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Location of Project:	**HRI-East Malling**
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Key words:	**hardy ornamental nurserystock, propagation, overwintering, cuttings**

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RESULTS

PRACTICAL SECTION FOR GROWERS

The aim of this project was to identify the reasons why rooted cuttings fail to establish and to understand why some cuttings die during their first winter. Although propagation *per se* is the most critical stage in liner production, relatively high failure rates and reductions in plant quality can occur in some species during the months following propagation. The precise reasons for this are unclear, but failure of cuttings to survive the winter period can be attributed to two primary causes:
1 - Direct injury resulting from tissues being exposed to sub-zero temperatures, when protective measures against frost have been inadequate.
2 - Indirect injuries in which tissues are exposed to prolonged, but less severe, environmental stress.

This work concentrates on the latter cause, where no immediate injury is sustained, but resources within tissues are gradually reduced, or cell viability is impaired over a period of time, resulting in an inability to break bud the following spring. The project aimed to determine what **environmental stresses** contributed to winter losses when cuttings are placed under protection. In addition to identifying the most damaging stresses encountered during winter, the research investigated the extent to which **factors at or before propagation** played a role in **affecting winter survival.**

The ability of cuttings to survive the winter period appears to be strongly species specific, with **cutting failure** being particularly associated with a number of economically important Genera e.g. *Acer*, *Rhododendron*, *Magnolia* and *Viburnum*. Even in species that are relatively easy to propagation and establish (e.g. *Ceanothus*), however, prolonged stress during the winter can **reduce vigour** resulting in non-uniform growth and **poor crop quality** in the spring.

The project yielded a number of intriguing findings. **Probably the most remarkable result was the extent to which factors early on in the production process affected a cutting's long-term viability.** The degree of **stock plant pruning**, the **type** and **size of cutting** selected and the **propagation environment** used all had strong influence over winter survival rates. Often this was the case irrespective of rooting percentage. For example, in *Rhododendron* rooting percentages could be very high but subsequent survival was influenced significantly by the size of cuttings originally selected (Figure 1). In cuttings propagated in 1997, there were also interactions between propagation environment and the location from which cuttings were removed from the stock plant; - greatest failure resulting from taking cuttings from the base of the stock plant and rooting under mist (Figure 1).

Although there was some variation in results between species and years, a number of **important trends** were identified when attempting to optimise rooting and survival. **With the exception of *Acer*, harder pruning of stock material, generally resulted in more vigorous shoot growth and the production of cuttings with greater potential to survive.** For a number of 'thin-stemmed' species, e.g. *Corylopsis, Acer* and *Rhododendron* taking **larger or thicker cuttings often improved rooting and survival rates**. This is likely to relate to carbohydrate accumulation in cuttings; with death of small or thin cuttings in *Corylopsis* correlating with lowest starch levels in the tissues.

Nurserymen, however, should be aware there is a **degree of balance required** in trying to optimise size, as waiting for larger cuttings to develop on the mother plant will result in later harvesting, and this was associated with reduced rooting and enhanced cutting failure. **Larger cuttings collected later in the season may not root as well** as those collected earlier. The precise reasons for this are not clear, but cuttings collected too late often has less shoot activity (active cuttings of *Acer* rooted and survived better than non-active cuttings) and very large cuttings may suffer stress in sub-optimal propagation environments (e.g. large cuttings of *Cotinus* rooted in mist).

Handling of cuttings after collection was also important. In one of the easier subjects, *Magnolia*, winter survival was reduced by leaving cuttings under polythene covers at ambient conditions for 24 hours prior to sticking, even though root initiation was unaffected. In contrast, holding cuttings in cold storage for up to 48 hours was not detrimental to later development.

Survival of rooted cuttings was also determined in many species by the type of environment the cuttings were placed in during winter. The use of poor environments could reduce cutting viability directly, or aggravate the effects of previous stress. Comparison were made by placing cuttings into cold store at 2°C, or placement into polythene tunnels, either kept well–ventilated, or enclosed during the winter months. **Interestingly, placing cuttings in an enclosed tunnel with minimal ventilation was often detrimental** (e.g. *Acer* and *Rhododendron*), even though there was no indication of increased pathogen activity in this treatment. In contrast, the placement of cuttings into **cold storage during winter appeared a feasible** and effective technique to ensure good survival rates for some species, although care is required to ensure successful transition back to ambient conditions (i.e. avoid excessive exposure to high temperature and high light levels).

An additional part of the project confirmed that a number of commercially available **films and fabrics were useful in providing additional frost protection** during short-term, radiation frosts, Temperatures were often 3 to 4°C higher than those recorded outside.

Action points

- For 'difficult' species, the selection of actively growing and relatively large cuttings is beneficial to long-term survival. However, large cuttings with greater leaf area will be more prone to water stress during propagation, and should only be used when 'supportive' environments are available.

- Nurserymen should familiarise themselves with the best pruning treatment for their stock plants. Cuttings from many, but not all, species will respond better if collected from stock plants that have been hard pruned the previous winter.

- Exposing cuttings to even a very moderate degree of stress during preparation and rooting can influence tissue viability many months later. Physical effects due to stress may not be apparent during the initial procedures, but can have a significant effect on the final numbers of cuttings produced and their quality.

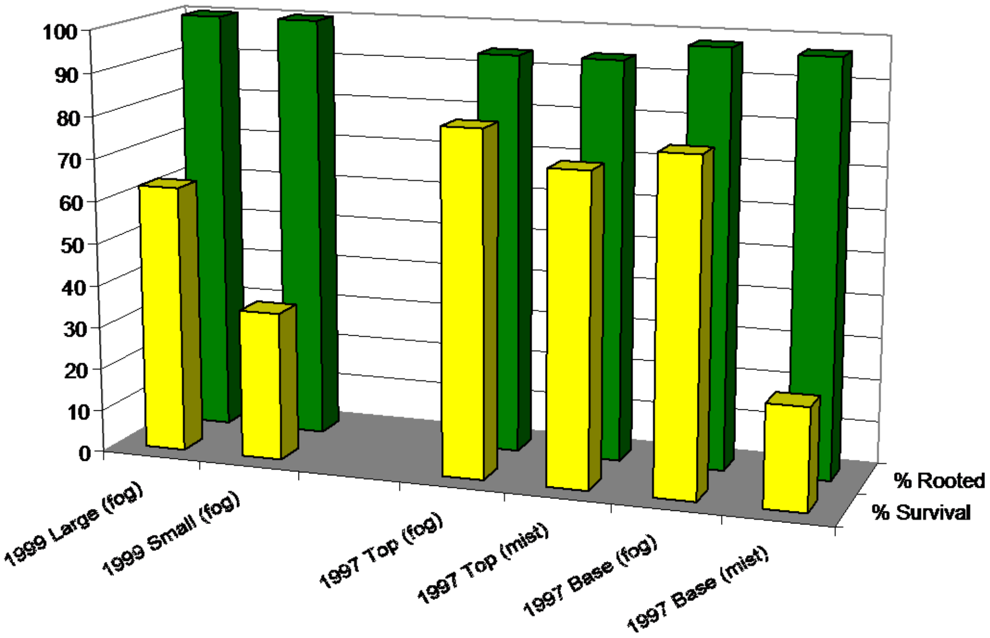
- Ensure module trays and young cuttings are evenly watered and kept moist, - evergreen species, in particular, may be prone to desiccation stress.

- Minimise the build-up of humidity in tunnels during winter. Open, well-ventilated environments combined with thorough, uniform irrigation may be one of the best mechanisms to ensure high survival rates.

- Nurserymen with access to cold storage facilities may wish to exploit these and investigate their potential for their own crops. Care should be taken in re-locating cuttings after storage and 'weaning' them back to ambient conditions.

- The use of polypropylene fleeces and polythene 'bubble' sheets appear to be very effective at maintaining air temperatures around the crop by approximately 3-4°C higher than temperatures outside.

Figure 1. *Rhododendron* cv. Coccineum Speciosum. Rooting and winter survival of rooted cuttings as affected by the original cutting size (Large ~12 cm v Small ~7 cm), shoot location on the stock plant (Top v Base) and propagation environment (fog v mist). Propagations carried out in 1999 and 1997.



SCIENCE SECTION

INTRODUCTION

Constraints in Production

Production of hardy nursery stock is increasingly ‘scheduled’ to meet the demands of the retail sector. This means crops need to be produced to a set specification and on a particular date. Therefore, nurserymen are under pressure to ensure targets are met successfully, and need to plan their entire production to enable the correct numbers of plants, of the appropriate quality, to be produced on time.

One of the most difficult aspects of this production process is predicting the number of cuttings to propagate in the first place, as cuttings may fail to root, or even if they do root, subsequently fail to establish at later stages. Obtaining an accurate prediction of cutting numbers required can be difficult, as rates of rooting and establishment may vary significantly between years and species. Nevertheless, this is clearly a very important aspect as overproduction can lead to inefficiencies and waste if the market is oversupplied, yet taking too few cuttings may result in under-supply and loss of sales potential.

Apart from the rooting process itself, one of the main ‘constraints’ on production is determining the number of cuttings that will successfully survive their first winter after propagation. Indeed, much of the effort involved in propagation can be wasted if cuttings fail to establish readily and young plants die in the months following propagation. Even in species where cuttings normally live through their first winter, loss of crop quality may result through poor management, or inadequate environments. This can lead to further expense, either through crops not attaining the appropriate retail specifications on time, or greater labour inputs being required to re-grade crops for uniformity prior to sale.

Project Objectives

The objective of this project was to identify why rooted cuttings may fail to survive the winter following propagation, even when held in protective environments such as polytunnels and glasshouses.

The reasons behind the death of rooted cuttings can be divided into two broad categories – direct injury from freezing damage during frost periods (Cameron and Dixon, 1997), and indirect injury from tissues being exposed to prolonged, but less severe environmental stress. In the latter case, no immediate injury is sustained, but resources within tissues are gradually reduced, or cell viability impaired over a period of time. It is this second category of winter stress that forms the focus of this project. However, although the project aims to identify causes for plant loss in the months following propagation *per se*, this period should not be viewed in isolation, and factors such as the source of cuttings and management at the propagation stage are likely to influence the potential for winter survival.

Factors Associated with Cutting Failure

A number of factors have been implicated in cutting failure during winter, over and above those of direct freezing injury. Temperature, particularly periods of relatively high winter temperature (>10^{o}C) may be detrimental, either through the loss of carbohydrate reserves through respiration, or interfering with bud dormancy, resulting in poor or uneven bud break in spring (many deciduous species require a chilling period during winter to break dormancy). Winter dormancy is normally controlled by the plant's natural hormones but can also be influenced by synthetic hormones such as those used to stimulate rooting (Perkins and Bassuk, 1995). In addition, nurserymen suspect that inappropriate management during the winter may be partially to blame, with loss of cuttings being attributable to watering (both under- and over-watering); nutrition; and mechanical root damage (caused by untimely potting-on).

Ironically, cutting failure during winter is often associated with those species where there is a high market value, e.g. *Acer, Rhododendron, Magnolia* and *Cornus florida* (Goodman and Stimart, 1987). In a number of these species, poor survival rates have been associated with limited shoot growth prior to winter. This factor is likely to play a role in determining the carbohydrate reserves within a cutting, and previous research indicates that the size of a plant's carbohydrate reserves may be important in determining its ability to tolerate winter stresses (Smalley and Dirr, 1986). Not only do carbohydrates provide the energy needed to repair damage to cells caused by stress, but they are required for the hardening processes during autumn, which increase the plants' tolerance to low temperature and desiccation (Ashworth *et al*., 1993). They also provide the resources for the first flush of growth in the spring.

Techniques that have been researched to improve cutting size and / or enhance carbohydrate levels prior to winter have included: varying propagation date, fertiliser additions (particularly nitrogen) and placing cuttings under long day light or night break regimes (Smalley *et al.*, 1987). In previous work on *Acer palmatum* cv. Bloodgood greater winter survival was associated with those cuttings that had new shoot growth prior to winter, but high nitrogen nutrition was detrimental, especially when added to those cuttings that did not re-grow (Goodman and Stimart, 1987). Extending daylength using 'night-breaks' encouraged a longer period of growth and delayed dormancy, but also delayed budbreak and reduced survival in *Cornus alba* cv. Argenteo-marginata (Scott, 1974).

The implication of the importance of carbohydrate reserves is that HNS producers tread a fine line between the need to protect against frost damage and the need to avoid conditions that stimulate wasteful depletion of reserves through respiration. For example, *Acer palmatum* cuttings suffered more from warm winter temperatures (15^{o}C) than from exposure to moderate frost (Cameron, 1995). Treatments that reduce the autumn accumulation of carbohydrate resources have been implicated in overwintering death (Harrison-Murray *et al.*, 1996). Experiments in this project aimed to verify this and focus on those treatments that enhance carbohydrate accumulation prior to the onset of dormancy and / or maintain reserves through the winter. As well as investigating morphological factors, such as cutting size or diameter that may influence carbohydrate levels, determination of starch concentration within cuttings of *Magnolia* was attempted in a number of experiments.

Guidelines for Minimising Cutting Failure

Guidelines are required on the management of cuttings during the winter period, to ensure that resources are not depleted and to minimise physiological disruption to those processes that control bud break. In addition, further information is required on practical measures to ensure that cuttings are not exposed to excessive stress, e.g. the extent to which low-cost frost protection measures, such as bubble polythene and fleece, are effective and the means of ensuring they are best utilised.

The project has the objective of developing guidelines for maximising the ability of young plants to tolerate environmental stress, and to examine the relative merits of different forms of environmental protection. The research concentrates on species recognised by the industry as being difficult to overwinter, and for which consumer demand is currently met largely by imported plants. The principles established, however, can be expected to be applicable to the majority of species produced from cuttings. Factors studied in the project focus include stock plant management, cutting type and vigour, date of propagation, and the effect of varying the environment at the propagation and the overwintering stages.

MATERIALS AND METHODS

General

A range of plant species and cultivars were selected by members of the industry. They were chosen on the basis of being either relatively difficult to root from cuttings in the first instance, or because plant failure as rooted cuttings during the winter period could be high. Plants used in the project were:

Thin stemmed types - *Acer palmatum* cv. Bloodgood
Acer palmatum cv.Aureum (considered to be more vigorous than *Acer palmatum* cv. Bloodgood)
Corylopsis pauciflora
Rhododendron cv. Coccineum Speciosum (Ghent hybrid type)

Thick stemmed types- *Magnolia x soulangeana*
Cotinus coggygria cv. Royal Purple
Viburnum carlesii cv. Aurora

An evergreen subject - *Ceanothus* cv. Autumnal Blue

The source of cuttings used were either well-established field-grown stock plants or containerised stock plants, depending on species and ease of management. Field-grown stockhedges of 6-8 years of age were used for *Magnolia*, *Cotinus* and *Viburnum*. Cuttings of *Ceanothus* were derived from a 2-year-old hedge. Motherplants of *Acer*, *Corylopsis* and *Rhododendron* were maintained in containers because the soil at East Malling was generally not suitable for field planting.

Acer plants were kept in 10 litre containers with a substrate comprising peat (33%), Cambark 100 (33%), grit (17%) and loam (17%) with Ficote 180, 16:10:10 fertiliser incorporated at 3 g l^{-1}. The *Rhododendron* and *Corylopsis* were potted into 3 litre containers using a peat (70%), Cambark 100 (30%) mix with 2 g l^{-1} Magnesium carbonate and 3 g l^{-1} Ficote 180, 16:10:10 fertiliser incorporated.

Handling of Cuttings

Stock plants were pruned during January of each year and 'softwood' cuttings collected from May onwards. Cuttings were trimmed to a standard length for each species and bases dipped into 1,250 ppm indole-butyric-acid solution (50:50, water / acetone, v/v). Prepared cuttings were stuck into a 50:50 peat / fine bark (Cambark) medium in 80 cm^3 modular cells. Once cuttings were placed in rooting environments fungicides were applied every three weeks to the cuttings, with sprays being altered between prochloraz (Octave) and chlorothalonil (Bravo 500).

Propagation Environments

For the majority of experiments, cuttings were rooted in a gradient fog environment (Agritech fogger). The high humidity levels associated with the fog, generally provide a supportive environment for cuttings and minimise stress through water loss, until the cuttings form roots. Comparisons were made, however, with a conventional mist bed system (as commonly found in industry) to determine how propagation environment could influence cutting viability. Mist beds were enclosed using clear polyethylene tents. Fog and Mist application were controlled by 'evapo-sensors' (See HDC HNS 27 - Harrison-Murray *et al.,* 1996), and in each environment basal heat was kept at a minimum of 20°C during rooting, using electric cables placed under the sand beds. After rooting, cuttings were progressively weaned over 2-3 weeks and then placed on sand beds within polythene tunnels.

Assessments of Growth

Assessments were made on cuttings for percentage rooting and viability during winter and spring. Final records of survival rates were carried out in early May after bud break and data for percentage survival of **rooted** cuttings are presented. Cuttings that survived were also scored at this stage for shoot vigour and foliage quality, i.e. Strong growth, with fully developed leaves = 5; Weak growth, with necrotic stems or leaves = 1.

Statistical Analysis

Where appropriate, analysis of variance was used to determine the statistical significance of differences between treatments. The results of statistical analyses were expressed in terms of the least significant difference (LSD) at the 5% level. This LSD indicates the size of difference between individual treatment means required to give a 95% probability that the effects were not due to chance. Where data representing two or more factors are presented, the LSD value is calculated from values based on any interaction between the factors. When comparison are made between different species or other factors, significance levels are sometimes also denoted by probability ‘P’, e.g. $P < 0.001$ - highly significant; $P = 0.1$ - marginally significant and n.s. - non significant.

Experimental Design

Cutting Size and Diameter

Over a number of experiments, cuttings were graded according to their size or diameter, to determine how these factors influenced rooting and survival. Tables Ia and Ib Appendix A, depict the types of cuttings selected.

Stock Plant Pruning

This was based on the severity of pruning. A light pruning treatment and a hard pruning treatment was used with stock plants of most species. The extent of pruning varied, however, depending on growth habit, age and position of stock material; the details for each species are highlighted in Table II Appendix A.

Propagation Date and Supplementary Lighting

The objective of this experiment was to determine the effect harvest date had on the type of cuttings available, how well these rooted and if winter survival could be improved by providing supplementary long day light during the autumn after propagation. Propagation times were based on the time that initial shoot growth on the stock plants was of a suitable length for cuttings to be taken, with later propagations being carried out at set periods afterwards. Populations of cuttings from each propagation date were divided, with one half being placed under sodium lamps (16 hour long day photoperiod treatment – LD) and the other half left under natural photoperiods and light intensities within a polytunnel (Natural treatment– Nat). Table III, Appendix A shows propagation dates and timing of LD regime. Trays of cuttings were then maintained in their appropriate treatments until 13 December, at which point the LD treatment was terminated.

Management of Cuttings at Collection

Nurserymen may have varying protocols and management techniques that they utilise in the collection and preparation of their cuttings. This experiment was designed to evaluate how the management of cuttings at the time of collection affects rooting or cutting viability. Cuttings of *Magnolia* were collected relatively late in the growing season (20 September) and divided into four treatments to represent handling procedures that might be found in industry. These were:

Control – Collected from the stock hedge, watered, and cuttings stuck directly into trays within 1 hour.

Ambient 24 h – Collected from the hedge and placed in trays under clear polythene and left at ambient temperatures for 24 hours, prior to watering and sticking.

Ambient 6 h – Collected from the hedge, but left on the preparation bench for 6 hours, before being stuck

Cold store 72 h - Placed in black polythene bags and stored at 2^{o}C for 72 hours, prior to sticking.

Cuttings were placed in fog to root and over-wintered in an enclosed tunnel, with assessments being implemented the following May.

Influence of Overwintering Environments

Over the course of the project, groups of rooted cuttings were divided on the basis of their overwintering environment. These were selected to provide variations in naturally occurring stress and to determine the effect of stress on the viability of cuttings throughout the winter period. There were three main contrasting environments:

1. **Cold-Store**. Cuttings were maintained in modular trays at a constant temperature of 2^{o}C for 16 weeks in the dark. This provided a ‘control’ treatment with a minimal temperature shift.

2. A **Well-Ventilated polytunnel (W-V tunnel).** This was used to house cuttings in an environment where excessive temperature shifts were kept to a minimum. Bottom heat was applied to keep basal temperature above 2°C and to avoid freezing injury during frost periods. Likewise, side and end ventilation were used to avoid excessively high temperatures during sunny periods and to avoid a build-up of humidity.

3. An **Enclosed polytunnel (Encl. tunnel).** This was used to represent environments where there was minimal control over environment variables such as temperature and humidity. Cuttings were placed on coarse sand beds, but there was no additional basal heat, or mechanisms to reduce humidity within the tunnel. To reflect ‘typical’ nursery management, however, a propane gas heater (40,000 BTU, RiteAir) was placed within the tunnel and switched-on during periods when there was a chance of severe frost. When there was only a minimal likelihood of light frost occurring, fleece was placed over the cuttings instead.

Influence of Additional Stress (Irrigation Regime) on Winter Survival and Carbohydrate Content

Experiments were repeated during the second year of the project to further investigate environmental influence during winter. In particular, information was sought on how stress factors may interact to affect cutting viability. Cuttings were again housed in different environments to provide contrasting aerial environments, but additional treatments were imposed on them to determine how management, in terms of how much irrigation was applied, could influence survival.

Rooted cuttings of *Ceanothus* and *Magnolia* were potted into 7cm pots with 50:50 peat/fine bark compost. These ‘liners’ were then placed in rows into polypropylene trays (75 x 45 x 8 cm) and put into different environments for the duration of the winter. In each environment, one tray of liner plants were exposed to the following sub-treatments:

Well-watered (Wet). Liners were irrigated overhead to maintain a shallow reservoir of water at the base of the tray (10 mm deep).

Moderately-watered (Mod). Liners were watered when it was visibly apparent that the surface of the growing medium had dried out. This treatment was designed to reflect optimum management of the young plants.

Watered infrequently (Dry). Watered only when the growing medium contracted sufficiently, to allow a gap to form between the medium and the side of the pot. The objective here was to mimic ‘dry zones’ that can occur in nurseries, when irrigation is infrequent or distribution uneven.

Treatments were imposed from 14 December 1998 until 24 March 1999, and water status of the medium was monitored throughout. In addition to growth measurements in *Corylopsis* and *Magnolia*, 20 cuttings per treatment (divided into 4 groups of 5) were harvested and used in destructive analyses to measure the carbohydrate content within the tissues. Starch was extracted from the tissues using 32 % perchloric acid and concentrations calculated using an iodine reaction test against a standard concentration curve.

Influence of Temperature and Humidity on Winter Survival

In addition to identifying the most appropriate winter environment in which cuttings should be housed, further experiments evaluated the effect of microclimate on cutting viability. In year 3 of the project, four treatments were set up on sand beds within an enclosed tunnel to investigate the effects of aerial temperature and relative humidity. Beds within the tunnel were covered with metal hoops and clear polythene placed over the hoops. In two of the ‘micro-environments’, slits were cut in the polythene tents to enhance ventilation and reduce humidity (i.e. low humidity treatment). In contrast the other two tents were left enclosed (i.e. high humidity). Each humidity treatment was then further sub-divided on the basis of temperature, with basal heating cables being set at 2°C (frost protection only – cool temperature), or 15°C in an attempt to raise air temperatures (i.e. warm temperature). Trays of rooted cuttings were placed in these micro-environments from December through until early April, before being removed to a well-ventilated tunnel and final assessments carried out in May.

Evaluation of Frost Protection Materials

This experiment was set-up to evaluate materials used to protect crops from frost injury. The objective was to determine how temperatures varied in the crop canopy, when comparisons were made between protected and non-protected plants.

Three commercially available products were used –

1/ ‘Thin’ polypropylene fleece woven at a density of 17g m^{-2} (Fleece 17)
2/ ‘Thick’ polypropylene fleece woven at a density of 25g m^{-2} (Fleece 25)
3/ Clear, tri-laminated ‘Bubble’ polythene insulation, with sealed bubbles, 30 mm diameter x 5 mm deep (bubble polythene).

Ceanothus plants, grown in 9 cm pots, were placed into pot carrier trays with a total of 20 plants per tray. Six trays were placed in four sites within an enclosed polytunnel on 3 November 1998. The sites were chosen to be as similar as possible in terms of location and aspect. Trays were placed on free draining sand and a temperature probe positioned on top of an individual pot within each of the blocks of plants. Three blocks were then covered with one of the frost protection fabrics, with a fourth block being left uncovered. An extra probe was placed at 3 m above the crop to record air temperature within the tunnel.

Temperature was recorded between 27 November 1998 – 24 March 1999 continually, with maximum, minimum and mean values being recorded on an hourly basis. After a period of frost, data was downloaded and comparisons made of the temperature profiles associated with different treatments.

RESULTS

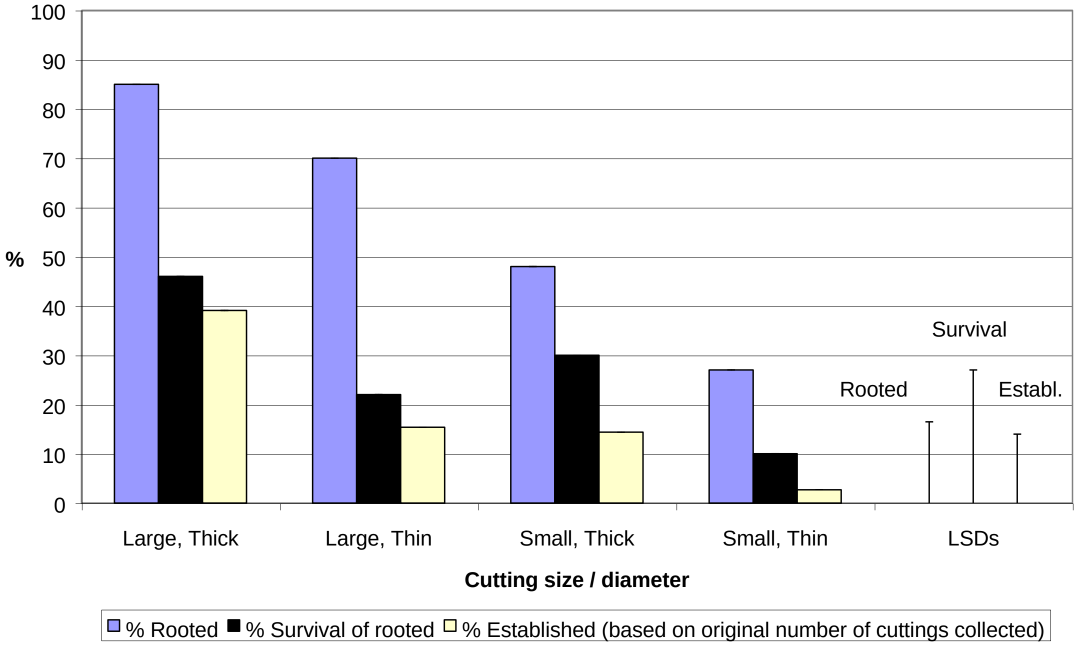
Cutting Size and Diameter

For the majority of the 'thin-stemmed' subjects included in the project, i.e. *Acer*, *Corylopsis* and *Rhododendron* cv. Coccineum Speciosum, cutting size or stem diameter could strongly influence survival, with the **use of larger or thicker cuttings being advantageous** (Table 1). Trends for rooting percentage could sometimes vary from that of survival, however, and thin cuttings in particular, could often root well, but fail to survive the following winter. A clear example of this was **with *Acer* cv. Bloodgood** (Figure 2), where establishment was optimised through the **use of large, thick cuttings** alone. Survival was also enhanced in this species, by selecting those cuttings with **active shoot tips present** (71 % survival), rather than where a terminal bud had formed (52 % survival).

Table 1. The effect of cutting size or diameter on rooting, survival and establishment. Data are pooled from various experiments and treatments, therefore no statistical data attached.

Species	Year of propagation		% Rooted	% Survival of rooted	% Established (based on cuttings taken)
Acer cv. Bloodgood	1999	Large	78	34	27
		Small	38	20	9
Corylopsis	1997	Thick	93	36	33
		Thin	87	21	18
Corylopsis	1998	Large	100	89	89
		Small	100	82	82
	1999	Large	95	44	42
		Small	98	27	26
Cotinus	1997	Large	68	86	58
		Small	84	92	77
Magnolia	1998	Large	100	98	98
		Small	98	100	98
Rhododendron	1999	Large	100	61	61
		Small	100	35	35

Figure 2. *Acer* cv. Bloodgood (1999). Rooting, survival and establishment as affected by cutting size and diameter.



In **species, where stem diameters were naturally quite broad**, i.e. *Cotinus*, *Magnolia*, *Viburnum***, cuttings size and stem diameter had little influence over winter survival** rates. However, the selection of **large cuttings of *Cotinus* reduced rooting, compared to smaller cuttings**, especially when cuttings **were placed in a less-supportive open mist**. Table 2 demonstrates how rooting could be affected by cutting size and rooting environment after stock plants had been either light or hard pruned.

Stock Plant Pruning

Results from this work and allied projects (e.g. MAFF ROAME HH1209SHN) demonstrate that one of the key factors influencing the morphology and physiological characteristics of cuttings is stock plant management. In particular, rooting and establishment of a number of ‘difficult-to-produce’ species can be strongly influenced by the pruning regime imposed on the mother plant, or the position within the hedge from which cuttings are removed.

Table 2. *Cotinus* (1997). The effect of stockplant pruning, size of cuttings and rooting environment on the percentage of cuttings that rooted.

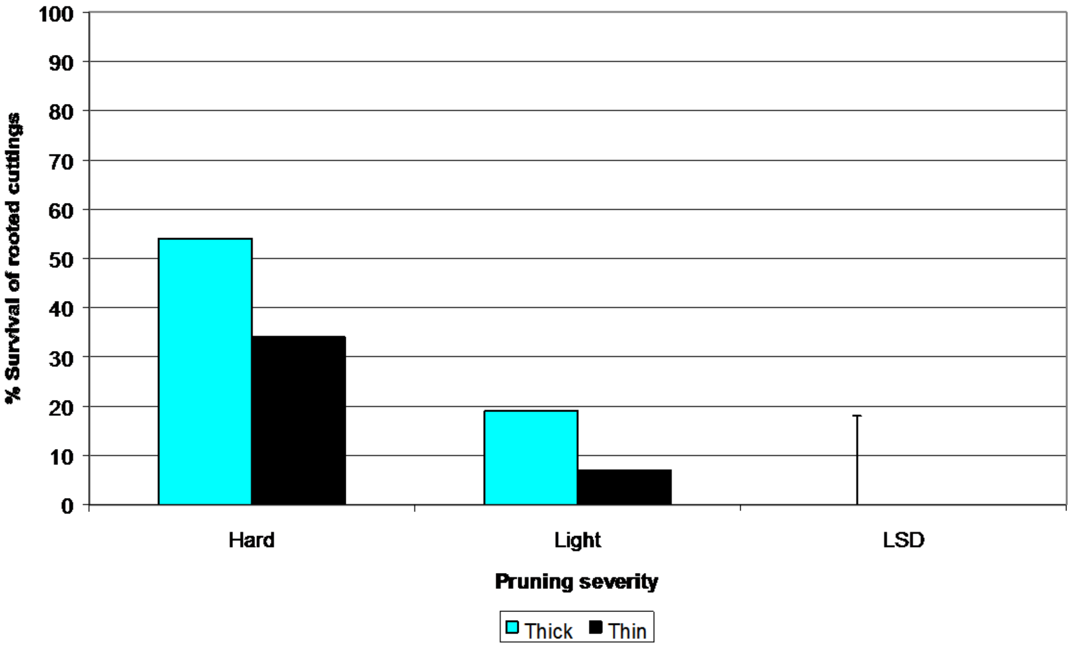
Prune / Size / Root. Env.	% Rooting
Light Pruned	
Large Fog	72
Small Fog	83
Large Mist	60
Small Mist	86
Hard pruned	
Large Fog	83
Small Fog	90
Large Mist	54
Small Mist	76
LSD	13.3

In ***Corylopsis,*** stock plant pruning treatment had a significant effect on rooting ability. **Hard pruning of stock plants induced more cuttings to root** (95%), compared to light pruning (86%), (LSD = 5.2%). Prior to placing plants in their overwintering environments, it was also evident that cuttings from the hard pruned treatment showed greater root development than those from the light treatment, with more cuttings rooting through the base of the modules.

Cuttings from each source were also graded on the basis of stem diameter. **Better rooting was promoted through the use of thicker cuttings**, i.e. combined mean values for thick cuttings was 93% compared to 87% for thinner cuttings (LSD = 5.2%).

The original **pruning regime**, and to some extent the **thickness of cuttings**, strongly **influenced survival rates** in the rooted cuttings. Greatest success rates were correlated with cuttings from the hard pruned mother plants, especially the thicker cuttings (Figure 3).

Figure 3. *Corylopsis* (1999). Survival of rooted cuttings as affected by cutting diameter and stock plant pruning.

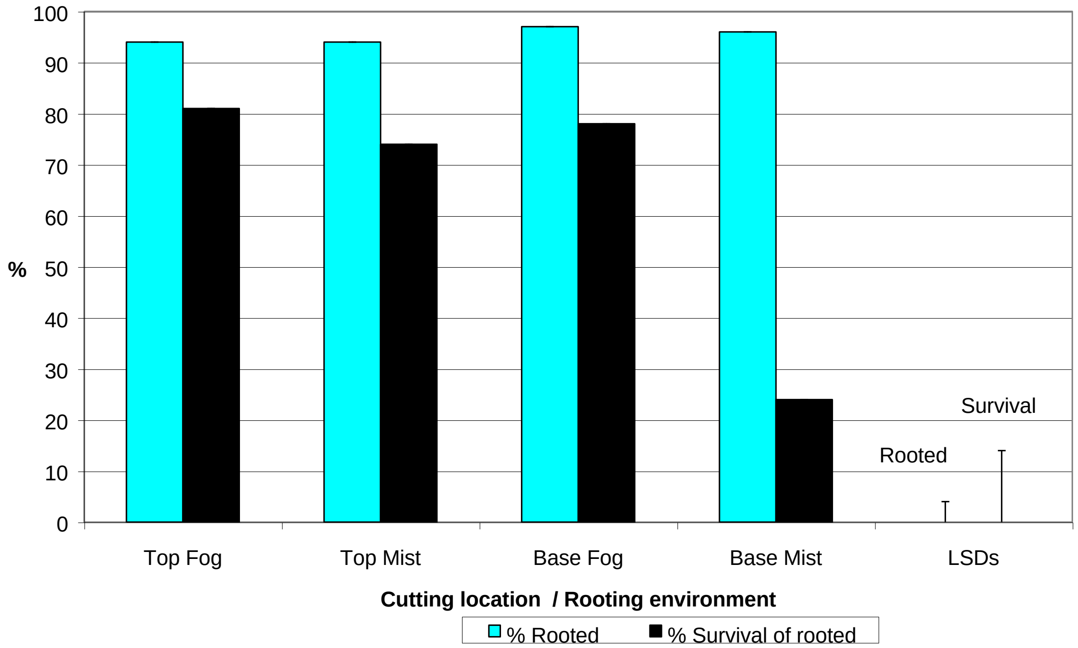


Different pruning regimes were not imposed on *Rhododendron*, as hard pruning removed all the visible axilliary buds, and it was suspected that this treatment may kill the stock plant entirely. Therefore, the influence of **cutting location** was investigated instead in this species, and developing shoots were divided into those derived from the basal region (small, with little vigour – 'Base') or from the top of the plant (larger active cuttings 'Top'). Cuttings from both locations were placed in either the fog or mist environments to root

Rooting was good in both the fog and the enclosed mist systems (Figure 4), although rooting was marginally slower with cuttings placed in mist with fewer roots emerging from the bases of modules by the time of weaning.

Cutting survival during the winter was affected strongly by cutting type and original rooting environment. There was a significant interaction between the rooting environment and cutting type; **greatest failure of cuttings was associated with basal cuttings placed in the mist** (Figure 4). In contrast, cuttings derived from the top part of the stock plant, i.e. the original vigorous apical shoots, had survival rates in excess of 70% regardless of the rooting environment. Similarly, survival rates of basal cuttings could also be high but only after they had been rooted in the fog. The implications from this are that even though base cuttings rooted well in mist, stress factors associated with this environment combined with small size of the cuttings from the base have interacted strongly to reduced survival capacity.

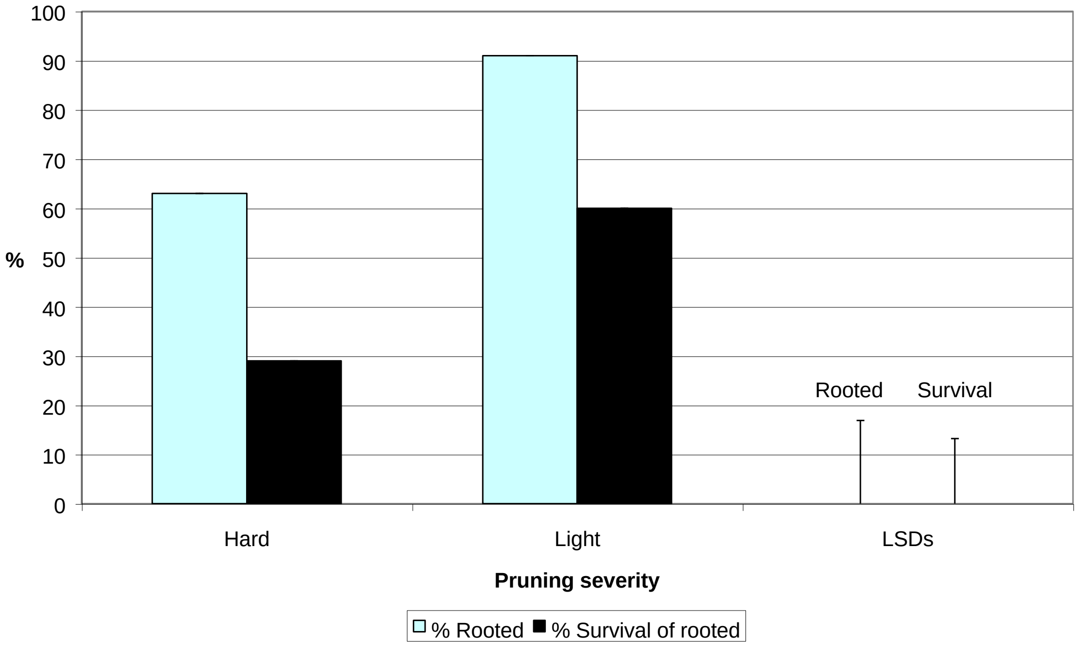
Figure 4. *Rhododendron* (1997). Rooting and winter survival of rooted cuttings as affected by shoot location on the stock plant (Top v Base) and propagation environment (Fog v Mist).



In contrast to the trend associated with *Corylopsis*, and *Cotinus* (when cuttings were placed in fog - See Table 2) where hard pruning of the stock plant was beneficial, **hard pruning of the stock material of *Acer* cv. Bloodgood, was detrimental.** Both rooting and winter survival was significantly lower after hard pruning compared to light pruning (Figure 5).

There was **no significant effect due to pruning severity on rooting and winter survival of *Magnolia* and *Viburnum*.**

Figure 5. *Acer* cv. Bloodgood. (1997). Rooting and survival of rooted cuttings as affected by stock plant pruning.



<u>Propagation Date and Supplementary Lighting</u>

The objective was to determine the effect of harvest date on the type of cuttings available, how well these rooted and if winter survival could be improved by providing supplementary long day light during the autumn after propagation.

<u>Acer</u>: Rooting success of *Acer* was strongly influenced by time of propagation, with those **cuttings forced early in the season in April having high percentage rooting.** In comparison, rooting rates were suppressed at the later propagation date of 12 June, and were particularly poor with the smaller cuttings (Table 3). Placing cuttings under LD light did not induce new shoot growth during the autumn, although leaf abscission was delayed in cuttings exposed to this treatment.

Table 3. *Acer* cv. Bloodgood (1998). The effect of propagation date and size of cutting on rooting and establishement.

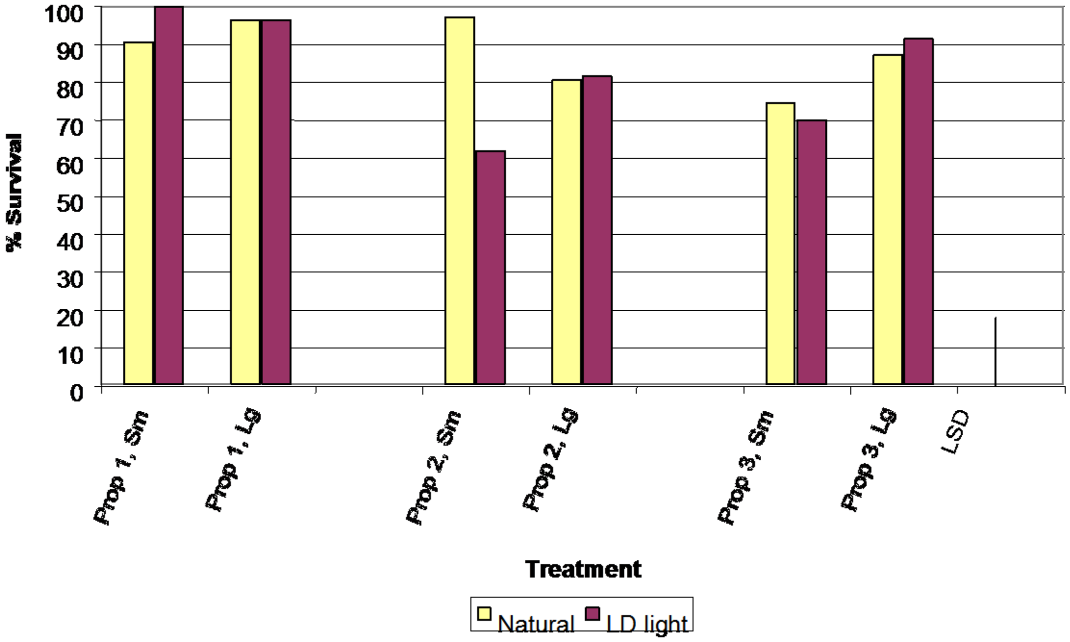
Prop	Date	Cutting type	% Rooted	% Established (based on cuttings originally collected)
1	3 April	Small	100	28
		Large	97	60
2	12 June	Small	32	9
		Large	68	50
		LSD	9.1	22.2

Data for winter survival of rooted cuttings was significantly affected by propagation date and the original type of cutting**. The use of LD supplementary light was overall not significant** (data not shown). The selection of larger cuttings at the first propagation date resulted in greatest survival, when the data was based as a percentage of the original cuttings collected (Table 3). A relatively large LSD value was recorded reflecting inherent variability within treatments, possibly relating to other contributory factors, e.g. extent of shoot activity.

Corylopsis: In experiments conducted on *Corylopsis* during the second year of the project, all cuttings rooted regardless of propagation date and size. However, **survival was significantly affected by propagation date, with greater success associated with cuttings propagated at the first date.** When data is pooled across other factors, survival rates were Prop 1 (12 May) = 96 %, Prop 2 (12 June) = 81 % and Prop 3 (24 Aug) = 81 % (LSD = 9.3).

There was **no overall benefit associated with placing cuttings under the LD regime**, and in small cuttings taken at the second propagation date, survival appeared to be suppressed by this treatment compared to cuttings under natural conditions (Figure 6). The reasons for this are unclear, but relatively low shoot and root scores associated with these treatment suggest that these small cuttings may be more prone to stress during weaning and after placement under lights. Although the LD regime had little overall effect on subsequent survival in other treatments, there did appear to be some physiological effects as leaf drop was delayed by approximately three weeks compared to plants under natural light conditions.

Figure 6. *Corylopsis* (1998). Percentage survival of rooted cuttings as affected by date of propagation (1=12 May; 2=12 June; 3=24 August), original size of cuttings (Large v Small) and lighting regime (Natural v Long-Day).



The influence of propagation date was further investigated during 1999, with cuttings being collected at Prop 1 (16 July) and Prop 2 (9 August). Rooting trends were similar to the previous year, i.e. > 95 % rooting throughout, however, winter survival followed a contrasting trend with greatest survival associated with larger grade cuttings taken at the later date: - Survival rates were Prop 1, Large = 32%; Prop 1, Small = 25%; Prop 2, Large = 52% and Prop 2, Small = 30%, LSD = 9.0). Although the overall reduction in survival rates during this year may be explained by the environmental treatments placed on cuttings during the winter (See later), this does little to explain the variable trend due to propagation date between years. The thin-stemmed *Corylopsis* appears to be susceptible to loss of carbohydrates during winter (See Report 2), and variations due to date of cutting collection may relate more to endogenous sugar levels than calendar date *per se*.

Rhododendron: The **percentage of cuttings that rooted was significantly affected by the propagation date during 1998**, with 100 % rooting occurring at the first propagation (11 May), and significantly lower rates at the later dates (Figure 7). During the second propagation (1 July), rooting success was significantly better with smaller cuttings compared to larger equivalents. At the last date (25 Aug.), less than one-third of the total number of cuttings collected had successfully rooted.

Of those cuttings that did root**, winter survival was significantly affected by original cutting size, with the larger cuttings of the first and last propagation dates having highest survival rates.** Survival rates were very poor for cuttings from the second propagation date throughout.

There was **no overall trend associated with placing cuttings under LD lighting**, and this treatment appeared to have no advantage in terms of plant survival or shoot quality and vigour the following spring. When survival is based on total numbers of cuttings originally collected and data pooled over Natural and LD regimes, it is clearly evident that large cuttings taken early in the season, results in greatest success rates (Figure 8).

Figure 7. *Rhododendron* (1998). Percentage rooting as affected by date of propagation (1=11 May; 2=1 July; 3=25 August) and original size of cuttings (Large v Small).

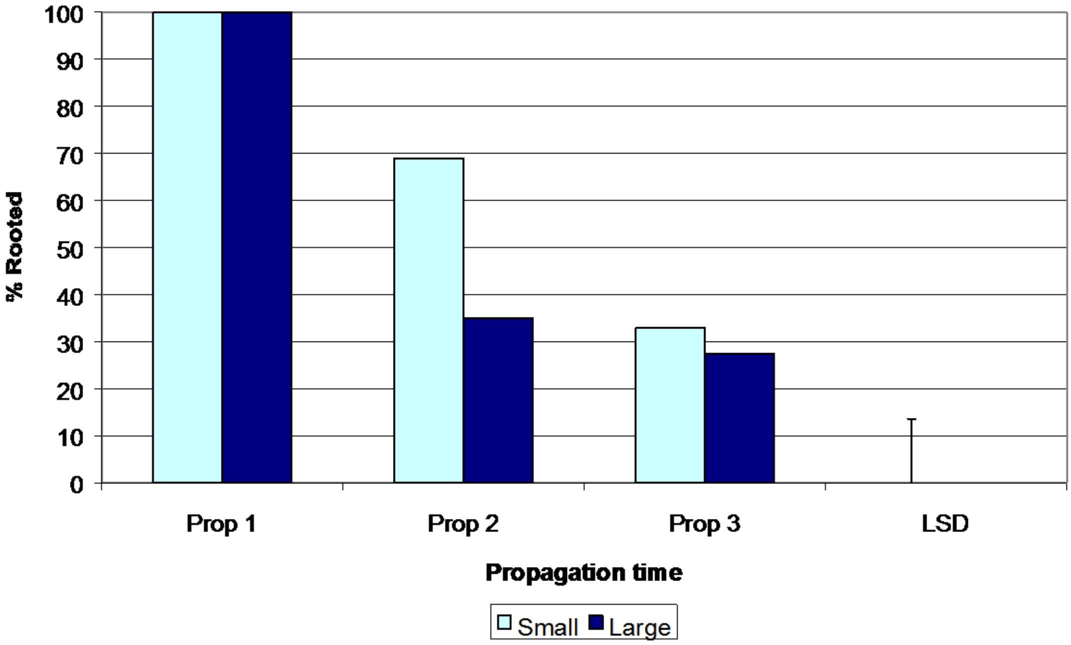
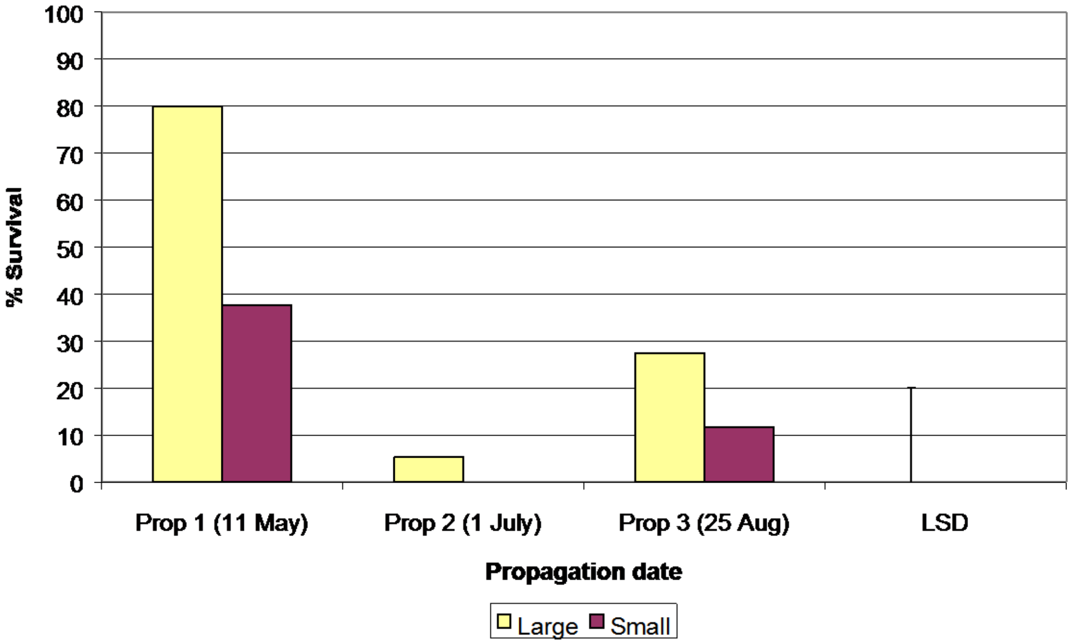
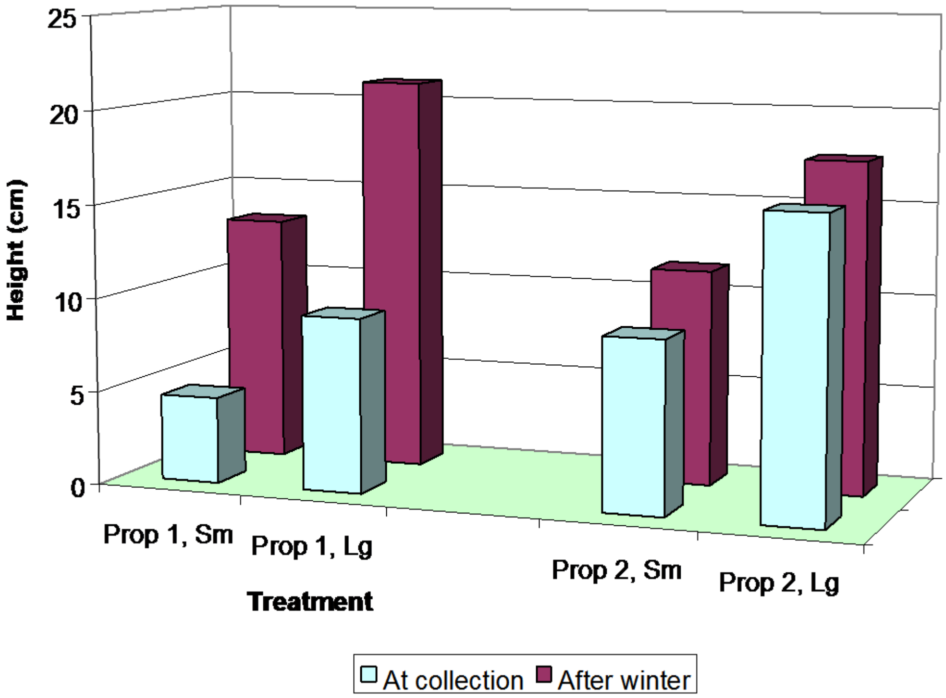


Figure 8. *Rhododendron* (1998). Percentage survival of rooted cuttings as affected by date of propagation (1=11 May; 2=1 July; 3=25 August) and original size of cuttings (Large v Small).



Magnolia: Cuttings of *Magnolia* rooted readily, with all treatments having greater than 98 % rooting. Winter survival rates were also generally high, although there were some cutting failures associated with large cuttings from the second propagation, when placed under Natural daylengths – 91 % survival compared to 100 % in all other treatments (LSD = 6.1). **Data on winter survival, however, showed no significant effects due to propagation time, cutting size or the addition of LD light.** When cuttings were assessed for shoot and root scores, however, results showed that **best quality cuttings were those large cuttings propagated at the first date.** Interestingly, these cuttings produced the greatest increase in shoot growth between collection of cuttings and final assessments in May 1999 (Figure 9).

Figure 9. *Magnolia* (1998). Height of cuttings at collection and after winter as affected by date of propagation (1=3 June; 2=24 August) and original size of cuttings (Large v Small).



Management of Cuttings at Collection

Pre-treatment of *Magnolia* cuttings had no effect on rooting with all treatments demonstrating > 98% rooting. Treatments, however, influenced the longer-term survival of cuttings. **Retaining cuttings for 24 h under clear polythene bags at ambient conditions reduced survival significantly compared to the other treatments** (57% survival). Interestingly, holding the cuttings in cold store for 72 h prior to propagation had no adverse effect (73% survival), with survival rates being similar to Control cuttings (75% survival, LSD = 9).

Influence of Overwintering Environments

Table 4 summarises the percentage survival of rooted cuttings for the first two years of the project and when other factors such as rooting environment and cutting size are pooled. Although results were not always consistent for different species or years, there appeared to be a strong trend associated with the environment cuttings were placed in during winter**. For many of the species tested lowest survival rates were recorded with cuttings placed in the enclosed tunnel.** This was particularly the case, with some of the species that fell within the 'thin-stemmed' category, e.g. *Acer* and *Rhododendron*. Placing cuttings in **cold storage** often appeared to be advantageous compared to placement in either of the treatments involving placement in tunnels, e.g. *Ceanothus*, *Corylopsis* (1997 data), *Magnolia* (1997 data) and *Rhododendron* ('base' cuttings).

In contrast to the trends in cutting survival, scoring for quality of shoot growth indicated that placement into cold store delayed bud break and lowest scores in some species were often associated with this treatment (e.g. *Ceanothus* 1997, *Corylopsis* 1997, *Magnolia* 1997 and *Rhododendron*, Table 5). Stress imposed during the transition from cold storage to ambient conditions may also partially account for the low scores associated with this treatment. Further investigations are required to develop effective techniques to minimise these 'transitional stresses' as cuttings are 'weaning' from cold store during spring.

In *Acer*, lowest shoot scores were linked with those cuttings placed in tunnels and were often a consequence of leaf tip necrosis in cuttings placed in these environments. The precise reasons for this are unclear, but may relate to the higher light and temperature profiles associated with these environments during spring. Similar leaf damage and tip necrosis was recorded in some of the cuttings of *Rhododendron* held in tunnels (although shoot scores do not necessarily reflect this), possibly due to similar reasons. Again, information is required to determine optimum shading and temperature profiles so as to minimise injury as cuttings break bud in early spring.

Table 4. Survival of rooted cuttings as affected by winter environment (Well-ventilated tunnel v Enclosed tunnel v Cold store) and sub-treatment (e.g. pruning - Light v Hard or location - Top v Base) or year.

Species	Sub-treat.	W-V	Encl	Cold	LSD	Sig. level
Acer cv. Bloodgood	Light	71	36	74	21	P=0.001
	Hard	50	11	28		
Acer cv. Aureum		72	69	81	13	n.s.
Ceanothus	1997	88	87	100	8.1	P< 0.01
	1998		85	100	6.2	P < 0.001
Corylopsis	1997	25	29	38	8.7	P< 0.05
	1998		56	49	15.4	n.s.
Cotinus		87	88	90	14	n.s.
Magnolia	1997	99	93	100	6.4	P< 0.01
	1998	94	96	92	10.9	n.s.
Rhododendron	Top	85	59	87	9.6	P< 0.001
	Base	49	34	70		
Viburnum		96	94	97	5.1	n.s.

Influence of Additional Stress (Irrigation Regime) on Winter Survival and Carbohydrate Content

***Magnolia* cuttings were relatively resilient to the imposition of additional stress** with high rates of survival in both liners that were over- and under-watered (Table 6). Environment had a significant effect on starch levels within shoot tissues at the end of winter, with lowest values associated with cuttings placed in the cold store (Table 7). However, most of the sugar reserves were held within the roots, and there were no overall trend associated with starch concentration in these.

Table 5. Shoot score as affected by winter environment (Well-ventilated tunnel v Enclosed tunnel v Cold store) and sub-treatment (e.g. pruning - Light v Hard or location - Top v Base) or year.

Species	Sub-treat.	W-V	Encl	Cold	LSD	Sig. level
Acer cv. Bloodgood	Light	2.16	1.67	2.39	0.26	P<0.001
	Hard	1.29	2.01	2.17		
Acer cv. Aureum		2.2	2.8	2.6	0.23	P< 0.001
Ceanothus	1997	2.6	2.1	1.5	0.19	P< 0.001
	1998		3.1	3.4	0.22	P< 0.001
Corylopsis	1997	1.75	2.24	0.74	0.16	P< 0.001
	1998		2.59	2.94	0.24	P = 0.06.
Cotinus		2.19	2.24	0.90	0.20	P< 0.001
Magnolia	1997	2.48	2.45	1.00	0.27	P< 0.001
	1998	3.14	2.72	3.21	0.25	P< 0.001
Rhododendron	Top	2.08	2.42	0.94	0.15	P< 0.001
	Base	1.77	1.83	0.96		
Viburnum		2.79	2.52	2.50	0.156	P< 0.001

Table 6. Survival of rooted cuttings (1998) as affected by winter environment (Well-ventilated tunnel v Enclosed tunnel v Cold store) and irrigation regime.

Species	Irrigation regime	W-V	Encl	Cold	LSD
Ceanothus	Wet	N.A.	88	100	11.5
	Moderate	N.A.	92	100	
	Dry	N.A.	72	100	
Corylopsis	Wet	N.A.	68	56	26.7
	Moderate	N.A.	64	36	
	Dry	N.A.	36	54	
Magnolia	Wet	97	93	93	10.8
	Moderate	90	97	90	
	Dry	97	97	93	

Table 7. ***Magnolia*** (1998). Mean starch content of shoot and root tissues at different times during production, and as affected by different treatments during winter.

Time	Environment	Irrigation regime	Starch content (% of dry weight)	
			Shoot	Root
At Propagation 7 July 1998			6.40	
Prior to winter 11 November 1998			0.95	14.78
After winter 24 April 1999	Well-ventilated tunnel	Wet	0.99	14.33
		Mod.	0.75	15.78
		Dry	0.55	11.01
	Enclosed tunnel	Wet	0.44	11.55
		Mod.	0.45	11.95
		Dry	0.40	16.01
	Cold store	Wet	0.27	14.29
		Mod.	0.20	12.76
		Dry	0.33	14.45
LSD			0.302	3.883

In *Ceanothus*, irrigation regime had no effect on those cuttings placed in cold store. There were also relatively high levels of survival for cuttings in the Wet and Moderate treatments in the enclosed tunnel. **Failure rates, however, were significantly increased in the Dry treatment in the tunnel.** This treatment corresponded to lowest moisture contents in the growing medium, and reduced survival rates in this evergreen species, may reflect the higher evaporative demand in the tunnel environment.

The 'thin-stemmed' ***<u>Corylopsis</u>*** had in general relatively low survival rates in the cold store, and **highest overall survival was associated with the wet and moderate irrigation treatments in the enclosed tunnel** (Table 6). Even in these treatments, however, up to one-third of the original liners failed to survive. Exposing liners to the drier regime in the tunnel resulted in very high losses, with only 36 % of the original liners becoming established after winter. These liners that survived this treatment, also had significantly lower shoot and root scores the following spring, compared to those plants maintained in wetter regimes.

Carbohydrate analyses for *Corylopsis* showed that starch levels were reduced considerably within tissues over time (Table 8). Levels were highest in shoots at propagation, with concentrations in both shoots and roots decreasing with time over winter. The resolution of analytical technique for starch determination decreases at very high or low concentrations and there may be some error associated with values less than 0.5%. Nevertheless, the results indicated that particularly low levels of starch were present in cuttings placed in the cold store, and with those cuttings exposed to the dry regime in the enclosed tunnel. Therefore, **low starch concentrations broadly correlated with treatments where cutting failure was greatest.**

Table 8. ***Corylopsis*** (1998). Mean starch content of shoot and root tissues at different times during production, and as affected by different treatments during winter.

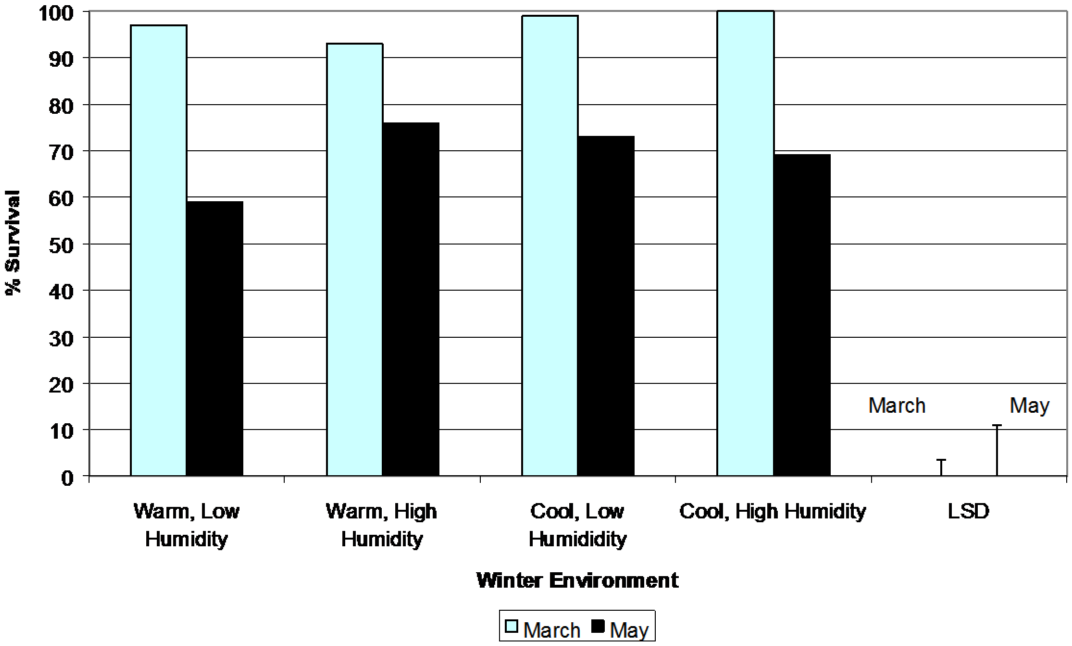
Time	Environment	Irrigation regime	Starch content (% of dry weight)	
			Shoot	Root
At Propagation 7 July 1998			3.40	
Prior to winter 11 November 1998			0.74	1.96
After winter 24 April 1999	Enclosed tunnel	Wet	0.16	0.44
		Mod.	0.09	0.73
		Dry	0.06	0.34
	Cold store	Wet	0.10	0.24
		Mod.	0.07	0.32
		Dry	0.08	0.33
LSD			0.081	0.251

Influence of Temperature and Humidity on Winter Survival

Placing slits into the 'mini-tunnels' to reduce humidity also marginally reduced the temperature profile compared to tunnels without slits. Mean recorded values of temperature and humidity during the winter for the different treatments were: - Warm, low humidity = 9.4°C, 93 % r.h.; Warm, high humidity = 11.1°C, 98% r.h.; Cool, low humidity = 7.7°C, 92 % r.h. and Cool, high humidity = 8.1°C, 98% r.h.

***Magnolia*: Initial analyses carried out on *Magnolia* at bud break (i.e. March 2000) showed a small but significant decline in survival rate with cuttings held in the** warm, high humidity **environment (Figure 10). However, after leaf expansion had taken place and cuttings were re-assessed in May, greatest cutting failure was associated with the** warm, low humidity **environment. This may indicate that the greater evapo-transpiration associated with this environment, may have caused localised desiccation as the cuttings developed and expanded their foliar tissues.**

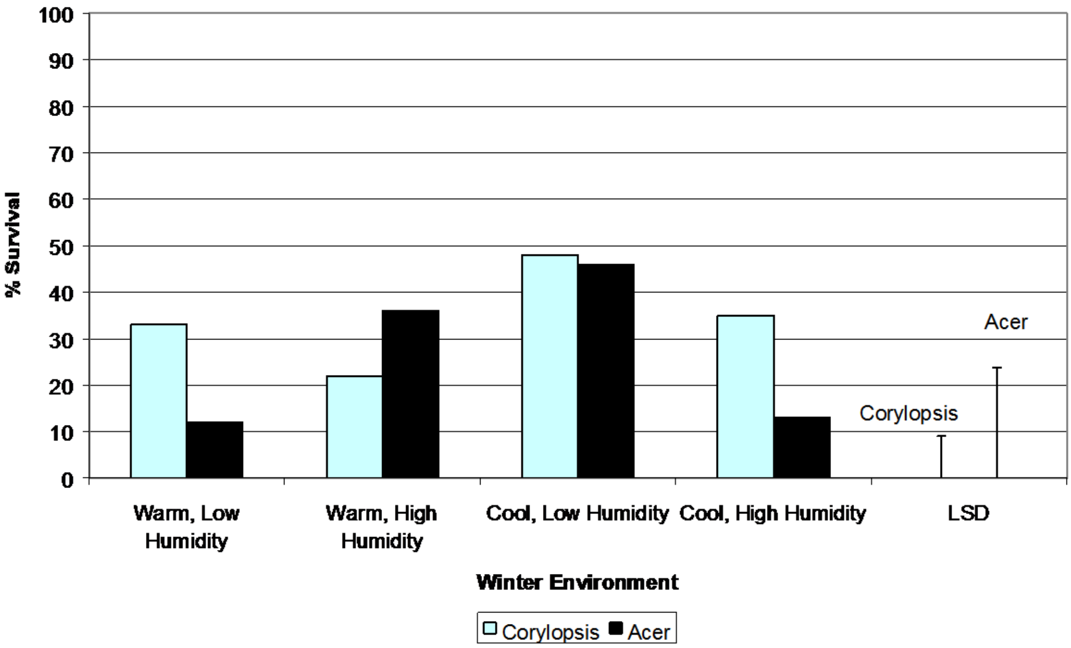
Figure 10. *Magnolia* (1999). Winter survival of rooted cuttings as affected by temperature and humidity treatments. Assessments at bud break (March) and after leaf expansion (May).



Corylopsis: As with previous results**, survival rates of *Corylopsis* in year 3 were relatively poor compared to other species** (Figure 11). Temperature and humidity both significantly influenced cutting survival. **Placement in the warm, high humidity environment aggrevated losses** (22 % survival) compared to the cool, low humidity environment (48%) with survival being intermediate in the cool, high humidity (35%) and warm, low humidity (33%) treatments.

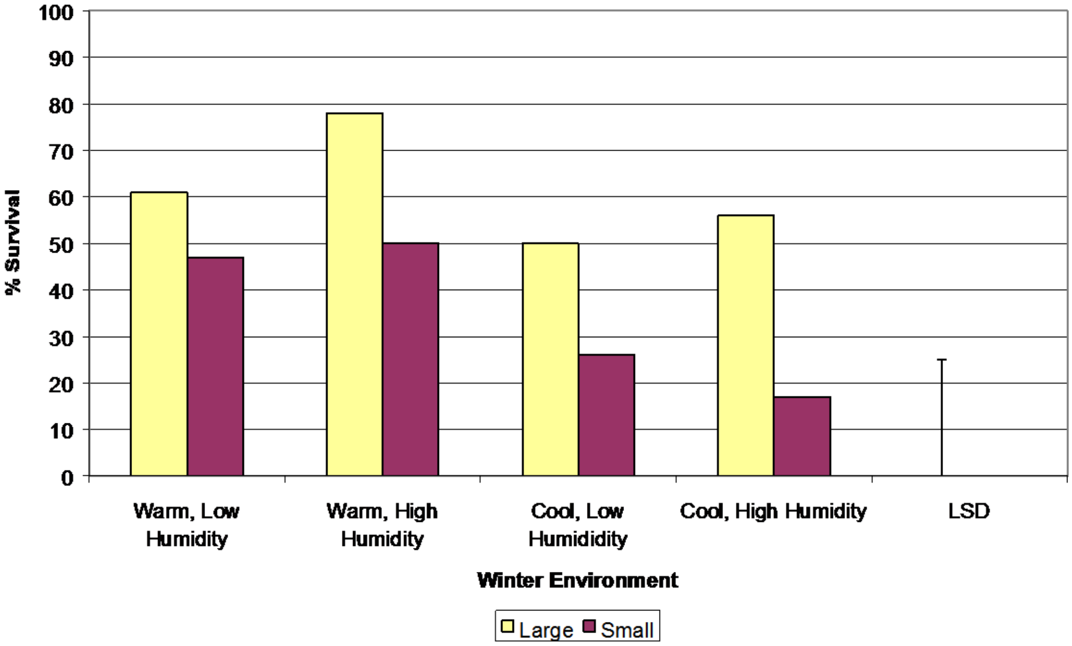
Acer: Greatest survival in *Acer* was also recorded in the cool, low humidity treatment (Figure 11). There were significant interactions (P=0.003) between the effects of temperature and humidity, however, and **cuttings placed in the cool, high humidity and the warm, low humidity had particularly low survival rates.**

Figure 11. *Corylopsis* and *Acer* cv. Bloodgood (1999). Winter survival of rooted cuttings as affected by temperature and humidity treatments



Rhododendron: Cutting size and temperature were highly significant in determining survival, **but unlike *Corylopsis* and *Acer*, high temperature promoted survival in this species** (Figure 12). This may relate to the cuttings ability to re-establish photosynthesis and generate new carbohydrates, as cuttings in the warm environments tended to break bud earlier than in those in cool environments. In particular, **losses were highest in small cuttings placed under cool conditions where bud break was delayed**. This implies that an extended dormant period in this species, even under cool conditions, may exhaust a cuttings carbohydrate reserves, and that small cuttings in particular have limited sugars available to maintain respiration throughout the winter and then to provide energy for new shoot and root development in the spring. Interestingly, and in contrast to results from year 1, varying the humidity of the winter environment had no significant effect on survival.

Figure 12. *Rhododendron* (1999). Winter survival of rooted cuttings as affected by temperature and humidity treatments.



Evaluation of Frost Protection Materials

Typical temperature profiles within a polytunnel during a frost cycle are shown in Figure 13. The lowest recorded air temperature in the tunnel was –3.8°C (air temperature outside was –5.1°C, not shown). **Placing fleece or bubble polythene over liners outside maintained temperatures approximately 3 to 4°C higher than non-protected plants,** and the lowest temperature under fabric was 1°C. During these relatively short durations of frost, there was no difference in insulating properties between the fleece and polythene products. It is interesting to note, however, that during periods of anticyclone weather patterns (little cloud cover), that temperatures could rise quite considerably under the bubble polythene during mid-day (Figure 14).

Figure 13. The influence of frost protection products on temperatures inside a polytunnel during a frost cycle.

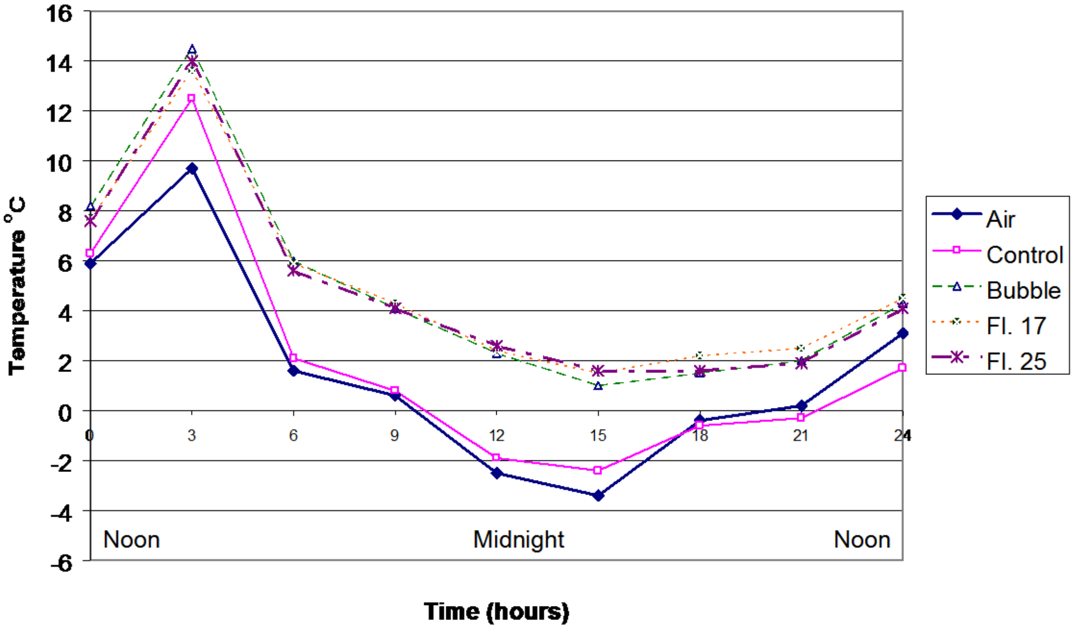
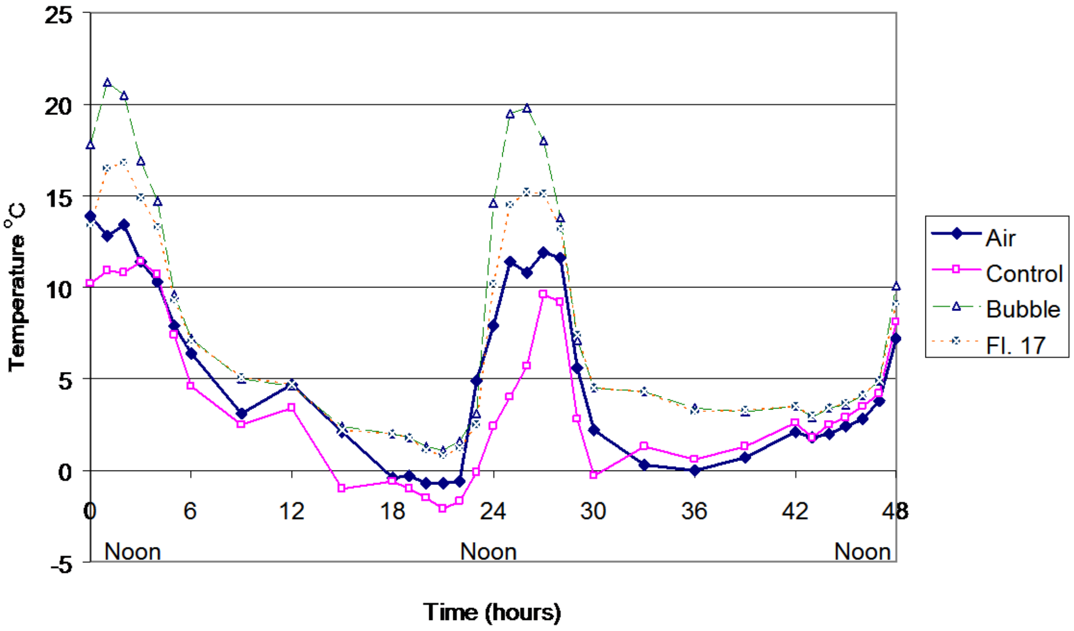


Figure 14. Temperature variation under different frost protection products placed outside, over a 48-hour period.



Key to Figures 13 and 14

Air = temperature 3m above a crop
Control = temperature at crop canopy level
Bubble = temperature at crop canopy level under bubble polythene film
Fl. 17 = temperature at crop canopy level under fleece fabric (17 g m^{-2})
Fl. 25 = temperature at crop canopy level under fleece fabric (25 g m^{-2})

CONCLUSIONS

Effects due to Species

The results from this project suggest that cuttings of woody plant species appear to fall into **'easy'** and **'difficult'** categories in terms of their winter survival ability. Some species such as ***Acer* and *Corylopsis* often failed even after good rooting success**, whereas, species such as ***Magnolia* and *Viburnum* were more robust** and, in general corresponded with **high survival rates**. Even in these 'easy' species, however, **poor management or placement in sub-optimal environments could cause foliar injury and reduced vigour**. In the worst scenarios, such as propagation late in the season combined with delayed sticking after collection, winter survival could be reduced by up to 40 % even in the 'easy' *Magnolia*.

Propagation Factors

The most striking result from the project was the extent to which management prior to and during propagation influenced the long-term survival of cuttings. The most interesting component of this was that some of these factors had little or **no influence over rooting *per se*, but still strongly influenced viability and establishment**. With the possible exception of direct frost injury (which most nurserymen adequately protect against), **greatest winter failure appears to relate to a number of key factors associated with the propagation stage.**

In the results presented here, **highest failure rates** could be often traced back to the **inappropriate selection of cutting type or size**, the **management of stock plants (particularly their pruning regime)**, and the **environment cuttings were placed in to root**. This re-enforces the need for nurserymen to ensure that maximum effort is applied early on in the production process to ensure success at subsequent stages. Cuttings which have intrinsic weaknesses from the start (some of which may not be visually apparent), or are mismanaged early-on, will be more likely to succumb to subsequent environmental stresses.

Success, both in terms of rooting and survival, was often linked with certain trends at the propagation stage. **With the exception of *Acer*, greater rooting and survival was generally associated with harder winter pruning of stock plants, and greater rates of shoot growth.** Many nurserymen as well as other researchers (e.g. Spellerberg, 1986), recognise that for difficult subjects forcing growth on mother plants and taking cuttings early, is beneficial in terms of rooting and subsequent development of the cuttings. What may be less well recognised is the importance of **cutting position or morphology**. In *Rhododendron* cuttings that were removed from the base of stock plants and rooted under mist failed to survive the winter. By comparison, cuttings removed from the top of stock plants and rooted in the same environment had significantly greater survival.

For subjects which are **naturally thin-stemmed**, i.e. *Acer* and *Corylopsis*, **survival could be improved by selecting the largest or the thickest cuttings available**. In contrast, selecting excessively large cuttings of *Cotinus* or *Magnolia* could reduce rooting and winter survival, especially when these were rooted under the less supportive mist environment.

The influence of **timing of propagation** was clearly seen in *Acer* and *Rhododendron*. In these two species, the **numbers of cuttings that successfully rooted decreased with later harvest dates.** The most dramatic effect of this was with ***Rhododendron*, where an inability to root cuttings during the latter part of the season was the major limiting factor to production of this species**. The reasons for this are not clear, but results are again likely to relate to shoot activity during the season.

In general terms, **placing rooted cuttings under sodium lamps during the autumn to extend the daylength, had little or no effect on survival.** New shoot growth was not evident in any of the species in this treatment, but a delay in leaf abscission was common place.

Environmental Factors during Winter

The environment cuttings were placed in during winter was also an influential factor determining survival, and the use of poor environments often acerbated the effects of previous stress or sub-optimal treatments. Again, results varied between species, but it was evident **for a majority of species that the use of enclosed tunnels during the winter was detrimental compared to placing cuttings in better ventilated tunnels** (or even cold storage for some subjects, e.g. *Ceanothus*).

It was assumed that the disadvantage associated with the enclosed tunnel was due to higher humidity, however, experiments carried out in the third year to focus on this aspect showed **contrasting results for different species**, i.e. *Rhododendron* had relatively high survival rates under a warm, high humidity regime, whereas *Corylopsis* had lowest survival in this treatment. The reasons for this are not clear and the influence of humidity merits further attention. A possible explanation for this variation, however, is that the influence of the aerial environment changes as the cuttings break from dormancy. For example a warm, humid environment may be advantageous once leaf expansion occurs, but detrimental to dormant, leafless cuttings by inducing excessive respiration, or encouraging pathogenic microflora.

In a number of cases, placement of cuttings into a cold store corresponded to increased survival rates and this proved a feasible means to overwinter cuttings. Even the exclusion of light during storage was not detrimental to the evergreen *Ceanothus*. **Cold storage treatment on occasions, however, resulted in relatively poor leaf and shoot quality,** and this may be a possible consequence of the rapid transition from storage to ambient conditions in spring. Therefore, to optimise this treatment some consideration should be given to the most appropriate techniques to rapidly ‘wean’ cuttings from the cold store environment.

Carbohydrate Assessments

Carbohydrate analyses suggested that **survival rates in *Corylopsis* correlated with the reserves of starch available within the cutting**. Treatments or environments which corresponded with reduced starch levels, often resulted in death of the cuttings, or poor shoot growth in spring. In contrast to the thin-stemmed

Corylopsis, starch levels were proportionally greater in *Magnolia* and this may be one reason for the greater winter survival rates associated with the latter species.

Frost Protection Materials

Results with the frost protection fleece and polythene film, indicated that these **products are very effective at maintaining a warm microclimate around a crop**, both outside and when used in a polytunnel. During the short frost episodes that occurred during 1998-99, temperatures were usually 3-4°C higher under such materials than equivalent air temperatures.

Endnote

It is clearly evident that winter failure can be very problematic in some HNS species. These results demonstrate that 'thin-stemmed' subjects, in particular, were susceptible to high failure rates and cutting death could frequently exceed 50 % in subjects such as *Acer* and *Corylopsis*. Obviously, this has clear implications in the scheduling of production of such plants and nurserymen should aim to identify superior cutting types (e.g. larger or thicker), in an attempt to maximise survival. The role of carbohydrates is implicated in determining winter survival, although research at a much more strategic level is required to investigate more precisely their action in cuttings of woody species, e.g. how quickly is starch metabolised under stressful conditions. Likewise, employing cost-effective systems that maximise starch accumulation prior to winter may merit further investigation in an attempt to offset subsequent depletion.

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APPENDIX A

Table Ia. Size range of cuttings selected from different years and categories

Species	Year	Cutting type	**Mean size range**	
			Length (cm)	Diameter (mm)
Acer cv. Aureum	1997	/	9 -10	1.3 -1.4
Acer cv. Bloodgood	1997	/	8 -10	1.2 -1.4
	1998	Large	15 - 20	1.6 - 1.8
		Small	7 - 8	1.2 - 1.4
	1999	Large / Thick	15 - 20	2.8 - 3.0
		Large / Thin	15 - 17	1.5 -1.8
		Small / Thick	10 - 12	1.5 -1.8
		Small / Thin	7 - 11	1.3 -1.4
Ceanothus	1997		8 - 9	2.2 - 2.5
	1998		10 -12	2.2 - 2.5
Cotinus	1997	Large - Hard pruned hedge	12 -14	2.8 - 3.0
		Large - Light pruned hedge	9 -11	2.4 - 2.6
		Small - Hard pruned hedge	10 -12	2.1 - 2.3
		Small - Light pruned hedge	6 - 8	2.0 - 2.2
Corylopsis	1997	Thick	/	1.2 -1.4
		Thin	/	0.9 -1.1
	1998	Large	14 -15	1 - 1.2
		Small	9 -10	0.8-11
	1999	Prop 1 Large	15 -16	1.2-1.3
		Prop 1 Small	11-12	0.9-1.0
		Prop 2 Large	15 -16	1.3-1.4
		Prop 2 Small	10 - 12	0.9-1.0

Table Ib. Size range of cuttings selected from different years and categories

Species	Year	Cutting type	Mean size range Length (cm)	 Diameter (mm)
Magnolia	1997	Hard pruned hedge	11 -12	2.9
		Light pruned hedge	9 -11	2.6-2.8
	1998	Large	9 -16	2.7 - 3.0
		Small	4 - 9	2.5 - 2.7
	1999	Large	12 -16	3.2-3.7
		Small	9 -10	3.1-3.2
Rhododendron	1997	Top	11 - 13	2.1 -2.4
		Base	6 - 8	1.7 - 2.1
	1998	Large	7 - 11	2.1 - 2.7
		Small	3 - 5	1.7 - 2.2
	1999	Large	11 - 12	2.3 - 2.5
		Small	6 - 8	2.1 –2 .3
Viburnum	1997		10 - 12	2.8 - 4.2
			6 - 8	2.6 - 3.0

Table II. Pruning regimes for stock plants of different species

Species		Light Pruning	Hard pruning
Acer cv. Bloodgood		Apical tip and small section of stem (5 cm) removed.	Strong growing shoots reduced by two-thirds.
Acer cv. Aureum		Apical tip and small section of stem (5 cm) removed.	Not applicable.
Corylopsis		Apical bud only removed.	Main and side laterals reduced by two-thirds, leaving plants 20-30 cm high.
Rhododendron	*	Flower buds only removed. Small basal shoots referred to as 'Base'.	Flower buds only removed. Large apical shoots referred to as 'Top'.
Magnolia		Only flower buds removed.	Previous season's wood reduced by two-thirds, leaving 2-3 nodes.
Cotinus		10-20 cm of previous season's wood removed.	Previous season's wood cut back severely, leaving 10-15 cm 'spurs' with basal buds.
Viburnum		5-10 cm of previous season's wood removed.	Pruned back into 2 year old wood leaving at least one pair of viable buds.
Ceanothus	**	Necrotic shoot tips removed, reducing previous season's growth by 10 cm.	Not applicable, due to the young age of stockplants.

NB.

* In *Rhododendron* 'Coccineum Speciosum', viable basal buds were difficult to identify when plants were dormant and there were large sections of bare stem below the apical buds. Therefore, to avoid killing the stockplant, no pruning was implemented but subsequent developing shoots were divided into those from the basal region (small, with little vigour - Base) and larger active cuttings from the top of the plant (Top). Interestingly, one specimen was pruned severely and this initiated strong growth from deeply dormant buds at the base.

** To allow the young plants to establish fully, stock hedges of *Ceanothus* were not hard pruned. Development and establishment had been slow in the previous year due to limited rainfall, and shortages of irrigation water.

Table III. Dates that cuttings were propagated and placed under the long day (LD) photoperiod.

Species	Propagation time	Date	
		Propagation	Start of LD regime
Acer cv. Bloodgood	1	3 April	26 Aug
	2	12 June	28 Sept
Corylopsis	1	12 May	26 Aug
	2	12 June	26 Aug
	3	24 Aug	6 Nov
Rhododendron	1	11 May	26 Aug
	2	1 July	5 Oct
	3	25 August	9 Nov
Magnolia	1	3 June	26 Aug
	2	24 Aug	9 Nov