate, data were subjected to statistical analysis to determine the likelihood that observed differences could have occurred by chance. In the tables and figures this appears as a 'least significant difference', or LSD, which is the minimum difference required to be 95% certain that the difference is due to the treatments and not to random effects. Probability values are sometimes quoted in the text, this being the probability that the results could have occurred by chance. For example, $P<0.05$ means that there was less than 0.05 (i.e. 5%) chance that the result was due to random effects, so that it is more than 95% certain that it was due to the treatments instead.

# Results

## *COTINUS* EXPERIMENT 1

The aim was to find out whether the use of very supportive rooting environments, such as wet fog, increases the need for weaning, and whether any one component of the weaning environment has a dominant effect on subsequent survival and growth. The environmental factors were those previously identified as the key components during rooting, that is to say humidity, leaf wetting, and shade (Harrison-Murray et al.,1993a). The experiment also examined the effects of cutting source and of root disturbance at the time of transfer from the rooting to the weaning environment.

Five different types of cutting were prepared from severely- and light-pruned stockplants, propagated in fog or mist for four weeks, and then weaned in one of four environments which differed with respect to wetting, humidity and light. Half of the cuttings were lifted and replanted before weaning, partly to record rooting and partly to simulate the root disturbance involved in potting-up from trays. Further experimental details are provided with the results and in the Appendix.

### Results

Survival to the end of the season

Counts of the plants still alive at the end of the year in which they were rooted showed that survival was significantly affected by all factors except root disturbance (Table 2). Best success rates were achieved by using a supportive environment for **both** rooting and weaning.

Table 2. Effects on survival and lateral shoot development at the end of the rooting year (recorded 16 October), averaged over root disturbance treatments.

| | % of plants alive | % of surviving plants with lateral shoots |
|---|---|---|
| Rooting environment: | | |
| Fog | 93 | 89 |
| Mist | 70 | 83 |
| *Mean LSD* $_{(P=0.05,\ 41\ d.f.)}$ | *6.0* | *9.3* |
| Weaning environment: | | |
| A (partially enclosed mist) | 94 | 86 |
| B (open mist) | 77 | 88 |
| C (shaded poly-tent) | 82 | 88 |
| D (shade tent) | 71 | 87 |
| *Mean LSD* $_{(P=0.05,\ 41\ d.f.)}$ | *8.5* | *13.2* |
| Source and type of cutting: | | |
| 1 (severely pruned, +tip) | 74 | 73 |
| 2 (severely pruned, -tip) | 79 | 91 |
| 3 (lightly pruned, -tip) | 81 | 85 |
| 4 (lightly pruned, flowering, -tip) | 92 | 89 |
| 5 (lightly pruned, trunk shoots, -tip) | 79 | 96 |
| *Mean LSD* $_{(P=0.05,\ 41\ d.f.)}$ | *9.4* | *14.7* |

The results in Table 2 also indicate that the conventional wisdom, which favours severe pruning of stockplants to create vigorous vegetative growth and suppress flowering, does not apply in this case. Averaged across all other factors, the highest survival rate (92%) was recorded in cuttings prepared from flowering shoots collected on the lightly pruned hedge. The lowest survival rate was recorded in cuttings from the severely pruned hedge that had not been pinched during preparation (i.e. Type 1). Leaving the tip intact reduced branching also.

To understand the effects seen at the end of the season it is necessary to analyze the effects at the successive stages of rooting, weaning and establishment.

The rooting phase

Generous misting prevented any obvious signs of stress under open mist but the proportion which had rooted after 4 weeks was less than in fog (73% and 99% respectively,

$P<0.001$). Roots were also fewer and shorter under mist, and basal rotting was confined to the misted cuttings (Table 3). Pinching out the tip during preparation also increased the number of cuttings which rooted and decreased the incidence of basal rotting, irrespective of the environment in which the cuttings were rooted.

Table 3. Effects of rooting environment and cutting type on root development after 4 weeks, when they were transferred to the weaning environments. As there was no significant interaction between environment and type, values shown are averages across the other factors.

| | Rooting % | Roots per rooted cutting | Average length of the longest root per cutting | Cuttings with >5 mm basal rotting, % |
|---|---|---|---|---|
| Rooting environment: | | | | |
| Fog | 99 | 8.2 | 10.4 | 0 |
| Mist | 73 | 5.3 | 6.3 | 12.5 |
| *LSD* $_{(P=0.05,\ 27\ d.f.)}$ | *3.2* | *1.06* | *1.62* | *2.5* |
| Cutting type: | | | | |
| 1( Severely pruned, +tip) | 69 | 6.3 | 7.3 | 17.2 |
| 2 (Severely pruned, -tip) | 87 | 6.6 | 7.3 | 6.3 |
| 3 (Lightly pruned, -tip) | 87 | 6.7 | 9.3 | 0 |
| 4 ( Lightly pruned, flowering, -tip) | 94 | 7.4 | 9.5 | 1.6 |
| 5 ( Lightly pruned, trunk shoots, -tip) | 94 | 6.7 | 8.6 | 6.3 |
| *LSD* $_{(P=0.05,\ 27\ d.f.)}$ | *10.25* | *1.67* | *2.55* | *7.83* |

The proportion of cuttings which developed lateral breaks during the rooting period was also significantly enhanced by the fog environment and by pinching out tips (Table 4). In mist the average length of new shoots, where present, was also reduced. Where non-pinched cuttings produced laterals it was generally because the original tip had rotted, or abscised.

Table 4. Effects of rooting environment and cutting type on shoot development after 4 weeks, when transferred to the weaning environments. There was no significant interaction between environment and type.

| | Cuttings with laterals, % | Length of new growth per growing cutting, cm | Number of laterals per growing cutting |
|---|---|---|---|
| Rooting environment: | | | |
| Fog | 91 | 2.0 | 1.9 |
| Mist | 35 | 0.3 | 1.4 |
| $LSD_{(P=0.05,\ 27\ d.f.)}$ | *4.0* | *0.37* | *0.30* |
| Cutting type: | | | |
| 1 (severe pruned, +tip) | 37 | 1.4 | 1.9 |
| 2 (severe pruned, -tip) | 75 | 1.3 | 1.8 |
| 3 (light pruned, -tip) | 67 | 1.5 | 1.7 |
| 4 (light pruned, flowering, -tip) | 70 | 1.6 | 1.7 |
| 5 (light pruned, trunk shoots, -tip) | 64 | 1.9 | 1.9 |
| $LSD_{(P=0.05,\ 27\ d.f.)}$ | *13.0* | *0.59* | *0.44* |

Weaning phase

There is a clear parallel between the percentage of cuttings surviving to the end of the season (Table 2) and the percentage which rooted (Table 3). This suggests that most cuttings which rooted were able to survive, but to examine what happened during the weaning stage more critically we examined the records of individual cuttings at different stages. In this way it was possible to eliminate the effect of the random variation in rooting percentage of the cuttings allocated to each weaning environment.

There was no evidence that cuttings rooted in fog were more prone to fail during weaning than those rooted in mist (Table 5). Failure of initially rooted cuttings was significantly more frequent in the driest weaning environment (D, the shade frame), which was the only environment in which any wilting of older leaves was observed. By contrast, it was in the most supportive environment (A, partially enclosed mist) that late rooting of previously unrooted cuttings was greatest.

Table 5. Components of changes in rooting percentage over the course of weaning: failure of originally rooted cuttings to 're-root' and late rooting of initially non-rooted cuttings. Data relate to a sample harvested at the end of weaning; cuttings unrooted at this stage would have died if they had been transferred to the growing environment.

| Rooting environment | Weaning environment | | | | |
|---|---|---|---|---|---|
| | A | B | C | D | Mean |
| | % of initially rooted cuttings which failed to 're-root': | | | | |
| Fog | 5.7 | 5.7 | 0 | 10.6 | 5.2 |
| Mist | 6.4 | 5.7 | 0 | 29.7 | 8.7 |
| *Mean LSD* $_{(P=0.05,\ 11\ d.f.)}$ = *13.4* | | | | | |
| | % of cuttings which rooted for the first time during weaning: | | | | |
| Fog | 0 | 0 | 0 | 0 | 0 |
| Mist | 15.0 | 5.0 | 5.0 | 5.0 | 7.5 |
| *Mean LSD* $_{(P=0.05,\ 11\ d.f.)}$ = *10.9* | | | | | |

Growth phase

On transfer to the growing environment, some of the long weak shoots that had grown in the warm, low light conditions of the poly-tent (weaning environment C) wilted, even on well rooted plants, but there was no wilting of the shorter shoots produced in the other weaning environments.

By mid-August, it became clear that many of the cuttings had grown so well that they were becoming overcrowded and they were therefore cut back hard. Records of the length and number of the prunings showed that on average there were only 1.3 branches per plant, not enough to provide the basis of a well shaped plant.

By the end of the season there was significantly more regrowth on the ex-fog plants, suggesting that they had greater carbohydrate reserves, but there was no effect on stem diameter, which is generally a good measure of plant vigour.

**Discussion and interim conclusions**

These results are discussed, together with those of the next experiment, on page 21.

## *COTINUS* EXPERIMENT 2

This examined a wide range of additional factors in parallel to the previous experiment, but started 5 weeks later. Whilst it includes only one additional weaning environment, by varying the timing of transfers into and out of the weaning environment, and incorporating a number of progressively modified environments, it introduced the concept of a weaning **protocol**. With a view to improving branching, the experiment also tested the effects of removing leaves, and of pinching out tips of laterals, **after** rooting.

For this experiment the trays used in the previous experiment were replaced by the 11 cm square pots (see General Material and Methods), providing an experimental unit of 4 cuttings that could be moved around independently of adjacent units without having to disturb roots. The cuttings were all of type 2 (i.e. severely pruned hedge; tips pinched out), rooted in fog, all without root disturbance.

It involved a total of 35 different weaning protocols addressing four separate questions:

1. *Does extending the time spent in the rooting environment affect the weaning requirement or the response to manual leaf removal (which reduces the potential to lose water)*? This sub-experiment consisted of the following factorial combinations:

transfer to weaning at 3, 4, or 8 weeks
x
3 weaning environments providing different levels of support
x
$\pm$ manual defoliation

2. *How long should cuttings be in a weaning environment?* After four weeks rooting in fog, cuttings were weaned for 1, 3, or 5 weeks in a shaded poly-tent (environment C).

3. *Can pinching of new shoots help create a well branched liner, and what is the effect of removing some or all of the leaves (which may stimulate lateral breaks)*? After four weeks rooting in fog, cuttings were weaned in a shaded poly-tent (environment C), with or without pinching of lateral shoots as they reached 3 cm. At the start of this weaning period either none, half, or all of the leaves were removed by hand.

4. *Is progressive change of weaning environment better than single-stage weaning?* Five weaning environments were compared with four protocols involving a progressive increase in evaporative demand (further details with the results).

### Results

1. <u>Time of transfer to the weaning environment and defoliation</u>

Destructive samples at the time of transferring cuttings from fog to the various weaning environments showed that root systems became progressively better developed with increasing time in fog (Table 6).

Table 6. Root development on cuttings in fog. Based on samples of 12 cuttings.

| Time in fog, weeks | % Rooting | Roots per rooted cutting | Maximum root length per rooted cutting |
|---|---|---|---|
| 3 | 92 | 7.0 | 5.5 |
| 4 | 100 | 6.7 | 9.7 |
| 8 | 100 | 9.2 | 17.9 |

Testing for firmly anchored cuttings at the beginning and end of weaning showed that rooting of initially unrooted cuttings during weaning was greatest in environment A and in non-defoliated cuttings (74% in that treatment combination). Such belated rooting was not sufficient to make up for the rooting deficit in the 3 week transferred cuttings, 9% of non-defoliated and 17% of defoliated cuttings remaining unrooted.

Most rooted cuttings survived the weaning process, even if transferred at 3 weeks. Defoliation, far from improving survival by reducing the potential water loss, actually increased losses (Table 7A).

Branching was significantly stimulated by defoliation, and by holding longer in fog, but the maximum number of breaks was little over 2 per plant (Table 7C).

Shoot growth was significantly affected by the time of transfer ($P<0.05$), though differences were small, with 4 weeks being optimal (Table 7B).

Ultimate survival reflected the number of cuttings which had originally rooted, and the adverse effect of defoliation (Table 7D). Amongst the 13% of non-defoliated plants that had not started to grow by the end of the season, 77% survived the winter, compared with 95% of those which had made new growth. This suggests that the resumption of growth, while not essential to overwinter survival, is related to a beneficial underlying factor, such as the amount of carbohydrate resources.

The number of shoots growing away strongly the following spring averaged only 2.0, with no significant effects of any of the treatments. A small observation sample showed that, despite growing well, this had reduced to a single dominant leader on many plants by the end of the year.

Table 7. Effect of time of transfer from rooting to weaning environment, with and without manual defoliation, for plants moved on to the growing environment 9 weeks after taking cuttings. Data for environments A, C, and F combined.

| Time in fog, weeks | Non-defoliated | Defoliated |
|---|---|---|
| **A.** Death of rooted cuttings during weaning, % | | |
| 3 | 3 | 6 |
| 4 | 0 | 40 |
| 8 | 0 | 0 |
| *LSD* $_{(P=0.05,\ 38\ d.f.)}$ | *9.0* | |
| **B.** Shoot length per surviving plant (5 Sept. 1990), cm | | |
| 3 | 8.8 | 7.8 |
| 4 | 11.1 | 9.1 |
| 8 | 6.0 | 6.6 |
| *LSD* $_{(P=0.05,\ 38\ d.f.)}$ | *3.56* | |
| **C.** Number of shoots per surviving plant (5 Sept. 1990) | | |
| 3 | 1.15 | 1.66 |
| 4 | 1.36 | 1.71 |
| 8 | 1.50 | 2.17 |
| *LSD* $_{(P=0.05,\ 38\ d.f.)}$ | *0.410* | |
| **D.** Survival to year 2 (May, 1991) | | |
| 3 | 79 | 67 |
| 4 | 94 | 39 |
| 8 | 94 | 81 |
| *LSD* $_{(P=0.05,\ 38\ d.f.)}$ | *13.5* | |

2. Weaning duration and defoliation

As long as cuttings were not defoliated, all rooted cuttings survived transfer to the growing environment even if the weaning stage was omitted altogether. Weaning increased subsequent shoot growth but not significantly.

3. Pinching and the severity of manual defoliation

Pinching out the tips of lateral shoots as they reached a length of 3 cm had the effect of increasing the number of shoots to an average approaching 3 shoots per plant (Table 8C, $P<0.05$). The extra shoots were all secondary laterals (i.e. branches on branches) rather than new breaks from the stem of the original cutting. Not surprisingly, pinching reduced the total shoot length per plant at the end of the first season (Table 8B). It had no significant effect on survival of either the weaning process or the winter.

Manual removal of all leaves resulted in some stimulation of branching, but dramatically reduced survival. Removing leaves from only the uppermost nodes seemed to stimulate branching without this risk (Table 8C and D).

Table 8. Some effects of the severity of manual defoliation after 4 weeks rooting in fog, and of pinching lateral shoots as they reached 3 cm whilst weaning in environment C for 5 weeks.

| Severity of defoliation | Pinched | Not pinched |
|---|---|---|
| **A. Death of rooted cuttings during weaning, %** | | |
| None | 0 | 0 |
| Half | 0 | 8 |
| Full | 17 | 37 |
| *LSD* $_{(P=0.05,\ 10\ d.f.)}$ | *20.8* | |
| **B. Shoot length per surviving plant (5 Sept. 1990), cm** | | |
| None | 7.2 | 14.1 |
| Half | 8.0 | 10.6 |
| Full | 9.8 | 14.0 |
| *LSD* $_{(P=0.05,\ 10\ d.f.)}$ | *5.55* | |
| **C. Number of shoots per surviving plant (5 Sept. 1990)** | | |
| None | 2.1 | 1.3 |
| Half | 3.3 | 1.8 |
| Full | 2.9 | 1.8 |
| *LSD* $_{(P=0.05,\ 10\ d.f.)}$ | *1.58* | |
| **D. Survival to year 2 (May, 1991)** | | |
| None | 100 | 92 |
| Half | 100 | 92 |
| Full | 50 | 33 |
| *LSD* $_{(P=0.05,\ 10\ d.f.)}$ | *23.0* | |

4. Progressive weaning protocols

Progressively reducing the support provided by the weaning environment, either by moving between discrete environments (A through to D) or by gradually removing shade, had no obvious benefits compared to 5 weeks in the same environment (Table 9). The results indicate that progressive reduction of shade over a polythene enclosure may help stimulate branching, but this requires confirmation.

Table 9. Effect of weaning protocol on cuttings rooted for 4 weeks in fog, not defoliated or pinched, and transferred to the growing environment 5 weeks later.

| Weaning protocol | Death of rooted cuttings during weaning, % | Shoots per surviving plant (5 Sept. 90) | | Survival to year 2 (May) |
|---|---|---|---|---|
| | | Length, cm | Number | |
| Env. A (partially enclosed mist) | 0 | 8.4 | 1.0 | 92 |
| Env. B (open mist) | 0 | 9.8 | 1.3 | 92 |
| Env. C (shaded poly-tent) | 0 | 14.1 | 1.3 | 92 |
| Env. D (shade cloth tent) | 0 | 8.3 | 1.3 | 92 |
| Env. F (lightly shaded poly-tent) | 0 | 10.9 | 1.8 | 100 |
| Moved from env. A→B→C→D | 0 | -[1] | 1.5 | 100 |
| Reducing shade[2] + contact polythene | 0 | 9.6 | 2.4 | 100 |
| Reducing shade[2] + poly-tent | 0 | 7.1 | 2.9 | 92 |
| Reducing shade[2] only | 8 | 6.7 | 1.5 | 83 |
| *LSD $_{(22\ d.f.)}$* | *14.1* | *5.87* | *0.61* | *16.0* |

[1] Mechanical damage prevented valid measurement
[2] Shade removed in weekly stages to increase light from 3%→6%→12%→20%→40%

**Discussion and interim conclusions from experiments in 1990**

Effects of the rooting stage

It goes without saying that cuttings must root if they are to survive in a normal growing environment, but concern is often voiced that using fog or similarly low-stress system to promote rooting may cause difficulty when cuttings are moved to drier conditions. The above results clearly suggest that this is not the case with *Cotinus*. Amongst cuttings which had already rooted when transferred to the low humidity of the shade cloth tent (env. D) there were actually fewer losses in those from fog (11%) than in those from mist (30%) (Table 5).

It had been thought that, by analogy with leafless winter cuttings, there might be an advantage of moving cuttings out of the rooting environment just **before** roots emerged, but this was not supported by these results. Even cuttings that had been in fog for three weeks, and were on the verge of rooting, often failed to complete the rooting process when moved to a weaning environment. Instead, holding them in fog for up to eight weeks, improved survival and also stimulated additional lateral breaks (Table 7).

Rooting ability was remarkably insensitive to how hard the stock-plants had been pruned and the type of shoots used for cuttings. Even cuttings made by removing the inflorescence from flowering shoots were acceptable. Pinching out the shoot tip during cutting preparation slightly improved rooting.

Effects of weaning environment

The nature of the weaning environment was less critical than the rooting environment, but amongst cuttings moved after just four weeks in fog, losses were greatest in the shade cloth tent (environment D), indicating that additional shade failed to compensate for lower humidity and lack of leaf wetting. The fact that one set of cuttings survived direct transfer from fog to the growing environment suggests that there may be no need for a specific weaning stage. However, if there is pressure to vacate propagation space, or a need to rapidly move cuttings on so as to give maximum opportunity for subsequent growth, then appropriate weaning may be crucial. This question was examined further in later experiments.

Stimulating branching

Recognising the difficulty of producing well shaped *Cotinus* plants in containers, at the start of the project much attention was given to developing multi-branched liners. None of the ideas for stimulating branching gave promising results. Pinching out the tips of cuttings had no effect, largely because many tips died naturally during rooting. Pinching the new shoots as they started to grow stimulated branching on those shoots but failed to stimulate buds further down the main stem where branches are needed for well shaped final plants. Manual leaf removal stimulated outgrowth of buds at the same node but the effect was small, and survival was drastically reduced. Removing only half the leaves appeared to retain the benefit whilst avoiding plant losses.

The severe effect of complete defoliation, in some cases resulting in death of two thirds of rooted cuttings, shows that the cutting's original leaves continue to be useful well beyond rooting, and means that any form of intentional defoliation should be applied with caution. The minimal carbohydrate reserves of this sort of cutting, and the consequent dependence on current photosynthesis, was further emphasised by an experiment in which 75% of rooted cuttings were killed by two weeks in darkness. It is possible that the common practice of preparing cuttings with trimmed leaves may reduce their ability to generate carbohydrate reserves after rooting.

Criteria for judging liner quality

The importance of branches which develop during the rooting year, in relation to the shape of the final plant, was called into question by these experiments. Such shoots tended to be borne too high, more than 5 cm above the compost surface, to be thin and weak and to partially die back overwinter. Furthermore, the number of strongly growing shoots in the following year bore little relation to the number of laterals present in the first year. It is also worth noting that new shoots were not essential for plants to survive the winter.

The decision was therefore made to concentrate in future experiments less on branching and more on the development of the plant's reserves, in the expectation that this would confer ability to produce useful branches in response to pruning. It was also clear that it would be necessary to extend experiments into the second year so as to relate the effects of treatments in the rooting year to the quality of the container plant and thereby establish reliable criteria for assessing liner quality.

## *COTINUS* EXPERIMENT 3

Having seen that *Cotinus* could **survive** transfer from fog to a dry polytunnel without a weaning stage (Experiment 2), the objective of this experiment was to determine whether there is **any benefit** from weaning for *Cotinus*, and if so how long the weaning period should be. The experiment included different amounts and timing of root disturbance to test whether the benefit of a well developed root system is lost in the damage caused by potting-off.

Fog propagated cuttings were either weaned for one or four weeks in a shaded polythene tent, or not at all. At the beginning and end of weaning, the roots on some cuttings were disturbed, either severely, as if potting-off from a tray, or very slightly, in potting-up cuttings rooted in modules.

Liners were grown on in 2 litre containers for one year to investigate how growth in the container relates to the appearance of the liner. Different times and severities of pruning were compared.

### Results

Rooting

Records made when root disturbance treatments were applied showed that 98% of cuttings had rooted after four weeks in fog with, on average, 7 roots per cutting up to 12 cm long. During weaning, rooting increased to 100% and there was a small but non-significant increase in the number and length of roots.

Weaning and growing on

In the absence of a weaning stage, many of the older leaves, together with any developing lateral breaks, shrivelled within three days of transfer to the growing environment, whether roots had been disturbed or not. However, new laterals soon started to grow on the majority.

By contrast, there were no signs of stress in the weaning environment, nor when plants were moved to the growing environment after one week's weaning, except where roots were disturbed just before transfer (i.e. post-weaning).

Both weaning duration and root disturbance significantly affected survival ($P<0.01$). Weaning for 1 week was optimal and largely counteracted the adverse effect of root disturbance (Figure 1).

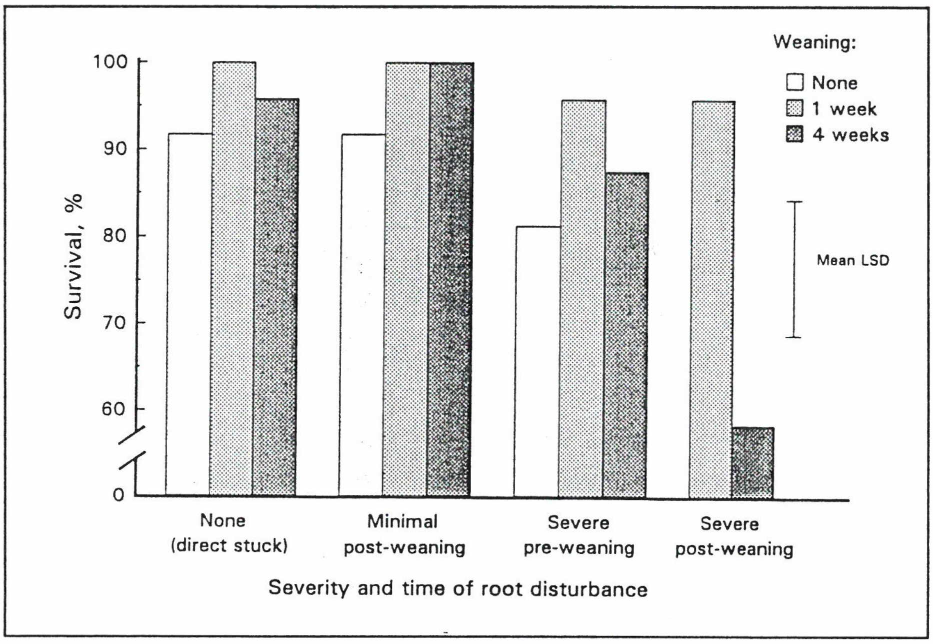


Figure 1. Effects of root disturbance, and weaning, on survival of *Cotinus coggygria* 'Royal Purple' following rooting in fog. Cuttings were either moved directly to the growing environment or weaned in a shaded poly-tent for 1 or 4 weeks.

Despite efforts to minimise temperature lift using reflective shade (env. J), four weeks weaning resulted in very long (around 30 cm), thin (around 2 mm) shoots with tiny leaves (around a quarter of normal size). Many of these shoots shrivelled on transfer to the growing environment, particularly where roots were disturbed at this time. Even the minimal disturbance involved in potting-up the modules visibly increased damage.

Liner quality

Stem diameter was significantly reduced by root disturbance and also by prolonged weaning ($P<0.001$, Figure 2). The increase in stem diameter from the time the cuttings were taken until the end of the season averaged 0.9 mm. Severe root disturbance post-weaning reduced this by 38%, whereas, if disturbance was minimised by using modules, or if it occurred before weaning, the reduction was only 18%. Weaning failed to increase stem diameter growth, in fact four weeks weaning reduced it by 33%.

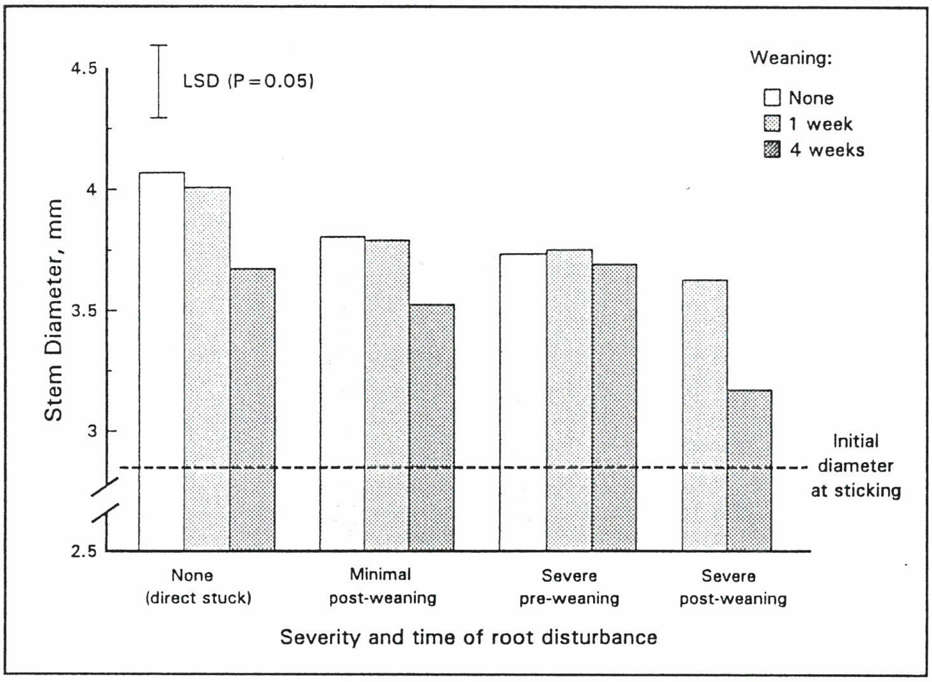


Figure 2. Effects of root disturbance, and weaning, on stem diameter of *Cotinus coggygria* 'Royal Purple' following rooting in fog.

By contrast, weaning for one week increased shoot growth by 46% compared to the non-weaned plants, though extending the weaning period to 4 weeks largely negated this benefit (Figure 3). Root disturbance reduced shoot growth, particularly when it occurred post-weaning (44% less than non-disturbed plants).

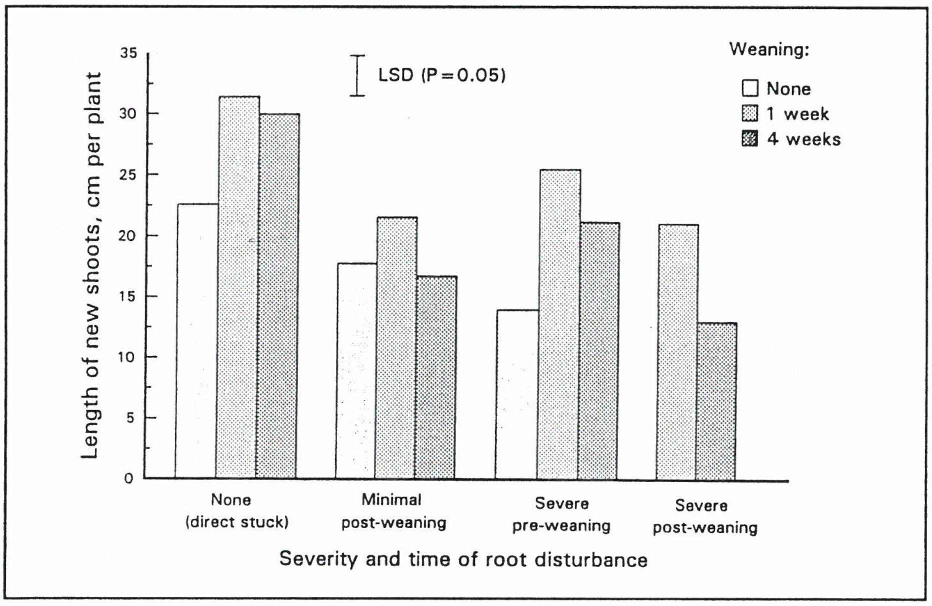


Figure 3. Effects of root disturbance, and weaning, on shoot growth of *Cotinus coggygria* 'Royal Purple' following rooting in fog, recorded on 15 August, 1991.

The effects on shoot length mainly reflect effects on the number of lateral breaks. However none of the treatments produced well branched liners, treatment means ranging from 1.1 to 2.3, the best plants being direct-stuck and weaned for one week.

Overwintering losses

The duration of weaning had a significant and very puzzling carry-over effect on overwintering losses. One week's weaning, which improved establishment and growth in the first year, led to significantly more overwintering losses than either no weaning or four week's weaning (Figure 4). Losses were also consistently greater following autumn pruning, averaging 42% compared to just 8% following spring pruning. Losses increased progressively with severity of pruning (Figure 4).

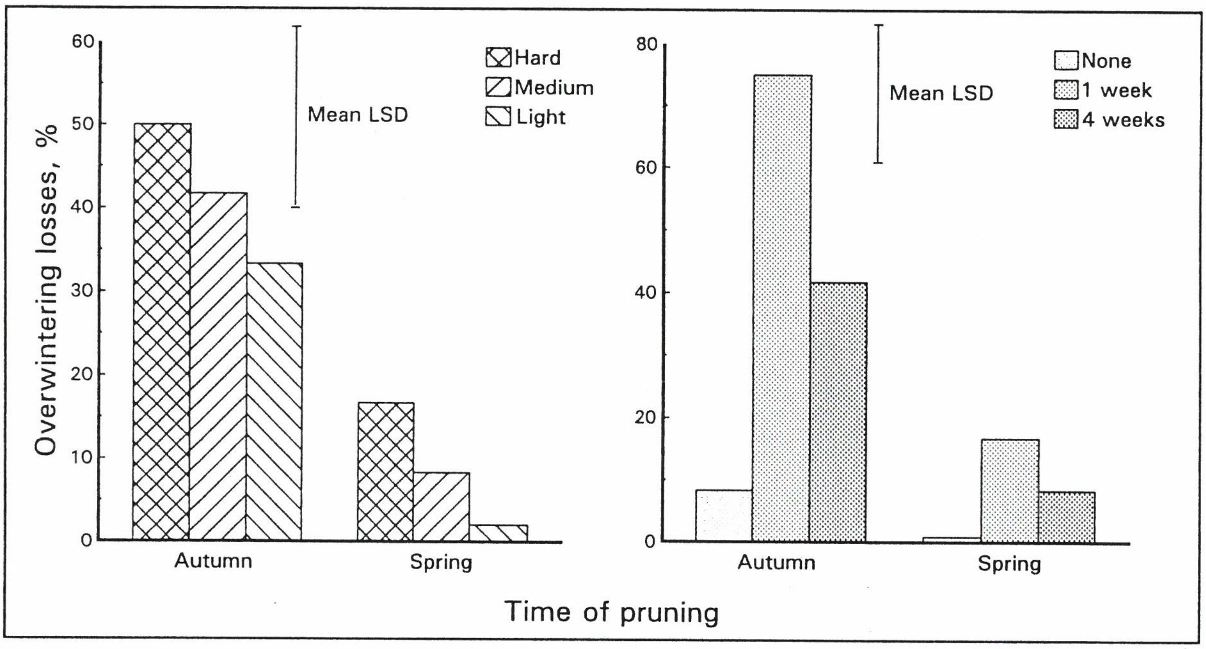


Figure 4. Overwintering losses of *Cotinus coggygria* 'Royal Purple' as affected by the time of pruning and its interaction with pruning severity (left) and weaning (right).

Quality of the final plant

The main influence on the size and shape of the final plants was the timing and severity of pruning. The number of shoots increased on average from 1.4 to 5.4 as the severity of pruning was reduced, but the effect was mainly attributable to the spring pruned plants and largely accounted for by minor-shoots (Figure 5). Light pruning led to many branches arising too high to create a compact bushy shape but there was no advantage of severe pruning compared to the intermediate severity treatment (Figure 5). The desirably low average branch height obtained by severe spring pruning was associated with the die-back of many stems to ground level, and was therefore not of practical value.

Plants grew more vigorously following spring pruning, with shoot growth 24% greater and thickening of the main stem 29% greater than on autumn pruned plants.

Growth in the container was also affected by the earlier treatments. The total length of thick shoots (i.e. >4 mm diameter), and also thickening of the main stem, were significantly smaller in plants which had been weaned than in those transferred directly to the growing environment. As in the case of overwintering, the effect of one week was again more severe than that of four weeks.

The importance of high quality liners for vigorous growth in the container was evident from regression analysis. After allowing for the effects of pruning, a significant amount of the variation in total shoot length of the final plants could be related to the diameter of the liner from which it had grown.

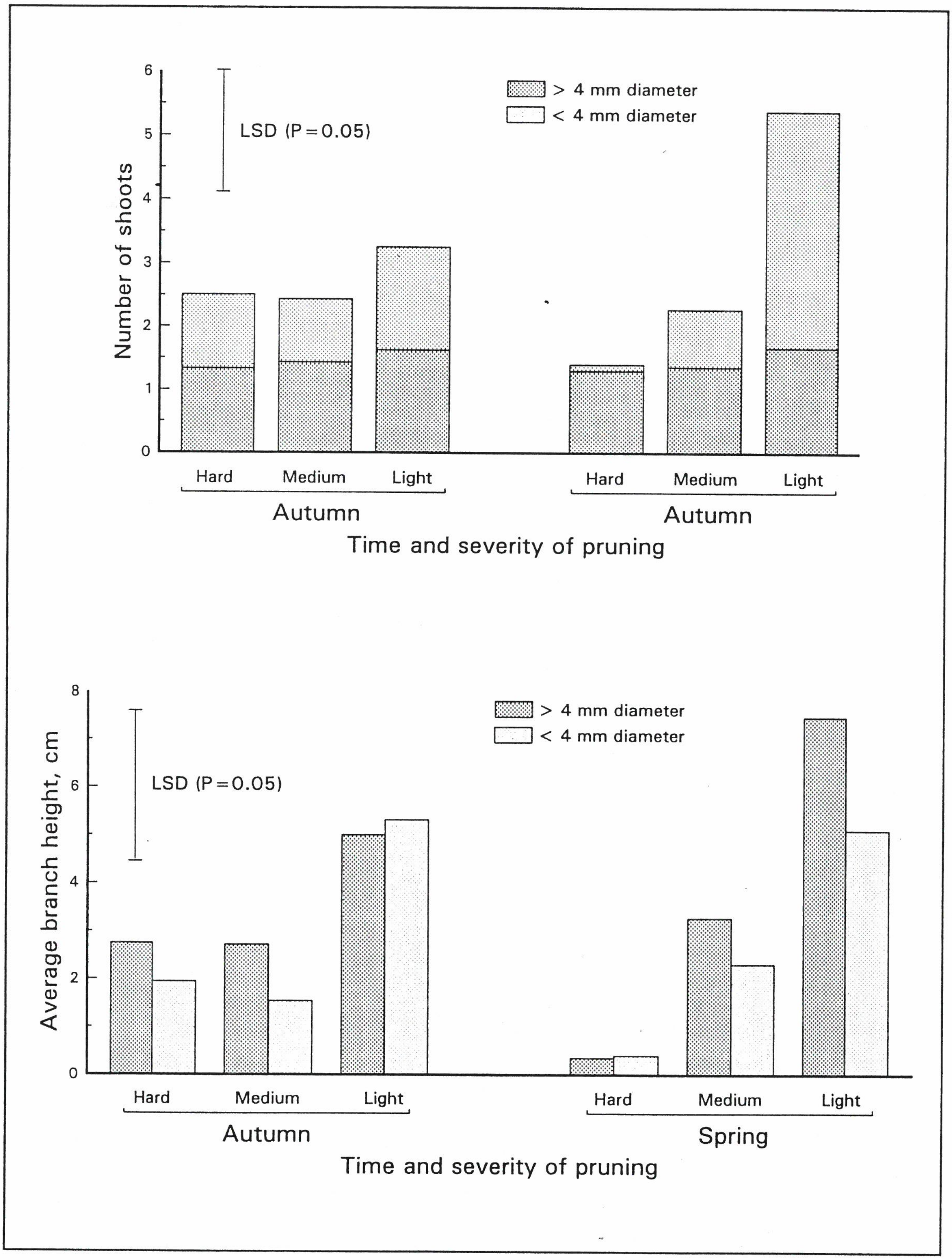


Figure 5. Effects of timing and severity of pruning on the number and length of branches on *Cotinus coggygria* 'Royal Purple' after one year in a container (the year after rooting).

**Discussion and interim conclusions**

This experiment confirmed that a weaning stage is not absolutely necessary for *Cotinus* because most cuttings survived direct transfer to the growing environment after 4 weeks in fog. However, weaning increased the percentage of cuttings which survived the transfer to the growing environment, particularly if roots were disturbed, and stimulated new shoot growth. On the other hand, weaning also **adversely** affected both overwinter survival and growth in the container the following year.

This result highlights a potential problem of weaning that new shoot extension, whilst a sign of successful establishment, is not necessarily valuable in the long run because it may occur **at the expense of root growth and the accumulation of reserves**. This was certainly the case for shoots which developed in the weaning environment, which were clearly **less able to survive** in the growing environment than the **cutting's original leaves**. As a result, some of the resources put into these shoots were lost as they died back when the plants were moved on.

The same may also apply to later growth, especially if plants become overcrowded, as was the case in this experiment. The supply of these resources (primarily carbohydrates) depends on the rate of photosynthesis and therefore depends on plants being spaced out as they grow so that new leaves are receiving enough light to photosynthesise. Support for this explanation comes from the similar effect of autumn pruning, which, by stimulating weak regrowth late in the year, would also have depleted plant reserves.

Compared with shoot extension, thickening of the main stem is likely to provide a much more reliable measure of the accumulation of useful reserves. The significant correlation between shoot growth in the container and the **diameter** of the liner from which it grew supports this proposition.

The weaning environment used in this experiment included a modification of the simple shaded polythene tent (env. C) used earlier, intended to reduce the problem of weak growth by reducing the temperature. Instead of netting in contact with the polythene, reflective shade was suspended above it, but the reduction in temperature was not enough to be effective. This highlights an inherent difficulty of using polythene to create a high humidity environment.

Severe root disturbance increased losses on average from 4% to 17%. The effect was only large when disturbance occurred at the end of 4 weeks weaning, because the disturbed roots were unable to meet the water requirements of the long weak shoots that had by then developed. The use of module trays to minimise disturbance was completely effective in preventing such losses. Severe disturbance also reduced subsequent shoot growth by 35% and stem thickening by 28%. In this case the use of module trays did not prevent the effect, perhaps because of residual effects of the more restricted root volume up to the time of potting-up.

Taken overall, these results clearly point to the importance of **building up reserves** in the liner plants, probably best judged by **thickening of the main stem**. They indicate that the apparent benefits of a weaning stage can eventually operate against this objective. For example, the benefits of one week's weaning were apparently negated by directing too much of the plants resources into extension of shoots that would eventually need to be pruned back anyway, rather than into reserves required for overwintering and vigorous growth the following year.  Overcrowding may also act against the accumulation of reserves, as may autumn pruning.

Later experiments therefore concentrated on using weaning to transfer well rooted cuttings quickly to an environment in which leaves received enough light to photosynthesise rapidly, care being taken to avoid overcrowding.

## *COTINUS* EXPERIMENT 4

This experiment measured the effects of a number of factors, other than weaning, on the size and appearance of liners, and how that related to quality of the container plant. The factors included were as follows:

**Dark preconditioning** of the stock plants was included to test whether it would stimulate branching, as has been seen in other species (e.g. Syringa vulgaris). The dark treatment was applied to stockplants that had been kept pruned to ground level, by covering them with a black polythene cloche (i.e. very low tunnel). These 'black cloches' would be much easier to use in commercial production than the larger tents generally used in research.

**Cutting thickness, propagation date, rooting duration, and extension of the season** using protection were included to test the hypothesis that accumulation of resources, in the form of thickening of the stem and increase in root mass, is the essence of liner quality. An integral part of this hypothesis was that 'resource-rich' liners would develop a good branch framework (ideally at least 3 main branches) in response to hard pruning.

All plants were given a **short** period of weaning, and were thinned out to prevent overcrowding immediately afterwards. This was expected to maximise growth and accumulation of reserves.

### Results

Preconditioning

The 'black cloche' proved a very convenient way of dark-treating stockplants, the only problem encountered being that the gap between the polythene and the ground, intended to provide ventilation and just enough light to keep leaves green, tended to close up. As a result, before cuttings could be taken, it was necessary to open up the north side of the tunnel to allow yellow shoots to become green before cuttings could safely be taken.

Rooting

Dark-pretreatment slightly hastened rooting so that the percentage which had rooted after three weeks was on average 15% greater than that of the controls. Later testing for firmly anchored cuttings indicated that almost all cuttings had rooted by six weeks even without preconditioning.

There was also evidence that rooting was slower as the season progressed. Rooting reached 75% in 3 weeks from the June propagation, but an extra week was needed to reach the same target for the July propagation. Cuttings from similar shoots taken in August were also slow but, by using instead laterals that were closer in appearance to the June cuttings, the 75% target was reached again in 3 weeks.

Survival and growth during rooting and weaning

Amongst those cuttings moved to the weaning environment after only 3 weeks in fog, 8 to 10% failed to survive except for the dark-pretreated June cuttings which all survived. After 6 weeks in fog a maximum of 2% of cuttings failed to survive irrespective of pretreatment. These results confirm the close link between rooting and survival.

Liner quality

The wide range of factorial treatment combinations resulted in liners of widely differing appearance. Mean total shoot length per cutting for individual treatment combinations varied from 0.8 to 62.0 cm, while stem diameter varied from 3.3 to 6.0 mm. Statistical analysis showed that many of the factors examined had significant effects, when averaged over all other factors (i.e. 'main effects'), and that the effect of extending the season with heated glass varied significantly depending on the time the cuttings had been propagated. The more important of these effects are summarised in Table 10.

Table 10. Effects on liner quality of propagation date and the use of heated glass and supplementary light to extend the growing season, averaged over other treatments.

| Protection | Propagation date | Main stem diameter, mm | Shoot length per cutting, cm | Number of shoots per cutting |
|---|---|---|---|---|
| Cold poly | 12 June | 4.52 | 37.9 | 1.79 |
| | 24 July | 4.64 | 10.6 | 2.00 |
| | 21 August | 3.51 | 1.4 | 0.46 |
| Heated glass | 12 June | 5.76 | 56.1 | 1.67 |
| | 24 July | 5.70 | 52.2 | 2.08 |
| | 21 August | 4.13 | 25.2 | 1.46 |
| *LSD* *(P<0.05, 115 d.f.)* | | *0.37* | *6.4* | *0.41* |

The results showed that the final size of the liners, in terms of total shoot length, depended strongly on the time available for their growth. Delaying propagation by six weeks (i.e. till late July) reduced growth by 70%, but this was turned into an increase of 50% by extending the season under glass for 12 weeks. There was no reduction in stem diameter from the same delay because cuttings taken in July were thicker to start with, but the **increase in stem diameter** paralleled the shoot length results more closely (data not shown).

The number of lateral shoots which developed was less sensitive to propagation date. Only when delayed until late August, close to the end of the growing season for *Cotinus* under UK conditions, was it reduced and only then did extending the growing season increase branching.

Liners from dark preconditioned cuttings had significantly thinner stems, but this closely mirrored differences in the diameter of the original cuttings rather than an effect on the subsequent **increase** in diameter. Nor was there any effect on shoot number or length.

The size-grade of the original cuttings also had a significant effect on diameter at the end of the season, but in this case the differences had reduced as a result of significantly greater increases in diameter of the thinner cuttings. Initial cutting grade also had a significant effect on the number of shoots per cutting, which increased from 1.3 on the smallest grade to 1.9 on the largest.

Performance in containers

The following spring, the liners were potted into 2 litre containers and all but 1-2 cm of the strongest shoot were removed to provide a standard starting point to assess the vigour of subsequent growth and branching.

The plants which grew best in the container were those which had been propagated early and kept under heated glass for 12 weeks after weaning, (Table 11), the treatment which also yielded the largest liners (Table 10). Comparison of these tables reveals further parallels of this sort and statistical analysis confirmed that container growth correlated significantly with both stem diameter and lateral shoot length of the liners.

The analysis also showed that, compared with other propagations, plants from the July propagation under-performed, perhaps reflecting that the cuttings had been thicker, more woody, and slower to root than those collected in June, or even in August when soft young lateral shoots were taken. Glasshouse protection to extend the growing season exacerbated the under-performance.

Early propagation also had the effect of preventing any overwintering losses (Table 11). By contrast, attempting to compensate for later propagation by extending growth into the winter, using a heated glasshouse, increased losses.

Table 11. Effects of propagation date and the use of heated glass to extend the growing season in the rooting year on the quality of the final plant in the container the following year, averaged over other treatments.

| Protection | Propagation date | Survival of overwintering and potting-up % | Number of shoots | Shoot length per plant, cm | Average height of branching, cm |
|---|---|---|---|---|---|
| Cold poly | 12 June | 100 | 5.29 | 57.0 | 4.68 |
| | 24 July | 92 | 3.96 | 32.8 | 6.25 |
| | 21 August | 92 | 2.83 | 32.0 | 5.91 |
| Heated glass | 12 June | 100 | 5.50 | 81.3 | 6.28 |
| | 24 July | 63 | 1.92 | 32.7 | 5.01 |
| | 21 August | 83 | 2.92 | 47.5 | 6.14 |
| *LSD* $_{(P=0.05,\ 100\ d.f.)}$ | | *15.5* | *0.97* | *8.6* | *1.26* |

**Discussion and interim conclusions**

The parallel between the size of the liners and the quality of the container plants supports the hypothesis that accumulation of reserves is the most important criterion of liner quality. In this experiment, overcrowding was avoided by early thinning with the result that shoot growth was able to proceed without preventing accumulation of reserves, as judged by the increase in stem diameter. As a result, on this occasion, shoot length and stem diameter were equally good measures of liner quality.

Early propagation provided the longest period for growth and accumulation of reserves and thus the best liners. Extending this period using a heated glasshouse and supplementary light was less successful. It promoted both shoot extension and stem thickening but this was not fully reflected in performance in the container year, particularly in the plants from the July propagation. The most likely explanation is that the plants were not sufficiently hardened before being moved, first to an unheated polytunnel and later outside, so that subsequent frosts not only killed some plants completely but also adversely affected others, perhaps by killing the more superficial roots, thus negating the benefit of the accumulated reserves.

None of the liners were well branched so that some pruning was clearly required to produce a high quality container plant. The pruning that was applied, removing virtually all the earlier extension growth, more than doubled the average number of branches, confirming that the potential to develop new branches is more important than the number of branches that the liner bears from the rooting year. The largest number of branches developed on the thickest stemmed liners, supporting the hypothesis that the potential to develop new laterals depends on some aspect of plant reserves.

## *COTINUS* EXPERIMENT 5

This experiment examined whether the quality of liner achieved following early propagation, was sensitive to the amount of light and degree of protection provided after rapid weaning, given that, in all other experiments, the 'growing environment' was a capillary sand bed in a lightly shaded unheated polytunnel.

The experiment also explored further the effects of pruning. All new shoots were cut back to 4 cm at the end of weaning and two different pruning treatments were applied to the liners the following spring. Some were cut back hard into the original cutting in an attempt to stimulate desirably low branches, while others were pruned less severely, all branches being trimmed back to about 1cm.

### Results

Liner quality - shoot growth

Plants that were moved outside immediately after weaning did not show any signs of acute stress, such as wilting, but leaves that had lost their natural purple colour during propagation developed slight bronzing as they turned purple again. New shoots developed with entirely normal looking leaves but they terminated much sooner than those in other environments. Shade averted the bronzing, without preventing the restoration of normal purple colour, and almost doubled shoot growth. The data for total shoot length (Table 12) show a clear trend of increased shoot growth with increasing level of protection. There is also some indication that, given the protection of a polytunnel, further shading slightly reduced growth.

The light pruning applied at the end of weaning stimulated some additional secondary branches to develop so that the liners were better branched than in previous experiments (Table 12).

Table 12. Effects of growing environment on liner quality

| Growing environment | Main stem diameter, mm | Shoot length per cutting, cm | Number of shoots per cutting | Dry weight of prunings g |
|---|---|---|---|---|
| Outside (100% light) | 5.08 | 11.0 | 4.0 | 0.17 |
| Outside + shade (40% light) | 4.83 | 20.3 | 4.0 | 0.35 |
| Polytunnel (60% light) | 5.18 | 28.5 | 6.0 | 0.44 |
| Polytunnel + shade (40% light) | 4.98 | 23.6 | 5.4 | 0.35 |
| Glasshouse + heat + supplementary light | 6.18 | 55.4 | 5.6 | 2.84 |
| *LSD* $_{(P=0.05,\ 16 d.f.)}$ | *0.50* | *10.6* | *1.6(n.s)* | *0.37* |

Liner quality - stem diameter and the weight of prunings

Stem diameter of the liners was also affected. Differences were established within two weeks of moving the plants, though none were large enough to be statistically significant until the end of the season (Figure 6). Even then it was only the glasshouse that was clearly better than the other environments, though, as was the case with shoot length, the unshaded polytunnel treatment was intermediate between the glasshouse and the rest. The same was true of another measurement of liner size, the weight of shoots pruned off before potting.

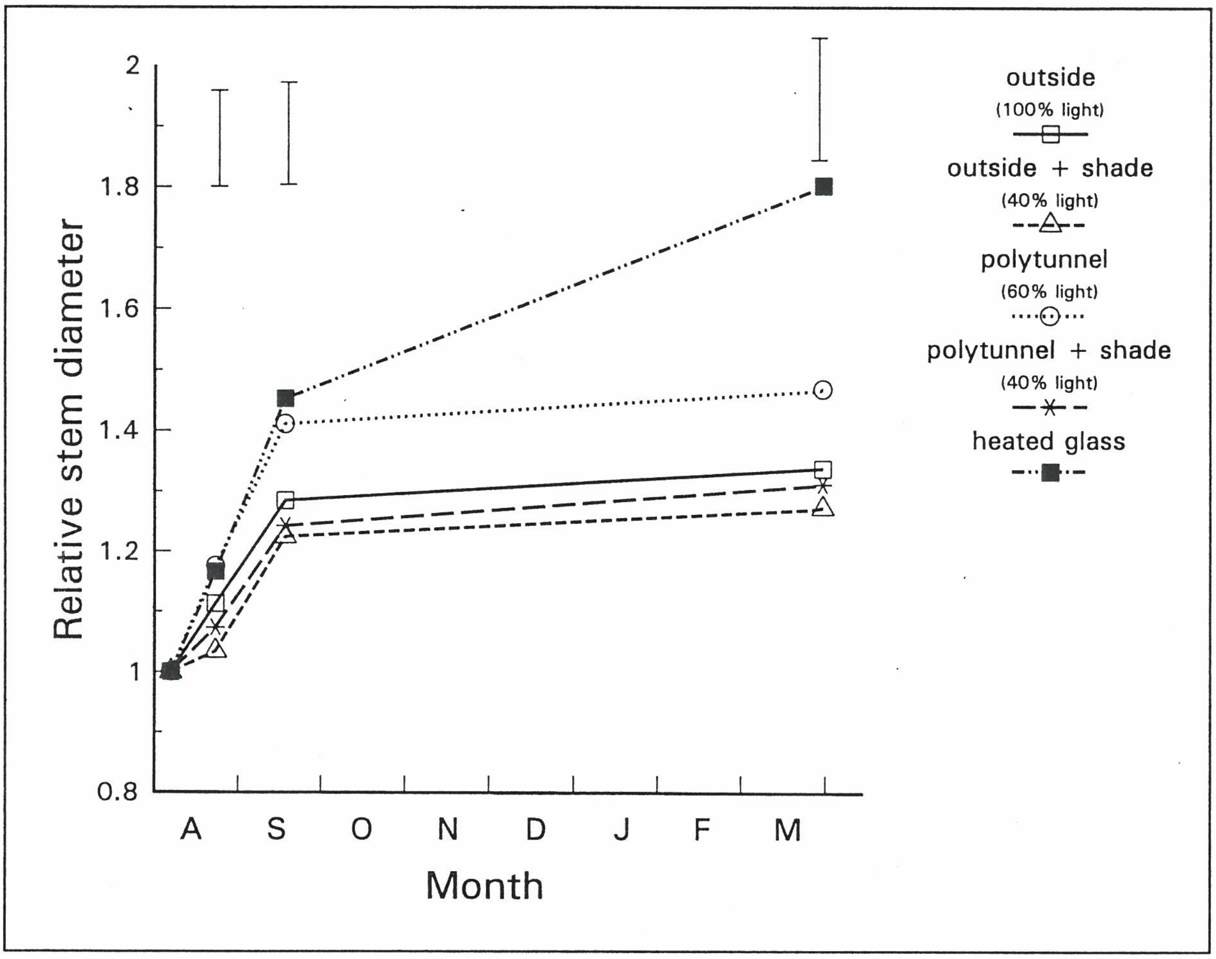


Figure 6. Increase in stem diameter in cuttings of *Cotinus coggygria* 'Royal Purple' grown in different environments after rooting and weaning. Vertical bars represent LSD.

Performance in containers

Growth in the container was significantly affected by the environment in which the cuttings were grown the previous year though the magnitude of the effects was smaller than the differences in size of the liners themselves (Table 13). This was particularly clear for the effect of the glasshouse environment: relative to the polytunnel treatments, it increased shoot growth in the container by just 31%, compared to an increase of 112% in liner shoot length. There was also some shift in the ranking of the treatments, particularly the relatively good performance of plants previously grown under shade outside. There were no significant effects on either the number or height of branches.

Table 13. Effects of growing environment after weaning on the quality of the final plant (averaged over levels of severity of pruning at the start of the container year).

| Growing environment | Number of shoots | Shoot length per plant, cm | Average branch height, cm |
|---|---|---|---|
| Outside (100% light) | 4.4 | 46.2 | 6.5 |
| Outside + shade (40% light) | 5.6 | 65.3 | 6.0 |
| Polytunnel (60% light) | 5.4 | 54.4 | 5.5 |
| Polytunnel + shade (40% light) | 6.0 | 50.6 | 5.0 |
| Glasshouse + heat + supplementary light | 5.4 | 68.8 | 6.2 |
| *LSD $_{(P=0.05,\ 14\ d.f.)}$* | *1.7 (n.s.)* | *17.0* | *2.2 (n.s.)* |

Cutting back the liners severely, to just 5 cm above the compost, was effective in forcing out lower branches but also reduced the number of branches to an unacceptable level (Table 14). At less than two shoots per plant this represented an 80% reduction compared to the moderately pruned plants. The difference in total shoot length was much smaller, reflecting the fact that individual shoots were significantly longer on the severely pruned plants. There were no overwintering losses but 20% of the severely pruned plants died following pruning.

Table 14. Effects of severity of pruning at the start of the container year on the quality of the final plant (averaged over all growing environments).

| Pruning severity | Number of shoots | Shoot length per plant, cm | Average branch height cm |
|---|---|---|---|
| Severe | 1.6 | 43.5 | 2.5 |
| Moderate | 7.9 | 66.1 | 8.1 |
| *LSD $_{(P=0.05,\ 14\ d.f.)}$* | *1.1* | *11.0* | *1.4* |

The link between liner size and final plant quality was examined directly by analysing the relation between total shoot length of individual final plants and the stem diameter of the liners from which they grew. Regression analysis showed that there was a significant relation ($P<0.05$) which, after allowing for the effect of severity of pruning, accounted for 36% of the variation. The relationship was virtually identical to that seen amongst plants propagated at the same time in Experiment 4 and is illustrated in Figure 7. For plants pruned moderately severely, the fitted line indicates that doubling liner diameter from 3 mm to 6 mm was associated with a doubling of the length of shoots on the final plant from 40 to 80 cm.

The same figure includes a line fitted to the data from the severely pruned plants. The offset of this line below the other indicates the adverse effect of severe pruning. This was statistically significant, whereas the difference in the slope of the lines was not, suggesting that stem diameter had a similar effect irrespective of pruning severity.

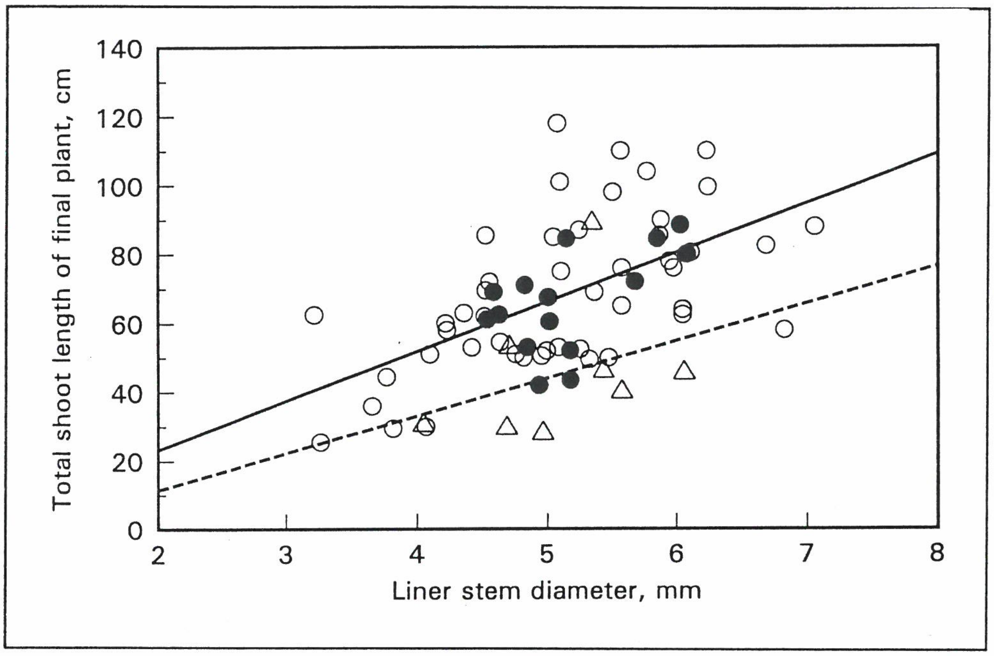


Figure 7. Shoot growth of *Cotinus coggygria* 'Royal Purple' in containers plotted against stem diameter of the liner for two levels of winter pruning (severe = triangles and dashed line, moderate = circles and solid line). Open circles refer to Experiment 4.

**Discussion and interim conclusions**

These results provide further confirmation of the usefulness of stem diameter as a measure of liner quality, in terms of the ability to grow well in the container. Artificially extending the season increased stem diameter but the effect was small (22% greater than plants in the polytunnel), particularly when compared with the increase in shoot length (112%), or shoot dry weight (628%). Subsequent growth in the container, being just 31% greater than in polytunnel plants, related more closely to the stem diameter of the liners than to the size of their lateral shoots. The value of stem diameter as a measure of liner quality was also evident at the individual plant level, as shown in Figure 7.

The improvement in final plant quality from the glasshouse treatment was clearly not large enough to make it economically worthwhile. Apart from that treatment, the results indicate that there is a real advantage of providing some form of protection but no convincing difference between the various levels of protection tested.

The final plants were of reasonable quality considering that they were produced in less than two years from taking cuttings whereas most nurseries would expect to take an extra year to achieve saleable *Cotinus*. Factors which continued to detract from quality were that the branches were too high, and that one or two more vigorous shoots became dominant, leading to an imbalanced appearance. Light pruning in the rooting year, whilst effective in promoting extra branches on the liner, did not help avoid this problem. On the other hand, severe pruning at the start of the container year was also ineffective. It had been hoped that the very robust looking liners produced by the best treatments would be capable of developing two or three vigorous and well balanced branches in response to severe pruning, as would occur on an established plant in the field, but this was clearly not the case.

## *COTINUS* EXPERIMENT 6

This experiment explored further the feasibility of producing high quality *Cotinus* plants in containers in the year after rooting cuttings. There were three important differences from earlier experiments. Tips were not pinched out in preparing cuttings, cuttings were direct-stuck in 9 cm pots (two cuttings per pot until thinned on day 50), and liners were overwintered in a polythene tunnel with under-bed heating to provide frost protection to the roots. The intention was to give maximum opportunity for the accumulation of reserves in the stem and root system and then to ensure that winter damage did not deplete these reserves, for example by killing superficial roots.

It also tested the effect, on cuttings rooted for three weeks in fog, of a weaning protocol that consisted of simply moving cuttings farther from the fogger. This move virtually eliminated wetting, whilst all other environmental conditions remained the same. For comparison, other cuttings remained in the wetter location.

Also examined further was the effect of pruning in the rooting year. Shoot tips were left intact when cuttings were prepared so that it was possible for the original shoot to continue to extend during rooting and weaning, after which half of the cuttings were pruned lightly. In the container year, plants were either not pruned or pruned severely in April or May.

### Results

Rooting and weaning

After 21 days, when the weaning treatment was started, 96% of the cuttings examined had rooted, with an average of 3.7 roots per cutting, up to 1.1 cm long.

After a further 21 days, all cuttings had rooted but there were slightly fewer roots on those transferred to the drier environment to wean (9.0 compared with 11.6, $P<0.05$). On the other hand, shoot extension had been greater in the weaned cuttings so that they were significantly taller (18.3 cm compared to 15.8cm, $P<0.05$). In both treatments, lateral shoots developed on fewer than one third of cuttings, and only on those whose shoot tip had abscised or rotted, but the number of shoots which then developed, and their combined length, was more than twice as great in the drier environment. By contrast there was no effect on stem diameter or leaf area.

There was evidence that the development of shoots on the weaned cuttings did not divert substantial resources away from the root system. First, lateral shoots accounted for only 3% of total dry weight gain from day 21 to 42, and second, total dry weight increase over this period was 32% **greater** in the weaned cuttings ($P<0.05$).

Liner quality

At the end of the rooting year the number and length of lateral shoots was sightly greater in the non-weaned plants (Table 15, $P<0.05$), reversing the earlier trend. Pruning in the rooting year, on 4th August, increased the number of liners with lateral shoots from 33%

to 96%, and also the number and length of laterals per branched plant, and reduced plant height by almost half ($P<0.001$). The laterals tended to arise just below the pruning cut so that the height of branching remained too high at about 10 cm from the compost.

There was also little effect on stem diameter or on the number of lateral buds that started to swell lower down on the stem (<7 cm above the compost) at the start of the next season. Such bud development had not been observed in previous years and was probably a benefit of overwintering the cuttings in a polytunnel, with frost-protection bed-heating. It seemed to promise an opportunity for new laterals to develop low down on the main stem, particularly if potentially dominant shoots above them were pruned off.

Table 15. Effects of weaning, and of pruning in the rooting year (1992), on the size and shape of *Cotinus* liners recorded in April of the next season.

| | Pruned in 1992 | | Not pruned in 1992 | | |
|---|---|---|---|---|---|
| | Weaned | Non-weaned | Weaned | Non-weaned | $LSD_{(P=0.05)}$ |
| Plant height, cm | 10.0 | 10.7 | 24.4 | 21.3 | 5.5 |
| Stem diameter, mm | 5.0 | 5.2 | 5.3 | 5.2 | 0.44 |
| Plants with lateral shoots, % | 92 | 100 | 25 | 42 | 40.8 |
| Number of laterals per plant | 3.7 | 5.2 | 0.8 | 1.7 | 1.56 |
| Length of laterals per plant | 22.2 | 30.0 | 7.3 | 12.6 | 10.28 |
| Height of the lowest lateral from compost, cm | 9.7 | 10.0 | 11.1 | 9.1 | 1.82 |
| Number of buds breaking at <7 cm from compost | 4.3 | 5.0 | 5.3 | 4.1 | 1.62 |

Final plant quality

Only 2 out of 48 plants were considered to be of ideal shape (classified as grade 1) with three or more strong branches inserted at < 7 cm above compost level. Both of these had been pruned early in the container year, a treatment that also resulted in 37% of plants dying. Even pruning one month later, in mid-May, resulted in 25% losses. Furthermore, average grade and other measures of quality were highest amongst plants which were not pruned in the container year (Table 16).

Table 16. Effects of severe pruning in the container year (1993) on survival and final plant quality, averaged over other treatments.

| | Time of pruning in 1993 | | | |
|---|---|---|---|---|
| | 15 April | 15 May | Not pruned | $LSD_{(P=0.05)}$ |
| Survival, % | 63 | 75 | 100 | 21.6 |
| Average grade [1] | 3.0 | 2.7 | 2.0 | 0.70 |
| Number of useful branches [2] | 2.1 | 3.3 | 3.4 | 0.70 |
| Stem diameter, mm | 8.3 | 7.9 | 9.1 | 0.54 |
| Root score [3] | 1.5 | 1.9 | 2.0 | 0.38 |

[1] subjective grading from 1(best) to 6(worst)
[2] branches >2.5 mm diameter inserted at <15 cm from compost
[3] subjective score of root quantity from 0 to 3

The appearance of the final plants was also influenced by treatments applied in the rooting year (Table 17). In contrast to earlier experiments, weaning improved plant quality in terms of significantly higher average grade, as well as increased stem diameter and more branching.

Pruning in the rooting year increased the number of plants which died the following year from 8.3% to 33.3%. Without exception all these losses occurred following further pruning in the container. Of the plants pruned in both years, 50% had died by the end of the second year.

Table 17. Effect of weaning, and of pruning in the rooting year (1992), on survival and final plant quality, averaged over other treatments.

| | Pruned in 1992 | | Not pruned in 1992 | | |
|---|---|---|---|---|---|
| | Weaned | Non-weaned | Weaned | Non-Weaned | $LSD_{(P=0.05)}$ |
| Survival, % | 75 | 58 | 100 | 83 | 35.3 |
| Average grade[1] | 2.0 | 3.3 | 2.0 | 3.0 | 0.99 |
| Number of useful branches [2] | 3.2 | 2.6 | 3.3 | 2.8 | 1.04 |
| Stem diameter, mm | 8.9 | 7.6 | 8.8 | 8.5 | 0.75 |
| Root score [3] | 1.9 | 1.9 | 2.0 | 1.5 | 0.54 |

[1] subjective grading from 1(best) to 6(worst)
[2] branches >2.5 mm diameter inserted at <15 cm from compost
[3] subjective score of root quantity from 0 to 3

**Discussion and interim conclusions**

Direct-sticking, combined with early transfer to the growing environment, resulted in liners that were relatively sturdy. Pruning shortly after rooting increased the number of branches on the liners but this was not reflected in the final plant. Furthermore, it increased the number of plants which died following later pruning. At the start of the container year, some plants were pruned severely, cutting back into the original cutting, in the hope of stimulating vigorous new branches low down on the plant. A few plants produced two or three well balanced branches, as had been hoped, but the majority did not and, despite their relatively sturdy appearance, many simply died. Several buds had already broken below the pruning cut, but very few developed further, even after pruning had removed all shoots above them. It is concluded that it is unrealistic to try to use hard pruning to create an ideal branch framework on *Cotinus* plants, one year after rooting.

The experiment also showed that weaning can influence final plant quality. In this case weaning involved only reduction of leaf wetting, achieved by moving cuttings within the fog house, but this was sufficient to advance early shoot growth and later to increase both survival and quality of the final plant the following year. Weaning, by reducing wetting 21 days earlier, increased dry matter production, most of which went into roots and main stem, and suppressed additional lateral breaks. As discussed earlier (page 30) extension of such laterals can sometimes be at the expense of accumulation of reserves in the roots and stem. In this case, no benefit of weaning was detected in terms of liner stem diameter, but it is quite possible that, with direct-stuck liners and overwinter protection, there were differences in the size of the root system that enhanced growth the following year.

## *COTINUS* EXPERIMENT 7

The final experiment with *Cotinus* tested whether cuttings could be prepared in such a way that branches would develop in the rooting year that would provide the foundation of an ideal branch structure in the container. It was based on the concept of designing the size and shape of the liner to meet a specific market requirement, an idea that took shape following discussions with growers during an HDC study day at East Malling, which has come to be known as the 'designer liner' concept. It was hoped that by incorporating improvements in weaning protocols, and using direct-sticking, branches could be formed that would be strong enough to form a framework for the container year, **if** they developed low enough on the liner. To this end cuttings were prepared as follows:

1. Standard (14 cm apicals, with the tip pinched out)
2. Short (7 cm apicals, with the tip pinched out)
3. Partially defoliated (like (1) but with lower leaves removed so that remaining leaves matched those on the short cuttings)
4. Short non-apicals (7 cm long, 3 or 4 nodes, from about 20 cm below the shoot tip.

Other treatments were included to test the interaction of cutting size with spacing and pot size. Also, cuttings were either weaned rapidly under reduced shade, or progressively over six weeks, the intention of being to vary the amount of shoot growth relative to accumulation of reserves (see Appendix for further details). Plants were all overwintered in a cold polytunnel, as in the previous experiment.

### Results

#### Rooting and weaning

After four weeks, 89% of the shorter cuttings (treatment 2) had rooted compared to 97% of the controls and 0% of the non-apicals. Such non-apical cuttings have been rooted quite successfully in the past but on this occasion leaves were already dropping and they were therefore discarded.

Despite having only 33% of their leaf area, dry matter increase over the rooting period in the shorter cuttings was almost 75% that of the controls. Where the same reduction in leaf area was achieved by removing lower leaves without shortening the stem (i.e. type 3 cuttings), dry matter increase was smaller, at just over half that of the controls. Much of the increase in dry matter was accounted for by roots, extra leaf area combined with generous spacing roughly doubling the number of roots per cutting to 7.3.

#### Liner quality

Removing lower leaves stimulated extra branching close to compost level, creating plants that appeared to have the foundations of an ideal branch framework (Table 18). The advantage was still evident, though less marked, at the end of the season.

Table 18. Differences amongst the apical cutting treatments in the development of lateral branches during 4 weeks rooting in fog. Branches were categorised as proximal if they arose from a node below the lowest leaf bearing node, and otherwise as distal.

| Treatment | Number of lateral shoots > 1 cm long | | |
|---|---|---|---|
| | Proximal | Distal | Total |
| 1. Control | 0.92 | 0.96 | 1.88 |
| 2. Shorter cuttings | 0.29 | 1.54 | 1.83 |
| 3. Lower leaves removed | 2.33 | 0.25 | 2.58 |
| 4. Reduced spacing | 1.13 | 0.37 | 1.50 |
| 5. Larger pot size | 0.63 | 1.29 | 1.92 |
| *LSD* $_{(P=0.05)}$ | *0.374* | *0.458* | *0.570* |

Slow progressive weaning encouraged additional breaks after rooting, the number increasing from 1.9 per cutting to 3.1, compared to no increase on plants weaned rapidly. Elongation of the laterals was also favoured, basal branches reaching on average 12.5 cm compared with 3.8 cm if rapidly weaned, such that total lateral shoot length per plant was much larger (Table 19). In general, shoot extension was slower than in previous years because temperatures were lower. This checked growth of the rapidly weaned plants particularly severely, which probably explains why rapid weaning did not benefit stem diameter in this experiment. However, diameter was reduced by close spacing and by removal of leaves, both of which would have been expected to reduce photosynthesis. Diameter of the liners from the shorter cuttings was significantly smaller than from the larger cuttings, but the amount that it had increased over the season was closely similar.

Table 19. Effects of weaning and other treatments on liner quality, assessed on 16 November, 1993

| Treatment | Lateral shoots per cutting | | Stem diameter, mm |
|---|---|---|---|
| | Number | Total length, cm | |
| Weaning protocol A: Rapid weaning | | | |
| 1. Control | 1.42 | 4.42 | 4.15 |
| 2. Shorter cuttings | 2.17 | 7.42 | 3.23 |
| 3. Lower leaves removed | 2.33 | 7.42 | 3.86 |
| 4. Reduced spacing | 1.42 | 4.33 | 3.99 |
| 5. Larger pot size | 2.33 | 10.96 | 4.12 |
| Weaning protocol B: Slow weaning | | | |
| 1. Control | 2.58 | 20.87 | 4.04 |
| 2. Shorter cuttings | 2.42 | 22.67 | 3.25 |
| 3. Lower leaves removed | 4.17 | 33.75 | 3.92 |
| 4. Reduced spacing | 3.33 | 36.50 | 3.92 |
| 5. Larger pot size | 3.00 | 29.50 | 4.08 |
| *LSD* $_{(P=0.05)}$ | *0.794* | *6.12* | *0.248* |
| Weaning protocol means | | | |
| A. Rapid weaning | 1.93 | 6.91 | 3.870 |
| B. Slow weaning | 3.10 | 28.66 | 3.840 |
| *LSD* $_{(P=0.05)}$ | *0.354* | *2.74* | *0.110* |

Final plant quality

Since most laterals on the liners were short, they were left unpruned. Quality of the final plants was higher than in any of the earlier experiments with some individual plants being of good size, with three well balanced branches (Figure 8). However, this quality was not achieved consistently in any treatment, the main problem being the tendency for a single shoot to become dominant leading to a poorly balanced plant. Nonetheless, growth was sufficiently vigorous and uniform to highlight an additional problem with this plant : in response to the close spacing **within** rows, plants located towards the edges of the bed tended to grow away from the vertical, as can be seen in Figure 9.

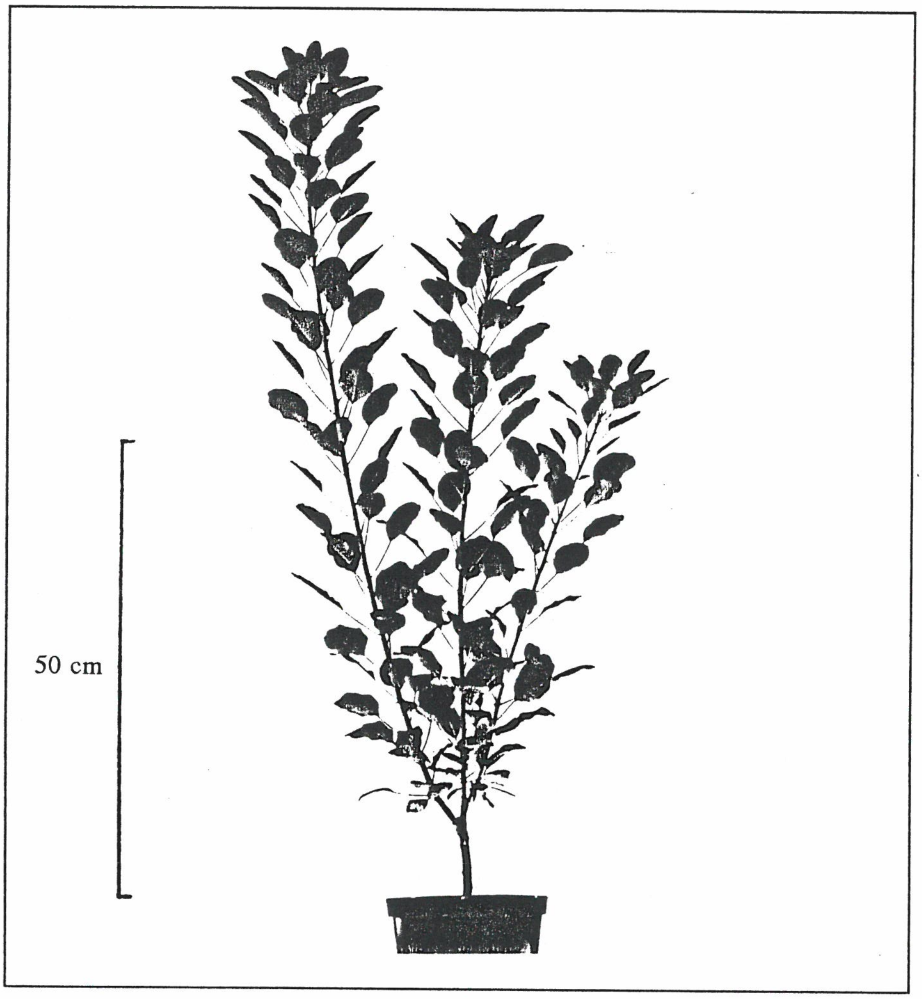


Figure 8. An example of a large and well balanced plant of *Cotinus coggygria* 'Royal Purple' produced in the year after cuttings were rooted.

There was no clear relation between the number of branches on the final plant and the number on the liner, reflecting the fact that some small branches recorded at the liner stage failed to grow any further, while a significant number of new branches were initiated from dormant buds on the main stem. As a result, on this occasion, significant treatment effects on the liners were not translated into significant differences in the final plants. Even the lower branching achieved by removing lower leaves was not reflected in lower branches on the final plant. As would be expected, branches were lower on the plants from shorter cuttings, by an average of 1.3 cm, but there were also fewer branches per plant.

The effect of rate of weaning could not be tested because the rapidly weaned plants had to be excluded from the container year phase due to vine weevil infestation.

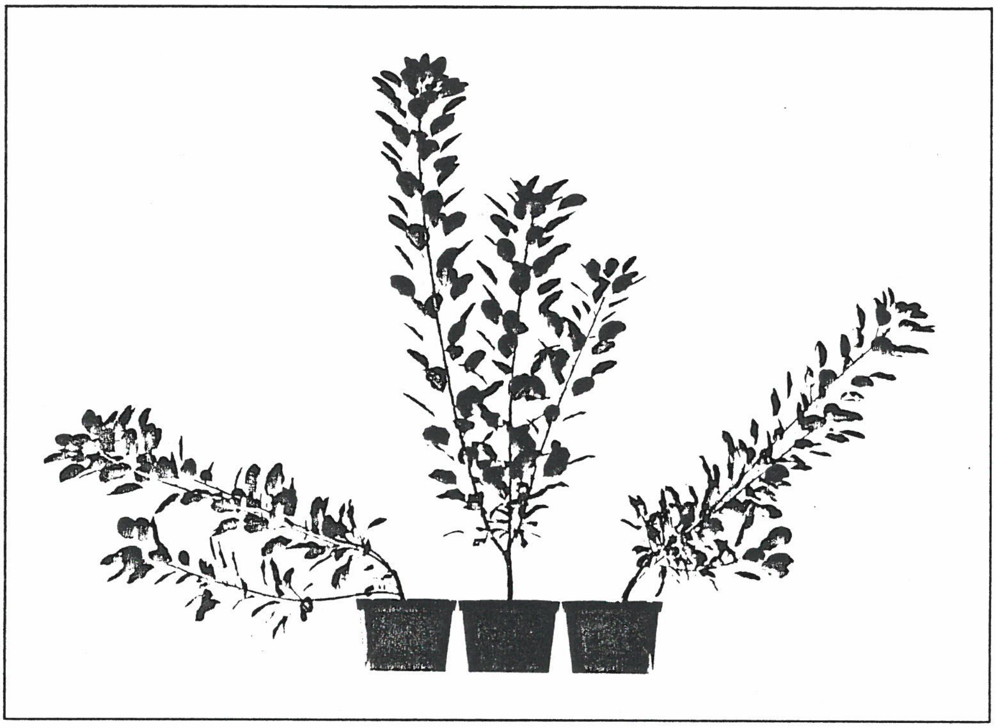

Figure 9. These three plants, from the extreme edges and centre of a 2 m wide bed, demonstrate how the strong phototropic response of *Cotinus coggygria* 'Royal Purple' can spoil the shape of the plants.

**Discussion and interim conclusion**

Large cuttings yielded the thickest liners but, in contrast to previous experiments, this was not reflected in final plant quality. However, the increase in diameter compared to that of the original cuttings was no greater in the larger cuttings than the small ones. This suggests that it may be the **increase** in stem diameter that provides the real measure of liner quality, probably because it reflects the amount of root development.

Removing lower leaves stimulated low branches as hoped but also reduced leaf area without a proportional reduction in stem size. In so doing, it would have tended to reduce carbohydrate production by photosynthesis without an equivalent reduction in loss of carbohydrate through respiration, thereby reducing the opportunity for growth and for accumulating reserves. As a result, the rate of dry matter accumulation during the rooting period was halved, as it was by spacing cutting so close that lower leaves received little light. These results demonstrate that using larger cuttings can only be expected to lead to greater growth rate if they carry a larger area of leaves, are well spaced to allow light to reach lower leaves, and if respiration in the larger stem does not offset the increase in photosynthesis. There are clear parallels here with the importance of the ratio of leaf area to stem size in the stimulation of rooting in Lilac cuttings (Howard and Harrison-Murray, 1995).

The use of shorter cuttings was effective at reducing branch height in the final plant. By contrast, removing additional lower leaves on a large cutting stimulated branching low down on the liners but the effect was not maintained in the container year, presumably because they were suppressed by shoots higher up the plant.

The quality of the final plants was the best achieved so far. The main problem remained the tendency for one shoot to become dominant, leading to a poorly balanced plant. The tendency to grow in flushes contributes to this problem. A detailed analysis of shoot growth (data not shown) showed that the imbalances arose largely as a result of variation in the number of flushes between shoots on the same plant. Light pruning or pinching in the container could improve the balance between shoots, though it would tend to reduce final plant size. Pruning systems to achieve the maximum improvement in shape with minimum reduction in size of a range of plants, including *Cotinus*, are the subject of another HDC project (Cameron and Howard, 1995).

## *ACER* EXPERIMENT 8

This experiment investigated many aspects of the weaning requirements of *Acer palmatum* 'Aureum', another subject which is difficult to grow well. In particular it compared direct transfer to the growing environment with transfer via two different weaning environments, combined with three different durations of rooting in fog (4, 5, and 8 weeks). In addition, with cuttings rooted for 5 weeks, different durations of the weaning phase, as well as three additional weaning environments, were included (see Appendix for further details).

### Results

Effects of duration of rooting

Root initials were observed on many cuttings after two weeks but it was a further 10 days before any emerged as roots. By four weeks, when the first cuttings were transferred to their weaning environment, 69% were firm in the compost and root initials were present on virtually all the others. At this stage a destructive sample showed that there were 5.1 roots per rooted cutting with an average maximum length of 0.82 cm. Comparison of the rooting percentage of this sample, with the assessment based on how firmly the same cuttings were anchored, showed close agreement.

Of the cuttings transferred at 4 weeks, survival was greatest if weaned in a high humidity environment under heavy shade but, even amongst those that were rooted, fewer than half survived if weaned in the less heavily shaded environment or if not weaned at all (Table 20). Survival to the end of the season closely reflected differences in leaf shrivelling observed over the first few days of the weaning period. When recorded shortly after transfer to the growing environment in July, many more were still alive (Project News 14, p.28) but most of those that had lost many leaves, and had not started to regrow, eventually died.

Table 20. Percent survival of apical cuttings of *Acer palmatum* 'Aureum' to the end of the season (recorded 12th November, 1991)

| | Weaning | | |
|---|---|---|---|
| Weeks in fog | Poly-tent, 8% light | Poly-tent, 30% light | None |
| 4 | 45 | 30 | 25 |
| 5 | 70 | 80 | 40 |
| 8 | 55 | 30 | 25 |

After a further week in fog, 93% of apical cuttings had rooted, with 7.5 roots per rooted cutting and average maximum root length of 1.4 cm. (For the 2-node non-apicals the figures were 95%, 7.2 roots and 2.6 cm respectively). Survival rates were correspondingly increased (Table 20) but transfer direct to the growing environment still resulted in greater losses than transfer via a high humidity weaning stage.

Further extending the period in the rooting environment, to eight weeks, **reduced** final survival rates. This reflects a problem of deterioration and abscission of leaves on the cuttings in fog, which restricted further root development. Also, new shoots developing in the fog appeared water-soaked and grew much less than those in the weaning environments.

Effects of duration of weaning

The effect of duration of the weaning period was studied with cuttings transferred from fog after 5 weeks. The results (Table 21) showed that most of the benefit was achieved with just one week, though survival continued to increase up to 4 weeks.

Table 21. Effect of duration of weaning, following 5 weeks in fog, on % survival of apical cuttings of *Acer palmatum* 'Aureum' to the end of the season.

| Weeks weaning | Weaning environment: Poly-tent, 8% light | Weaning environment: Poly-tent, 30% light |
|---|---|---|
| 0 | 40 | |
| 1 | 65 | 60 |
| 2 | 50 | 65 |
| 4 | 70 | 80 |

However, delaying transfer to the growing environment by extended weaning reduced the opportunity for the liner to build up resources, as measured by the diameter of the main stem (Table 22). This was not avoided by using relatively light shade during weaning.

Table 22. Stem diameter, mm, of surviving apical cuttings of *Acer palmatum* 'Aureum', as affected by duration of weaning following 5 weeks rooting in fog. Recorded on 12th November, 1991.

| Weeks weaning | Weaning environment: Poly-tent, 8% light | Weaning environment: Poly-tent, 30% light |
|---|---|---|
| 0 | 2.5 | |
| 1 | 2.2 | 2.2 |
| 2 | 2.1 | 2.0 |
| 4 | 1.7 | 1.7 |

Weaning environment and type of cutting

There was no significant difference in survival rate between any of the poly-tent weaning environments (Table 23), despite the threefold difference in light reaching the cuttings, which would have had a substantial effect on potential transpiration. In contrast to the polythene tents, neither shade alone, nor shade combined with light misting, increased survival compared with direct transfer to the growing environment. Therefore, **high humidity** is the crucial component of a successful weaning environment for apical cuttings of this subject. On the other hand, two-node cuttings, prepared from lower down the same shoots, showed no significant benefit from any weaning environment, 80% surviving direct transfer to the growing environment, 68% of which had started to grow when recorded 4 weeks later.

Table 23. Percentage survival of *Acer palmatum* 'Aureum' as influenced by type of cutting and the nature of the environment used for 4 weeks weaning, following 5 weeks rooting in fog. Recorded on 12th November, 1991

| Weaning environment | Apical | Two-node |
|---|---|---|
| C. Poly-tent, 10% light | 70 | 95 |
| J. Poly-tent, reflective, 10% light | 75 | 85 |
| H. Poly-tent, 34% light | 80 | 80 |
| B. Light misting, 20% light | 40 | 85 |
| K. Shade-cloth tent, 10% light | 40 | 55 |
| G. None | 40 | 80 |

**Discussion and interim conclusions**

In contrast to *Cotinus coggygria*, the opportunity for cuttings of *Acer palmatum* 'Aureum' to develop an extensive root system before being moved from the low stress fog environment was limited by the way leaves deteriorated in fog. Deterioration was evident after just two weeks and was severe by the time rooting reached 93% after five weeks. At this time roots were still very short, the longest on each cutting averaging just 1.4 cm, so that it is not surprising that an intermediate weaning environment greatly enhanced survival. Further time in fog was not beneficial because leaves deteriorated further and many dropped. Whether this is true of all rooting environments was examined in the next two experiments.

Comparison of different durations of weaning in a shaded polythene tent showed that survival rates continued to increase up to four weeks but that this restricted the opportunity for growth before the end of the season. From comparisons of different weaning environments, it was clear that high humidity was the essential component of an effective weaning protocol for this subject.

In contrast to apical cuttings, there was no convincing evidence of any benefit from weaning non-apical two-node cuttings, prepared from near the base of the longest shoots and bearing more mature leaves on thicker stems.

## *ACER* EXPERIMENT 9

The first experiment with *Acer palmatum* identified a conflict between the need to achieve a high proportion of well rooted cuttings and the need to keep leaves in good condition in order that they can contribute to the establishment process. This experiment tested the hypothesis that the leaf deterioration resulted from excessive leaf wetting and explored ways to reduce wetting without increasing stress.

Four rooting environments were included as follows:-

(i) Fog - about 2 m from the fogger
(ii) Fog - about 9 m from the fogger
(iii) Enclosed mist under 'evapostat' control
(iv) Enclosed mist under 'wet leaf' control

The evapostat is an East Malling invention which regulates mist or fog according to the evaporative demand experienced by the cuttings, thereby matching the environment to the cutting's needs better than other systems (Harrison-Murray, 1995, and Harrison-Murray *et al.*, 1993b).

Cuttings were either kept for seven weeks in the rooting environment, followed by one week's weaning in a poly-tent, or rooted for five weeks and weaned for three (for further details see Appendix)

### Results

Rooting and survival

Table 24 shows that both mist systems succeeded in almost eliminating leaf deterioration but, compared to the drier location in fog, this was achieved at the expense of rooting, especially if the mist was under the conventional control system.

Table 24. The effect of rooting environment on rooting and leaf condition after five weeks, in a sample of apical cuttings, and on survival, 3 weeks after transfer to the growing environment (averaged over weaning protocols).

| Rooting environment | Healthy leaves per cutting[1] | Rooting % | Longest root per cutting, cm | Survival % |
|---|---|---|---|---|
| (i) Fog (wet location) | 0.9 | 69 | 2.45 | 56 |
| (ii) Fog (drier location) | 2.0 | 88 | 3.77 | 92 |
| (iii) Evapostat mist | 4.7 | 75 | 1.33 | 73 |
| (iv) Conventional mist | 4.7 | 56 | 0.25 | 40 |

[1] i.e. the number of expanded leaves without any necrotic areas, out of a total of approximately 6 per cutting.

Survival of the transfer to the growing environment was greatest amongst the cuttings rooted in the drier fog environment (Table 24). These were the best rooted cuttings, but not the cuttings with least leaf damage. It follows that successful weaning depended more on the size of the root system than on leaf condition.

Growth after weaning

There was no evidence that leaf condition had any effect on subsequent shoot growth under the conditions of this experiment. Records of stem diameter, shoot length, and shoot number, after the period of growth under heated glass, showed no significant differences attributable to treatment. Instead there was a strong negative correlation of these variables with the number of surviving cuttings in each pot, suggesting that competition between plants within the same pot was a major factor restricting growth.

**Discussion and interim conclusions**

The reduced deterioration of leaves observed when cuttings were placed in a drier part of the fog house supports the hypothesis that leaf wetting contributes to deterioration of *Acer palmatum* leaves. The further improvement seen in cuttings under enclosed mist is more difficult to interpret. It may have been important that leaves would sometimes have dried out briefly in mist but not in fog, or that there was no water deposited on the undersurface of leaves, or that transpiration would have been greater under mist.

While none of the environments prevented leaf deterioration completely, results obtained with mist controlled by evapostat were encouraging. Under most conditions the evapostat gave light misting, but during hot and sunny weather, when the danger of stress is greatest, it gave much more generous misting than the conventional 'wet leaf' system. Evapostat control increased rooting without any loss of leaf condition compared to the conventionally controlled mist, supporting the belief that it creates conditions which match the cuttings' requirements more effectively than conventional control systems.

Both overall survival rates, and the percentage of **rooted** cuttings which survived, were greatest amongst the cuttings from the drier fog environment. Since these cuttings had the longest roots, as well as the highest percentage rooting, this demonstrates again the importance of root development as the key to straightforward weaning.

## *ACER* EXPERIMENT 10

This experiment extended the search for a rooting environment which would avoid water stress without causing leaves to deteriorate and drop, so as to make it possible to achieve extensive root development before weaning. Following the encouraging results achieved by running enclosed mist on evapostat control, our ventilated wet fog house was converted to evapostat control for this experiment.

The wet and humid conditions that can be achieved with fog allow cuttings to receive more light without suffering water stress, potentially allowing cuttings to photosynthesise more and thus root and establish faster. For this experiment, shade was removed from a heavily wetted part of the fog house to test whether the combination of extra light with extra wetting would be useful, either at the rooting or at the weaning stage.

Conventional **open** mist, with generous leaf wetting, was also included, partly to relate to normal industry practice, but also to determine whether the leaf deterioration is linked with heavy leaf wetting *per se* or to the low evaporative demand achieved in wet fog. Cuttings were kept in their rooting environment for six weeks followed by three weeks in various 'weaning' environments before transfer to the growing environment.

### Results

Rooting and weaning

Leaves on the cuttings in fog remained in much better condition than in previous experiments and there was no leaf drop at all, yet close to 100% rooting was still achieved (Table 25). There was even less damage under open mist but there was also significantly less rooting. After six weeks rooting in fog, the longest root per cutting averaged 6.9 cm, with 8.8 roots per rooted cutting, while in mist the figures were 3.15 cm and 2.6 roots respectively.

Table 25. The effect of rooting environment on rooting and leaf condition of apical cuttings of *Acer palmatum* 'Aureum'.

| Rooting environment | Percentage rooting | | Necrotic leaves, % |
|---|---|---|---|
| | (at 28 days) | (at 57 days) | (at 57 days) |
| 1. Fog: wet + shade | 80 | 90 | 20 |
| 2. Fog: wet - shade | 83 | 97 | 15 |
| 3. Fog: drier + shade | 89 | 100 | 22 |
| 4. Open mist + shade | 63 | 80 | 10 |
| *Mean LSD $_{(P=0.05)}$* | *15* | *11* | *10* |

'Survivability' tests

The ability of the cuttings to survive transfer to a drier environment was first tested six weeks after taking cuttings, with remarkable results. Only one cutting failed to survive in the sense that all leaves shrivelled, despite some of the others having no roots. Many cuttings showed some leaf curling or slightly drooping petioles but there was no evidence that such signs of stress were related either to rooting environment or to the number and length of roots. The tests involved a progression from a humid dimly-lit chamber, through a number of intermediate stages, until they were brightly lit, 1 m below a sodium lamp, at moderate humidity and with fan ventilation. To test whether this progressive change might have enabled the cuttings to survive, additional cuttings were transferred directly to the final stage, but with similar result. Porometer measurements showed that stomata were already nearly closed when cuttings were removed from the rooting environments, and soon closed completely, very effectively restricting water loss.

Very similar observations were made when the tests were repeated three weeks later, two weeks into the weaning phase. No differences in behaviour were observed between cuttings from the three different weaning environments. Acting on the basis of this result, all remaining cuttings were moved directly to an unshaded and well ventilated polytunnel one week later. A combination of sunny and windy conditions shortly after transfer caused **new growth** to wilt severely, but this recovered quickly after covering the bed with white polythene overnight.

Evidence for salt sensitivity

Plants generally grew strongly thereafter and were potted-on two months later, in early September. Shortly after this repotting, scorching of leaf tips started to develop which increased in severity, eventually involving complete leaves and leading to premature leaf drop. In contrast, another batch of cuttings propagated at the same time but in cell trays, and which had been potted -up earlier, showed no such symptoms. Consideration of all the differences in the handling of these two sets of plants pointed to the fertiliser level in the medium as the most likely cause of this difference in behaviour. The healthy plants were potted into a 1:1 peat:bark mix containing just 1 $kg/m^3$ of controlled release fertiliser (Ficote 140, 16:10:10) whereas the plants which suffered leaf scorch were potted into a standard mix containing 4 $kg/m^3$ (OsmocotePlus Spring Potting) as well as 0.15 $kg/m^3$ of Nitram in a peat:bark:loam:grit (6:2:1:1) base.

Growth

Non-destructive end-of-season measurements showed that rooting environment significantly affected stem diameter and the number and length of new shoots (Table 26). Plants rooted in the drier part of the fog house grew best, both in terms of length of new shoots and stem diameter.

Table 26. The effect of rooting environment on vigour of *Acer palmatum* 'Aureum' plants at the end of the rooting year (recorded 11 November, 1993).

| Rooting environment | Stem diameter, mm | New shoots | |
|---|---|---|---|
| | | Number | Total length, cm |
| 1. Fog: wet + shade | 2.44 | 3.17 | 19.4 |
| 2. Fog: wet - shade | 2.48 | 4.52 | 24.0 |
| 3. Fog: drier + shade | 2.65 | 4.33 | 31.5 |
| 4. Open mist + shade | 2.29 | 4.32 | 23.4 |
| *LSD $_{(P=0.05)}$* | *0.204* | *0.986* | *7.06* |

Weaning in the driest part of the fog house resulted in larger plants than leaving them in the slightly wetter environment in which they were rooted (Table 27, weaning a v. c), but not significantly so. On the other hand, subsequent growth was significantly reduced by the alternative weaning strategy being tested for the first time here, which involved an increase in light level combined with heavier wetting to limit stress (i.e. weaning b).

Table 27. The effect of weaning environment, following rooting in a drier part of the fog house (environment 3), on vigour of *Acer palmatum* 'Aureum' plants at the end of the rooting year (recorded 11 November, 1993).

| Weaning environment | Stem diameter, mm | New shoots | |
|---|---|---|---|
| | | Number | Total length, cm |
| (a) Humid but dry | 2.65 | 4.33 | 31.5 |
| (b) Humid; wet; no shade | 2.22 | 3.63 | 18.2 |
| (c) Humid; light wetting | 2.40 | 4.13 | 25.9 |
| *LSD $_{(P=0.05)}$* | *0.204* | *0.986* | *7.06* |

## Discussion and interim conclusions

Comparison of the results of this experiment with the previous two, clearly suggests that evapostat-control greatly improved the environment in our fog house, and confirms the overriding importance of getting the rooting environment right for this subject. More than 90% rooting, and root lengths of 7cm, were achieved with minimal leaf damage, after six weeks in evapostat-controlled fog. It is impossible to exclude the possibility that other factors, such as stock plant condition, may have contributed to this improvement in success, but the performance of a wide range of other material in the same house suggests that the evapostat had provided a very satisfactory rooting environment.

The relatively good condition of leaves in open mist, despite very generous wetting, suggests that wetting does not in itself cause leaves to deteriorate. Instead, it is probably low transpiration rate, combined with wetting of the undersurface of leaves (where most stomata are found), that leads to the problem. Heavily wetted parts of the fog house would provide this combination, and the evapostat would help to avoid it, by cutting back wetting except when sunny conditions were tending to push up transpiration rate.

The good condition of the leaves in this experiment may help to explain how resilient the cuttings proved to be in survivability tests. Stomatal closure was shown to be very effective in limiting water loss in this material such that even unrooted cuttings showed very little signs of stress in these short-term tests. Stomata closed even on the best rooted cuttings, suggesting that either they were responding directly to the sudden reduction in humidity, or that the roots were unable to supply water rapidly enough to prevent a water deficit developing.

Stomatal closure may also explain why there was no benefit from increasing the light level during the weaning period because it would have prevented the cuttings making use of the extra light in photosynthesis. This is made more likely by the fact that wetting in the unshaded part of the house was not always enough to keep leaves thoroughly wet.

By comparison with the original leaves, those on new shoots that had developed after three weeks weaning proved less able to tolerate an abrupt increase in evaporative demand. No measurements of stomata were made but it is likely that they were quite wide open at the time of transfer and failed to close quickly enough to prevent wilting. However, after temporarily raising the humidity again overnight, no further wilting occurred, probably because the stomata had adjusted to the drier conditions.

To summarise, the main conclusions which can be drawn from all three experiments on *Acer palmatum* 'Aureum' are:

1. It is difficult to create a rooting environment that will allow full expression of rooting potential without serious deterioration of leaf condition, leading eventually to necrosis and leaf drop. This makes it difficult to ensure that cuttings will have an extensive root system before it is necessary to remove them from the rooting environment.

2. Evapostat control helps achieve the required rooting environment by providing very supportive conditions only when weather conditions make it really necessary.

3. When it is necessary to remove cuttings from the rooting environment before they are well rooted, weaning in a shaded poly-tent, or other high humidity environment, greatly enhances survival of sensitive apical cuttings but does not appear to be necessary for non-apical cuttings prepared from the more mature parts of shoots.

4. One or two weeks in such a humid weaning environment represents a reasonable compromise between enhanced survival and possible restriction of growth. Any longer is likely to be detrimental, particularly since shoots which develop under such conditions will

be ill-adapted to more stressful growing conditions and, if allowed to grow too large, will create the need for a second stage of weaning.

## General discussion and conclusions

To prevent desiccation injury, plants must be able to maintain an approximate balance between water loss and water uptake. In a normal healthy plant, whenever water uptake fails to balance water loss, stomata in the leaves start to close, reducing transpiration and restoring the balance. For cuttings, with no roots, special propagation environments are required to assist this regulatory process by reducing evaporative demand until new roots reestablish the capacity for water uptake. The ability of the newly rooted cutting to survive in a normal environment depends on how much water the new roots can supply and how effectively the stomata can restrict water loss to match that supply. After a period in the unnatural conditions of a fog or mist unit, it is possible, but by no means certain, that the stomata, or indeed the roots, may fail to function normally. In that case, a period in an intermediate 'weaning' environment should increase survival by limiting the increase in evaporative demand until roots and stomata are fully functional. This project explored the need for such weaning, the potential benefits, and how best to go about it.

The results established a close link between good root development and survival in a drier environment, suggesting that achieving a sufficiently large root system is the main requirement for success. A period in an intermediate weaning environment, such as a humid polythene tent, generally achieved no better survival than leaving cuttings longer in the rooting environment so that the root system could grow larger. Serious wilting was confined to cuttings which had little or no root, and those on which soft new shoots had developed. Such shoots often started to develop during rooting in fog, but grew rapidly in the various types of humid enclosure tested as possible 'weaning' environments. This suggests strongly that it is only when leaves **develop** under wet and/or humid conditions that stomata are unable to control water loss enough when exposed to normal conditions. Sometimes such leaves survive and adapt quite quickly, as was seen with *Acer* in Experiment 10. Often the new growth collapses rapidly, as was seen with *Cotinus* in Experiment 3, thereby avoiding further water loss which would otherwise threaten survival of the plant as whole.

For some plants then, the development of soft new growth during rooting sets an upper limit on the length of time that cuttings can be held in the rooting environment to develop a large root system before starting to wean them. In practice, a limit is often set by the need to make room for fresh batches of cuttings in the valuable propagation space. The experiments with *Acer* also showed that deterioration of the leaves in the rooting environment is another reason why it will sometimes be necessary to start weaning before roots are well developed. Under these circumstances, weaning can substantially increase survival, as was seen in Experiment 3 (*Cotinus*) and Experiment 8 (*Acer*).

However, as well as increasing survival, the aim of weaning should be to improve subsequent performance of plants. Cuttings which survive direct transfer to a normal growing environment may not grow well, particularly if, in the process, some leaves are lost and stomata on the remainder close tightly, preventing not only water loss but also the demonstrated the benefit that a weaning stage can have on the amount of new shoot growth made by the end of the first season (e.g. Experiment 3). The same experiments also showed that such extension growth is generally a poor indicator of the long-term quality potential of the plant, apparently because it competes for resources with growth of the roots and main stem, parts of the plant that will remain when pruning has removed most of the new shoots. The conclusion is that weaning should be aimed at helping the plant make the transition to the normal environment by avoiding a shock that prevents virtually any activity for some weeks, but sufficiently quickly to prevent unnecessary stimulation of extension growth. Often this will conflict with the desire to achieve maximum survival, but this should be seen as a price worth paying for better quality amongst the survivors, especially if production times can thus be shortened by a year. This highlights a danger of interpretation of poor survival rates: good rooting of some cuttings, with roots emerging through the base of the trays, can often give the false impression that all cuttings have rooted, leading subsequent failures to be attributed, incorrectly, to problems at the weaning stage.

There was little to choose between the various weaning environments tested, though there was some evidence that using shade cloth alone did not provide enough protection to be useful (Experiment 1) while high humidity was essential for *Acer* (Experiment 8). Although no convincing evidence of the advantage of multistage progressive weaning emerged in any of these experiments, it is likely that it is inherently safer, particularly if the aim is to wean as rapidly as possible. For example, polythene enclosures can be progressively opened up so that humidity gradually falls, being closed again if there are signs of severe stress. Such systems are hard to standardise, and very sensitive to changes in weather, and we have found that evapostat-controlled open mist is a more convenient and reproducible alternative. It has the advantage over other 'weaner mist' systems that it responds in a more appropriate way to weather variations. For cuttings from fog it is initially set to apply generous mist, but as the set point is raised, the amount of water applied decreases until eventually no mist is applied at all unless the sun is very bright or the humidity very low. Ideally, this process would be a seamless extension of the rooting phase, without any need to move the cuttings. This should be feasible where batches of cuttings are large enough to occupy a whole house, or independently controlled bed, the fog or mist is under evapostat control, and the cuttings can be allowed to occupy the facility for a few additional days.

The weaning responses of a number of other species were examined in much less detail, generally behaving similarly to *Cotinus*, with an emphasis on ensuring as much root development as possible before starting to move to drier conditions. One notable exception was *Corylus maxima* 'Purpurea', on which most leaves shrivelled even when an extensive root system had formed, and almost irrespective of weaning protocol. With this subject, even the cutting's original leaves lose the ability to control their water loss, a phenomenon that is currently being investigated as part of a project funded by MAFF.

In addition to the need to wean quickly, the results pointed to many other opportunities to improve liner quality, in terms of their ability to perform well in a container, through maximising opportunities for accumulating reserves in roots and the main stem. For example, although cuttings were successfully rooted from June to August, early propagation gave by far the best liners because they had longer to a accumulate reserves before the end of the growing season (Experiment 4). Extension of the growing season under protection was able to compensate for late propagation to some extent but is unlikely to be cost effective. On the other hand, overcrowding prevented accumulation of reserves in early propagated plants (Experiment 3), and autumn pruning depleted reserves by stimulating growth of new shoots too late in the season for them make any positive contribution to those reserves (Experiment 3).

The thickness of the main stem seemed to be a useful indicator of the size of these reserves (e.g. Experiment 6), but there was evidence that it is actually the **increase** in thickness that is important (Experiment 7). This increase is probably a good indicator of the size of the new root system, and it may be this that confers on the liner the ability to grow well in the container. It is also likely that the size of the root system influences the number of branches that develop in response to pruning, operating through internal control mechanisms that keep the size of the shoot and the root in balance. Since the number of branches is crucial to good quality in many plants, including *Cotinus*, size of the root system may thus be the essence of liner quality for many species. This has a number of important implications, not least that overwintering conditions need to ensure not only survival of the plant as a whole, but preservation of the entire root system in as good a condition as possible.

For more detailed discussion of the results of individual experiments the reader is referred to the discussion sections following the results of each experiment. The main conclusions are presented from a more practical viewpoint in the summary on page 3.

## Glossary

**Evapostat** - A control system based on the East Malling evapo-sensor, a device which estimates **potential evapotranspiration**, i.e. the 'evaporative demand' of the environment as experienced by plant leaves. As such it responds to the combined effects of humidity, light, temperature, wind and leaf wetting.

**LSD** - 'Least significant difference', a useful statistic for judging whether differences between treatments are likely to be real, rather than due to chance variations between plants. See page 11 for further explanation. Subscripts often state the significance level being tested, and the number of 'degrees of freedom', a feature of the experimental design.

**Stomata** - the pores in the outer layers of the leaf through which gas exchange takes place with the air around it. The size of the pore orifice varies in response to factors such as light and water stress, and in this way it exercises some control on transpiration rate.

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# Appendix

## Additional experimental details

### *COTINUS* EXPERIMENT 1

Cuttings

Cuttings were from two sources which had been managed very differently over the preceding years:

| | |
|---|---|
| Severely pruned - | cut back close to ground level annually so that cuttings were borne within 10 cm of the ground; little flowering (unselected clone). |
| Lightly pruned - | cuttings borne on framework about 1m high; many shoots flowering (clone EM84) |

Five types of cuttings were prepared as follows:

(1) Severely pruned source: intact apical cutting
(2) Severely pruned source: apical cutting with tip pinched out
(3) Lightly pruned source: apical cutting with tip pinched out prepared from a non-flowering shoot
(4) Lightly pruned source: cutting from a flowering shoot, the terminal inflorescence being removed during preparation.
(5) Lightly pruned source: apical cutting with the tip pinched out, born on older framework, closer to the ground than (3) and (4).

Cuttings were collected on 23rd May 1990, as shoots became long enough. All were prepared to a finished length of approximately 12 cm by recutting just below a non-basal node.

Propagation environments

(1) ventilated fog
(2) open mist.

Unlike all subsequent experiments, cuttings were stuck in deep trays, but the rooting medium and general procedures were as detailed earlier. Trays were 30 x 40 cm and cuttings were planted at a spacing of about 5 x 8 cm.

Weaning protocols

After 4 weeks in the rooting environment, cuttings were transferred to one of the following weaning environments for 5 weeks:

A. Partially enclosed mist, 20% of outside light
B. Open mist, 20% of outside light
C. Polythene tent, 10% light
D. Reflective shade cloth tent, 10% light

(for further details see the General Materials and Methods section).

Root disturbance

At the time of transfer to the weaning environments, half the cuttings were lifted to record rooting, then planted back into the trays. Comparison with the undisturbed trays provided a measure of the effect of root disturbance such as would be involved in potting up from an undivided propagation tray or from a propagation bed.

Assessment of plant responses

At the end of the weaning period (23rd July), half the previously disturbed cuttings were again lifted to record the amount of root development which had occurred over the course of weaning. The remaining plants were transferred to the growing environment (environment G) and survival and shoot development were measured three weeks later (16th Aug). At this stage many plants were growing strongly but starting to become drawn because of the close spacing. All shoots greater than 3 cm long were therefore cut back to 3 cm and the length and weight of the shoots removed was recorded.

After a further 9 weeks (16 Oct), during which plants were liquid-fed weekly, the diameter of the main stem, and the number of new shoots which had developed following this late pruning, were recorded.

Experimental design

The experimental unit was a plot of 8 cuttings. At the rooting stage these were in randomised blocks consisting of two trays, each 30 x 40 cm, in each rooting environment. For the subsequent stages blocks were combined to form new plots of 8 cuttings (disturbed treatment), or were confounded with weaning environment (non-disturbed). Some measurements, e.g. rooting assessment at the end of weaning, were made on a subsample of half of the cuttings in each plot (i.e. 4).

## *COTINUS* EXPERIMENT 2

Cuttings were collected on 3 July, 1990, all corresponding to Type 2 cuttings of Experiment 1 (i.e. from the severely pruned hedge and with tips pinched out), and rooted in fog before being subjected to one of 35 different weaning protocols, organised into four sub-experiments

### Sub-experiment 1 : Timing of transfer to weaning environment and defoliation

There were three weaning environments (including environment F, a clear polythene tent at about 20% of outside light) and half the cuttings were manually defoliated at the time of transfer from rooting to weaning, in an attempt to stimulate lateral breaks. All cuttings were transferred to the growing environment 9 weeks after sticking, but the proportion of that time for which they were in the rooting environment (fog) varied from 3 to 8 weeks.

In brief : transfer to weaning at 3, 4, or 8 weeks
x
weaning environments A, C, and F
x
± defoliation

### Sub-experiment 2 : Weaning duration and defoliation

Cuttings rooted for 4 weeks in fog were weaned for 0, 1, 3, or 5 weeks in environment C, with and without manual defoliation at the start of the weaning process.

### Sub-experiment 3 : Pinching and severity of defoliation

Cuttings rooted for 4 weeks in fog were subjected to 3 levels of manual defoliation (none, complete, or uppermost 50% of leaves), with or without pinching of all new shoots greater than 3 cm long. They were then weaned for 5 weeks in environment C, with further pinching at weekly intervals as required.

### Sub-experiment 4 : Other weaning protocols

Cuttings were rooted in fog for 4 weeks before being subjected to one of the following protocols:

1. Environment A for 5 weeks
2. Environment B for 5 weeks
3. Environment C for 5 weeks
4. Environment D for 5 weeks
5. Environment F for 5 weeks
6. 1 week in A, then B, then C, and 2 weeks in D.
7. Contact polythene (38 μm, transparent), under progressively reduced shade*.
8. Polythene tent under reducing shade*.
9. Shade only, progressively reduced as above*.

* Initially two layers of Ludvig Svenson 70% reflective shade (OLS70) plus one of 40% shade cloth giving about 3% of outside light. On a weekly basis shade was adjusted to increase light level to 6%, 12%, 20%, and 40%.

### Measurements

To follow root development and dry weight growth, samples of cuttings were destructively harvested after 3, 4, and 8 weeks in fog, and also at the end of October, after 7 weeks in the growing environment. Non-destructive assessments of survival and growth were made on all plants at the beginning of September, when cuttings in all treatments had reached the growing environment. After overwintering in a polythene tunnel, with bottom heat providing frost protection to the roots, the number of liners which survived to the beginning of the following year, and the number of shoots starting to grow away strongly, was recorded.

## *COTINUS* EXPERIMENT 3

### Phase 1: the rooting year (1991)

Cuttings were collected on 4th June, 1991, as shoots on the moderately hard-pruned hedges reached sufficient size to prepare 10 cm apical cuttings. To minimise variability in rooting potential, the basal cut was made at least 1 cm above the shoot base so that the basal cluster of nodes was excluded irrespective of shoot length.

Depending on treatment, they were inserted into either modular propagation trays QP 77 (PG Horticulture Ltd., Thornham Magna, Eye, IP23 8HB), or into 11x11x11 cm square pots (4 cuttings per pot, giving very similar spacing to the trays).

All cuttings were rooted for four weeks in ventilated wet fog (timer operated at 90 seconds every 15 minutes). Thereafter they were either transferred directly to the growing environment (environment G), or first weaned for either one or four weeks in a shaded polythene tent (environment J).

The treatment combinations are summarised in the table below:

Treatment matrix showing the type of containers used for each combination (rooting / growing on)

| Root disturbance: | | Weaning Period, weeks | | |
|---|---|---|---|---|
| Severity | Timing | None | 1 | 4 |
| None | - | pot | pot | pot |
| Minimal | Post-weaning | module / pot | module / pot | module / pot |
| Severe | Pre-weaning[1] | pot / pot | pot / pot | pot / pot |
| Severe | Post-weaning | | pot / pot | pot / pot |

[1] Applied post-rooting, and before transfer to the weaning or growing environment according to treatment.

'Severe' root disturbance involved knocking the medium out of the pots so as to completely expose the root system, thus affording the opportunity to make detailed rooting records. Afterwards the cuttings were replanted into the same medium. For the treatments with no weaning, there could clearly be no distinction between pre- and post- weaning disturbance. In this case the cuttings were knocked out, recorded and repotted at the end of the rooting period, and then transferred directly to the growing environment.

'Minimal' root disturbance refers to cuttings rooted in module trays being transferred to pots of the same size and at the same spacing (i.e. 4 per 11x11 cm pot) as used for the other treatments. To eliminate any difference in the medium between the treatments, additional cuttings were rooted in pots to be replaced by those from the module trays at the designated time.

There were six replicate plots per treatment combination. As far as was possible these were handled as randomised blocks. However, some limitations were imposed on the mixture of pots and trays in the early stages, and later by the transfers between environments at different times.

By the 2 August, the last cuttings were transferred to the growing environment. Survival and growth were recorded two weeks later, on 15 August, and stem diameter was measured again on 16 September. At this time the plants were thinned to one per pot in preparation for the second phase of the experiment.

**Phase 2 : the container year (1992)**

Different pruning treatments were introduced at this stage. The treatments, consisting of three levels of severity and two times of pruning, were applied at the block level of the experimental design used in phase 1. This meant that the previous treatments would not confuse interpretation and the experiment could be expected to yield useful information about the interaction between pruning and the way the cuttings had been treated earlier, at the weaning stage.

The pruning severity levels were:

| | |
|---|---|
| Severe | Cut into the original cutting at just below the junction with the uppermost new shoot. |
| Medium | Cut the uppermost new shoot to 1 cm above its junction with the original cutting. |
| Light | Cut the uppermost new shoot to 12 cm above the compost surface. |

In all cases, any other new lateral shoots on the original cutting were removed, leaving the basal 2 mm to provide dormant buds for potential regrowth from the main stem.

The two pruning times were:

| | |
|---|---|
| Autumn | 17 September in the rooting year |
| Spring | 12 March in the container year |

The liners were kept in an unheated polytunnel until January when they were moved outdoors. The pots were plunged into raised beds to protect their roots from frost, with bubble polythene pulled over the plants during severe weather. On 4 June they were potted into 2 l containers using a loam-based compost. For two months they were held on drained sand beds and irrigated with a hose lance as required, before being transferred to a sprinkler-irrigated raised bed.

At the end of the season the length and height of insertion of all branches, together with the diameter of the main stem, were measured to provide a detailed picture of the shape of the final plants. Shoots were categorised on the basis of their thickness as either major (>4mm) or minor (<4mm).

## *COTINUS* EXPERIMENT 4

Dark pretreatment

The hedge used for this experiment, which was not of the selected clone EM84, had been pruned annually to within about 10 cm of the ground. Dark pretreatment was achieved using lightweight wire hoops of the sort normally used for vegetable cloches to support a black polythene (0.125 mm) cover. A small gap between the ground and polythene provided limited ventilation and light penetration.

This 'black cloche' was in place from 26 April to 5th June, 1991, after which the polythene was replaced by 50% shade netting to prevent scorching. Cuttings were collected from the dark treated bushes, and adjacent untreated controls, on three dates as follows:

12 June, 1991
24 July, 1991
21 August, 1991

Only actively growing shoots were collected and from them cuttings were prepared to 15 cm length, with the tip pinched out. The material for the August propagation came from lateral shoots stimulated into growth by the removal of the first cuttings 9 weeks earlier. By this time, many of the weaker primary annual shoots had stopped growing and cuttings from the shoots that were still growing were twice as thick as those taken earlier. A sample was taken to compare their rooting.

Cuttings were graded according to stem diameter into six size classes which were identified with the blocks in the experimental design. It was therefore not possible to separate effects of size from other variables, such as location on the bed, which differed between the blocks.

Rooting

Cuttings were rooted in ventilated wet fog (timed at 90s per 15 min.) at a spacing of approximately 7 x 7 cm, using four cuttings per 11 cm square pots. Spacing was increased slightly for blocks of the largest size grades so that overlap of adjacent cuttings was uniform.

According to treatment, cuttings were kept in fog either:

(a) until about 75% were rooted (3-4 weeks) or
(b) for 6 weeks, by which time at least 95% were rooted and roots were emerging from the base of the pots.

These are referred to as the 3-week and 6-week treatments.

Weaning

Cuttings were held for one week in weaning environment C (polythene tent at about 10% of outside light) before transfer to the normal growing environment (environment G). When the 6-week cuttings reached this stage the weaning phase for that propagation was considered complete, survival and growth were recorded, and plants thinned to leave one representative plant per pot. The shoots removed in this process were oven dried to provide an estimate the increase in shoot dry weight over the rooting and weaning process.

Autumn protection

After weaning, the plants were further divided, half being transferred for 12 weeks to heated glass (18C with supplementary high pressure sodium light, 16h day) and half remaining in a polytunnel under natural light, unheated except for frost protection bottom heat.

Assessment of liners

Detailed measurements were made on 9 January, 1992, once all plants were together again in the polytunnel.

Measurements included the length and height of insertion of all lateral shoots, and the diameter of the main stem 2 cm above the compost surface.

Container stage (1992)

After assessment, liners were moved outdoors, plunged into a raised bed to protect their roots from frost damage, with a bubble polythene cover pulled over during severe weather.

In late March they were pruned, removing most of the growth made during the rooting rear (equivalent to the medium severity pruning of Experiment 3). On 4th June they were potted into 2 l containers of loam-based compost and transferred to a capillary sand bed.

The quality of the resulting plants was assessed at the end of July by detailed measurements of the length and height of insertion of all branches.

## *COTINUS* EXPERIMENT 5

Cuttings were collected on the same day (12 June, 1991) as the first propagation of Experiment 4, from adjacent control bushes, and were prepared and planted in exactly the same way.

After 4 weeks in ventilated fog, they were weaned in environment C for 3 weeks and then transferred to one of the following 5 growing environments :

(1) Polythene tunnel, shaded internally (40% of outside light), i.e. our standard growing environment (env. G).
(2) Polythene tunnel, unshaded (60% of outside light).
(3) Outside, under a miniature shade tunnel (40% of outside light).
(4) Outside, unshaded (100% of outside light).
(5) Glasshouse, unshaded (about 70% transmission) and with supplementary light and heat (18C day/15C night).

The supplementary light in (5) provided approximately 200 $\mu mol\ m^{-2}\ s^{-1}$ photosynthetically active quanta, from high pressure sodium lamps, whenever solar radiation was less than 200 $Wm^{-2}$, over a 16h day.

In the process of transfer to these environments, plants were thinned to a single plant per pot. The plants retained had all developed 2 new shoots. These were cut back to about 4cm, the precise location of the cut depending on how the shoot had developed. Where a cluster of nodes indicated the end of an earlier flush in the right position, the cut was made at this cluster. Otherwise, it was made just above a node. Shoots which had terminated at 4 cm or less had the tip pruned off. A record was made of the category of each shoot to check whether regrowth was affected. Stem diameter was also measured at this stage and on 3 subsequent occasions, to monitor the effect of growing environment.

At the end of the year, liners were assessed by measuring the lengths of new shoots which had developed from each of the individually identified stubs left by the earlier pruning.

From 8 January, heat and light were switched off in the glasshouse compartment so that plants in that treatment would go dormant and harden up before being moved outside. From 25 February, all plants were outside, with their pots plunged into a raised bed to protect the roots from frost.

<u>Container stage (1992)</u>

Two of the five experimental blocks were cut back hard, to just 5 cm above the compost and well into the original cutting. On the remaining 3 blocks, the secondary laterals produced after weaning were cut back to about 1cm, this being roughly equivalent to the 'medium' severity treatment of Experiment 3.

Pruning was done in late March, while still dormant. On 4 June, the plants were potted into 2 l containers of loam-based compost and transferred to a capillary sand bed.

The quality of the resulting plants was assessed at the end of July by detailed measurements of the length and height of insertion of all branches.

***COTINUS* EXPERIMENT 6**

Apical cuttings of clone EM84, from a hedge planted two years earlier, were collected on 22nd June, 1992, and prepared to about 14 cm long. The shoot tips were not pinched out.

Pairs of cuttings were inserted close together into 9 cm square pots (0.5 litre capacity) using the standard peat:bark rooting medium. These pots were placed with approximately 3 cm gaps between them, equivalent to about 96 $cm^2$ per cutting and similar to Experiment 4.

After 21 days in a moderately wet location in the ventilated fog house, half the cuttings were moved to the driest part of the same house to wean for a further 21 days before all cuttings were moved to the growing environment (G). The drier location used for weaning was about 17 m from the Agritech fogger where there was almost no visible leaf wetting, and it was necessary to water the rooting medium occasionally. However,the humidity remained close to saturation and other factors such as temperature, light, and carbon dioxide concentration were identical to that experienced by those cuttings which remained in the wetter 'rooting' environment. This thus provided a more critical test of the effect of continuing to keep leaves wetted after cuttings had rooted.

This comparison was combined with the comparison of various pruning strategies as shown below:

± weaning in dry fog (day 21 - 42)
x
± pruning in rooting year (on day 43)
x
pruning in the container year (year 2) on : 14 April 1993, 14 May 1993, or not at all

Pruning in the rooting year consisted of removing the apical growth made during the preceding rooting and weaning period, which generally meant cutting in the middle of a cluster of nodes formed where extension had slowed at the start of rooting. If there was no sign of new growth, or the tip had aborted or rotted, then about 5 mm was removed from the apex.

Pruning in the container year involved cutting at about 7 cm from the compost and, as such, was similar to the 'severe' pruning treatment applied in Experiment 3. When the first pruning was applied, in mid-April, all plants had started to grow, with longest shoots being 1-5 cm long.

The liners were overwintered in a well ventilated polythene tunnel, unheated except for bottom heat providing frost protection for the roots. On 13 May they were potted into 2 l containers of peat:bark based medium (1:1 medium grade Irish peat : Cambark 100, with 3kg $m^{-3}$ of Ficote 180 16-10-10, 1kg $m^{-3}$ Dolodust, and 300 g $m^{-3}$ WM255 fritted trace elements) and transferred to a capillary bed outside.

Measurements

Rooting and weaning stage. To determine the effect of the weaning treatment on growth rate and the distribution of dry matter, samples were designated at the outset for destructive measurements on day 0, 21, and 42. Measurements included leaf area, dry weight, and the development of roots and lateral shoots.

Liner assessment. Non-destructive measurements of plant height, stem diameter,and the number and length of lateral branches were made at the start of year 2. In contrast to previous observations, many buds had broken on the main stem (i.e. original cutting) as well as near the tips of laterals formed the previous year. The number of these buds was counted.

Final plant assessment. At the end of year two the quality of the final plants was assessed in terms of plant height, main stem diameter, and the number of useful branches, defined as those of more than 2.5 mm diameter and inserted less than 15 cm from the compost surface. In addition, the plants were knocked out of the containers and the amount of root visible was estimated against a simple 3 point scale as follows :

| | |
|---|---|
| 1 = | 0 to 50% of the exposed surface densely covered by roots |
| 2 = | 50 to 75% so covered |
| 3 = | 75 to 100% so covered |

The plants were also subjectively graded for quality based on their branch structure as follows:

| | |
|---|---|
| 1 (best) = | 3 or more useful shoots, all inserted less than 7 cm from the compost and well balanced. |
| 2 = | 3 or more useful shoots but the main stem remains dominant and bears a second tier of branches higher up |
| 3 = | 3 or more useful branches, well balanced but small |
| 4 = | 3 or more useful branches (as defined above), but unbalanced. |
| 5 = | 2 lateral shoots, reasonably well balanced |
| 6 (poorest) = | a single lateral shoot giving a very unbalanced appearance |

Experimental design

The pots, initially containing two cuttings but thinned to one plant on day 50, represented the experimental units in a randomised block design with four blocks.

*COTINUS* **EXPERIMENT 7**

There were initially 6 treatments as follows:

1. **Control** :
   our standard apical cutting, 13-15 cm long with about 6 leaves almost fully expanded (>75% of final area) and many less expanded. Spaced at 9x9 cm (120 cuttings per $m^2$ ) in 7 cm (¼ litre) pots.
2. **Shorter cuttings** :
   approximately half as long as the controls (i.e. 7cm), with no well expanded leaves (i.e. > 75% of final area). Spaced at 7x7 cm (200 cuttings per $m^2$ ) in 7 cm (¼ litre) pots.
3. **Partially defoliated cuttings** :
   identical to the controls except that additional leaves had been removed from the lower nodes to match those of treatment 2. This reduced leaf area by two thirds, from about 120 to 40 $cm^2$. Cuttings were also spaced to match treatment 2.
4. **Reduced spacing** :
   cuttings identical to the controls but spaced to match treatment 2 (i.e. 200 cuttings per $m^2$ instead of 120).
5. **Larger pot size** :
   cuttings and spacing identical to the controls but in twice the volume of rooting medium (½ litre, 9x9 cm pots).
6. **Short non-apical cuttings** :
   7 cm cuttings from the section of stem 15 to 25 cm from the tip, with two fully expanded leaves (leaf area 40 $cm^2$). Spacing and pot size as for the controls.

These were interacted with two weaning/establishment treatments as follows:

A. **Rapid weaning** :
   10 days in an unshaded but heavily wetted part of the ventilated fog house before transfer to the growing environment, in this case an unshaded and well ventilated polytunnel.

B. **Extended weaning** :
   4 weeks in a shaded but relatively dry part of the ventilated fog house (as used in Experiment 6), followed by 2 weeks in a progressively opened polythene tent at similar shade level (20% light transmission) before transfer to the growing environment.

Cuttings of clone EM84, from a 3-yr old hedge, were collected on 7 July, 1993. Shoot tips were pinched out of the apical cuttings. Cuttings were planted singly in pots, pot size varying according to treatment as detailed above, and placed in a moderately wet part of the ventilated fog house.

After four weeks rooting was assessed on the basis of roots emerging from the pot or gentle testing of anchorage. This record was used to allocate evenly rooted sets of cuttings to the experimental blocks and, after a further week, weaning treatments were commenced. There were twelve replicate plants per treatment. With spacing as a treatment it was impractical to randomise the blocks.

The quality of liners was assessed on 16th November. They were overwintered with frost-protection bottom-heat in a ventilated polytunnel.

On 24 May, 1994, liners from weaning treatment B were potted into 2 litre containers of a 1:1 peat:bark (Cambark 100) mix containing 3 kg $m^{-3}$ Ficote 180 16-10-10 plus magnesian limestone and fritted trace elements. In January it became evident that the plants in treatment A had become severely infested with vine weevil and they were discarded. It was therefore not possible to assess the effect of weaning protocol on growth in the subsequent container year, but at this stage of the project this was considered less important than the effect of cutting size.

Containers were placed on an capillary irrigated bed outside, in pot-thick rows with 15 cm between rows. The quality of the final plants was assessed in December, 1994, when leaves had fallen.

## *ACER* EXPERIMENT 8

Cuttings were collected from container-grown stock plants in a polytunnel on 24th May, 1991. Most were from 2-year-old stock plants but about a quarter were from larger 5-6 year old plants. Apical cuttings were prepared to a length of 10-15 cm. Three quarters were still in active growth, the others had reached the end of their first flush and terminated. Where shoots were long enough, 2-node non-apical cuttings were also prepared from below the apical cutting.

The experimental plots consisted of pots of 4 cuttings, with the different sources and states of growth spread as evenly as possible over the plots and the different treatments. There were five replicate plots per treatment combination, the factorial nature of the design providing additional 'hidden replication' for main effects.

It was not feasible to include all possible combinations of factors and the rationale for the selection of combinations is best understood by considering the experiment as divided into three sections, each focused on one of the questions of interest.

**Section A**
This examined whether the time allowed under fog for a root system to develop influenced the sort of environment that apical cuttings could tolerate at the weaning stage:

Rooting in fog for 4,5, or 8 weeks
x
Weaning under polythene at 10% v. 34% light v. no weaning
(i.e environment C v. H v. G)

The duration of the weaning stage was linked inversely to the duration in fog, all weaned plants being transferred to the growing environment together at 9 weeks after collection.

**Section B**
Adopting 5 weeks in fog as standard, this section examined the effect of the time spent in a weaning environment:

Weaning for 1, 2, or 4 weeks
x
Weaning under polythene at 10% v. 34% light
(i.e. environment C v. H)

**Section C**
Adopting 5 weeks rooting, and 4 weeks weaning as standards, this section examined a wider range of weaning environments, on both apical and 2-node cuttings, as follows:

High humidity environments:
Environment C: Polythene tent shaded with light absorbing shade-cloth (10% of outside light).
Environment J: Polythene tent shaded with light reflecting shade-cloth, supported above the polythene, so as to reduce warming (11% of outside light)
Environment H: White polythene tent (34% of outside light)
Low humidity environments:
Environment B: Open mist, adjusted to keep leaves just moist (20% of outside light)
Environment K: Shade cloth tent only (20% of outside light)
Environment G: Very light shade only (40% of outside light). Normally the 'growing' environment.

Assessments Subjective assessment of leaf condition was made frequently during rooting and weaning. Firmness of anchorage was tested (as a rough measure of rooting) on all cuttings after 4 and 5 weeks in fog, supplemented by destructive harvests at 4, 5 and 8 weeks. The number of surviving plants and the amount of new growth was assessed on 27th July, a few days after transfer to the growing environment. Survival was recorded again in November, along with stem diameter, as a measure of vigour achieved by the end of the rooting year.

## *ACER* EXPERIMENT 9

Four rooting environments were included as follows:-

- (i) Fog - about 2 m from the fogger
- (ii) Fog - about 9 m from the fogger
- (iii) Enclosed mist under 'evapostat' control
- (iv) Enclosed mist under 'wet leaf' control

Compared to the first experiment, leaf wetting was slightly heavier in (i) and lighter in (ii). The 'evapostat' used in (iii) estimates the evaporative demand in a way that relates closely to transpiration of cuttings, responding to all the factors which influence transpiration. It was originally developed for fog control, under an earlier HDC project (Harrison-Murray, et al. 1993b). Its use resulted in minimal misting under most conditions but very generous misting whenever hot and sunny conditions prevailed. The conventional wet leaf' system (iv), which is much less responsive to varying weather conditions, was adjusted to provide minimum wetting compatible with avoiding severe stress. As expected, slight wilting was observed occasionally in (iv) but not in (iii).

Apical cuttings, similar to those in Experiment 8 from the 2-year old stock plants, were inserted on 8 August, 1991. After 5 weeks in each rooting environment they were subjected to one of three weaning protocols as follows:-

- (1) 2 further weeks in the same rooting environment + 1 week in environment H (poly-tent at 34% of outside light)
- (2) 2 weeks in environment C + 1 week environment H (poly-tents at 10% and 34% light respectively)
- (3) 3 weeks in environment H (poly-tent at 34% light)

They were then transferred to heated glass, with supplementary light, until 8th January, when heat and light were turned off. Final records were taken in April once plants had started to grow away.

There were 4 replicate pots of 4 cuttings of each treatment combination.

### *ACER* EXPERIMENT 10

Apical cuttings were collected on 30th April, 1993, from container-grown stock plants in an unheated glasshouse, as shoots approached the end of their first growth flush. The prepared cuttings averaged 13 cm and were graded into six categories based on stem diameter and leaf area, each of which were divided between the following rooting environments:

| | | | |
|---|---|---|---|
| 1. | Fog, evapostat controlled : | wet zone (2-3 m from fogger) | shaded |
| 2. | | wet zone (2-3 m from fogger) | unshaded |
| 3. | | drier zone (10-11 m from fogger) | shaded |
| 4. | Open mist, 'leaf' controlled to provide generous wetting, | | shaded |

Light measurements showed that about 20% of outside light reached cuttings in the shaded part of the fog house, about 30% in the mist bed and 50% in the unshaded fog.

After 46 days most cuttings were moved to a weaning environment for three weeks (part of the fog house which was humid but without wetting, 13-15 m from the fogger). To test the benefit of such weaning, cuttings rooted in the drier fog zone (environment 3) were divided between the following three environments:

(a) Moved to the above weaning environment - humid but no wetting
(b) Moved to environment 2 - humid and wet but unshaded
(c) Remaining where rooted (environment 3) - humid with slight wetting

The experiment thus consisted of the following six combinations of rooting and weaning environments:

1+a
2+a
3+a, 3+b, 3+c
4+a

After weaning, all cuttings were moved to an unshaded and ventilated polythene tunnel. In September they were potted on into 1 litre pots of a standard loam-based container medium.

There were 50 replicate cuttings per combination, inserted individually into 7 cm square pots. Of these 20 were taken for destructive samples over the course of the season.

'Survivability' tests

The ability of cuttings to survive in a dry environment was measured on a sample of 5 cuttings from each treatment, first after 6 weeks rooting and again after 2 weeks in their designated weaning environment. Cuttings were exposed to a succession of increasing levels of evaporative demand in a semi-controlled environment, symptoms of wilting or leaf shrivelling being recorded after at least an hour. At the end of this test, the extent of root development on each plant was recorded followed by oven drying to monitor changes in dry weight (DW). To increase the precision of these estimates, the fresh weight (FW) of all such cuttings was measured at the start of the experiment, along with the FW:DW ratio of a sample of cuttings (i.e. Day 0 sample).

Various non-destructive measurements were made over the course of the season, including rooting assessments made by testing firmness of anchorage.

Contract between HRI (hereinafter called the "Contractor") and the Horticultural Development Council (hereinafter called the "Council") for a research/development project.

**PROPOSAL**

1. **TITLE OF PROJECT** — **Contract No: HNS/27 (Modified contract)**

PROPAGATION: STOCKPLANT AND CUTTING PROCESSES INFLUENCING SUBSEQUENT PLANT QUALITY

2. **BACKGROUND AND COMMERCIAL OBJECTIVE**

As for HNS/27.

3. **POTENTIAL FINANCIAL BENEFIT TO THE INDUSTRY**

As for HNS/27.

4. **SCIENTIFIC/TECHNICAL TARGET OF THE WORK**

As for HNS/27.

5. **CLOSELY RELATED WORK - COMPLETED OR IN PROGRESS**

As for HNS/27.

6. **DESCRIPTION OF THE WORK**

As for HNS/27, with the exception that the work at Efford on growth regulators will only continue for 1 year.

7. **COMMENCEMENT DATE AND DURATION**

As for HNS/27.

8. **STAFF RESPONSIBILITIES**

As for HNS/27.

9. **LOCATION**

HRI-East Malling and Efford (year 1 only)

# PROPOSAL

**Reference No. HNS 27**

1) **Title of Project :**
**STOCKPLANT AND CUTTING PROPAGATION PROCESSES INFLUENCING SUBSEQUENT PLANT QUALITY**

2) **Background and commercial objective:** The majority of containerised plants derive from leafy cuttings, which is the single most intensive propagation system employed by HNS producers, supplemented now by micropropagation. The original approach to HDC work in this crucial area was one of a succession of related topics, the first being the rooting environment (HNS/9). It is a logical and natural progression to now shift the emphasis towards the market place by considering effects on plant quality carried over from the improved propagation phase.

3) **Potential financial benefit to the industry:** Given a unit value of 10p when rooted and assuming 1 cutting per container, an approximate 'propagation stage value' = £13 millions. In addition to the absolute loss associated with failed cuttings, problems at this stage can create management difficulties and reduce final plant quality and uniformity. In the face of ever more intense competition, the need for high production efficiency together with a quality product can only increase.

4) **Scientific/technical targets of the work:** To assess the carryover of effects from the many components of propagation by leafy cuttings (e.g. stockplant management, selection of cutting material, rooting environment, and weaning/hardening) to the quality of the resultant plants.

5) **Closely related work - completed or in progress :**
**Résumé of work in HNS/9 and HNS/10 1987-1990** Experiments with a range of species revealed that leaf wetting was of overriding importance amongst the various factors that promote rooting by reducing water loss. Optimum environments for different types of cutting were identified as were the characteristics of a good "general purpose" environment. Considerable progress was made in developing sensors for monitoring/controlling propagation environment in a way that relates to the cutting's needs, and in specifying the requirements of an ideal fogging system.

Other studies, funded by MAFF, identified opportunities for improving the ability of cuttings to root and grow away quickly using "rejuvenation" or dark pretreatments. HDC micropropagation studies identified sources of variation in plants raised by this method that should lead to ways of minimising this variability in future.
At Efford, schedules in the form of options to fit producer's requirements were tested and proved for quality liner production of *Pyracantha*, *Prunus*, *Cornus* and *Mahonia*, and reasons for *Ilex* leaf-drop during propagation were monitored.

Strategic Studies: The essential and complementary strategic work is in place and MAFF funding will continue at both East Malling and Efford (although justified by Farm Woodlands requirements in the latter case). At East Malling this will include understanding the processes of *in vitro* rejuvenation and dark preconditioning, and the effect of preconditioning on responses to the rooting environment. Anatomical, carbohydrate physiology, and possibly auxin physiology studies will dominate. A new initiative into the physiology of weaning recently rooted cuttings including root function, stomatal control, water transport and carbohydrate resources. Relevant micropropagation studies are closely integrated with those on conventional propagation so that nurserymen generally are likely to benefit.

6) **Description of the work:** This is described under two heads but, in practice, it would be essential to integrate the two parts to ensure efficient use of resources.

**Influence of stockplant management on subsequent production.**
Develop practicable methods to exploit dark pre-treatments and protected forcing of container and field-grown stockplants, combined with severity of stockplant pruning treatments. The study would centre on facilitating commercial uptake by the use of simple low tunnels for field-grown stock and dark-room treatment for container-grown material. Assessment would be in terms of productivity, and the speed of growth, size and branching of resulting plants. Whilst mainly based at East Malling, other aspects would be studied at Efford where new stock plantings are currently being established. For example, the use of growth inhibitors to shorten internodes on stockplants of subjects such as *Cornus alba* will be examined as a way of improving plant form following propagation. Management of stock beds will also be monitored

Rooting potential can also be increased by using micropropagated stockplants ("rejuvenation"). The shape and quality of such plants appears to depend on which buds are taken into culture initially and on the extent of lateral production during culture. This knowledge will influence any work involving micropropagated liners.

**Improved weaning systems**
Weaning protocols will be developed for various conventional cuttings showing a range of rooting potential determined by variety, preconditioning, timing, and pre-rooting treatments, and which have been rooted in a range of environments. Key questions will include whether high humidity propagation alters weaning requirements, and the possibility of stimulating new growth by defoliation treatments. It may also be possible to consider the special weaning requirements associated with micropropagation.

**Species to be studied**
Work will concentrate on subjects, selected on the advice of the Project Coordinator, which are relatively difficult to root and which subsequently present difficulties in handling (overwintering, lack of vigour or reluctance to branch, poor establishment after potting off, etc.).

7) **Commencement date and duration:** 01.10.90 for 3 years.

8) **Staff Responsibilities:** Project leader: Dr R.S. Harrison-Murray assisted by Mrs L.J. Grout (East Malling).
Other staff: Miss M.A. Scott, assisted by Miss L. Andrews (Efford)