Strategies for liner production designed to achieve high quality container plants

R.S. Harrison-Murray, B.H. Howard and L.J. Knight

Final Report on HDC Project HNS 55

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Project title:	**Strategies for liner production designed to achieve high quality container plants**
Report:	**Final (January 1998)**
Previous reports	**1st Annual (December 1994)** **2nd Annual (May 1996)**
Project no:	**HNS 55**
Project leaders:	**Dr. R.S. Harrison-Murray** **Dr. B.H. Howard**
Key staff:	**Linda Knight, Research assistant**
Location:	**Horticulture Research International - East Malling, East Malling, West Malling, Kent, ME19 6BJ**
Project co-ordinators:	**Mr. Brian Humphrey** **Mr. Richard Oliver**
Date project commenced:	**1st October, 1993**
Date completed:	**30th September, 1996**
Key words:	**Rooting, cutting, environment, liner, 'environmental fingerprint', *Acer, Aubrieta, Berberis, Ceanothus, Convolvulus, Cornus, Corylus, Cotinus, Cryptomeria, Daphne, Elaeagnus, Forsythia, Fremontodendron, Garrya, Pieris, Potentilla, Rhododendron, Weigela***

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PRACTICAL SECTION FOR GROWERS

Background and objectives

Under increasingly competitive market conditions, nurseries need to plan their production to meet market-led targets whilst at the same time minimising costs. This requires information on the potential performance of their plants under different conditions so that production methods can be optimised. This project explored means of generating this information as efficiently as possible.

The main focus was on the propagation stage and the variation in environmental requirements amongst a wide range of plants, and in relation to the type of cutting prepared. It made use of the unique 'gradient controlled propagation environment' (G-CPE) facility at East Malling, a matrix of 54 different combinations of light and wetting, to generate 'environmental fingerprints' for 24 different plants. Light and moisture are the two environmental factors that require most attention in optimising the environment for rooting leafy cuttings. They interact strongly because light, whilst essential for photosynthesis, stimulates water loss and thereby increases the danger that cuttings become water stressed. The G-CPE provided the ideal means of evaluating the importance of this interaction and identifying optimal combinations of the two factors.

The choice of plants was determined by suggestions from the industry and by the need to include cuttings varying in shape, size and ease of rooting. The aim was to identify groups of plants with similar environmental needs, and seek visible features, such as the size or hairiness of leaves, that could be used to predict the needs of other plants.

In parallel with this 'strategic' approach, work on a few plants examined other aspects of the production process. These were three clonally propagated cultivars of *Aubrieta*, two cultivars of *Fremontodendron*, and *Corylus maxima* 'Purpurea'.

Summary of Results

The G-CPE facility was used successfully to describe the environmental responses of 24 different cultivars, from 18 different genera in the form of 'environmental fingerprints'. The results revealed very wide differences in response to environment, especially to wetting. At one extreme were plants such as *Cryptomeria japonica* 'Elegans Compacta' which only rooted where there was little or no wetting. At the other extreme were those like *Garrya elliptica* 'James Roof' which required very heavy wetting. Between these extremes were many, like *Cotinus coggygria* 'Royal Purple', which rooted best when heavily wetted at high light but could tolerate less moisture at lower light levels. Most subjects failed to root if the light level was very low.

The following **response-types** were identified amongst the subjects studied:

- High moisture requirement:
  Acer cappadocicum 'Rubrum' (page 81)
  Corylus maxima 'Purpurea' apical cuttings (page 59)

Corylus maxima 'Purpurea' non-trimmed proximal cuttings (page 64)
Cotinus coggygria 'Royal Purple' (page 85)
Elaeagnus pungens 'Maculata' (page 100)
Garrya elliptica 'James Roof' (page 105)
Pieris 'Flaming Silver' (page 139)
Rhododendron 'Gold Flimmer' (page 108)
Rhododendron 'President Roosevelt' (page 112)

- Moderate moisture requirement:
  Acer palmatum 'Aureum' (page 115)
  Aubrieta 'Red Carpet' (page 28)
  Aubrieta 'Greencourt Purple' (page 28)
  Cornus alba 'Sibirica' (page 143)
  Corylus maxima 'Purpurea' leaf-trimmed proximal cuttings (page 64)
  Ceanothus 'Autumnal Blue' (page 130)

- Low moisture requirement:
  Cryptomeria japonica 'Elegans Compacta' (page 89)
  Convolvulus cneorum (page 134)
  Daphne x *burkwoodii* 'Somerset' (page 98)
  Potentilla fruticosa 'Tangerine' (page 147)

- High light requirement
  Berberis x *stenophylla* (page 120)
  Fremontodendron 'California Glory' (page 44)

- Tolerant of almost all conditions:
  Forsythia x *intermedia* 'Lynwood' (page 145)
  Pieris japonica 'Little Heath' (page 137)
  Weigela florida 'Variegata' (page 151)

The main **general conclusions** were as follows:

- 'Environmental fingerprints' provide a unique overview of the needs of a particular plant that can guide improvement of conventional facilities.
- Most cuttings fail if the light level, averaged over daylight hours, is less than about 2150 lux (40 μmol m^{-2} s^{-1} PPFD; equivalent to what cuttings would receive on average during cloudy weather, in summer, if shaded to 10% of outside light).
- Most subjects show no further increase in rooting percentage of light levels above 3250 lux (60 μmol m^{-2} s^{-1} PPFD).
- A few subjects have higher light requirements - up to at least 8100 lux (150 μmol m^{-2} s^{-1} PPFD). These tend to be those with a small amount of leaf area relative to the thickness of the stem (e.g. *Berberis* x *stenophylla*).
- As light levels increase, more moisture (i.e. wetting and/or elevated humidity) is required to avoid reduction of rooting due to water stress.
- At a given light level, subjects vary greatly in their moisture requirement. The larger the leaf area per cutting the greater the moisture requirement tends to be.

- Rotting is not a reliable symptom of over-wetting : rotting can occur when there is too little moisture, and almost always occurs when there is not enough light.
- Many 'difficult-to-root' subjects (e.g. *Cotinus coggygria* 'Royal Purple') have high rooting potential but a narrow range of environments in which that potential is expressed.
- 'Easy-to-root' subjects are those which tolerate an unusually wide range of environments, often including very low light.
- Some subjects failed to achieve 100% rooting percentage in any environment (e.g. *Rhododendron* 'President Roosevelt'), suggesting that some cuttings did not have the potential to root or that another factor was sub-optimal (e.g. temperature or amount of auxin applied).
- The rooting environment can affect subsequent growth and thus the quality of liners and container plants, especially in slower growing plants which do not require much pruning to create a desirable shape.

Action points for growers

General

- To improve production of a subject not included in this study, try to apply the general conclusions listed above to optimise the rooting environment and thus provide a good foundation for all subsequent stages of production.
- To reduce production times, try starting with larger cuttings.
- In conventional facilities, light is difficult to control within tight limits. It is therefore wise to aim for slightly higher light levels than the minimum acceptable, and to provide correspondingly more moisture to avoid water stress. Fog / mist controllers must increase output as light level increases if water stress is to be minimised.
- For plants with a high moisture requirement (i.e. members of the first two response groups listed on page 6 - 7), leaf wetting alone will usually not be sufficient, high humidity will also be required.
- The combination of high humidity and leaf wetting can be achieved with fog or by enclosing mist under a polythene 'tent'. Minimising ventilation to retain humidity leads to high temperatures during sunny weather so that appropriate shade is essential.

Aubrieta (further details, page 28)

- Despite being a plant which can grow in dry conditions, cuttings rooted best under moderately heavy mist. Treatment with auxin (e.g. IBA) is unnecessary.
- By attention to nutrition, stockplants can provide many crops per season.
- Cuttings can be propagated whenever suitable material is available

Fremontodendron (further details, page 44)

- Avoid excessive shade; during summer 25% of available light should be satisfactory.
- Ensure the rooting medium is well drained and avoid overwetting.
- Grow stockplants in an unheated polytunnel and make cutting from every node.
- Treatment with auxin (e.g. IBA) is unnecessary.

- Removal of felt like hairs from the stem is unnecessary.

Corylus maxima 'Purpurea' (further details, page 59)
- Almost 100% rooting of apical cuttings is possible if leaves are kept moist, humidity is high. Wet fog or enclosed mist are ideal, with about 20% of available light.
- Given careful progressive weaning, rooted cuttings produce high quality liners, capable of growing away strongly and branching well without pruning.
- Non-apical cuttings can also be used and tolerate slightly drier conditions.

Pieris 'Flaming Silver' (further details, page 139)
- Roots best from small (4 cm long) cuttings under wet conditions.

Acer cappadocicum 'Rubrum' (further details, page 81)
- Nearly 100% of soft apical cuttings root in a wet and humid environment.
- It may not be necessary to cut to a node (preliminary result)

Cotinus coggygria 'Royal Purple' (further details, page 85)
- 100% rooting achievable in a very wet environment at moderate to high light.
- Make apical cuttings from elongating shoots. When growth stops rooting ability is lost rapidly.

Cryptomeria japonica 'Elegans compacta' (further details, page 89)
- Avoid environments that suppress transpiration too much. Benefits of ideal rooting environment carry over into subsequent growth.
- Large cuttings with small branches yield high quality plants quickly.

Elaeagnus pungens 'Maculata' (further details, page 100)
- Needs high humidity and heavy wetting. IBA promotes rapid rooting.
- Large cuttings root well and result in larger final plants.

Garrya elliptica 'James Roof' (further details, page 105)
- Given high humidity and generous wetting nearly 100% of soft apical cuttings root. Fan-distributed fog is probably ideal, with 20% of available light.

Practical and financial benefits from study

The work has clearly demonstrated the potential to optimise production of difficult subjects by a systematic scientific study of major constraints on the production process, starting with the propagation phase. It has identified light and moisture as two interacting components of the rooting environment critical to success with difficult plants and proved the G-CPE approach for rapidly characterising the response to these factors with the minimum of plant material in the form of an 'environmental fingerprint'. The benefits of optimising the propagation stage are not confined to maximising the rooting percentage but form the foundation for achieving high quality plants as quickly as possible and with the minimum of losses, as shown by effects of propagation environment and type of cutting still evident more than a year after propagation. This approach also offers the potential to bring new plants to the market which would command a scarcity premium because of the difficulty of propagation. The potential financial benefit therefore goes far beyond the saving of material and labour in cuttings which fail to root and is impossible to quantify.

In addition to providing the HDC with information that growers can apply directly to the production of the plants featured in the study, it has established principles to help growers identify the needs of other subjects and adjust conditions in existing facilities to suit. It has also established a method for optimising environmental conditions that could be applied in future to other subjects where growers have identified a market demand for a plant that they are unable to meet due to technical difficulties in production. This is likely to be particularly relevant to smaller companies developing niche markets for high value plants. This benefit will be enhanced if commercial production of the evapo-sensor is secured. The evapo-sensor is an instrument that was developed at HRI East Malling for monitoring and control of the evaporative demand. It was further tested in this project and it is clear that it would be of great value to all growers seeking to optimise propagation and weaning environments.

SCIENCE SECTION

Introduction

Under increasingly competitive market conditions, nurseries need to plan their production to meet market-led targets whilst at the same time minimising costs. The targets relate not just to quantity but also to quality and timing. Such planning demands the best possible information on the behaviour of the plants being used so that production methods can be optimised. This project was aimed at generating this sort of information. The emphasis was on the liner stage, but since quality of a liner must ultimately be judged in terms of its ability to develop into a high quality finished plant, the liner stage cannot be considered in isolation.

The main focus was on the propagation stage and the variation in environmental requirements for optimal rooting between species and cultivars, and also within a cultivar in relation to the time of taking cuttings and the type of cutting prepared. This aspect of the work exploited unique controlled propagation environment (CPE) facilities at East Malling (Howard *et al.*, 1995). In particular, the gradient-CPE, a matrix of 54 different combinations of light and wetting, was used to generate 'environmental fingerprints', detailed pictures of environmental responses, for over 20 different plants.

In addition, some liners were grown-on in containers for one year to measure the extent to which sub-optimal conditions during rooting can result in poor quality of the finished plant. The aim of these studies was to establish principles which would be of value to the majority of nurseries.

In parallel with this strategic approach, work on a smaller number of plants, identified by the industry as particularly difficult to produce **efficiently**, examined all aspects of the production process including such factors as management of stock plants for maximum cutting production. These provide examples of the scope for practical progress achievable by a systematic analysis of the factors which limit production efficiency, starting with identification of a suitable propagation environment.

In the 'Results and Discussion' section of the report, these three components of the work are brought together plant by plant, so that the reader can readily find all the information obtained on those plants that are of interest. In the 'Overview and Conclusions' section (page 153), the results of all the environmental fingerprinting are presented in summary form, as a basis for grouping plants with similar responses and establishing common principles. In particular, a number of morphological characteristics are compared for their usefulness in predicting the optimum environment for subjects which have not yet been tested.

Environmental fingerprints

It is well-established that the rooting process is highly sensitive to environmental conditions and variation in environmental conditions probably explains much of the inconsistency in rooting of the more difficult subjects, between nurseries and between years. Getting the environment right is made difficult by the number of component factors (light, humidity, temperature, wetting, drainage, etc.) and the fact that their effects interact. A previous HDC project highlighted the fact that the combination of extremely high humidity with generous leaf wetting was particularly effective in reducing water loss from cuttings, and that this allowed a beneficial reduction in shading, thus demonstrating one particularly important interaction (Harrison-Murray *et al.*, 1993). However, this light x moisture interaction is not one that can be studied readily using conventional facilities, in which the ambient light level is constantly varying. Fortunately, new facilities provided by MAFF at East Malling, designed primarily with detailed physiological studies in mind, have been made available for the present project, allowing the optimum combination of light and moisture to be determined for a range of plants. In these new facilities, cuttings are rooted under artificial light in Controlled Propagation Environment (CPE) chambers in which conditions are tightly controlled and can be reproduced exactly from one month to the next.

Before describing these studies it may be useful to explain the two major effects of light on cuttings, and the conflicting requirements that these can create. Firstly, light drives photosynthesis, the process by which plants create sugars and other substances essential for survival, rooting, and growth. Secondly, it stimulates transpiration which can lead to water stress and thus prevent rooting. Since one process helps rooting while the other hinders it, it is clear that the ideal light level is the one which achieves the best compromise between these opposing requirements. Further, other factors that influence transpiration will tend to influence the optimum light level. Principle amongst these are the aerial humidity and leaf wetting.

The reason that light stimulates transpiration is that most of the light energy absorbed by leaves is used not in photosynthesis but instead in warming the leaf, which increases the rate at which water evaporates from it.

The particular CPE chamber used in this project provided a wide range of combinations of light and wetting to provide a picture of how particular types of cutting respond to these crucially important factors. The results are conveniently summarised in 3D graphs for which the term 'environmental fingerprints' has been coined.

Choice of subjects for study

The plants which received the more detailed practical appraisal were clonally propagated varieties of *Aubrieta* and *Fremontodendron*. Clonal *Aubrieta* affords the opportunity to produce forms with particularly large and strongly coloured flowers, which as well as being important in their own right, have the added role of stimulating the sale of *Aubrieta* generally, the majority of which is still raised from seed. There is considerable interest in Europe to find a cost-effective method to replace cumbersome procedures, such as the Dutch practice of growing mother plants in sandy soil to encourage a degree of pre-rooting before taking large cuttings. This is both inefficient with respect to time and use of stock material. In neither the Netherlands nor Denmark is there much attention given to the environment in which rooting of cuttings is attempted.

The 'evergreen' wall shrub *Fremontodendron californicum* is a niche plant which many nurserymen find difficult-to-propagate. Many nurserymen identify stem-rotting as a major problem and some remove the layer of down-like hairs from the stem in an attempt to reduce water accumulation on and in the stem, although Macdonald (1986) describes the hairs as effective for retaining auxin applied as powder to the stems.

The purple leaved hazel, *Corylus maxima* 'Purpurea', is difficult-to-propagate by cuttings and is currently produced mainly from imported rooted layers. It was studied in some detail, partly to examine the practical feasibility of production from leafy cuttings and partly as a suitably large-leaved subject for studies of the influence of leaf trimming on the environmental requirements of cuttings.

Other subjects were chosen so as to provide environmental fingerprints of a wide range of shapes, sizes, and types of cutting using the G-CPE facility. The aim of these experiments was to identify groups of plants with similar environmental needs, and seek visible features, such as the size or hairiness of leaves, that could be used to predict the needs of other plants. The range of plants included broad leaved deciduous shrubs known to be difficult-to-root, such as *Garrya elliptica* 'James Roof', others known to be very easy such as *Weigela florida* 'Variegata', as well as evergreens such as *Elaeagnus pungens* 'Maculata', a single conifer, *Cryptomeria japonica* 'Elegans Compacta', and a grey-leaved plant, *Convolvulus cneorum*. A complete list is provided in the following section.

Materials and Methods

This section deals with materials and methods common to many experiments, and particularly the work in controlled propagation environments. Materials and methods specific to individual subjects or experiments are described with the relevant results.

The gradient CPE (G-CPE)

The large range of conditions required to identify optimal combinations of light and moisture were created within one controlled propagation environment (CPE) chamber (Figure 1 and 2) by setting up steep gradients of light and wetting at right angles to each other (Figure 3). This is referred to as the gradient CPE (G-CPE). How these conditions relate to a normal propagation unit is considered in the next sub-section. The light came from a bank of high pressure sodium lamps (Type SON-T plus, 400 W, in Philips SGR 140 luminaires) which were on for 12 hours per day, from 09.00 to 21.00 h, arranged in a line above one side of the chamber. Carefully positioned reflective curtains helped concentrate the light on that side so as to achieve about a 10-fold variation in light level across the 2 m wide chamber. Along the 10 m length of the chamber, a wetting gradient was achieved by injecting fog at one end. Two pneumatic fog nozzles (Sonicore type 052 from Jeff Donovan Ultrasonics, 85 Riverside Park, Otley) were run at an air pressure of 65-70 p.s.i. and a combined water flow rate of 14 litre h^{-1}. A timer switched the nozzle on for 20 s per 50 s during the photoperiod and for 30 s per 900 s during the dark period.

The chamber itself consisted of a clear polyethylene tent, 2.2 m high to a central ridge, the slope of the roof being enough to minimise drips which would otherwise disturb the wetting gradient. The polythene was supported from tensioned nylon monofil within a galvanised steel framework, which also supported the lamps above the chamber. Access was provided from one end through overlapping polythene flaps; these were sealed with clips so that the humidity was maintained above 95% throughout. A 10 cm layer of fine sand over the concrete floor provided drainage for the heavily wetted area and capillary water supply to cuttings at the dry end.

For practical purposes the continuous gradients of light and wetting were considered to be subdivided into discrete levels, designated L1 (highest) to L10 (lowest) for light and W1 (wettest) to W6 (driest) for wetting (Figure 2). No cuttings could be placed in L7 as this zone provided an access path. Light zones were 18 cm wide, whereas wetting zones were 100 cm wide with additional access space between each zone. The wetting zones were thus sufficiently wide to allow up to about six subjects to be tested together, arranged as parallel rows within each wetting zone.

The chamber was constructed within a large controlled temperature room (11.9 x 6.6 x 4.0 m high) equipped with enough cooling capacity to remove the heat from about 25 lamps. Air from the coolers was distributed by a textile 'sock' running the length of the room, resulting in an effective distribution without strong draughts (Figure 1). Temperature was controlled to 20 °C ± 2°C. Within the chamber the air was relatively still, with only a gentle stirring action provided by the air and fog emerging from the nozzles. Consequently, heat exchange between the air around the cuttings and that outside the chamber was rather slow. As a result the temperature around the cuttings rose to an average of 23 °C when the lights were on, falling back to 20 °C during the dark period. There were also temperature differences of up to 2 °C between the lowest and the highest light level.

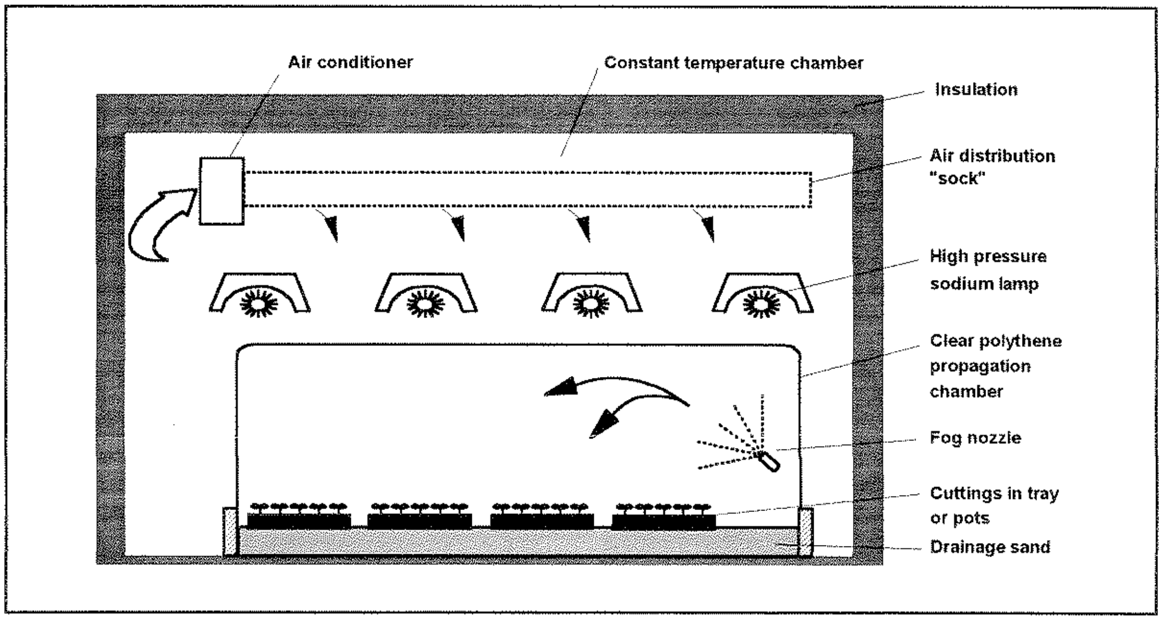


Figure 1. Diagram illustrating the principle of the controlled propagation environments (CPE) facilities.

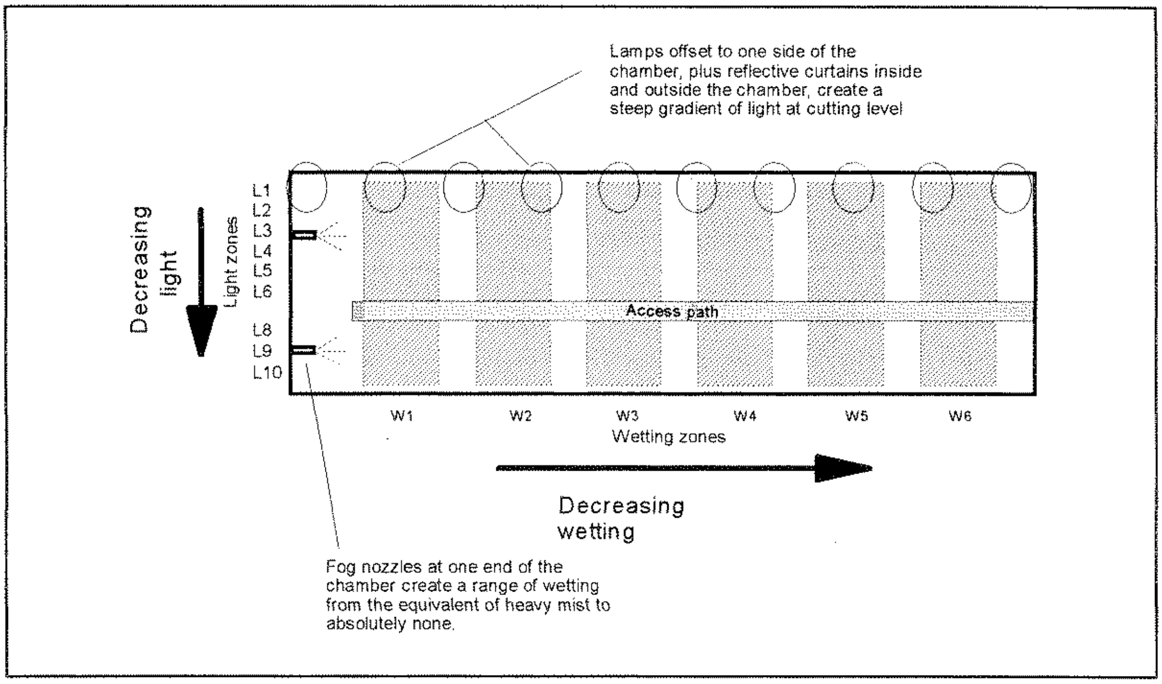


Figure 2. Plan view of the gradient CPE chamber. Dimensions are 10 x 2 m.

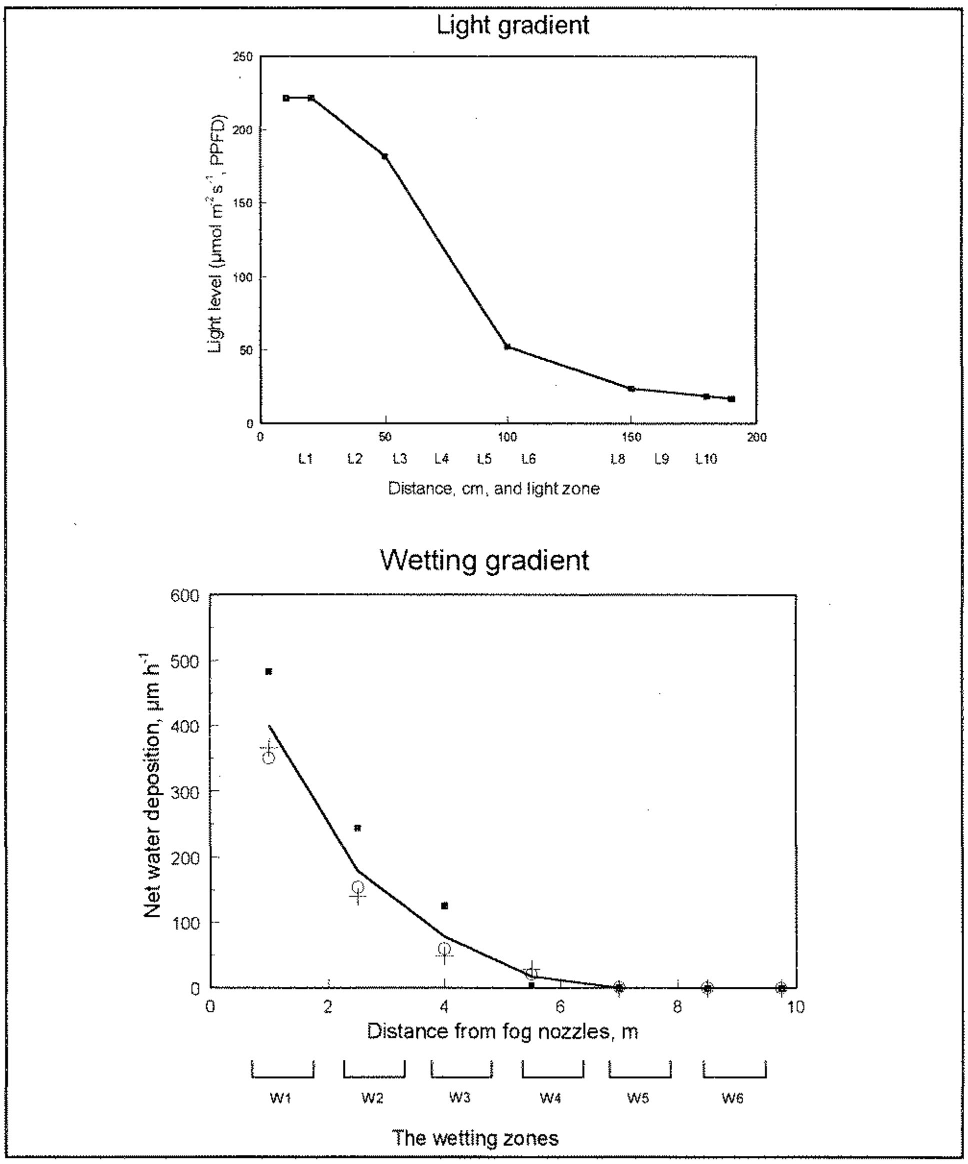


Figure 3. Gradients of light and wetting in the gradient CPE chamber. On the wetting graph, the points indicate values obtained at three positions across the gradient.

Relating G-CPE conditions to conventional propagation facilities

The two environmental gradients are illustrated in Figure 3. Wetting was measured by weighing the water which collected in plastic dishes over the course of about an hour. Using transparent dishes, and special stands which held them at about 10 cm above the sand base, minimised absorption of radiation and thus the rate of evaporation from the dishes. The results are expressed as depth of water deposited per hour, measured in µm (1 mm = 1000 µm). Data collected in conventional facilities (Harrison-Murray *et al.*, 1993) showed that water deposition in an open mist system, adjusted to keep leaves wet at all times, averaged about 2000 μm/day, equivalent to 167 μm/hour over a 12 hour day. Wetting at the wet end of the G-CPE gradient (i.e. in W1 zone) was consistently above this value, while that in W2 was equivalent to that of the wet zone of our ventilated wet fog house (Agritech house) during sunny weather.

Light was measured with a quantum sensor, which responded only to the photosynthetically active radiation (PAR, i.e. wavelengths in the range 400-700 nm), placed horizontally, 12 cm above the sand bed, averaged over 100 s to smooth out fluctuations associated with the fog bursts.

Clear overhead sunshine corresponds to about 2000 μmol m^{-2} s^{-1}, which is equivalent to about 400 μmol m^{-2} s^{-1} in a typical propagation house with 80% shade (including the effect of the structure and its cladding) whereas Figure 3 shows that the maximum level in the G-CPE was about 220 μmol m^{-2} s^{-1}. However, such conditions can only arise briefly around noon, and it is probably more appropriate to consider the total amount of light received over the course of the day. On this basis, very fine midsummer weather is equivalent to 12 h/day at a constant 200 μmol m^{-2} s^{-1}, whereas, during very cloudy weather, we have recorded 5-day averages as low as 72 μmol m^{-2} s^{-1}. Away from midsummer, shorter days would reduce these values, but if less shade were used then they would be proportionately higher. A total of 80% shade, achieved with 60% reflective shade cloth, combined with losses from the structure and from condensation, is the standard used on our own mist and fog houses from May to September, and is satisfactory for many subjects.

Conversion to alternative light units

Making certain assumptions about light quality, 1 μmol m^{-2} s^{-1} is approximately equivalent to 0.5 W m^{-2} total radiation, or 80 lux in the G-CPE, and 0.4 W m^{-2} or 54 lux in natural light (Thimijan and Heins, 1983). Taking into account the daylength of 12 hours, it is also possible to equate 60 μmol m^{-2} s^{-1} with 1.0 MJ m^{-2} day^{-1}, which was earlier proposed as a target minimum light level for satisfactory rooting (Loach and Whalley, 1978).

Evaporative demand

The combined effects of light, humidity and wetting determine the evaporative demand of the environment. In relation to plants, this can be expressed as the 'potential transpiration' rate, that is the rate of at which leaves would lose water if their stomata were wide open. This is very difficult to measure directly but can be estimated using an 'evapo-sensor', an invention for which we are currently seeking a manufacturer. As part of the development and testing of the sensor, data were collected from six replicate sensors in 18 of the 54 locations in the G-CPE. The data, along with some results of associated MAFF - funded work into actual transpiration rates from cuttings, is presented in the results section.

Drip irrigation for additional wetting of the medium

After an initial watering in, no further water was applied to the medium or the sand base, in most experiments. The sand remained moist at the dry end of the chamber, due to capillary transfer from the wet end.

For one experiment, additional water was applied to the medium close to individual cuttings so as to separate the effects of leaf wetting and wetting the medium. Drip irrigation nozzles, rated at 1 L h^{-1}, were operated for 1 s every 30 min, delivering about 0.5 cm^3 on each occasion. Taking the output of 2 drippers to be spread over the whole of the surface of the pot (11 x 11 cm), this is equivalent to water deposition of 180 $\mu m\ h^{-1}$. It was necessary to remove as much air as possible from the irrigation tubing, and to put drippers all at the same height, to ensure reasonably even output from all nozzles. Periodic checks ensured all nozzles remained operative.

Rooting 'trays'

Initially 11 x 11 cm square pots were used as miniature 'trays', with usually one cutting in each corner (equivalent to about 140 cuttings/m^2). Later, with an increased emphasis to the performance of the cuttings after rooting, these were replaced by Quick Pot propagation trays (PG Horticulture Ltd) to minimise root disturbance at potting-on. Using QP24 and QP96D trays it was possible to maintain the same spacing and placement of cuttings in relation to the environmental gradients. These trays are 330 x 520 mm but they were cut in two with a bandsaw to create units 165 x 520 mm which provided enough space for a single subject in the G-CPE. The QP24 trays, with a cell volume of 240 cm^3 and a distance between cell centres of 80 mm, were suitable for large cuttings. the QP96D trays, with a cell volume of 75 cm^3 and a distance between cell centres of 42 mm, provided the flexibility to place smaller cuttings at closer spacing.

Measurements

A sample of at least 15 cuttings was set aside when cuttings were prepared to describe their shape and size, particularly the leaf area (i.e. area through which water would be lost by transpiration) and the basal stem diameter (related to the cross sectional area available for uptake of water).

After a rooting period appropriate to the subject, as judged by regular inspection for roots emerging from trays, cuttings were generally removed from the rooting medium so that the extent of rooting, callusing, and basal rotting could be carefully recorded. In some cases, where the emphasis was on the subsequent performance of rooted cuttings, rooting was assessed without disturbance. In these cases, rooting was scored on the basis of whether the cutting seemed firmly anchored or not (scored 1 or 0 respectively) and the amount of root growing out of the base of the tray (scored as 2 or 3).

Methods of analysing and presenting the results

The gradient CPE was primarily intended to study response *trends* rather than to compare specific environments. The large number of environmental combinations that it provided could not have been achieved, within the resources available, in any other way. The disadvantage of the gradient approach is that treatments are inherently non-randomised and there can be no true replication. Most of the results are therefore presented graphically, generally showing such clear trends that they speak for themselves without formal statistical treatment (e.g. Figure 4). Such graphs, referred to as **'environmental fingerprints'**, effectively characterise the cuttings' response to environment.

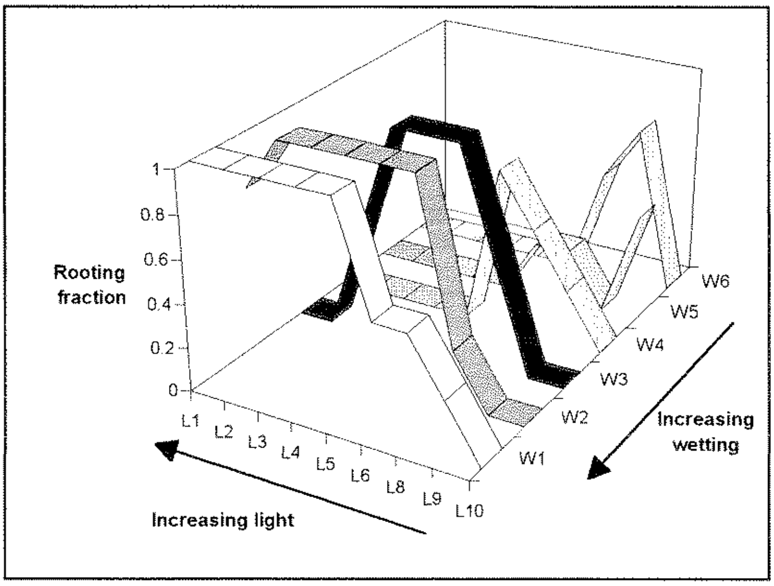


Figure 4. Example of an 'environmental fingerprint', a 3D graph showing variation in rooting in relation to wetting and light in the G-CPE. The lines across the 'ribbons' are plotted points, representing the fraction of cuttings rooted at one of the 54 combinations of wetting and light. The arrangement of the light and wetting axes reflects the arrangement of the gradients within the G-CPE (see Figure 2). Rooting fraction can be converted to percentage by multiplying by 100. (Data are for *Cotinus coggygria* 'Royal Purple')

Three dimensional graphs have been used throughout so as to make it easier to appreciate the way the response to wetting is influenced by light level, i.e. the interactions between these two factors. When examining such graphs it is important to look for the overall trends rather than the detail, because the number of cuttings contributing to each plotted point is small and the random variation correspondingly large. For example, the greater fraction of cuttings which rooted where light level 10 was combined with wetting level 5 (abbreviated to L10 x W5) was 0.5, or 50%, but that is based on two cuttings rooting out of 4. Therefore the difference from the fraction rooting at L9 x W5, which was zero, is very likely to be due to chance effects. On the other hand the decrease in rooting to zero, within wetting level 5, at the higher light levels (i.e. [L1-L5] x W5) is most unlikely to be due to chance, being based on many more cuttings, especially when the similar pattern evident in W4 and W6 is taken into account.

Greater precision could be achieved with greater replication but this was not found necessary in this project. Furthermore, the repeatability of the G-CPE allows one to home in on the range of environments that are relevant and then use more intensive replication of this restricted range in a later experiment.

Simplified presentation of data using larger environmental zones

Where trends were less clear, or where a difference in the environmental response between two types of cutting needed testing, the environmental gradients were divided into nine large zones and variation between plots within these zones was used to generate an 'error' term for analysis of variance. Each of these zones was made up of combinations of two wetting levels and three light levels, i.e. six of the original 54 locations in the G-CPE. For ease of reference these groupings are defined as follows:

Wetting zones:

W1 + W2	=	'Wet'
W3 + W4	=	'Moist'
W5 + W6	=	'Dry'

Light zones:

L1 - L3	=	'Bright'
L4 - L6	=	'Medium'
L8 - L10	=	'Dim'

In some cases the data have also been presented graphically in relation to these zones. For this purpose, bar graphs proved easier to interpret than the ribbon graph used for the full environmental fingerprint. Figure 5 is an example of this alternative, based on the same data as Figure 4.

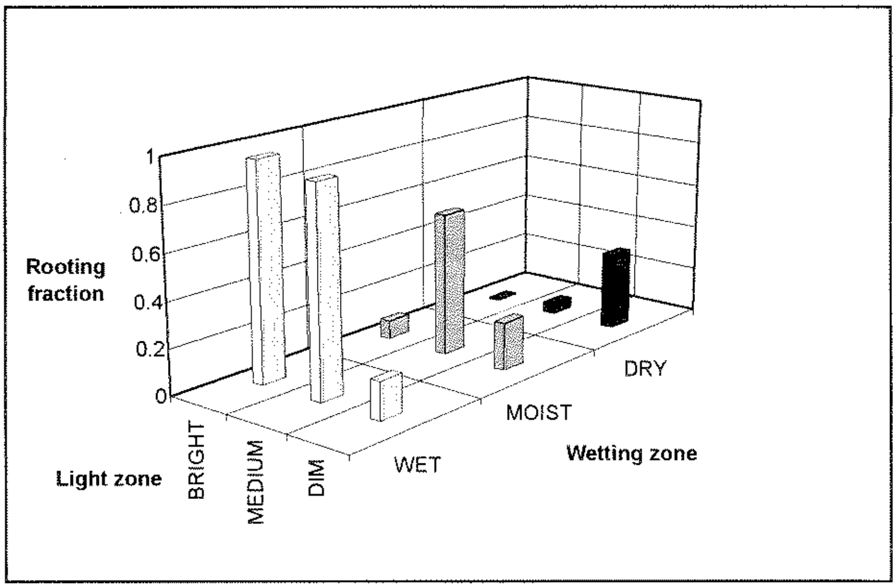


Figure 5. Example of a simplified presentation of data from the G-CPE, with the gradients divided into broader zones, so that each bar represents the average of 6 of the values plotted in the full 'fingerprint'. This figure relates to the same data as shown in Figure 4.

Alternatively, multiple regression techniques were used to fit response surfaces (i.e. 3-dimensional curves) to the data. Such curve fitting helped identify trends and optimum conditions when they were not obvious from the raw data.

Other propagation environments

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. This type of fogger has a high output (about 150 L h^{-1}) 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).

The fogger operated in a 7 x 19.5 m polytunnel, well sealed along edges and end panels to retain humidity, and covered with reflective shade (Ludvig Svenson OLS 60) fixed over the outside of the tunnel, in contact with the polythene. Combined with the absorption of light by the polythene and reflection by condensation and fog, this resulted in about 20% of outside light reaching the cuttings.

Mist

Six independently controllable mist beds were housed in a slightly smaller polytunnel, shaded as described for the fog house. The tunnel itself was well ventilated through adjustable side vents but ventilation of individual beds was modified as required for particular experiments, either by erecting a 1 m high polythene 'curtain' around the bed to reduce the movement of air around the cuttings, or by enclosing the bed under a polythene tent to retain humidity.

Other propagation details

Rooting media and drainage

Except where stated otherwise, the rooting medium used was a 50:50 (v/v) Peat:Bark mixture (medium grade Irish moss peat (Shamrock), and fine grade pine bark (Cambark Horticultural Products)). Except where experiments were concerned only with the rooting stage, or where specifically investigating effects of alternative nutrition, controlled release fertiliser (Ficote 140 16-10-10) was either incorporated, or placed at the base of the rooting cells, at a rate of 1 kg m^{-3}.

All propagation environments were equipped with drained sandbeds, 7.5 cm deep, to provide positive drainage so that rooting media never became waterlogged even where wetting was very heavy. To ensure good contact with the rooting medium, the sand was raked immediately before placing trays or pots in place. To determine the benefit of positive drainage for *Fremontodendron* 'California Glory', a subject recognised as particularly prone to basal rotting, a sheet of polythene laid over the sand under some of the pots was used to simulate propagation on a solid base.

Base temperature

There was no separate heating of the medium in the CPE, but both mist and fog house beds were equipped with electrical base heating, thermostatically controlled to maintain a minimum temperature of 20 °C.

Fungicides used during propagation

All cuttings were initially treated with Benlate (2 g L^{-1}) either by dipping before sticking or by spraying immediately afterwards. Thereafter, further prophylactic fungicide sprays alternating between Rovral and Benlate at 2 g L^{-1} were applied once or twice every week.

Preparation of cuttings

Except where otherwise stated, cuttings were collected from well-established hedges at East Malling, covering them with damp hessian to avoid desiccation. Further preparation was carried out in a cool humid room, cuttings being sprayed with water from time to time if there was any sign of wilting. The material collected and the method of preparation were as uniform as possible, but cuttings were generally also graded on the basis of leaf area and/or stem thickness so that sets of cuttings allocated to each location in the G-CPE matched as closely as possible. When the grades differed substantially cuttings were planted systematically within each plot so that the grades could be identified when rooting was recorded, to determine whether rooting was affected by grade.

All cuttings received a 5 s dip, to a depth of about 10 mm, with 1.25 g l^{-1} (i.e. 1250 ppm) IBA in a 50:50 (v/v) mixture of acetone and water.

DETAILS OF COMPARISONS OF DIFFERENT TYPES OF CUTTINGS, TIME OF PROPAGATION, ETC. ARE PROVIDED IN THE SECTIONS RELATING TO INDIVIDUAL SUBJECTS.

For details of agrochemicals and other products used please refer to the Glossary on page 168.

Species and cultivars studied

Plants included in G-CPE studies:

Acer palmatum 'Aureum'
Acer cappadocicum 'Rubrum'
Aubrieta 'Red Carpet'
Aubrieta 'Greencourt Purple'
Berberis stenophylla
Ceanothus 'Autumnal Blue'
Ceanothus impressus
Ceanothus impressus 'Puget Blue'

Convolvulus cneorum
Cornus alba 'Sibirica'
Corylus maxima 'Purpurea'
Cotinus coggygria 'Royal Purple'
Cryptomeria japonica 'Elegans Compacta'
Daphne x *burkwoodii* 'Somerset'
Elaeagnus pungens 'Maculata'
Forsythia x *intermedia* 'Lynwood'
Fremontodendron 'California Glory'
Garrya elliptica 'James Roof'
Pieris japonica 'Little Heath'
Pieris 'Flaming Silver'
Potentilla fruticosa 'Tangerine'
Rhododendron 'President Roosevelt'
Rhododendron 'Gold Flimmer'
Weigela florida 'Variegata'

<u>Plants studied in relation to practical production problems:</u>

Aubrieta 'Dr Mules'
Aubrieta 'Red Carpet'
Aubrieta 'Greencourt Purple'
Fremontodendron 'California Glory'
Fremontodendron 'Pacific Sunset'

Statistics

The special considerations relevant to analysis of the G-CPE data were discussed above. In all other experiments, where cutting numbers allowed, treatment comparisons were made in randomised and replicated layouts and the data analysed by appropriate methods. These statistical analyses estimate the likelihood that the observed differences amongst treatments occurred by chance. The results are expressed in terms of probabilities, abbreviated to P. For example, $P<0.05$ means that there is a probability of less than 0.05 (or 5%) that the differences amongst the treatments were due to random variation. Smaller values of P, such as $P<0.001$, indicate that it is *less* likely that the results could have occurred by chance and therefore imply that the result is *more* reliable. Probabilities any higher than 5% are generally considered too high for the results to be accepted as reliable, and the observed differences are then said to be not statistically significant (often abbreviated to NS).

Where there are more than two treatments, the least significant difference (LSD) is often given to allow the reader to identify which particular pairs of treatments are significantly different. The LSD is the smallest difference between any two values that is significant at the 5% level of probability.

Results and Discussion

Part 1: Evaporative demand in the G-CPE

The tendency for cuttings to suffer water stress depends strongly on a combination of environmental factors that determine difference in water vapour concentration between the air spaces within the leaves and the free air outside the leaves, the scientific term for which is the 'leaf-to-air vapour pressure difference'. Simpler terms which convey the same idea are the 'potential transpiration rate' or, more generally, the 'evaporative demand' of the environment.

The opportunities for the plant propagator to reduce evaporative demand by raising humidity, reducing light, and wetting the leaves have been considered in both theoretical and practical terms in the report on an earlier project (Harrison-Murray et al., 1993).

Evapo-sensor

That project also involved the development of a novel sensor which produces an electrical signal approximately proportional to the potential transpiration from a typical leaf and which has come to be known as the 'evapo-sensor'. It was therefore of interest to use the evapo-sensor to quantify the effect of the light and wetting gradients of the G-CPE. The results for 18 of the 54 light x wetting combinations is shown in Figure 6.

The evapo-sensor readings for the drier zones (i.e. W4 - W6), show that evaporative demand increased roughly ten-fold from L10 to L1, which is approximately the same as the increase in light level (see Figure 3). Wetting was able to offset this increase completely, indeed in the wettest zones the evapo-sensor reading approached zero. However, zero transpiration from a cutting is unlikely to occur unless the leaf is completely wetted on <u>both</u> sides.

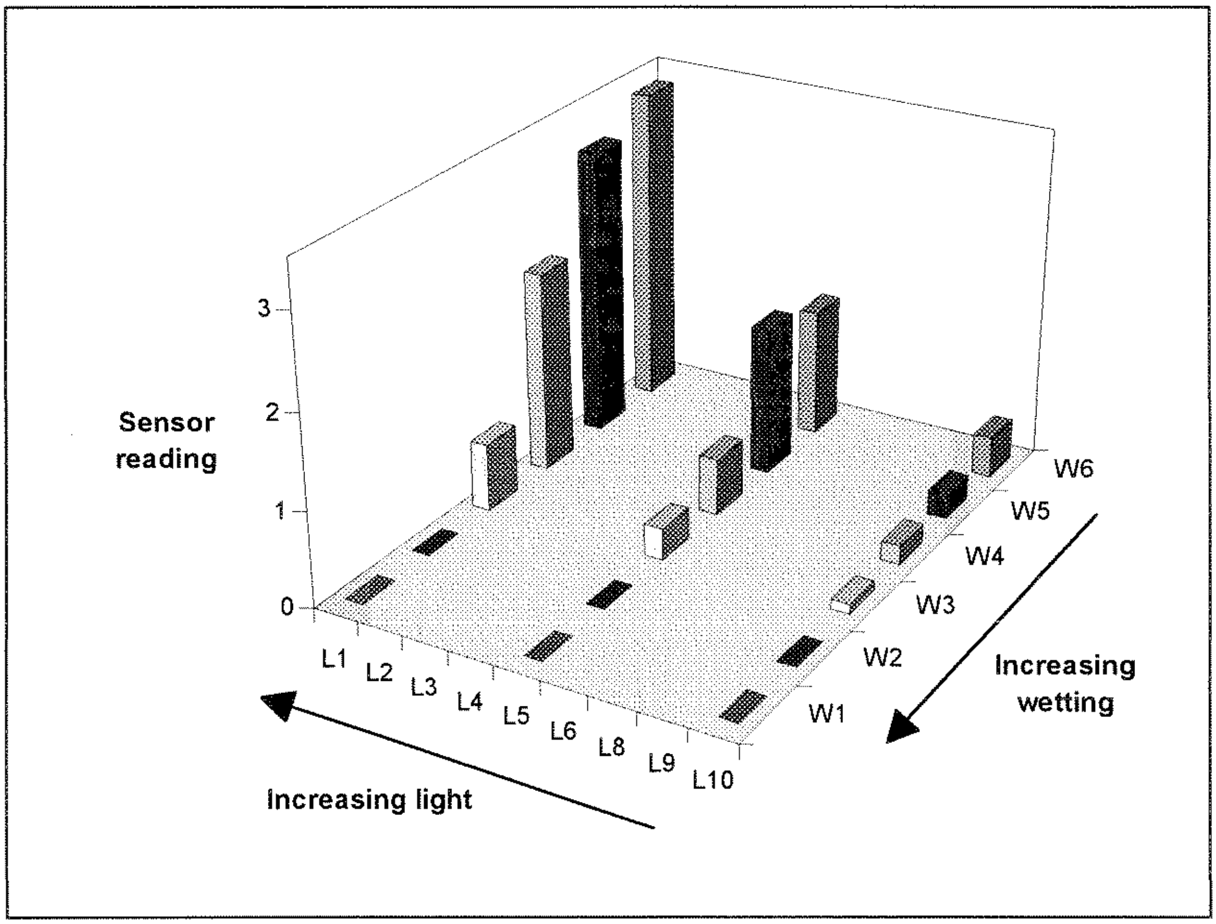


Figure 6. Evapo-sensor readings in a selection of locations in the gradient CPE. Values are averages over at least one hour, with lights on.

Potometer measurements

Direct measurement of potential transpiration using plants is not straightforward, especially where water is being deposited. However, as part of a MAFF - funded project, measurements of water uptake by fresh cuttings were made using an automatic 'potometer' system. These measurements give some indication of potential transpiration. Instead of planting the cuttings in rooting medium they were sealed into tubes filled with water so that their water uptake could be monitored over 15 minute intervals. Measurements were confined to the high light zone (L1 to L3 in Figures 2 & 3) so as to concentrate on the effect of leaf wetting. Data are presented as the bars in Figure 7, together with evapo-sensor readings for comparison.

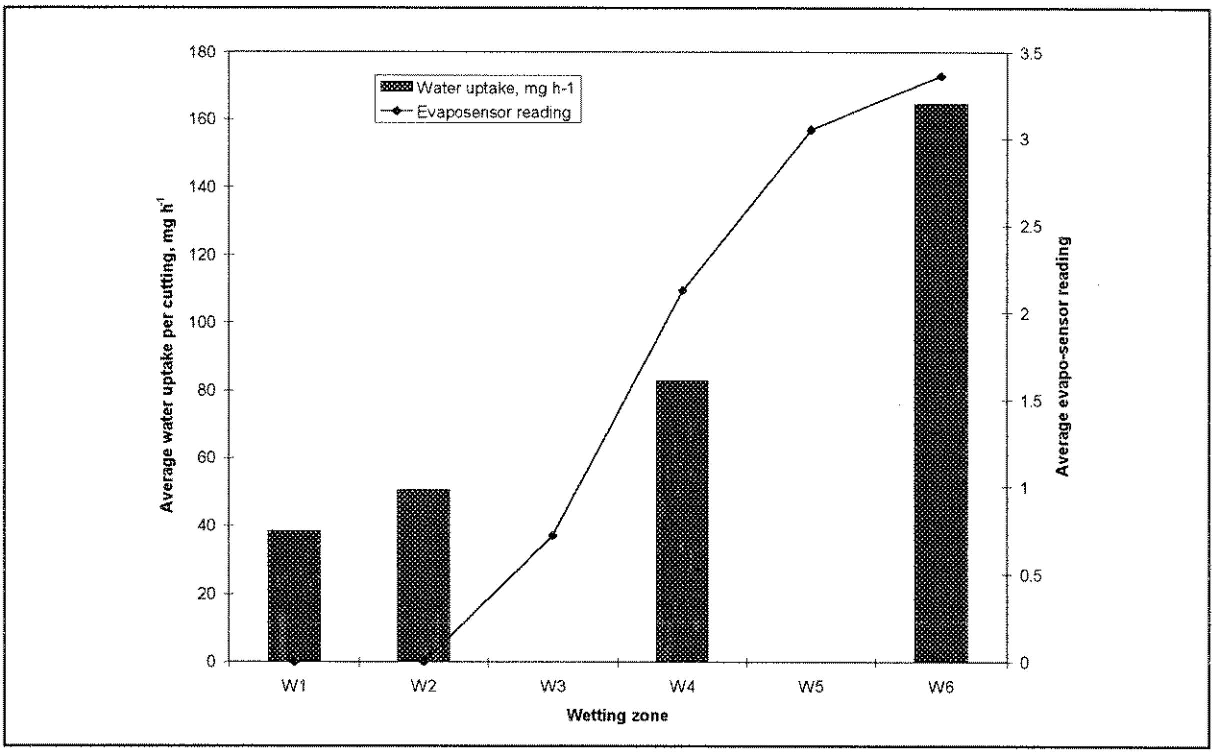


Figure 7. Variation in water uptake by cuttings (average of 11 subjects), and evapo-sensor reading in relation to wetting zone (W1 = wettest) at high light level (i.e. L1 to L3)

There is a clear parallel between the evapo-sensor readings and water uptake by cuttings, though the data suggest that the evapo-sensor may somewhat exaggerate the ability of heavy leaf wetting to suppress transpiration. However, some of the water taken up by the cuttings in the potometer system may have contributed to growth rather than transpiration. Further work will be required to resolve such possibilities.

Discussion

These data illustrate the huge range of evaporative demand provided within the G-CPE, making it relevant to a very wide range of conventional facilities, probably including simple polythene tent systems. The performance of the evapo-sensor was encouraging, although in very wet conditions it may give a zero reading when real cuttings may continue to transpire at a slow rate.

Interest in the further refinement and commercial development of the evapo-sensor is currently being solicited. One of its many potential applications is as an aid to the management of propagation environments, by providing an objective means of measuring the level of support in any environment, and making comparisons both within and between nurseries. In this context, clearly it would provide the ideal way of applying the results obtained in the G-CPE to conventional commercial propagation units. For mist and fog systems, the preferred option would be to use the sensor to control the fog or mist, simply adjusting the control set point to match the reading in the optimum part of the G-CPE. For simpler systems, evapo-sensor readings averaged over a few days would provide a guide to which plants could be expected to succeed. Similarly, it provides a tool for testing the benefit of changes to a system, such as a reduction in the ventilation of a mist house or the introduction of daily wetting to a simple polythene enclosure system.

Part 2: Studies of the production problems of selected plants

The remainder of the 'Results and Discussion' section deals with each of the plants studied in turn. This part deals with those subjected to detailed study of the entire production process. The much larger number of subjects studied in less detail are the subject of Part 3 (page 59). All these results are considered as a whole, and general conclusions drawn, in the 'Overview and Conclusions' section (pages 153-166).

Aubrieta

Clonally propagated *Aubrieta* was identified by the industry as a group of plants which are found difficult to propagate despite having tested numerous different approaches. The results are divided into two sections, the first dealing with the response of cuttings to environment, the second with methods of optimising production scheduling.

At the start of the project, 8 potted plants of 'Greencourt Purple' and eight of 'Dr. Mules' were obtained as stockplants and later two plants of 'Red Carpet' were added. During the summer, the stockplants were grown on well-drained sandbeds outside, being transferred into a ventilated house on a drained sandbed for overwinter protection and to promote spring growth.

Rooting environment

Experiment A (Autumn 1993): Cuttings of 'Greencourt Purple' and 'Dr. Mules' were treated with or without the rooting hormone indolyl butyric acid (IBA), in the form of Seradix No 2 powder formulation, preceded by dipping the bases in 50% (v/v) aqueous acetone.

Cuttings, approximately 5 cm long and with leaves stripped from the lower 2 cm of stem (which ranged from green to 'brown and woody'), were planted in four different rooting media:

1:1 (v/v) peat : fine bark (i.e. standard rooting medium)
1:1 (v/v) peat : coarse bark (Cambark 100)
fine sand
1:1:1 (v/v) peat, sand and grit

A 4 cm deep layer of the required rooting medium was placed in 30 x 40 cm trays over a similar depth of a growing compost with the intention that rooted cuttings would establish into the growing compost and rapidly increase the plants available to provide further cuttings.

Trays were placed under open mist, in fog, and in a cold frame protected only by a fine plastic mesh roof.

High levels of rooting, ranging from 70 to 94%, were obtained, with no substantial differences due to treatment, except that some of the more difficult 'Greencourt Purple' failed to survive over winter in the cold frame (Table 1). As would be expected, the plants outside were also much smaller.

Table 1. The effects of various treatments and environments on percent rooting and survival of *Aubrieta* varieties (the values shown in each section of the table are averaged over the other two factors).

		'Dr. Mules'	'Greencourt Purple'
IBA	+	89	84
	-	92	83
Rooting compost:	Sand	94	84
	Peat:sand:grit	89	80
	Coarse bark:peat	91	83
	Fine bark:peat	88	87
Rooting environments:	Fog	89	92
	Mist	93	88
	Cold frame	89*	70*

* markedly smaller but hardier plants

Experiment B: G-CPE

On 22 September, one cutting each of 'Greencourt Purple' and 'Red Carpet' were inserted into 7 x 7 cm pots in each location in the G-CPE. In view of the small numbers of cuttings the results are presented using the simplified format (Figure 8)

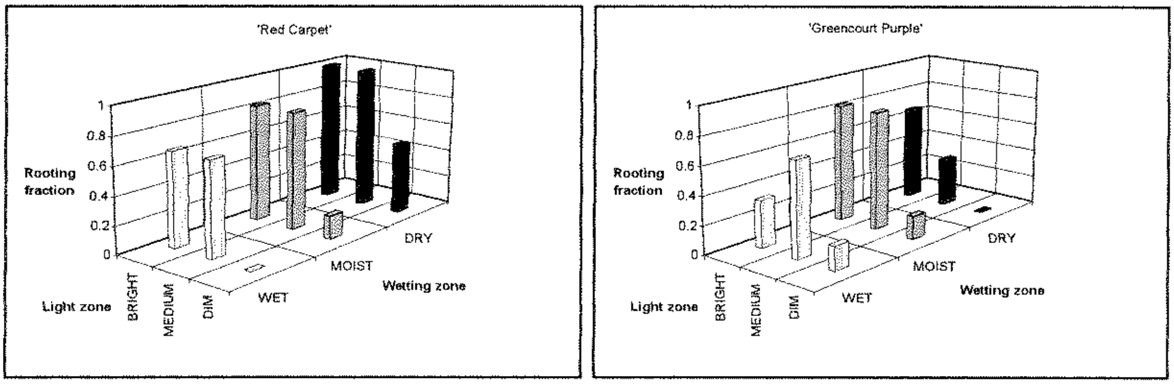


Figure 8. Rooting of *Aubrieta* cuttings in the G-CPE, from cuttings inserted on 22 September and recorded after 6 weeks. Plotted values are based on 6 cuttings.

The greater difficulty of 'Greencourt Purple' is evident not only from the lower rooting percentage but also from the greater sensitivity to overwetting and the desiccation stress at the dry end of the G-CPE. Rooting of both varieties was severely suppressed by very low light, but such low light levels would only occur in conventional facilities where shading was obviously excessive.

These results therefore suggest that the most common cause of difficulty in rooting *Aubrieta* is the probably extremely over-dry conditions, beyond the range of conditions provided in the G-CPE. This could occur where little shade is used, little water applied and little attempt made to retain humidity. For *Aubrieta* and similar plants, the fact that the plant thrives under dry conditions should not be taken as an indication that it will not need wetter conditions to suppress transpiration during rooting.

Experiment C (August 1995)

To test this hypothesis, the use of more extreme conditions was tested in conventional facilities.

Three environments were compared:

1. Mist controlled by a wetness sensor, set to keep cuttings lightly wetted.
2. Mist controlled by evapostat control set to 4° wet leaf depression. This is a higher evaporative demand than any location in the G-CPE (see Figure 7) and equivalent to conditions in the final stages of our standard weaning protocol.
3. Hand watered only once per day.

The three environments were within a single shaded polythene house. The cuttings in treatments 1 and 2, but not 3, were protected from draughts by a curtain around the bed.

There were 18 cuttings of each of three varieties in each treatment. Cuttings were inserted on 9 August and weaned at 5 weeks, and their establishment was assessed on the 19th September. The quality of roots was assessed when potted-on, on 9th October, by scoring the extracted root plug (highest = plug intact and roots visible all round; lowest = no visible roots, and roots insufficient to prevent disintegration of the plug).

The results in Table 2 confirm that rooting is impaired by extremely unsupportive environments and that conventional mist, adjusted to keep the cuttings just lightly wetted, is satisfactory.

Table 2. Effects of propagation environment on rooting of *Aubrieta cuttings*

	'Red Carpet'	'Dr. Mules'	'Greencourt Purple'	Means
% Establishment				
Normal mist	83	83	94	87
Weaning mist	72	61	50	61
Hand-watered	33	56	33	41
Root score				
Normal mist	2.5	2.7	2.1	2.4
Weaning mist	2.2	1.8	2.8	2.3
Hand-watered	1.3	1.6	1.5	1.5

Production scheduling

Once it became clear that relatively high rooting percentages were readily achievable given a modest level of environmental support, emphasis shifted to other aspects of production, starting with the possibility of spreading production over the year for flexibility of management and to help meet market demand.

Experiment D: timing and nutrition

Four successive propagations were carried out during 1994, using the original stockplants and new stockplants produced from experiment A.

A standard method of propagation was adopted as follows:
Cuttings were propagated without IBA treatment, in 5 cm (0.08 L) modules containing equal parts fine bark and peat, placed on a drained sandbed with 20 °C minimum bottom heat and under intermittent mist. Cuttings, approximately 5 cm in length and with the proximal 2 cm basal stem section stripped of leaves, were given 6 weeks to root and a further week for weaning under reduced misting frequency. After this, the first data were collected and the plants were potted-on as required.

Propagation 1: 12th May: This first propagation was made immediately after flowering, from stockplants held in a ventilated polythene house. After only four days the leaves on many cuttings, and especially those from the older stockplants, had yellowed and developed *Botrytis*, signifying moribund tissue. The worst infected leaves were removed by hand and twice weekly alternating sprays of Benlate and Rovral at 2 g L^{-1} per litre were applied. Following this treatment, a number of cuttings which appeared to have died regenerated from their tips. Rooted plants were potted-up in early July into 9 cm square ½ litre pots, using a mix of equal parts fine bark and peat at two nutrient levels (1 and 2 g L^{-1} Ficote 140 16-10-10).

Table 3. Percentage survival of *Aubrieta* cuttings propagated mid-May and assessed early July (-, no sample).

Source	'Red Carpet'	'Dr. Mules'	'Greencourt Purple'
Original stockplants	6	55	13
Re-propagated stockplants	85	-	78

Table 3 shows percent survival at the time of potting. Age of stockplant clearly had a major influence in the two varieties where comparisons were possible, probably because the original stockplants had not been repotted and their growth was becoming weak due to shortage of nutrients.

Propagation 2: 22nd June: The original stockplants were therefore repotted on 16th May. The growing medium 30% (v/v) peat, 60% bark, 5% loam and 5% grit with 2 kg m^{-3} calcium carbonate, 1 kg m^{-3} magnesium limestone, 75 g m^{-3} Nitram and 2 kg m^{-3} Osmocote Plus. Cuttings taken on 22nd June from the different sources were again kept separate, but those from the repotted stockplants appeared healthier than on the first occasion. Procedures were similar to those already described with each of the 6 variety x source combinations represented by 54 cuttings. Weaning started on 3rd August and results were recorded one week later, followed by potting-up into the higher and lower nutrient levels using ½ litre pots on 15th August. Table 4 gives the results.

Table 4. Percentage survival of *Aubrieta* cuttings propagated mid-June and assessed early August.

Source	'Red Carpet'	'Dr. Mules'	'Greencourt Purple'
Original (repotted) stockplants	83	70	63
Re-propagated stockplants	65	72	30

Statistically significant effects: Variety ($P< 0.001$), Source ($P< 0.001$)
LSD = 17.2

Repotting the original stockplants raised production significantly, and results for 'Greencourt Purple' confirmed the view that it is relatively difficult to propagate, being significantly poorer than the other varieties, especially when not propagated from newly repotted stockplants.

Propagation 3: 12th July: Stockplants of each variety were graded for apparent viability and divided into two equally weighted sets, one of which had all cuttings removed to simulate complete commercial harvesting and the other partial harvesting, with a view to assessing the effect of harvesting method on regenerative capacity at the next (fourth) propagation. Sufficient cuttings were available to replicate and randomise the 6 treatment combinations of 3 varieties and 2 stockplant sources. The basic experimental unit was 9 graded cuttings (equivalent to one row of cells in a tray) and the 6 treatment combinations were randomised across the tray to fill one tray with 54 cuttings. This unit was replicated six times (blocks).

Weaning commenced on 23rd August, and cuttings were assessed on 5th September and potted-up the following day into high and low nutrient media. As before, 'Greencourt Purple' rooted and survived least well and there was an overall improvement due to repotting the original stockplants. (Table 5).

Table 5. Percentage survival of *Aubrieta* cuttings propagated mid-July and assessed early September.

Source	'Red Carpet'	'Dr. Mules'	'Greencourt Purple'
Original (repotted) stockplants	89	85	69
Re-propagated stockplants	89	76	50

Statistically significant effects: Variety (P< 0.001), Source (P<0.05)
LSD = 15.8

Propagation 4: 7th September: Cuttings from stockplants of the totally-harvested and selectively-harvested sources created in early July were compared for each of the three varieties, with the mother plant sources (original repotted versus repropagated) kept separate but consigned to blocks. The previously totally-harvested source was producing more vigorous darker green shoots compared to those from the selectively-pruned plants, the latter characterised by woodier stems and more senescent foliage.

Weaning commenced on 19th October, and cuttings were assessed and potted-up one week later. The method of previously harvesting the cuttings and the subsequent difference in the woodiness of cuttings had no effect and, on this occasion, there was no significant difference between varieties (Table 6).

Table 6. Percentage survival of *Aubrieta* cuttings propagated in early September and assessed late October.

	'Red Carpet'	'Dr. Mules'	'Greencourt Purple'
Previously totally-harvested source	81	76	72
Previously selectively-harvested source	74	87	72

No statistically significant effects
LSD = 11.6

Growing-on. All plants from the first 3 propagations, potted-up and held in a ventilated polythene tunnel, reached saleable size and quality by the end of October. Plants from the earliest propagation were showing signs of *Botrytis* infection, probably associated with the higher density of shoots on these older plants. Commercially, these plants, along with those from Propagations 2 and 3, should either have been sold, potted into larger containers, or grown outside to produce a hardier smaller plant.

Plants established from the third and forth propagations, potted-up into ½ litre pots at two levels of Ficote, were grown on a drained sand-bed in a ventilated polythene house until assessed in November.

Data showed 'Red Carpet' to be significantly taller; it covered more of the pot surface and was more compact than the other two varieties while 'Dr. Mules' gave significantly better cover and was more compact than 'Greencourt Purple'. The effect due to Ficote level was smaller than that due to variety, but height and cover were significantly greater at the higher level of fertilizer (Table 7).

Amongst plants from the fourth propagation, no significant effects due to Ficote level were evident at this stage (Table 8).

Table 7. Growth of *Aubrieta* cuttings propagated mid-July and assessed late November.

		'Red Carpet'	'Dr. Mules'	'Greencourt Purple'
1. Height (cm)				
Ficote per litre	1 g	8.6	6.8	6.7
	2 g	8.9	7.1	7.7
Statistical probabilities: Variety P<0.001, Nutrient level P<0.01. LSD = 0.53				
2. Cover (%)				
Ficote per litre	1 g	88	81	63
	2 g	94	88	70
Statistical probabilities: Variety P<0.001, Nutrient level P<0.001. LSD = 5.6				
3. Compactness (score 1=low to 3=high)				
Ficote per litre	1 g	2.3	1.8	1.3
	2 g	2.3	1.7	1.1
Statistical probabilities: Variety P<0.001, Nutrient level - NS. LSD = 0.21				

Table 8. Growth of *Aubrieta* cuttings propagated in early September and assessed late November.

		'Red Carpet'	'Dr. Mules'	'Greencourt Purple'
Height (cm)				
Ficote per litre	1 g	5.8	3.7	4.9
	2 g	5.6	4.0	5.0
Statistical probabilities: Variety P<0.01, Nutrient level NS. LSD = 0.44				
Cover (%)				
Ficote per litre	1 g	23	27	21
	2 g	24	29	22
Statistical probabilities: Variety P<0.05, Nutrient level NS. LSD = 3.8				
Compactness (score 1=low to 3= high)				
Ficote per litre	1 g	1.0	1.3	1.0
	2 g	1.1	1.3	1.0
Statistical probabilities: Variety P<0.01, Nutrient level NS. LSD = 0.09				

Experiment E: The influence of stockplant and growing-on environment

This experiment examined the possibility that propagation could be extended even later than September, together with the effects of the environment in which the stockplants were grown and the growing-on environment.

Cuttings were collected from stockplants grown in two litre pots on capillary sand beds either outside or in a ventilated polythene tunnel. After rooting and weaning, the surviving cuttings were potted-up into 9 cm (0.5 litre) square pots and the plants from each stockplant source were then divided equally between capillary beds outside and under polythene. The rooting medium contained 0.5 g L^{-1} Osmocote Mini 18-6-12 and rooted cuttings were potted into a 50:50 (v/v) mix of peat and fine bark containing 0.5 g L^{-1} Ficote 140 16-10-10.

The calendar of events was as follows:

	Propagation	Weaning	Potting-on
1.	18th July, 1995	4th September, 1995	27th September, 1995
2.	28th September, 1995	2nd November, 1995	12th December, 1995
3.	8th November, 1995	13th December, 1995	1st February, 1996

Compared to propagation in July, propagation in September had no effect on percent establishment, but the quality of root system was reduced across all varieties (Table 9). 'Red Carpet' and 'Dr. Mules' propagated well in November, but establishment of the less ready-rooting 'Greencourt Purple' was almost halved by late propagation. Root quality of all varieties suffered when cuttings were collected from the outside source in November.

Those plants grown-on under polythene from the first (July) propagation were prone to *Botrytis* infection. Those propagated in late September produced soft 'leggy' growth, and though there was less time for botrytis to become established, these smaller plants were less resilient and some died. Plants propagated in early November, which were hardened-off sooner, were smaller, healthier, more compact and of a darker green colour than those from earlier propagations.

Plants grown-on outside were generally smaller, more compact and darker green than those grown under polythene, and no *Botrytis* was seen on these plants.

Table 9. The effect of stockplant environment and propagation date on rooting and establishment of *Aubrieta* cuttings, assessed at the time of potting-on.

	'Red Carpet'	'Dr. Mules'	'Greencourt Purple'	Means
% Establishment				
Inside, July	93	100	78	90
Outside, July	93	80	83	85
Inside, September	94	87	80	87
Outside, September	96	100	76	91
Inside, November	93	98	41	77
Outside, November	76	93	43	71
Average root score of rooted cuttings				
Inside, July	2.9	3.0	2.9	2.9
Outside, July	2.9	2.8	2.9	2.9
Inside, September	2.3	2.3	2.1	2.2
Outside, September	2.2	2.1	2.2	2.2
Inside, November	2.0	2.0	2.0	2.0
Outside, November	1.4	1.8	1.7	1.6

Statistical probabilities:

	% establishment	Root score
Variety	P< 0.001	NS
Season	P<0.05	P<0.001
Environment	NS	P<0.001
Environment x season		P<0.01
LSD within the table	8.7	0.19

Final records were taken in April 1996, coincident with peak Easter sales (Tables 10 and 11). Plant height was measured, and the size and compactness of the cushion of shoots were scored on five point scales.

Of the plants propagated in July all of those potted-up survived, whereas those from the September and November propagations sustained some losses. Despite the fact that cuttings rooted and weaned well from the late September propagation, potting-on cuttings at the beginning of December 1995 led to the greatest number of losses, irrespective of whether they were then placed outside or under polythene. 'Greencourt Purple' was again particularly sensitive, with 44% of plants dying. Plants from the September propagation grown-on outside experienced greater losses then those grown-on in an unheated polytunnel.

The generally poorer rooting from November propagation ('Dr. Mules', 96%; 'Red Carpet', 85%; 'Greencourt Purple', 42%) was not reflected in poor survival of those which rooted. It may be relevant that, after potting-up, even plants designated for growing-on outside were held back under polythene until a severe cold spell had passed.

Plants grew well but not as many reached 'saleable size' (cushion of shoots covering top of 9 cm square pot) by Easter as in experiment D, perhaps as a result of the reduction in fertiliser level in potting-up mix (0.5 g L^{-1} of Ficote 140 16-10-10 instead of either 1 or 2 g L^{-1}). Plants grown-on inside the polytunnel were larger, but less compact than those grown-on outside. Plants from the July propagation, which had to be cut back severely in January 1996 to remove shoots infected with *Botrytis*, had regrown strongly and were larger than the later propagations which had not been cut back. Plants from the July and November propagations were more compact than those from the September one and the variety 'Red Carpet' was generally more compact than the other 2 varieties.

Table 10. The effect of date of propagation and variety on the survival and growth of *Aubrieta* plants, assessed in the spring following propagation (April 1996). Data for plants grown-on with and without protection have been combined.

	July	September	November	Mean
Survival (% of cuttings which rooted)				
'Dr. Mules'	100	90	98	96
'Red Carpet'	100	93	99	97
'Greencourt Purple'	100	56	90	82
Mean	100	80	96	
Size score	(from 1=smallest to 5=largest)			
'Dr. Mules'	3.29	2.79	2.49	2.85
'Red Carpet'	3.58	2.38	2.65	2.87
'Greencourt Purple'	3.24	1.93	2.54	2.57
Mean	3.37	2.36	2.56	
Compactness Score	(from 1=loose to 5=compact)			
'Dr. Mules'	3.04	2.75	2.96	2.91
'Red Carpet'	3.11	2.66	3.48	3.08
'Greencourt Purple'	2.89	1.75	2.50	2.38
Mean	3.02	2.38	2.98	

Statistical probabilities

	%Survival	Size score	Compactness score
Variety	P<0.001	P<0.05	P<0.001
Season	P<0.001	P<0.001	P<0.001
Variety x Season	NS	P<0.01	P<0.001
LSD			
Variety means	1.3	0.228	0.150
Season means	1.69	0.228	0.150
within the table	-	0.395	0.260

Table 11. The effect of date of propagation and the growing environment after potting-up on the survival and growth of *Aubrieta* plants assessed in the spring following propagation (April, 1996). Data are averages of three varieties.

	July	September	November	Mean
Survival (% of cuttings which rooted)				
Inside	100	87	97	95
Outside	100	72	95	89
Mean	100	80	96	
Size score	(from 1=smallest to 5=largest)			
Inside	3.50	3.04	2.99	3.18
Outside	3.24	1.69	2.13	2.35
Mean	3.37	2.37	2.56	
Compactness Score	(from 1=loose to 5=compact)			
Inside	2.61	2.69	2.89	2.73
Outside	3.42	2.07	3.06	2.85
Mean	3.02	2.38	2.98	

Statistical probabilities	%Survival	Size score	Compactness score
Grown-on	P<0.01	P<0.001	P<0.05
Season	P<0.001	P<0.001	P<0.001
Grown-on x Season	NS	P<0.001	P<0.001
LSD			
Grown-on means	1.1	0.228	0.150
Season means	1.4	0.228	0.150
within the table	-	0.395	0.260

In Table 12 the data for rooting and survival have been combined to show the percentage of cuttings stuck which produced plants that survived to the following spring. It is clear from this that early propagation is more reliable, especially for more difficult varieties such as, Greencourt Purple'.

Table 12. The effect of propagation date on the percentage of *Aubrieta* cuttings that rooted and survived to the following spring.

	Time of propagation		
	July	September	November
'Dr. Mules'	90	84	94
'Red Carpet'	93	88	84
'Greencourt Purple'	81	44	38

Experiment F: Fertilizer in the rooting medium

Each variety was propagated in modules as described above, with or without the inclusion of 1 g L^{-1} of Osmocote Mini 18-6-12.

Cuttings were taken from indoor-grown stockplants on 6th June, 1995, weaned from 13th July, and recorded for rooting on 19th July. The quality of the root system was assessed when potted-up on 8th August.

The inclusion of Osmocote Mini granules had no effect on rooting and establishment percentage, but there was a small but consistent improvement to the quality of the root system.

Experiment G: Growing medium and irrigation

This experiment examined the possibility that *Aubrieta*, being a plant that thrives in well drained soil, might be adversely affected by the continuously moist conditions provided by capillary irrigation of small containers, particularly in a fine textured medium such as the mixture of peat and fine bark which had been adopted as our standard for *Aubrieta*.

Cuttings of all three varieties collected from outside-grown stockplants were rooted under the standard conditions described earlier. After 6 weeks, selected rooted cuttings were potted-on into either the standard peat bark mix (50:50 [v/v] peat : Cambark fine grade bark) or a similar mix containing 20% coarse grade Perlite (i.e. 40:40:20 [v/v] peat : bark : Perlite). Ficote 140 16-10-10 was added to both mixes at a rate of 1 g L^{-1} per litre. Pots were placed in a polytunnel either in contact with a capillary sand bed ('wet' treatment) or separated from the sand by a layer of 'Netlon' coarse plastic mesh to break the capillary contact with the sand ('dry' treatment). Plants in the dry treatment were hand watered sufficiently to keep the medium moist but distinctly drier than the capillary irrigated pots.

At the end of the growing season plant quality was assessed in terms of plant height, percentage of the pot covered by the cushion of shoots, a compactness score and a root quality score, based on total quantity of roots and the number of thick roots.

Air filled porosity. The physical characteristics of the medium in which plants are grown influence the supply of air and water to a plant. To obtain a measure of these properties in the composts used, porosity tests were carried out. Square pots (9 cm) were adapted for use as sample holders by covering most of the drainage holes with waterproof self-adhesive tape. These were filled with medium to the base of the rim and stood in a water trough for 2 hours before the remaining holes were sealed with rubber bungs and the pots were removed for drainage measurements. The pots were weighed and then allowed to drain for 30 minutes before weighing again. The medium was then dried and weighed. The volume of the samples was determined by filling sample holders with water instead of medium, and pouring this into a measuring cylinder.

The results showed no effect of the method of irrigation but the addition of Perlite significantly reduced the height and root quality score of 'Greencourt Purple'.

The porosity tests showed that addition of 20% coarse Perlite was ineffective in increasing the porosity of the medium, air filled porosity remaining at 10% (Table 13). Perlite, and other coarse textured materials, are often added to rooting and growing media with the intention of increasing air content, but this result is consistent with evidence that the proportion needs to be more than about 50% if it is to be effective (Heiskanen, 1995).

Table 13. The effect of adding coarse Perlite to the standard medium on its physical properties

	Medium	
	Peat:Bark	Peat:Bark:Perlite
% Air Filled Porosity	10	10
% Water Filled Porosity	78	79
% Total Porosity	88	89

Conclusions

These results illustrate the gains to be derived from a systematic investigation of the various stages of production of a plant that is proving troublesome to produce commercially. The key conclusions are:

- Despite being a plant which can grow in relatively dry conditions, rooting of cuttings is sensitive to water stress. Therefore, prepare cuttings in a cool and humid environment and root under moderately heavy mist.

- Stockplant nutrition is important to maintaining high rooting ability of cuttings. It is therefore advisable to repot annually in late winter. A growing medium of equal parts of medium Irish moss peat and fine bark (Cambark), with 2 g L^{-1} Ficote 140 16-10-10, was satisfactory.

- Cuttings can be rooted whenever they are available. At least 2 crops of cuttings can be obtained per year.

- Treatment with IBA is unnecessary.

- Once rooted cuttings are well established, grow-on outside to develop a compact cushion of shoots. Protection can be used to target particular marketing dates but *Botrytis* infection is a hazard.

- The type of rooting medium is not critical. One satisfactory medium consists of equal parts by volume of medium Irish moss peat and fine grade Cambark, with 0.5 g L^{-1} Osmocote Mini 18-6-12.

The following were standard methods adopted for the work. They appeared to be satisfactory but were not compared with any alternatives:

- Cuttings were 5 cm long, with leaves stripped from the lower one third of the stem.

- Cuttings were rooted in module trays, placed on sand beds for positive drainage (10 cm depth of fine sand).

- After 6 weeks in a rooting environment, weaning was commenced, and rooted cuttings were potted-off into 0.5 L pots three weeks later.

Fremontodendron

This plant was suggested by the industry because it is in demand and is proving difficult to produce, mainly due to failure of cuttings to root, related to high incidence of rotting.

Stockplants: Initially, three potted one-year-old stockplants of the variety 'California Glory' were obtained from Loder's Nursery and grown in a high coir compost on a free-draining sandbed in a ventilated polythene house. Later, plants produced in the experiments provided additional stockplants. In 1995, 3 plants of the variety 'Pacific Sunset', said to perform slightly better in containers than 'California Glory' were provided by Notcutts Nursery

Type of cutting: Unless otherwise stated, *Fremontodendron* cuttings were non-apical and single-node, comprising an upper node with leaf and axillary bud or short lateral, but with the base of the cutting prepared above the next node, so that the base of the cutting was non-nodal. Since the downy hairs on stems and leaves are liable to cause skin irritation, shoots were wetted during collection and surgical gloves were worn. Cuttings were inserted into either square 9 cm (½ litre) pots, or QP24 module trays, containing the standard rooting medium.

Experiment A (Autumn 1993): a multifactorial experiment

A wide-ranging investigation was conducted, encompassing the following factors:

± removing hairs from the cutting stem
IBA concentration (1.25 g L^{-1} or 0.312 g L^{-1}[i.e 1250 and 312 ppm respectively] applied as a quick-dip in 50% [v/v] acetone)
aerial environment (wet v. relatively dry zones within the fog house, as determined by distance from the Agritech fogger)
drainage (± a layer of polythene separating the pots from the drained sandbed)

Cuttings were propagated on 7th September and assessed for rooting and growth on 26th October, before being moved to a sandbed for weaning and overwintering in a ventilated polythene house. Surviving plants were then potted-on in early May 1994 for use as further stockplants.

Results showed that the influence of environment on water relations was the most important factor determining success in this subject. Best rooting (90%) was obtained in the drier part of the fog house environment, where leaf wetting was light, combined with positive drainage. Where pots were separated from the sandbed, to simulate standing on a solid floor, rooting was reduced to 35% by the impaired drainage. Only 10% rooting occurred closer to the fogger, where leaves were kept continuously very wet, and only in pots with positive drainage. There was evidence in most locations that cuttings were susceptible to basal stem rotting, but rotting was present in the drier location only where drainage was impeded. When drainage was impeded, the length of rotted stem increased from 16 mm to 45 mm, averaged across the whole experiment.

There was little effect of removal of hairs or of the application of different concentrations of IBA; there was an indication that rotting might be increased when the higher concentration of IBA was combined with non-removal of hairs. That combination would presumably have resulted in the highest dose of IBA per cutting, because the hairs would have retained additional IBA solution in the dipping process.

Experiment B (summer 1994): rooting medium, drainage, and propagation environment

This experiment concentrated on those treatments which had emerged as important in experiment A, with additional replication provided by using new stockplants established from the first experiment. Mist was added to the comparison of aerial environments, and a proprietary coir-based rooting medium was compared to the standard medium.

Newly established stockplants were graded for size and all available stems and branches were cut into non-apical non-nodal cuttings as previously described; terminal parts of shoots were prepared as multinode cuttings, but without a node at the base. No hairs were intentionally removed and no IBA was applied; otherwise the protocol was as described earlier. Cuttings were inserted on 28 July, and assessed after 6 weeks.

Representative rates of water deposition recorded in the three aerial environments were: mist 113 $\mu m\ h^{-1}$, wetter fog 58 $\mu m\ h^{-1}$, and drier fog 33 $\mu m\ h^{-1}$ (1 $\mu m\ h^{-1}$ = one thousandth of a millimetre per hour, thus 113 $\mu m\ h^{-1}$ is equivalent to a little over 1 mm in 10 hours).

As before, rooting was superior in the drier fog than in the wetter fog, but mist was marginally better still, with 80% rooting in the best treatment combination (Table 14). When drainage was impeded by placing pots on polythene, rooting in all environments was severely depressed. A similar result was obtained with the coir-based rooting medium irrespective of the environment or drainage conditions. Coir-based media are supposed to be more free-draining but data for water content showed no substantial difference in drainage properties between the media so that the suppression of rooting by the coir must be attributable to some other factor. By contrast, impeding drainage increased the water content of the medium from 45 to 67 % (v/v) on average.

Table 14. Percent rooting of *Fremontodendron* 'California Glory' in relation to propagation medium and rooting environment.

		Free drainage	Impeded drainage	Means
Fog (wetter end)	Peat/bark	25	5	15.0
	Coir-based	5	0	2.5
Fog (drier end)	Peat/bark	75	45	60.0
	Coir-based	40	0	20.0
Mist	Peat/bark	80	20	50.0
	Coir-based	40	5	22.5
Means		60.0	12.5	

Differences in age and size of stockplants were associated with the blocks of a randomised block experiment. It was therefore not possible to carry out a valid statistical test of their effect (unlike all other factors) but the results suggested that cuttings from newly established stockplants rooted at least as well as those from the older stockplants.

A number of cuttings developed new shoot growth and trends generally reflected those for rooting, with more growing cuttings produced from the peat/bark medium and the free-draining sandbed, although the drier fog was superior to mist in this respect.

Basal necrosis was present in most treatment combinations, with almost all cuttings affected in the coir-based medium with impeded drainage. The extent of die-back was greater in the coir-based medium and with impeded drainage also (Table 15).

Table 15. Extent (mm) of basal necrosis in *Fremontodendron* 'California Glory' in relation to propagation medium and rooting environment.

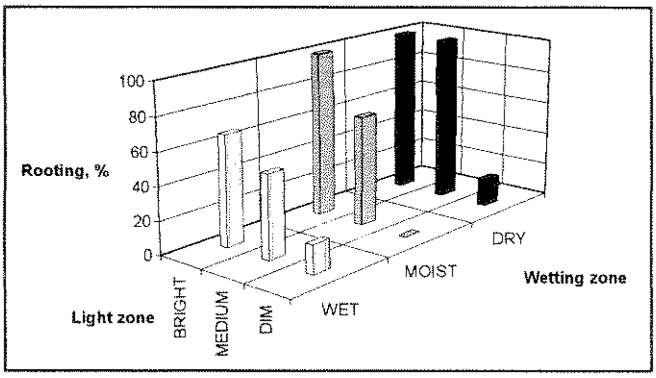
		Free drainage	Impeded drainage	Means
Fog (wetter end)	Peat/bark	39	47	43
	Coir-based	44	54	49
Fog (drier end)	Peat/bark	7	37	28
	Coir-based	31	61	50
Mist	Peat/bark	18	34	31
	Coir-based	27	40	35
Means		25	38	

Experiment C (Autumn 1994): preliminary G-CPE experiment

This was the first experiment with *Fremontodendron* in the G-CPE, making use of all the cuttings available on both the original stockplants and those from cuttings propagated the previous year. This provided enough material for only 2 cuttings in each of the 54 locations in the G-CPE, one of which was a single node cutting, the other consisted of at least two nodes and the shoot tip. The two types were designated 'single node' and 'apical' respectively. As before, neither type had a node at the base.

Cuttings were inserted on 22 September, 1994, and rooting was assessed after six weeks. The rooting results are shown in Figure 9, in which results for cuttings in 6 adjacent individual locations were combined to give a rooting percentage for nine larger 'zones'. It shows that the apical cuttings rooted better than the nodal cuttings at the wet end but less well at the dry end of the G-CPE, this interaction being statistically significant ($P<0.05$). High light was required for good rooting of both types of cutting, and there was no significant difference between the types when averaged over all environments.

Most of the unrooted cuttings showed some rotting at the base, the length of necrotic tissue being greatest at low light level.



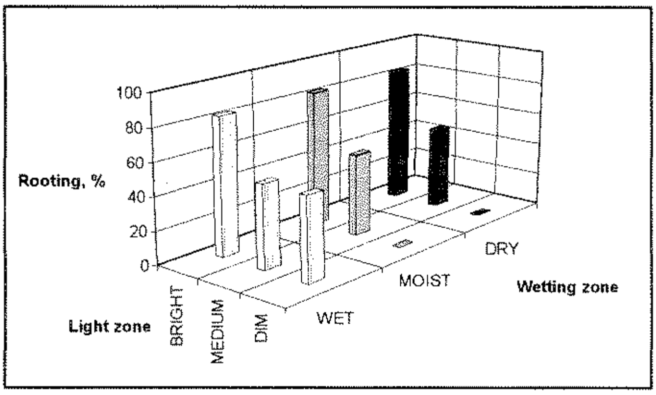


Figure 9. Rooting of *Fremontodendron* 'California Glory' in the G-CPE from either single node cuttings (upper) or multinode apical cuttings (lower). Neither type of cutting had a node at their base. Plotted values are based on six cuttings. Statistically significant effects: light ($P<0.001$), and wetting x cutting type ($P<0.05$).

Experiment D (Summer 1995): nodal versus internodal, drainage, and propagation environment

The presence of a node at the base of a cutting improves rooting in many species and also tends to limit the extent of rotting at the base. While the earlier experiments showed that internodal cuttings could be used successfully for *Fremontodendron*, enabling large numbers of single node cuttings to be obtained from a limited stock material, this experiment examined whether nodal cuttings would have advantages, particularly in terms of avoidance of rotting.

Cuttings of 'California Glory' were prepared either with a single node at the top of the cutting as described earlier ('non-nodal' treatment), or with the basal cut just below an additional node ('nodal' treatment). They were inserted into the standard peat:bark medium in modules on 25th July, 1995. They were then placed in mist (run relatively dry by suitable placement of the controlling wetness sensor), or on one of two locations in the fog house differing in distance from the fogger and therefore the amount of water deposited. To compare the amount of wetting in these three environments, the weight of water deposited into transparent dishes over 24 h was measured on two occasions, after the cuttings had been removed. Results were as shown in Table 16.

Table 16. The rate of water deposition in three different propagation environments. Data are mean values, in thousandths of a millimetre per hour.

	Sunny day	Cloudy day
Wetter fog	112	22
Drier fog	31	9
Mist	7	6

These data show that the mist system deposited less water than it did during experiment B, and the difference between the two locations in the fog house was larger. As in that experiment, half of the modules were stood directly on the sand bed, while the others were placed on a sheet of polyethylene to impede drainage.

Rooting and other features were assessed after six weeks on 7th September.

It was confirmed that the use of single-node cuttings prepared by excising just above each node, which greatly increases the number of cuttings available, had no detrimental effect on propagation; 100% of non-nodal cuttings rooted under favourable conditions (Table 17).

Rooting percentage of nodal cuttings averaged about 5% greater than that of the non-nodal cuttings but the difference was not statistically significant. Furthermore, the presence of a node at the base of the cutting had no consistent effect on the proportion of cuttings which rotted at the base. Rotting accounted for most of the non-rooted cuttings and most cuttings that rooted established (Table 17).

Responses to environment were broadly similar to those observed in experiment B, but with an even larger difference between the aerial environments and somewhat smaller effect of drainage. This reflected the more extreme differences in water deposition achieved by running the mist bed relatively dry, and using slightly different locations for the two environments within the fog house. In the wetter fog environment, all cuttings rotted and failed to root if drainage was impaired, and only 17% rooted even if the medium was well-drained. In the drier environments, between 80 and 100% of cuttings rooted and impeding drainage reduced rooting by an average of 9%, much less than in experiment B.

TABLE 17. The effect of cutting type and propagation environment on stem rotting, rooting and establishment of *Fremontodendron* 'California Glory'

Cuttings	Environment	Drainage	Basal rotting, %	Rooting %	Establishment %
Nodal	Wetter fog	+	87	13	7
		-	100	0	0
	Drier fog	+	7	87	66
		-	7	80	80
	Mist	+	0	93	93
		-	20	80	80
Non-nodal	Wetter fog	+	73	20	13
		-	100	0	0
	Drier fog	+	0	100	87
		-	20	80	80
	Mist	+	0	87	87
		-	7	93	93
Statistical probabilities for main effects:					
	Environment		P<0.001	P<0.001	P<0.001
	Drainage		P<0.001	P<0.05	NS
	Cutting type		NS	NS	NS
	LSD		6.2	7.2	7.6

Experiment E (Summer 1995 in G-CPE): effects of environment on rooting and subsequent performance

The response to the G-CPE environments was examined again in 1995, on this occasion using four non-apical single-node cuttings per location.

Cuttings were subdivided into those from the proximal part of the shoot (i.e. that nearest the main stem of the stock plant) and those from the distal part and each type was further divided into two classes according to the their leaf area. One cutting of each of these four classes was inserted in each location. Proximal cuttings were thicker and had larger leaves than distal cuttings (stem diameter 5.4 mm compared with 3.9 mm, and leaf area 43.9 cm^2 compared with 15.5 cm^2).

Cuttings were inserted into QP24 module trays on 2 August, 1995 and rooting was assessed after 6 weeks. In this experiment, rooting was assessed without disturbing the roots to allow for more realistic assessment of the effects of environment on subsequent growth and development. Rooting was scored as 1 if the cutting was firm in the rooting medium, and 2 if roots were emerging from the base of the module. They were then transferred to a lightly-shaded part of a well-ventilated polythene tunnel to determine whether the environment in which they rooted would influence their ability to tolerate minimal care at the 'weaning' stage.

Survival and growth was recorded on 24 November, 1995. Survivors were potted up into 2 L pots in early May, 1996, and grown on under polythene until mid-August when final records were made. The growing medium was a peat:bark mix (70:30 [v/v] medium Irish moss peat : Cambark 100), with 3 kg m^{-3} of Ficote 180 16-10-10, 1 kg m^{-3} of magnesian limestone, and 0.3 kg m^{-3} of fritted trace elements (WM255).

The environmental fingerprint (Figure 10) shows that the main requirement is to avoid excessive shade, there being no rooting at all in the three darkest zones. It also shows that rooting could be suppressed by excessive wetting, though only in the wettest zone (W1). Even in W1, rooting was not suppressed as much as at the wetter end of the Agritech fog house (Table 17), despite the recorded amount of wetting being similar. The most likely explanation is that, in the case of the Agritech fogger, fog is blown out by a fan so that some wetting of the undersurface of leaves occurs, especially at the wet end of the house, close to the fogger.

Statistical analysis showed that the effects of light and wetting were highly significant ($P<0.001$ and 0.01 respectively), but in this case there was no interaction between them. Nor was there any difference between the responses of proximal and distal cuttings despite proximal cuttings carrying almost three times as much leaf area.

Survival of transfer to normal growing conditions was affected by the environment in which cuttings had rooted. All those rooted at the dry end of the gradient (i.e. W4 to W6) survived, whereas 28% of those from wetter conditions failed. Failures were all amongst distal cuttings, and included some which had roots emerging from the module at the time of transfer.

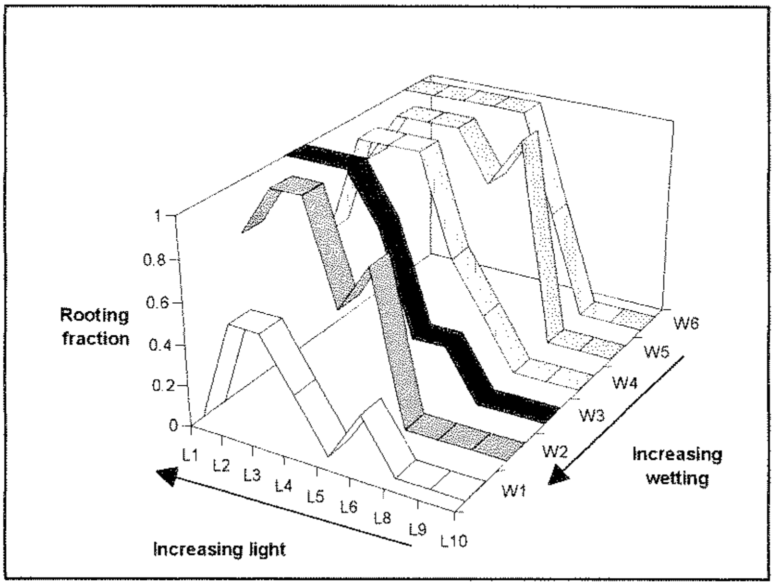


Figure 10. Environmental fingerprint for rooting of *Fremontodendron* 'California Glory' cuttings, inserted on 2 August for six weeks. Statistically significant effects: light ($P<0.001$), and wetting ($P<0.01$) but not the interaction between them.

Figure 11 shows that the numbers of cuttings which had resumed growth by the end of the rooting period was greatest under dry/bright conditions. The effects of wetting and light were highly significant ($P<0.001$) but they were not reflected in the height of the liners at the end of the growing season (Figure 12).

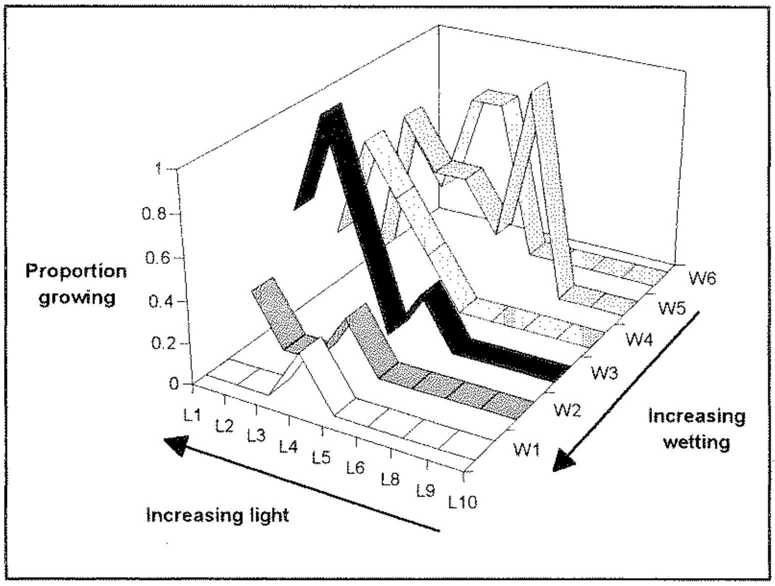


Figure 11. Effect of rooting environment on the proportion of *Fremontodendron* 'California Glory' cuttings that had resumed growth by the end of the rooting period. Statistically significant effects: wetting ($P<0.001$), light ($P<0.001$) but not the interaction between them.

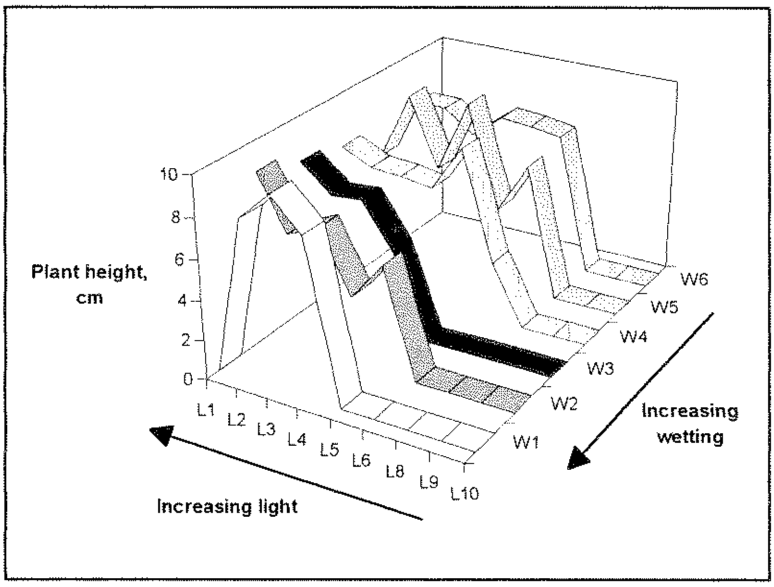


Figure 12. Height of *Fremontodendron* 'California Glory' liners at the end of November, four months after propagation. Points plotted as zero represent locations from which no rooted cuttings were obtained. At this stage there were no significant effects of rooting environment.

Liners potted on into 2 L containers grew rapidly in a well-ventilated polytunnel reaching an average of 120 cm by mid-August. There was no evidence that the environment in which cuttings had rooted had any effect on plant height at this stage, but both the thickness of the main stem and the total length of lateral branches were greatest in plants from the high light zone (Table 18), effects which approached statistical significance (P=0.08). There were on average 13 branches and this was not influenced by any of the treatments.

Table 18. Effects of rooting environment on the vigour of *Fremontodendron* 'California Glory' plants in containers one year after rooting. (- indicates absence of any rooted cuttings)

Wetting zone	Light zone		
	Bright (L1 - L3)	Medium (L4 - L6)	Dim (L8 - L10)
Diameter of base of main stem, mm			
Wet (W1&2)	10.3	9.9	-
Moist (W3&4)	10.7	9.9	-
Dry (W5&6)	10.5	10.4	-
Total length of lateral branches, cm			
Wet (W1&2)	143	138	-
Moist (W3&4)	172	125	-
Dry (W5&6)	174	161	-

Experiment F (Summer 1995): nodal versus internodal cuttings of 'Pacific Sunset'

The favourable drier end of the Agritech fog house was used to compare nodal and internodal cuttings of 'Pacific Sunset'. Cuttings were taken on 2nd August and rooting success was assessed after 6 weeks, using the same non-disruptive method as was used for Experiment E (see above). They were then moved to an even drier part of the fog house to wean for two weeks before transfer to a lightly-shaded well-ventilated polythene tunnel to grow on. Survival and growth were assessed on 24 November.

All the non-nodal and 85% of the nodal cuttings rooted (Table 19), the percentages being almost identical to those observed in 'California Glory' in the same environment (drier fog, + drainage, in Table 17). However many more of these failed to establish, possibly that many cuttings rooted through into the drainage sand during rooting and weaning and these fleshy roots were then broken when the plants were moved. This explanation was suggested by the observation that failures were confined largely to cuttings which were recorded as well-rooted (i.e. which had roots emerging from the base of the pot) six weeks after insertion.

Table 19. Effects of cutting type on rooting and subsequent establishment of *Fremontodendron* 'Pacific Sunset' cuttings rooted in a well-drained medium in the 'drier fog' environment.

	Basal rotting %	Rooting %	Average root score	Establishment %
Nodal	15	85	1.7	50
Non-nodal	0	100	1.8	65

Experiment G (Summer 1996): management after rooting

This experiment was designed to test the suggestion, arising from the results of experiment F, that establishment of rooted cuttings could be jeopardised by breakage of roots which had grown into the drainage sand during rooting or weaning.

Non-nodal cuttings of both 'California Glory' and 'Pacific Sunset' from 1-year-old container-grown plants in an unheated polytunnel were inserted into 9 cm pots of the standard rooting medium on 4 July. They were provided with good drainage in the 'drier fog' environment used in earlier experiments. After 25 days, when 96% of cuttings of both varieties had rooted, they were transferred to a well-ventilated polytunnel. Roots were already emerging through the base of the pots from 51% of 'California Glory' cuttings and 64% of 'Pacific Sunset' cuttings. Rooted cuttings were then divided equally between the following treatments:

1) Control - stood directly on sand bed
2) Early Potting - potted-up into 2 L pots of the same medium and stood on sand bed
3) Air Pruning - pots separated from the sand by an upturned plastic tray
4) Frequent Moving - pots lifted and set down approximately every 2 weeks

Except for the 'Early Potting' treatment, plants remained in 9 cm pots in Empot carriers. Survival and growth were assessed in early November.

In contrast to the previous year, all but one plant survived. The one failure was a 'Pacific Sunset' plant in the 'Early potting' treatment. That plant did not have roots emerging from the pot when moved from the fog house. The reason for the reduction in losses compared to the previous year (Experiment F) is not clear but may be related to the earlier transfer from the fog house to a normal growing environment, with little shade and lower humidity. It was expected that this might cause some losses due to water stress but the comparison with Experiment F suggests that the transfer was tolerated better at this stage, when the first roots had only recently emerged, than after an extended period at high humidity and 20% of ambient light.

Table 20. The effect of growing-on treatment on the development of two *Fremontodendron* varieties.

	Control	Early Potting	Air Pruned	Moved	Mean
Height, cm					
'California Glory'	47.5	71.2	36.3	43.6	49
'Pacific Sunset'	49.6	61.3	36.4	38.0	46
Mean	48.5	66.4	36.4	40.9	
Diameter, mm					
'California Glory'	6.94	9.14	6.31	6.46	7.18
'Pacific Sunset'	6.27	8.15	6.05	5.58	6.48
Mean	6.61	8.66	6.18	6.03	
Lateral Lengths					
'California Glory'	19.4	49.3	9.6	12.5	24.4
'Pacific Sunset'	11.9	39.5	9.0	4.7	17.0
Mean	15.5	44.6	9.3	8.4	
No. of Laterals					
'California Glory'	4.3	7.1	2.6	3.5	4.5
'Pacific Sunset'	4.1	6.6	3.6	2.9	4.4
Mean	4.2	6.9	3.1	3.1	

Statistical probabilities	Height	Diameter	Lateral Lengths	No.of Laterals
Variety	NS	P<0.001	NS	NS
Growing-on Treatment	P<0.001	P<0.001	P<0.001	P<0.001
LSD				
Variety	5.25	0.36	6.78	0.76
Growing-on Treatment	7.44	0.51	9.59	1.07
Within the table	10.52	0.72	13.57	1.51

With respect to growth, 'Early potting' was significantly superior to the 3 other treatments in every respect (Table 20). Disturbing roots that had grown out into the sand, by frequently moving the pots, inhibited all aspects of growth, though only with respect to stem diameter was the effect significant ($P<0.05$). However, the air pruning treatment also inhibited growth compared to the 'Control' plants, the effect on height being significant ($P<0.05$). These results are consistent with growth being restricted by the small root volume in the 9 cm (0.5 L) pots. Cuttings in the Control treatment would have benefitted from an improvement in water supply as a result of roots exploring the sand bed. Plants in the 'Early Potting' treatment would have benefitted additionally from a greater nutrient supply.

The two varieties behaved very similarly, the only significant difference being the greater stem diameter of 'California Glory'.

Conclusions

These experiments have shown that high success rates are readily achievable with *Fremontodendron* cultivars. The key factors for success that were identified were as follows:

- Ensure that the medium is well drained. If possible, place trays on a layer of fine sand to provide positive drainage (i.e. capillary tension drawing water out of the medium at the base of the tray or pot). Otherwise, regulate misting carefully to prevent overwetting.

- Avoid excessive shading. In summer, 25% of outside light proved satisfactory but the environmental fingerprint indicates that as much as 50% would be acceptable if it did not lead to excessively high temperature (e.g. in an open mist system) and humidity/wetting were sufficient to prevent wilting.

- Light wetting of foliage is sufficient to prevent water stress under most conditions. Extremely heavy wetting can reduce rooting.

All the stockplants used in this study were grown in an unheated polythene tunnel to maximise the supply of cutting material. It is likely that the rapid growth achieved under protection also increases the inherent rooting potential of the cuttings, but this was not tested.

Other conclusions were as follows:

- IBA treatment is not necessary.

- The dense layer of hairs on the stem do not need to be removed. (However, the hairs can be irritant and suitable precautions must be taken to minimise this potential health hazard.)

- To minimise production time, wean rapidly to a normal growing environment and grow under protection.

- Single node cuttings, without a node at the base, root well and allow the maximum number of cuttings to be obtained when the availability of stockplants is limited.

- A rooting medium consisting of equal parts of medium Irish moss peat and fine grade Cambark was satisfactory, at least when in contact with a sand bed (see the first key point above).

Part 3: More strategic studies using the G-CPE

This final part of the 'Results and Discussion' section covers the wide range of plants that were tested in the G-CPE with the primary aim of establishing general principles that could be applied to all HNS. The first is a plant that was used as a 'model' difficult-to-root plant in many experiments. Thereafter, 20 other plants are considered in less detail, starting with further difficult-to-root examples and finishing with a few easy-to-root plants.

***Corylus maxima* 'Purpurea'**

This subject was included partly because cuttings are difficult to root and wean, and partly because they have very large leaves, particularly if prepared from the older parts of the shoot, on which leaves are fully expanded. As such, it was an ideal plant with which to examine if the practice of trimming large leaves influences rooting and whether it alters the environment which is optimum for rooting. The difficulties of producing liners from cuttings are such that commercial container production is currently based largely on the field techniques of stooling and layering, rooted shoots being imported from continental Europe.

Cuttings were taken from well-established field hedges at East Malling, which had been severely pruned every year during early spring.

Experiment A: Apical cuttings in June

On 23 June, 1994, apical cuttings were collected and divided into four grades based on leaf size. The average length of the prepared cuttings was 16.1 cm, with a leaf area of 92.9 cm^2 and basal stem diameter of 2.8 mm. Leaf area varied between the grades from 59 to 124 cm^2, with parallel but much smaller variation in length and diameter.

The standard peat:bark medium, without fertilizer, was used. One of each grade of cutting was inserted in each of the 54 locations in the G-CPE, at a spacing of 9 x 9 cm. In addition, 16 cuttings were placed in the fog house, at a moderately wet location about 5 m from the fogger.

After five weeks, cuttings were removed from the rooting medium for detailed assessment of rooting and condition of the cuttings. A few representative cuttings were potted up for preliminary assessment of the effect of rooting environment on subsequent performance of rooted cuttings. These were carefully weaned over the course of a further four weeks, starting in a drier part of the fog house, followed by a mist bed operating under evapostat control, the setting of which was increased every few days until virtually no mist was being applied. They were then moved to an unshaded ventilated polytunnel to grow on.

Figure 13 shows that almost 100% of these cuttings were able to root when given medium-to-heavy wetting combined with medium-to-high light. As wetting diminished, rooting decreased; the decline was most abrupt at hight light (L1 to L3), from 100% in W3 to zero in W5. No cuttings rooted in the driest zone, irrespective of light level. The grade of cutting had no significant effect on rooting, nor did it alter significantly the response to environment.

There was a close parallel between rooting and the amount of basal callus (Figure 14), though most roots emerged through the epidermis rather than from the callus.

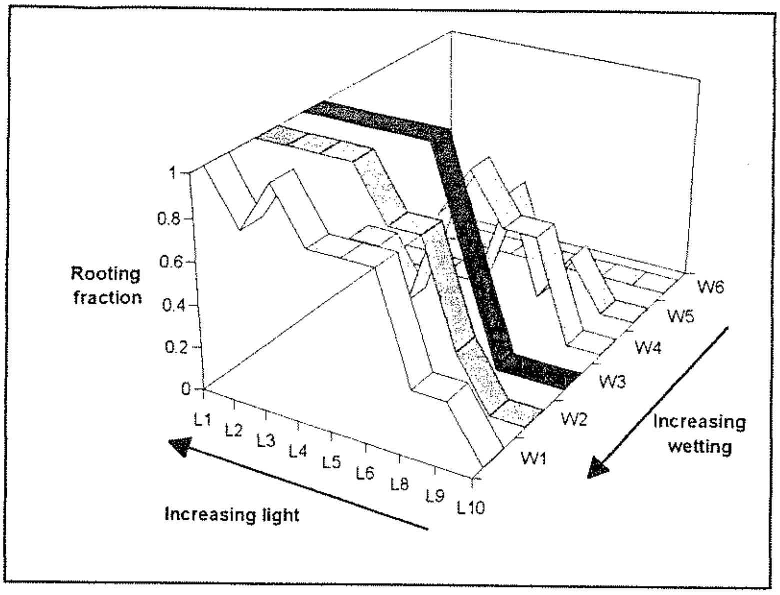


Figure 13 Rooting of *Corylus maxima* 'Purpurea' cuttings inserted on 23 June for 5 weeks. Statistically significant effects: wetting ($P<0.001$), light ($P<0.001$), and the interaction of wetting x light ($P<0.05$).

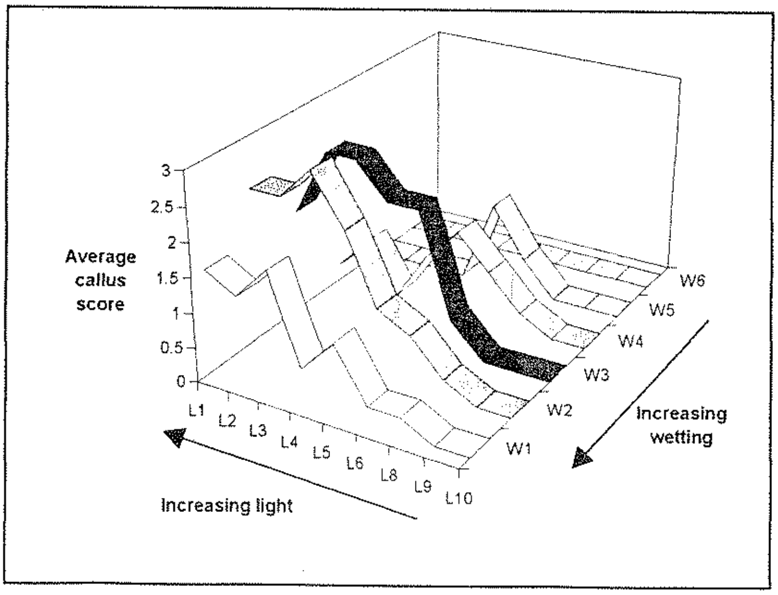


Figure 14 The amount of basal callus on *Corylus maxima* 'Purpurea' cuttings inserted in the G-CPE on 23 June for 5 weeks. A score of 3 = complete ring of callus; 0 = no callus visible. Statistically significant effects: wetting ($P<0.001$), light ($P<0.001$), and the interaction of wetting x light ($P<0.01$).

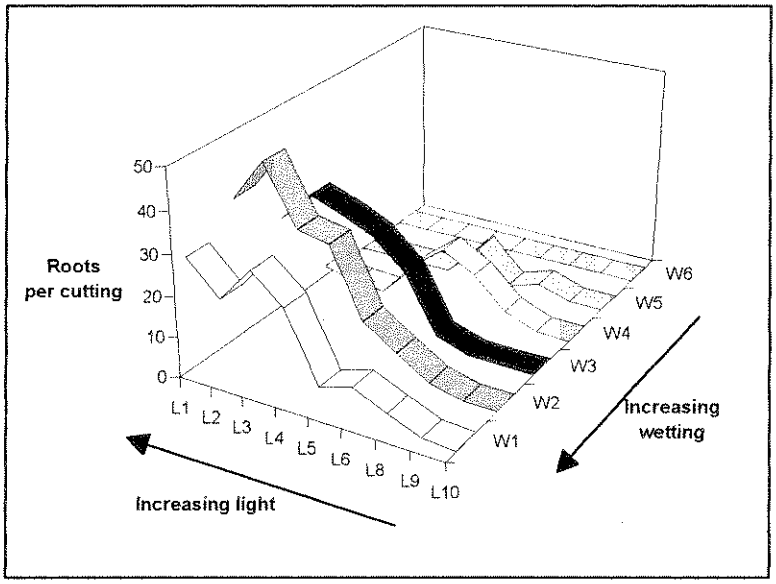


Figure 15 The number of roots per cutting of *Corylus maxima* 'Purpurea' inserted in the G-CPE on 23 June for 5 weeks. Statistically significant effects: wetting (P<0.001), light (P<0.001), and the interaction of wetting x light (P<0.001).

The graph of roots per cutting revealed a similar trend (Figure 15), but when converted to roots per rooted cutting the only significant effect was the increase in root number which resulted from increasing light. There were more than three times as many roots per rooted cutting in the Bright zone as in the Dim zone (Table 21), high light clearly favouring the formation of many roots. Root length was similarly reduced by low light and also by dry conditions (Table 22).

Table 21. Roots per rooted cutting of *Corylus maxima* 'Purpurea' inserted in the G-CPE on 23 June for 5 weeks. Statistically significant effect: Light (P<0.001).

Light zone	Wetting zone			
	Wet	Moist	Dry	Mean
Bright	32.3	23.6	-	27.9
Medium	17.5	18.2	16.0	17.2
Dim	8.3	6.5	10.0	8.3
Mean	19.4	16.1	13.0	

Table 22. Average maximum root length per rooted cutting of *Corylus maxima* 'Purpurea' inserted in the G-CPE on 23 June for 5 weeks. Statistically significant effects: wetting (P=0.05), light (P=0.05), wetting x light interaction (P=0.06).

Light zone	Wetting zone			
	Wet	Moist	Dry	Mean
Bright	9.0	5.6	-	7.7
Medium	6.6	7.5	2.5	6.8
Dim	2.9	3.5	2.5	3.0
Mean	7.6	6.5	2.5	

Most cuttings had a millimetre or more of rotted tissue at the base; although this included many of the rooted cuttings the proportion of cuttings which rotted was highest, and the length of rotted tissue was greatest, in those environments where rooting was least (Figure 16). Basal rotting is often interpreted as a sign that conditions are too wet but this result shows that for this subject it can be a sign that quite the opposite is true.

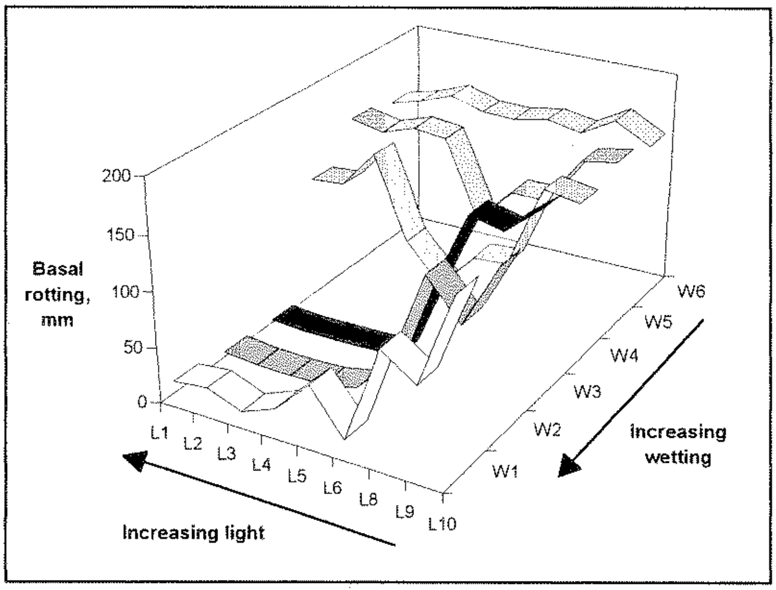


Figure 16. The length of rotted stem on *Corylus maxima* 'Purpurea' cuttings inserted in the G-CPE on 23 June for 5 weeks. Statistically significant effects: wetting ($P<0.001$), light ($P<0.001$), and the interaction of wetting x light ($P<0.001$).

All of the 16 cuttings placed in the fog house rooted, with an average of 21 roots, with a maximum length of 9.1 cm and average callus score of 1.9. This matches closely the performance of the cuttings in the optimum environment within the G-CPE.

A common problem in *Corylus* is abortion of lateral buds such that rooted cuttings are unable to make new shoot growth (Proebsting and Reihs, 1991). This was not observed in these experiments with *Corylus maxima* 'Purpurea', but the shoot tip, together with one or two of the youngest nodes, frequently died and was abscised during rooting. This happened in all environments but the frequency was significantly affected by light and by wetting, being least in those environments where rooting was highest; 67% abscission was observed in the Bright/Wet zone.

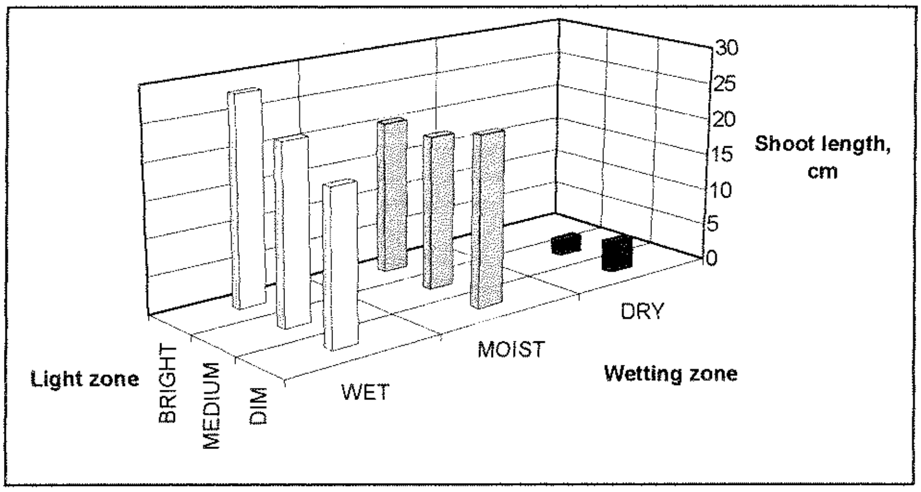


Figure 17. Effect of rooting environment on subsequent growth of rooted cuttings. The graph shows the total shoot length per plant of *Corylus maxima* 'Purpurea' grown from cuttings rooted in the G-CPE (potted-up on 27 July and recorded on 26 October).

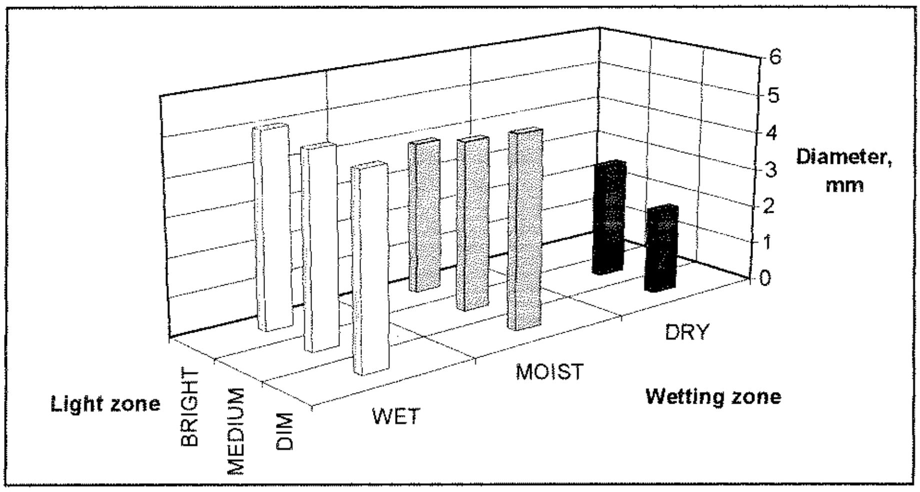


Figure 18. Effect of rooting environment on the subsequent growth of rooted cuttings. The graph shows the average stem diameter recorded on plants of *Corylus maxima* 'Purpurea' grown from cuttings rooted in the G-CPE (potted-up on 27 July and recorded on 26 October).

Effect on growth after rooting

Towards the end of October, the size of the plants that had grown from a subsample of rooted cuttings was recorded. The adverse effect of dry conditions during rooting was still evident, both in terms of shoot length (Figure 17), and the thickness of the main stem (Figure 18), whereas there was little evidence of any effect of low light level during rooting on the subsequent growth of those cuttings that rooted.

Experiment B: Apical and proximal cuttings in August

By early August shoots on the hedge had grown to 80 cm long and a second experiment was carried out to compare the environmental needs of cuttings prepared from different parts of the same shoots. On 8 August shoots were collected and three types of cuttings prepared as follows:

Apical - similar to those in Experiment A, with 3 to 5 leaves most of which were still expanding. Spaced at 9 x 9 cm.

Trimmed proximal - prepared from immediately below the apical cuttings, with much more heavily lignified stem and two large fully-expanded leaves which were trimmed to one third of their original size. Spaced at 9 x 9 cm.

Non-trimmed proximal - As above except that leaves were not trimmed and planting density was halved by spacing at 9 x 18 cm. The number of cuttings per location was also reduced from four to two because of shortage of material.

The morphological differences between the types of cuttings are summarised in Table 23. The apical cuttings were on average a little larger than those in the earlier experiment, both in terms of length and leaf area.

Table 23. Measurements made on a sample of 12 cuttings of three different types.

	Apical	Non-trimmed proximal	Trimmed proximal
Stem length, cm	19.3	15.5	15.4
Stem diameter, mm	2.9	4.1	4.1
Leaf number	3.9	2.0	2.0
Leaf area, cm^2	111	249	91
Specific leaf area, cm^2 g^{-1}	202	196	174
Stem dry weight, g	0.291	0.650	0.610

The severity of wilting was recorded at 1, 2, 8, and 29 days after insertion. Detailed records of rooting and other measurements were commenced on 15 September, 37 days after insertion.

Effect of time of propagation

Figure 19 shows that the response of the apical cuttings was broadly similar to that observed in cuttings propagated seven weeks earlier, with the best rooting achieved where medium to high light (L6 to L1) was combined with heavy wetting (W3 to W1). The number of roots per rooted cutting was significantly greater than in the earlier propagated cuttings (P<0.001), averaging 22.9 compared with 16.4. Once again light strongly promoted root numbers (Table 24). There was also a significant but smaller increase in average maximum root length (P<0.05). These increases may be partly attributable to the rooting period being three days longer in this experiment.

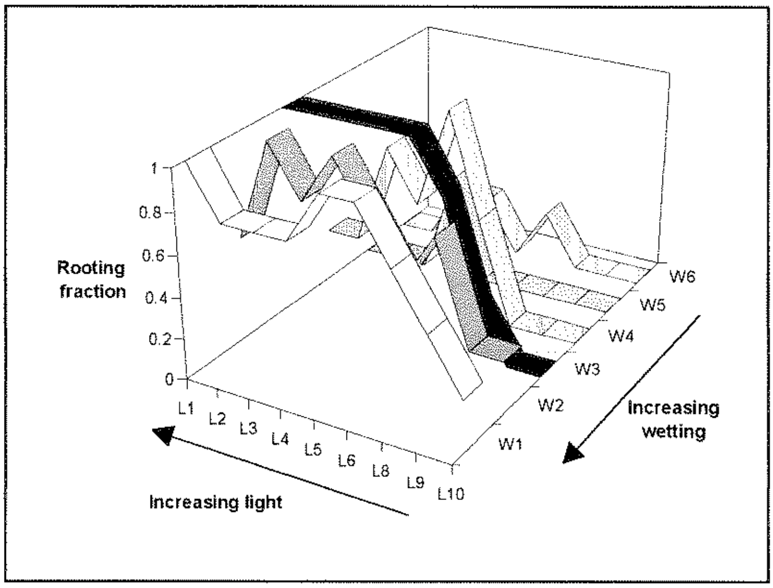


Figure 19 Rooting of *Corylus maxima* 'Purpurea' apical cuttings inserted on 8 August for 5 weeks. Statistically significant effects: wetting (P<0.001), light (P<0.001).

Table 24. Effect of propagation date on the number of roots per rooted cutting of *Corylus maxima* 'Purpurea' in the G-CPE environments. Statistically significant effects: light ($P<0.001$) and date ($P<0.001$).

Light zone	Wetting zone			
	Wet	Moist	Dry	Mean
		Inserted 23 June		
Bright	32.3	23.6	-	27.9
Medium	17.5	18.2	16.0	17.2
Dim	8.3	6.5	10.0	8.3
Mean	19.4	16.1	13.0	16.4
		Inserted 8 August		
Bright	39.5	41.2	5.0	28.6
Medium	29.3	29.4	22.0	26.9
Dim	9.2	8.0	-	8.6
Mean	26.0	26.2	13.5	22.9

Effect of type of cutting

The environmental fingerprint for the trimmed proximal cuttings (Figure 20) shows that the optimum environment for this type of cutting is substantially drier than for apical cuttings (Figure 19), with rooting suppressed strongly by heavy wetting (W1 and W2). The comparison between the types is perhaps more easily seen in the simplified presentation of Figure 21, which also includes the results for the non-trimmed proximal cuttings. The latter were more tolerant of wet conditions but no less tolerant of dry conditions.

The differences in rooting under drier conditions reflect differences in water stress, as judged by the severity of wilting. Wilting was already evident in the more desiccating locations (i.e. high light / little wetting) when the lights came on at the beginning of the first day after insertion. By the second day, apical and non-trimmed proximal cuttings were clearly wilting more severely than the trimmed proximals in the area W4-W6 x L1-L3. By the eighth day, all leaves in W5-W6 x L1-L3 area (i.e. the Bright/Dry zone) were either completely flaccid or shrivelled and crisp, irrespective of type of cutting, whereas in W4, the proximal cuttings were markedly less wilted at high light than the apical cuttings. Similarly, in W3 slight wilting was evident in the apicals only. By the 29th day, most cuttings in the Bright/Dry zone had defoliated completely, though a few lateral buds were breaking.

Under optimal conditions, rooting percentage of all three types of cuttings was similar, at about 80%, but there were more than twice as many roots on the apical cuttings as on the proximal cuttings, irrespective of whether leaves were trimmed (Figure 22). By contrast, the length of roots did not differ consistently between the types of cutting.

There were also significant differences between the types of cutting in both the amount of basal rotting and the way it varied in response to environment (Figure 23). Fewer proximal cuttings rotted completely so that the average length of rotted tissue was smaller.

The decline in rooting in the wettest zones was matched by an increase in rotting. Leaf trimming generally increased the proportion of cuttings with some basal rotting except in the Bright/Dry zone, probably because it suffered less stress as a result of its reduced leaf area, as indicated earlier.

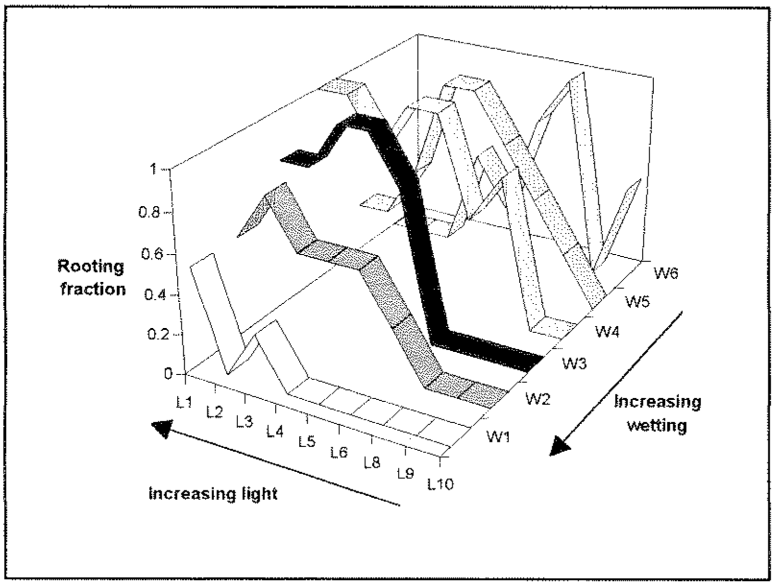


Figure 20 Rooting of trimmed proximal cuttings of *Corylus maxima* 'Purpurea' inserted on 8 August for 5 weeks. Statistically significant effects: wetting (P<0.001), light (P<0.001) and the interaction of wetting x light (P<0.001).

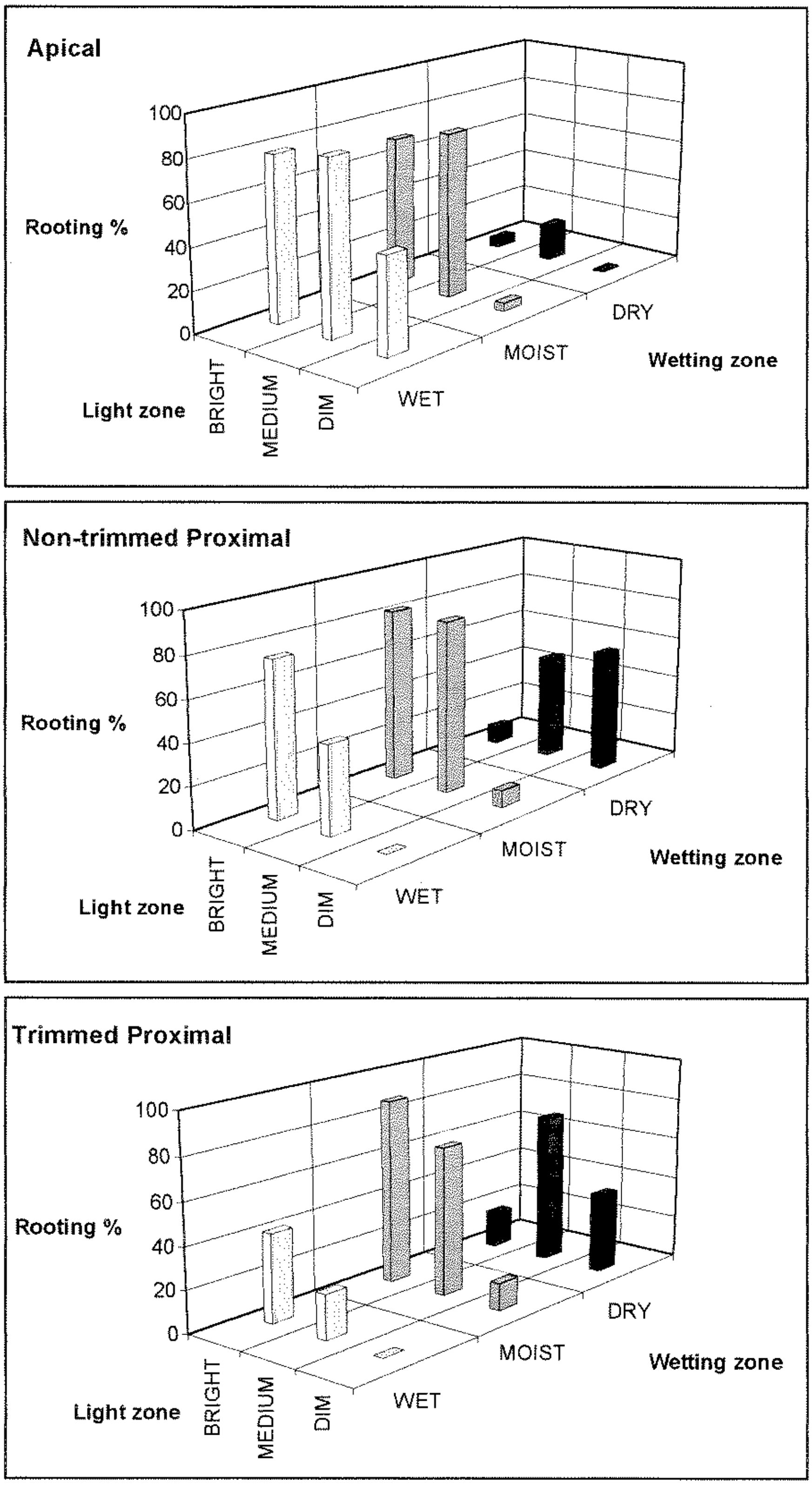


Figure 21. The response of rooting to environment in different types of cutting of *Corylus maxima* 'Purpurea' inserted on 9 August. Statistically significant effects: wetting ($P<0.001$), light ($P<0.001$), and the interactions of wetting x light ($P<0.001$) and wetting x cutting type ($P<0.001$).

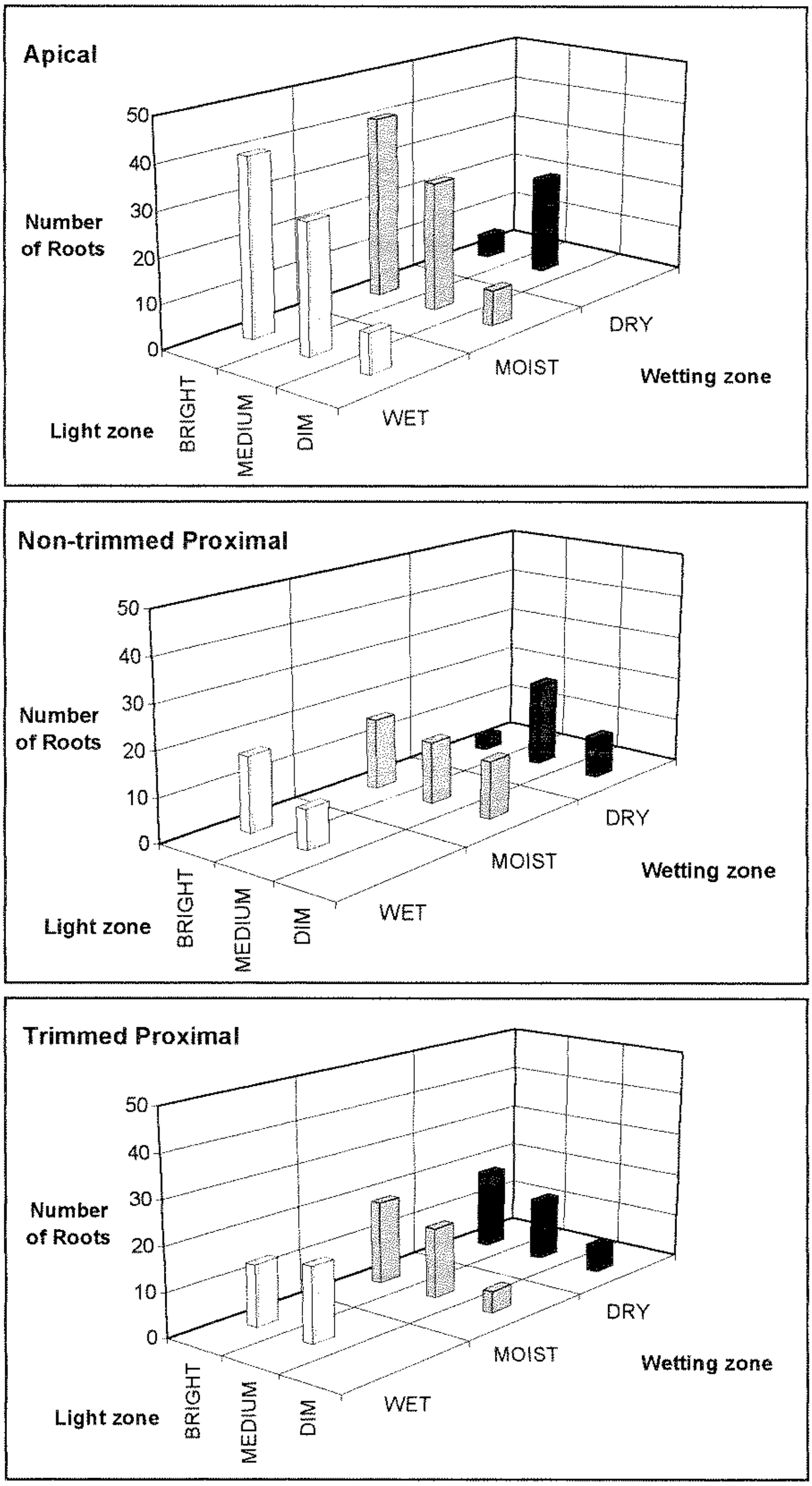


Figure 22. The effect of environment and type of cutting on the number of roots per rooted cutting in *Corylus maxima* 'Purpurea' inserted on 9 August. Statistically significant effects: wetting ($P<0.001$), light ($P<0.001$), and cutting type ($P<0.001$). The interaction of light x type was close to significant ($P=0.06$).

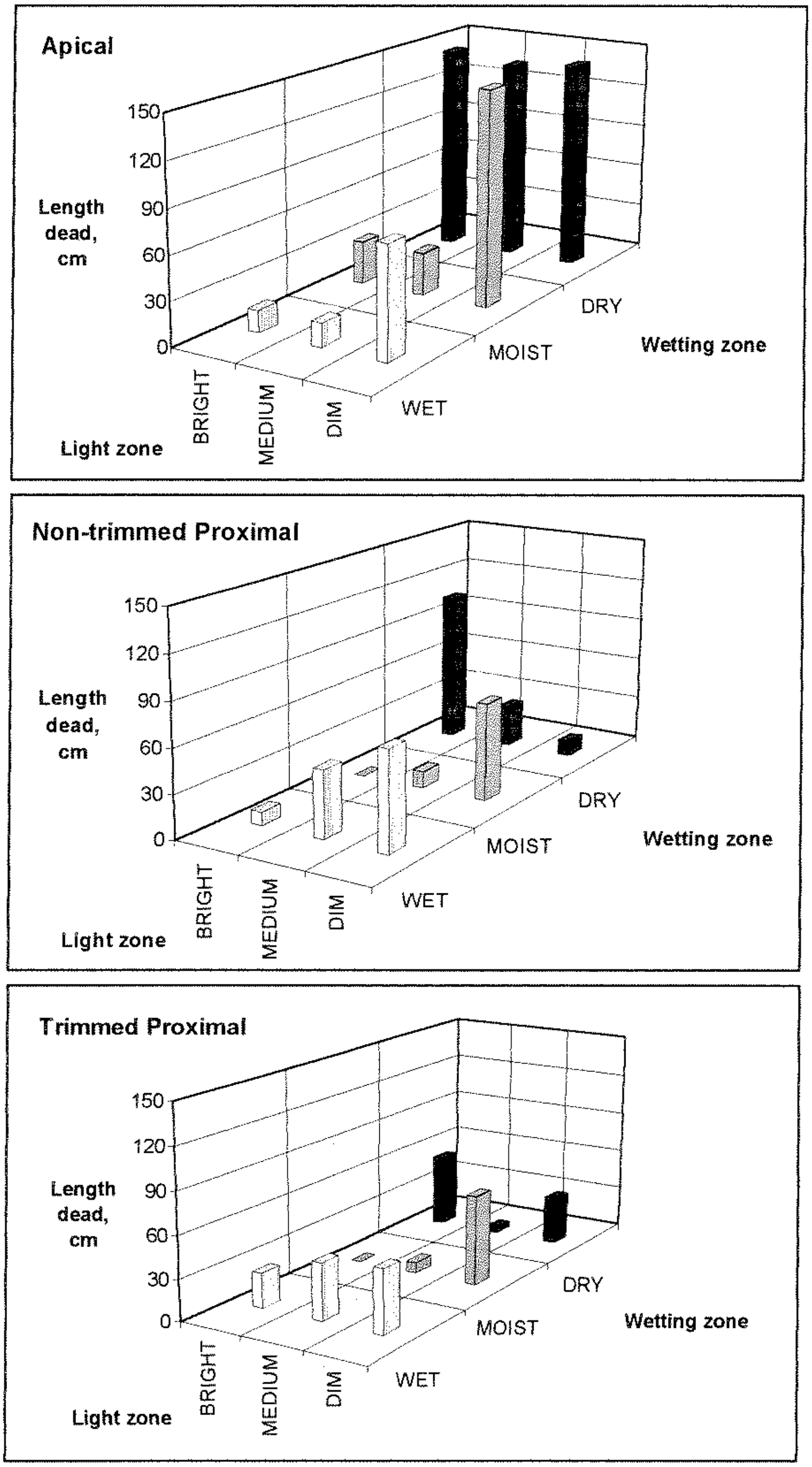


Figure 23. The effect of environment and type of cutting on basal rotting in *Corylus maxima* 'Purpurea' cuttings inserted on 9 August. Statistically significant effects: wetting ($P<0.001$), light ($P<0.001$), cutting type ($P<0.001$) and their interactions ($P<0.001$).

Experiment C: Effect of wetting the rooting medium in comparison with wetting the leaves

This experiment, which was run in parallel with Experiment B, examined whether rewetting of the rooting medium is an important component of the benefit of heavy wetting, for subjects such as *Corylus maxima*. The ability of the medium to maintain the maximum rate of uptake through the base of the cutting depends on maintenance of a high water content close to the point of uptake (Thomas and Harrison-Murray, 1995). If capillary movement of water from the surrounding medium is not sufficiently rapid to avoid local depletion of water content around the base of the cutting, then water deposited on the surface of medium, percolating downward under gravity, could substantially enhance the water status of cuttings. Water may reach the medium directly but in many cases will instead run off leaves and trickle down the stem ('stem flow'). To simulate this, drip irrigation nozzles were used to apply a few drops of water very close to the cuttings every 30 minutes, 24 h/day. The amount applied was equivalent to the water deposition in wetting zone W1 to W2, and thus stimulated the extreme situation in which **all water** deposited runs off the leaves as stem flow. For further details refer to the Materials and Methods section.

The experiment used apical cuttings identical to those in Experiment B and propagated on the same day. The dripper-irrigated pots were placed in three of the gaps between the main wetting zones (between W1 and W2, W3 and W4, W5 and W6). Within each pot, two cuttings were close to a dripper (referred to as 'direct-drip' treatment) while 2 were not ('indirect-drip').

Irrigation had no visible effect on the early stages of wilting but the direct-drip treatment appeared to reduce the severity of wilting in the driest conditions so that fewer cuttings collapsed completely. The direct-drip treatment also brought about a modest increase in rooting, and decrease in rotting, compared to non-irrigated cuttings in the same pots (i.e. indirect-drip, Table 25) and these effects were statistically significant ($P<0.05$). Table 25 also includes the results for cuttings in separate non-irrigated pots.

Table 25. Effect of drip irrigation on rooting and rotting of *Corylus maxima* 'Purpurea' apical cuttings. Irrigated cuttings were either very close to a dripper ('direct-drip') or not ('indirect-drip'). Results are averaged across light zones (n = 6 for irrigated treatments, n = 24 for non-irrigated).

	Treatment		
Wetting zone	Direct-drip	Indirect-drip	No drip
% rooting			
Wet	61	39	69
Moist	67	44	51
Dry	22	6	7
Length of stem rotted, mm			
Wet	75	104	36
Moist	52	72	69
Dry	108	137	141

The apparent suppression of rooting in the 'indirect-drip' cuttings probably reflects random variation in small samples of cuttings but might have resulted from the practical necessity of placing the irrigated pots in a more exposed position in the gaps between two wetting zones to provide access to the irrigation pipework. What is quite clear is that even direct-drip irrigation of cuttings in the dry zone was much less effective in preventing wilting and allowing cuttings to root than a similar amount of water applied as fog (i.e. compared to non-irrigated cuttings in the wet zone). From this result it can be concluded that the benefit of heavy wetting in protecting subjects such as *Corylus* from water stress, is mainly due to leaf wetting rather than wetting the medium.

Good contact with 10 cm of drainage sand ensured that drip irrigation would not cause waterlogging. The water content of the medium was determined by measuring the weight loss following oven drying. In the drip irrigated pots it averaged 45% (v/v), compared to 37% in the non-irrigated pots. Even in the wettest pots, the air content was never below 36% (v/v).

Experiment D: Effect of rooting environment on subsequent plant performance

As in Experiment B, the effect of environment on different types of cutting was examined but the emphasis in this case was towards effects on the performance after rooting: firstly in weaning, establishment and development to the liner stage, and secondly as plants in containers the following year. To this end, cuttings were inserted singly into the cells of

QP24 trays and roots were not disturbed to record root development. Instead, rooting was assessed on a scale of 0 to 3 by testing whether cuttings were firmly anchored in the medium and observing the length of any roots emerging from the base of the cell. Other details were as follows:

Cuttings inserted:	12 July, 1995
Time in the G-CPE:	44 days
Types of cutting:	Apical ± leaf trimming (to ⅓ of original size) Proximal ± leaf trimming (to ⅓ of original size)
Replication:	2 cuttings of each type per location
Spacing:	9 x 9 cm approximately, for all types of cutting
Weaning:	Open mist in a polytunnel shaded to ca. 20% of outside light, controlled by evapostat the set point of which was raised progressively over 24 days.
Overwintered:	In a polytunnel with base heating to provide frost protection to the roots (thermostat setting 2 °C)
Growing on:	Surviving cuttings were potted on into 2 L containers on 10 April, 1996. The medium was 70:30 Peat : Bark (medium grade sphagnum peat : Cambark 100) with 3 kg m^{-3} Ficote 180 16-10-10 controlled release fertiliser, 1 kg m^{-3} magnesian limestone, 300 g m^{-3} fritted trace elements (WM255). Plants were moved outside on 13 May, initially watered by hand, later capillary irrigated on sandbeds. Plants were spaced at 25 x 25 cm, using Empot carriers to stabilise them.

The morphological differences between the types of cutting are summarised in Table 26.

Table 26. Measurements made on a sample of 6 cuttings of each type.

	Apical		Proximal	
	Non-trimmed	Trimmed	Non-trimmed	Trimmed
Stem length, cm	22.8	21.7	12.3	11.3
Stem diameter, mm	3.1	3.3	3.7	4.0
Stem dry weight, g	0.328	0.343	0.429	0.429
Leaf number	4.3	4.0	2.0	2.0
Leaf area, cm^2	109	33	216	69
Specific leaf area , cm^2 g^{-1}	222	129	196	172

Rooting and weaning

The effects of environment on rooting percentage, were similar to those observed in the earlier experiments and this was reflected broadly in the numbers of cuttings surviving weaning and subsequent establishment. However, some of the cuttings originally recorded as non-rooted at the time of transfer to the weaning mist system (i.e., that did not seem firmly anchored in the medium) were alive at the end of weaning. This suggests that some cuttings had rooted during the early stages of weaning. This was most frequent in the trimmed apical cuttings (8%), and the proximal cuttings (5%). It was associated with zones where rooting was already high, suggesting that some cuttings required more time to root, rather than that the conditions in the weaning facility were more favourable for rooting.

In view of the slight uncertainty associated with estimates of rooting percentage based on how firmly cuttings seem to be anchored in the rooting medium, the percentage of cuttings alive at the end of the weaning process is presented instead (Figure 24). The combination of high light and intermediate wetting (i.e. the Bright / Moist zone) was satisfactory for all types of cutting, success rates varying from 92 to 100%. Outside this zone, success rates with proximal cuttings declined more than with apical cuttings, particularly in response to additional wetting. In the more favourable environmental zones, trimming of leaves reduced subsequent rooting, especially in proximal cuttings (Figure 25). By reducing the leaf area per cutting, trimming might be expected to make cuttings more tolerant of dry conditions, and there is some evidence that this was the case, especially in apical cuttings. However, it reduced substantially the tolerance of heavy wetting by proximal cuttings (Figure 24).

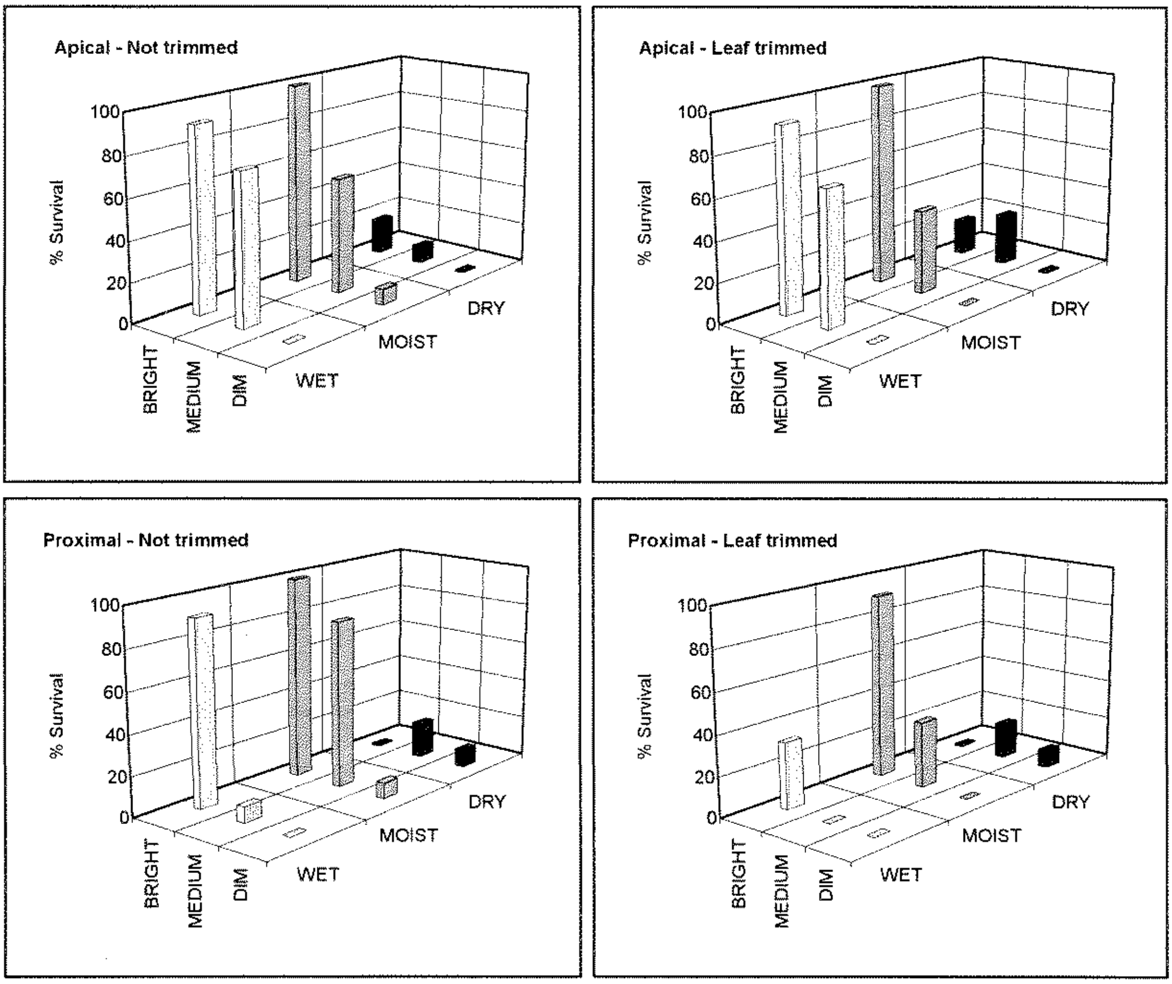


Figure 24. Effects of type of cutting and leaf trimming on the environmental response of *Corylus maxima* 'Purpurea' cuttings inserted on 12 July. Plotted values are the percentage of cuttings which had rooted and also survived weaning to a normal growing environment. Statistically significant effects: wetting (P<0.001), light (P<0.001), type of cutting (P<0.01), leaf trimming (P<0.05), and the interactions of wetting x light (P<0.001), wetting x type (P<0.001), wetting x leaf trimming (P<0.05).

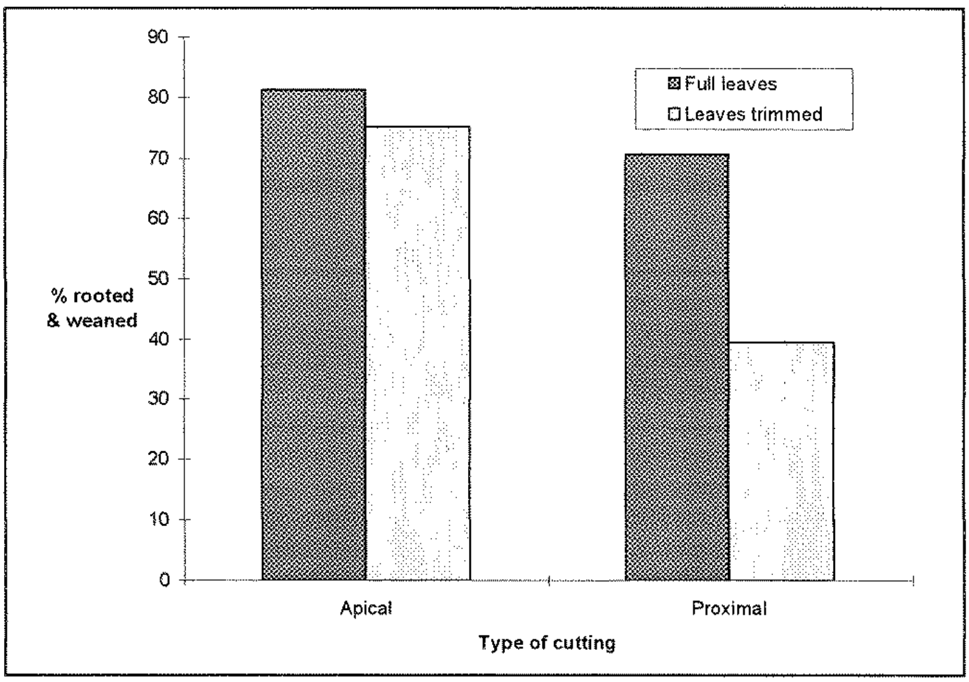
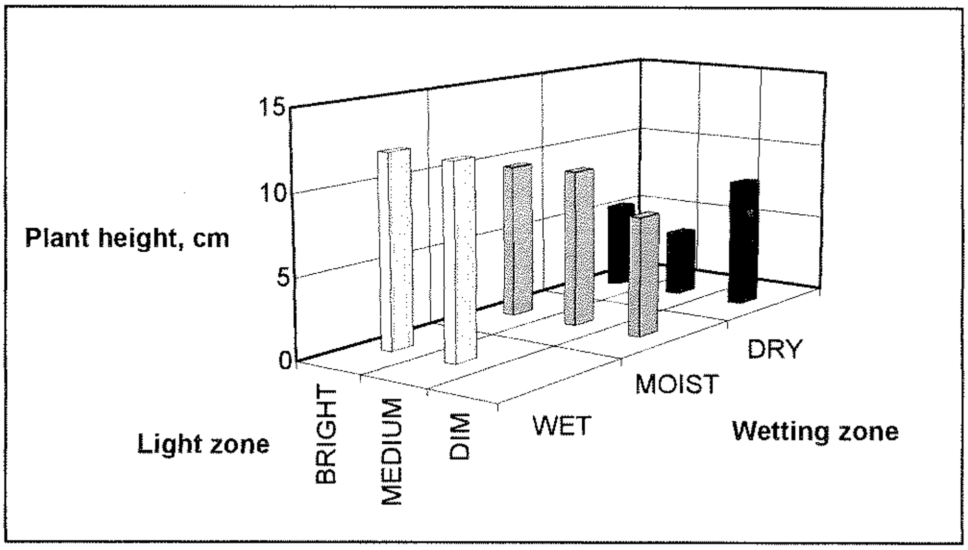


Figure 25. Effects of type of cutting, and trimming leaves by two thirds, on the percentage of *Corylus maxima* 'Purpurea' cuttings successfully rooted and weaned. The values shown are averaged over the four environmental zones that supported the highest rooting percentages (i.e. excluding all 'Dim' and 'Dry' zones).

Quality of liners

Measurements at the liner stage, made in January 1996, showed significant effects of the environment in which they had been rooted. Both the height of the plants and the thickness of stem increased with increasing wetting (Figure 26). Leaf trimming also significantly reduced diameter ($P<0.001$), and the original differences in the length and diameter of the stem, between apical and proximal cuttings, were still evident.



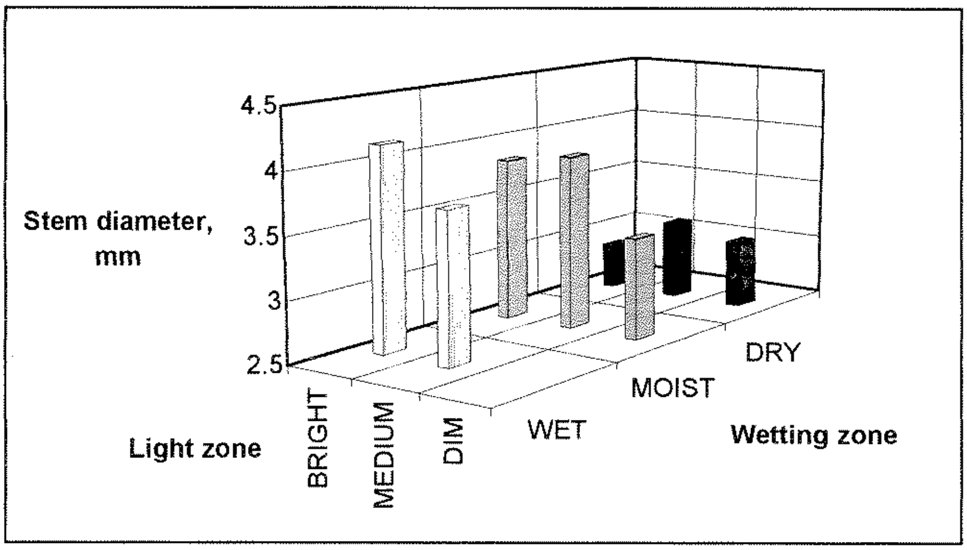


Figure 26. Effects of the environment in which cuttings of *Corylus maxima* 'Purpurea' were rooted on the size of the resulting liners six months later. Plotted values of plant height and stem diameter are averages over the four types of cutting combined. Statistically significant effects: wetting on height and diameter ($P<0.001$).

Quality of final plant

The plants grew well and by mid August had reached an average height of 98 cm but, even at this stage, effects of rooting environment were still clearly distinguishable.

Stem thickness increased significantly with light level, from 7.4 mm in plants originating from the 'Dim' zone, to 11.5 mm in those from the 'Bright' zone ($P<0.001$).

The number of lateral branches averaged 2.25 and increased significantly with wetting level, from 0.8 in the 'Dry' zone to 2.7 in the 'Wet' zone (Figure 27). Apical cuttings were significantly more branched than proximals, having on average 2.7 and 1.7 branches respectively ($P<0.01$). The best branched plants were from apical cuttings which had been rooted in the Bright / Wet zone, which averaged 3.5 branches per plant.

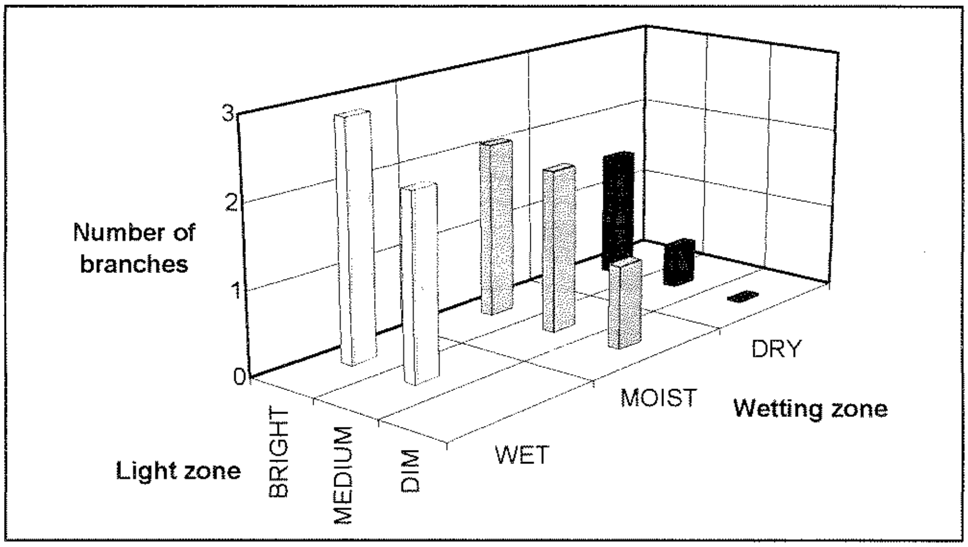


Figure 27. Effects of the environment in which cuttings of *Corylus maxima* 'Purpurea' were rooted on the number of branches on container plants 11 months later. Plotted values are averages over the four types of cutting combined. The effect of wetting but not of light was significant ($P<0.01$).

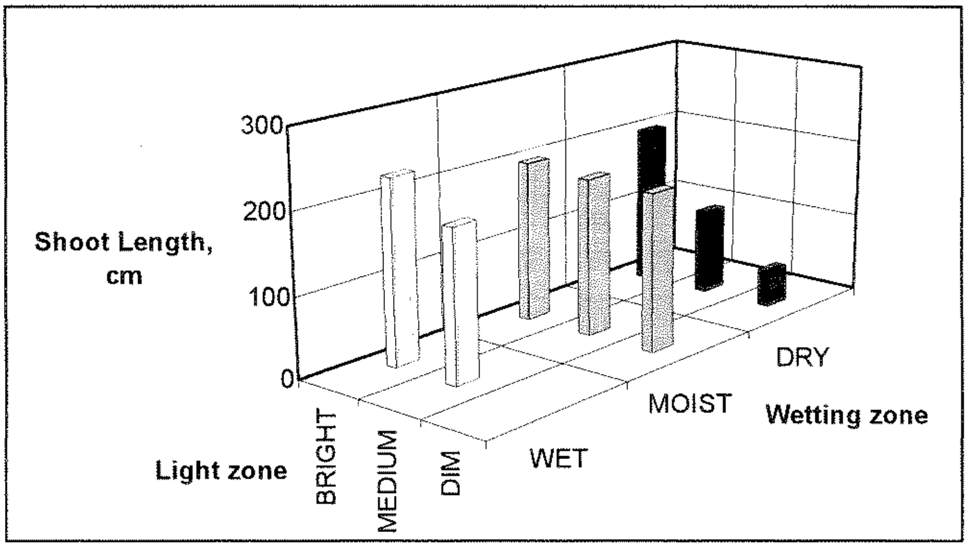


Figure 28 Effects of the environment in which cuttings of *Corylus maxima* 'Purpurea' were rooted on the total length of shoots per plant 11 months later. Plotted values are averages over the four types of cutting combined. Statistically significant effects: wetting ($P<0.01$) and light ($P=0.001$).

These effects on the number of branches, together with effects on the vigour of growth of individual shoots, led to variation in total shoot length (i.e. main stem and primary branches) ranging from 47 to 290 cm amongst means for individual treatment combinations. The significant effects of light and wetting are shown in Figure 28. There was also significantly greater shoot length on plants from apical cuttings than on plants from proximal cuttings, related to the difference in number of branches which was referred to earlier.

Discussion and conclusions

These results show that the main difficulty in producing *C. maxima* 'Purpurea' from leafy cuttings, as is the case with many difficult-to-root plants, is in providing the appropriate rooting environment. Almost 100% of apical cuttings rooted in the Bright / Wet zone of the G-CPE whether propagated in June or August, and similar success has been achieved previously in the wetter parts of the fog house. Sensitivity to water stress is such that high humidity is virtually essential - suppressing transpiration sufficiently by heavy wetting alone, which would be equivalent in its effect to light wetting at high humidity in the G-CPE, is barely sufficient and reduces the maximum light level that is acceptable. Therefore, success using open mist would depend on carefully controlled shade in order to limit water stress during fine weather while allowing sufficient light for rooting to reach cuttings during cloudy weather.

Weaning the rooted cuttings is also difficult and the weaning method used in this work (i.e. progressive increase in evaporative demand under evapostat-controlled mist) was developed in a previous project (Harrison-Murray *et al.*, 1996).

The response to rooting environment of non-apical cuttings from the woodier parts of long shoots ('proximal cuttings') was different from that of apical cuttings. They were tolerant of slightly drier conditions and, particularly if the large leaves were trimmed, were adversely affected by heavy wetting (Figure 21). However, the difference was not large enough to present a reliable basis for propagation using a less supportive environment such as open mist. Also, such cuttings resulted in less branched plants, eroding one of the potential advantages of cuttings compared with the use of layering/stooling.

Trimming leaves to reduce the leaf area of cuttings by two thirds slightly increased the tolerance of dry conditions during rooting but made the cuttings substantially more sensitive to overwetting (Figure 21). As a result, over a range of reasonably supportive rooting environments, leaf trimming reduced rooting (Figure 25). Leaf trimming also reduced growth after rooting leading to significantly thinner liners (Experiment D). These results suggest that the main benefit of leaf trimming is to allow closer planting of cuttings and, when propagation space allows, it is better not to trim.

The result of Experiment C showed that a small proportion of the benefit of wetting evident in the G-CPE may be attributable to rewetting of the medium, which would be expected to reduce the development of locally drier zones around the base of the cuttings and thus facilitate water uptake. This effect is likely to be particularly important when transpiration rate is relatively high despite heavy wetting. This could apply, for instance, to an open mist system, when transpiration is enhanced by low humidity air moving around the cuttings between mist bursts. However, it is likely that in most situations the benefit of wetting is due mainly to wetting of the foliage.

Experiment D provided important evidence that the benefits of optimising rooting environment go well beyond improved rooting percentage. It showed that cuttings rooted in the most favourable environments went on to produce significantly better quality plants than cuttings rooted under conditions which were marginal for rooting (Figures 27 and 28).

In conclusion, the results provide the basis for successful propagation of *C. maxima* 'Purpurea' from cuttings and have also revealed a number of principles that are likely to apply to many other water-stress-sensitive difficult-to-root plants.

Acer cappadocicum **'Rubrum'**

This subject was included in the G-CPE experiments as an example of a difficult-to-root plant with medium sized leaves, no hairs, and latex in the stems. Very soft cuttings were collected from a well-established stock hedge at East Malling. Other details were as follows:

Cuttings inserted:	14 June, 1996.
Time in G-CPE:	34 days.
Types of cutting:	Apical cuttings divided into four grades on the basis of length and stem diameter. The differences amongst the grades are summarised in Table 27.
Replication:	One cutting of each grade per location.
Spacing:	9 x 9 cm in QP24 trays.
Additional environment:	Moderately wet part of the fog house, at about 8 m from the fogger, which was used to compare nodal with internodal cuttings

Table 27. Measurements on a sample of 6 cuttings of each grade.

	Grade				
	Short Thin	Short Thick	Long Thin	Long Thick	Mean
Length, cm	9.3	8.9	12.5	12.9	10.9
Diameter, mm	2.56	2.88	3.00	3.34	2.95
Number of leaves	4.0	4.7	5.0	5.7	4.8
Leaf area, cm^2	52.2	76.6	75.1	100.2	76.0

The results in Figure 29 show that rooting percentage tended to increase as wetting increased and only reached 100% at the heaviest level of wetting (W1). Trends are less clear with respect to light; whilst there was no rooting at the lowest light levels, there was no indication that increasing irradiance above that in L5 stimulated additional rooting, even at the heaviest levels of wetting. However, when root number is also taken into account, there is some evidence that root initiation was slightly stimulated by additional light (Figure 30).

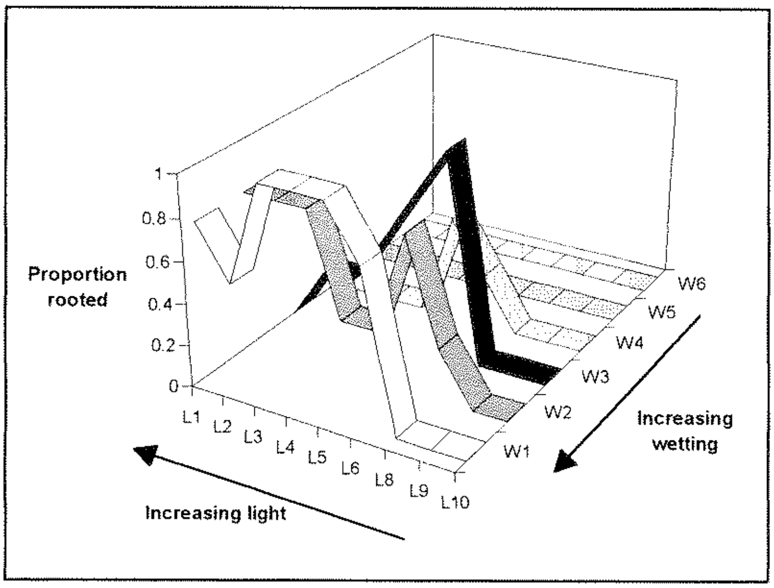


Figure 29. Rooting of *Acer cappadocicum* 'Rubrum' cuttings inserted on 14 June for 5 weeks. Statistically significant effects: light ($P<0.001$), wetting ($P<0.001$) but not the interaction of wetting x light.

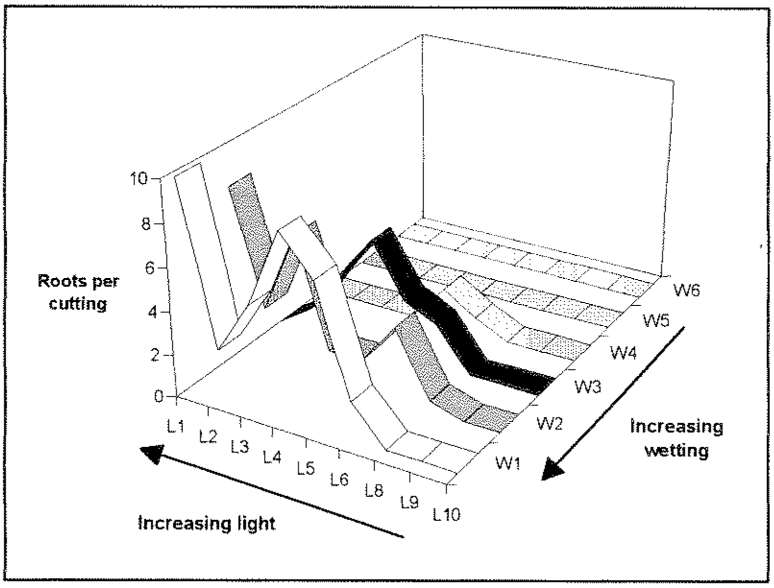


Figure 30. The number of roots per *Acer cappadocicum* 'Rubrum' cutting inserted on 14 June for 5 weeks. Statistically significant effects: light ($P<0.001$), wetting ($P<0.001$) and the interaction of wetting x light ($P<0.001$).

Very few cuttings showed any callus development and most cuttings suffered some rotting at the base of the stem, even amongst those that rooted. At the lowest levels of both light and wetting, virtually all cuttings were severely rotted (Figure 31). Most of this was due to collapse of the foliage, followed by infection with *Botrytis* which then invaded the whole cutting.

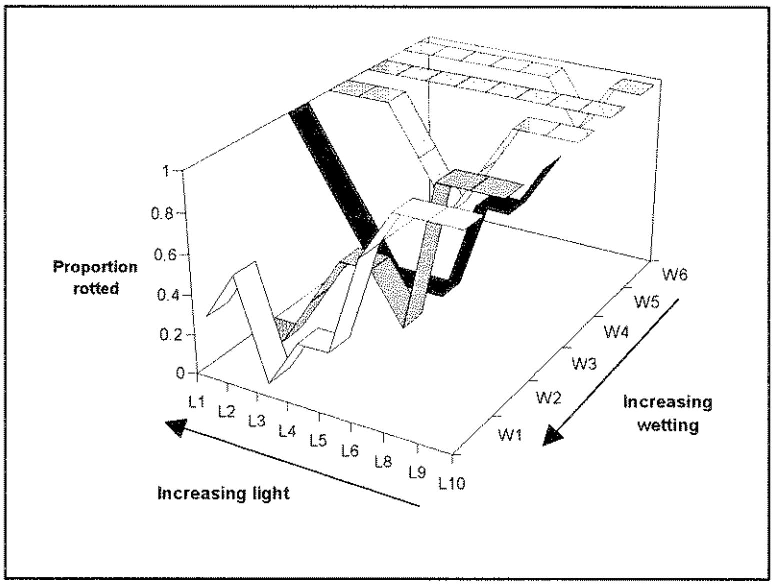


Figure 31. The frequency of rotting (>5 mm of stem) in *Acer cappadocicum* 'Rubrum' cutting inserted on 14 June for 5 weeks. Statistically significant effects: light ($P<0.001$), wetting ($P<0.001$) and the interaction of wetting x light ($P<0.001$).

Cuttings in the fog house

Out of the few spare cuttings available, eight were prepared to a node as in the main experiment, and of these 75% rooted. This is consistent with the results achieved in the Bright / Wet and Medium / Wet zones in the G-CPE.

Out of four cuttings prepared with the basal cut in the middle of an internode, two rooted and rotting was no more severe than in the nodal cuttings. This is an extremely small sample but the result is of interest because *A. cappadocicum* has very long internodes which make it impossible to prepare nodal cuttings to a consistent size. The result indicates that the presence of a node at the base is not essential and the use of internodal cuttings is worthy of further examination.

Cutting size

No significant differences in rooting or rotting amongst the four grades of cutting were detected.

Discussion

These results indicate that a high percentage of very soft cuttings of *A. cappadocicum* 'Rubrum' can be rooted given a combination of high humidity, generous wetting and moderate to high light level. Excessive shade (i.e. more than about 80%) could prevent rooting if combined with a period of dull weather but high light levels appear to be of little benefit for this subject and increases the need for heavy wetting.

It is not essential to prepare cuttings to a node, but further work is required before the use of internodal cuttings could be recommended.

***Cotinus coggygria* 'Royal Purple'**

Cotinus coggygria 'Royal Purple' is one of a number of popular red-leaved cultivars of this species that are moderately difficult to propagate and grow well. As such it has featured in previous projects and it was therefore of interest to see how its response to the range of environments in the G-CPE would relate to our experience of its performance in conventional propagation facilities.

Cuttings inserted:	17 June, 1994.
Time in the G-CPE:	34 days.
Types of cutting:	Apical cuttings, with about 4 well-expanded leaves (>2.5 cm width).
Replication:	4 cuttings per location.
Spacing:	9 x 9 cm in pots (4 cuttings per 11 x 11 cm pot)
Additional environment:	Moderately wet location in the fog house (about 8 m from the fogger).

There was not sufficient variation in the material to justify use of separate grades. Table 28 provides further detail of the size of the cuttings.

Table 28. Measurements on a sample of 12 cuttings

Length, cm	15.4
Diameter, mm	3.50
Number of leaves	12.9
Leaf area, cm^2	70.7

It can be seen from Figure 32 that all cuttings were able to root within a narrow range of environmental conditions, in which heavy wetting was combined with moderate to high light. Some cuttings rooted at lower irradiance and/or with less wetting. When high light was combined with little or no wetting, none of the cuttings rooted. These were the conditions in which cuttings visibly wilted within the first few days after insertion.

Additional light increased substantially the number of roots per rooted cutting (Figure 33), but not their length (Figure 34). Added wetting increased both root number and length.

None of the cuttings had visible callus, and almost all showed some browning of the tissue immediately adjacent to the basal cut. It was only at low light that rotting was extensive (Figure 35).

The shoot tip was not pinched out during preparation of the cuttings but in many cuttings it rotted or abscised. The proportion of tips lost in this way was significantly increased at low light ($P<0.05$) but not by heavy wetting (data not shown).

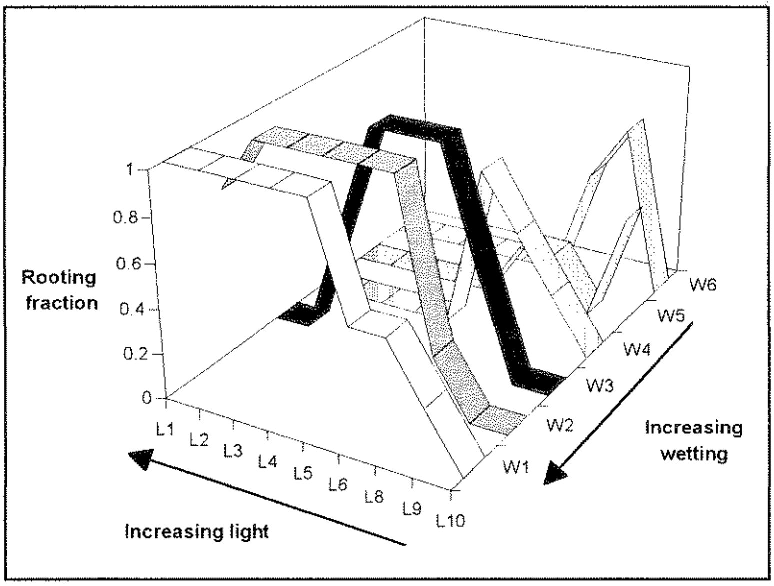


Figure 32. Rooting of *Cotinus coggygria* 'Royal Purple' cuttings inserted on 17 June for 5 weeks. Statistically significant effects: light ($P<0.001$), wetting ($P<0.01$) and the interaction of wetting x light ($P<0.001$).

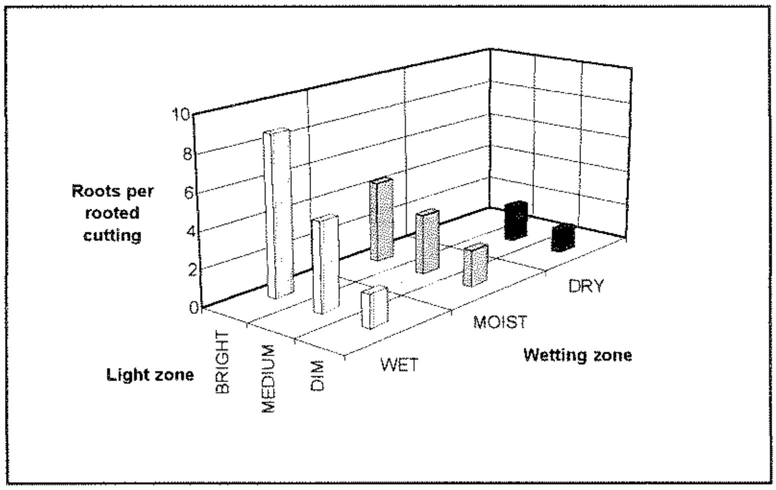


Figure 33. The number of roots per rooted cutting of *Cotinus coggygria* 'Royal Purple' inserted on 17 June for 5 weeks. Statistically significant effects: light ($P<0.01$) and wetting ($P<0.001$).

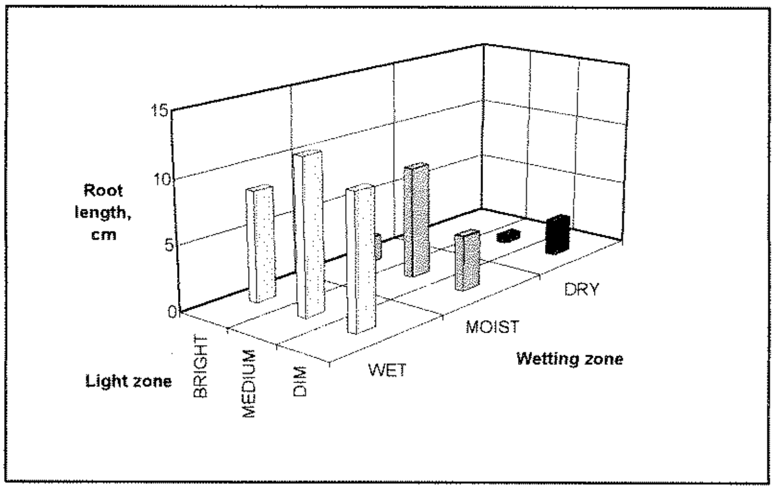


Figure 34. The average maximum root length on cuttings of *Cotinus coggygria* 'Royal Purple' inserted on 17 June for 5 weeks. Statistically significant effects of light ($P<0.05$) and wetting ($P<0.001$).

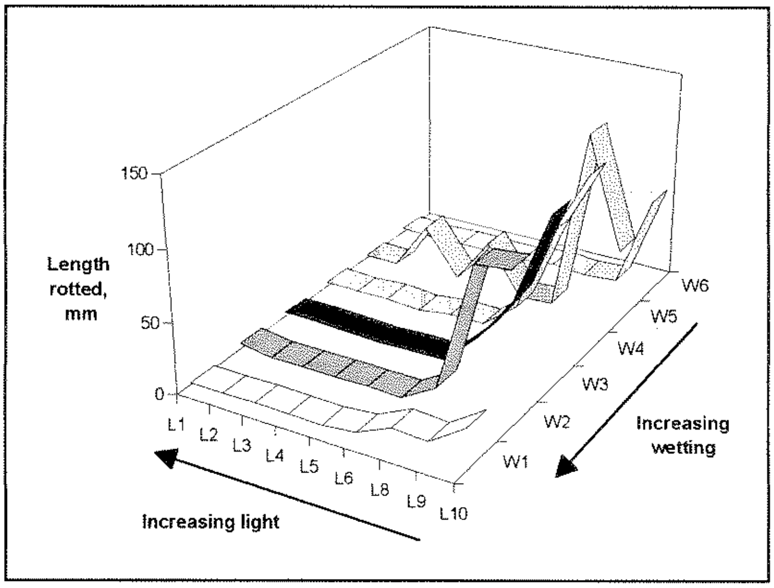


Figure 35. Average length of stem which was rotted on cuttings of *Cotinus coggygria* 'Royal Purple' inserted on 17 June for 5 weeks. Statistically significant effects of light ($P<0.05$) and wetting ($P<0.001$).

Cuttings in the fog house

Of a sample of 16 cuttings in the fog house, on average 93% rooted with 6.3 roots per cutting and an average maximum root length of 12.6 cm.

Discussion

The results from the G-CPE illustrate very effectively that *Cotinus coggygria* 'Royal Purple' is an excellent example of a subject which is considered difficult-to-root because it has a very narrow environmental tolerance. It is clear that virtually all cuttings of the sort used in this experiment have the potential to root; some fail to do so if they do not receive moderately high light combined with sufficient humidity and wetting to minimise water stress. These conditions are easily achieved in a wet fog system or under mist if enclosed to retain humidity, but would rarely be achieved in less supportive systems. For example, even with very generous wetting, poor results are usually achieved in open mist systems (Harrison-Murray *et al.* 1993). The results from the G-CPE are therefore consistent with the observations on the behaviour of cuttings placed in the fog house, and also with results from many previous experiments which used a wide range of conventional facilities.

The high rooting potential of the material used in this experiment is not always present. In a separate experiment, conducted after shoots had stopped growing in the autumn, cuttings inserted on 5 October failed to root in all environments in the G-CPE. We have also observed that if shoot elongation terminates temporarily in the middle of the growing season due to dry weather, then rooting occurs more slowly. It is important therefore to select shoots that are in active growth to be sure of the highest rooting potential.

Cryptomeria japonica 'Elegans compacta'

Cryptomeria japonica 'Elegans compacta' was included in the G-CPE experiments as an example of a plant with extremely narrow, needle-like leaves. As the only example of a conifer tested, it was a convenient experimental subject because it is quicker to root than most conifers. There were two experiments, the first looking in detail at the rooting response, the second examining effects on subsequent growth.

Experiment A: Effects on rooting

Cuttings inserted:	15 June, 1994.
Time in the G-CPE:	34 days.
Types of cutting:	Apical cuttings, divided into 4 grades on the basis of overall size (see Table 29 for comparison of grades)
Replication:	One cutting of each grade per location.
Spacing:	9 x 9 cm in pots (4 cuttings per 11 x 11 cm pot)
Additional environment:	Relatively dry location in the fog house (about 11 m from the fogger).

Table 29. Measurements on a sample of 3 cuttings of each grade.

	Grade				
	1 (smallest)	2	3	4 (largest)	Mean
Length, cm	14.4	11.6	13.4	13.2	13.2
Diameter, mm	1.57	1.56	1.78	1.69	1.65
Number of laterals	1.7	5.0	3.3	5.0	3.7
Dry weight, g	0.34	0.42	0.52	0.60	0.47

The data in Table 29 reflect that the grading was based on a visual assessment of the 'heaviness' of the cuttings by a combination of the length, stem thickness and 'bushiness'. Of the various measurements, only dry weight increased progressively across the grades. Measurement of the area of the needle-like leaves was very time-consuming and was therefore restricted to just one cutting, selected as representative of each grade. On average there were 68 leaves per cutting, with an area of 16.7 cm^2.

The environmental fingerprint for this subject (Figure 36) reveals a strongly adverse effect of heavy wetting on rooting. The highest proportion of cuttings rooted when little or no wetting was combined with high light. Rooting was also suppressed by low light, the minimum light level for any rooting to occur becoming greater as the amount of wetting increased. There were an average of 7.3 roots per rooted cutting, with a mean maximum length of 5.5 cm and little variation associated with environment (data not shown).

Some callus was seen on 2 out of 216 cuttings, and all but one cutting had at least 1 mm of dead brown tissue at the base. Rotting was somewhat more extensive in the wet and low light conditions, in which rooting was suppressed (Figure 37). However, many of the unrooted were not extensively rotted, and many rooted cuttings had up to 20 mm of rotted tissue below or alongside the sites of root emergence. This suggests that rooting was inhibited independently of the death of tissues in the potential rooting zone.

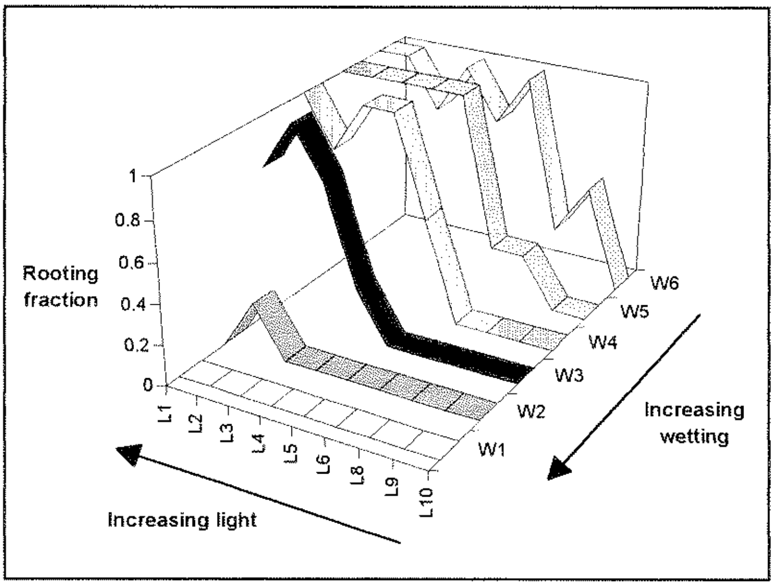


Figure 36. Rooting of cuttings *Cryptomeria japonica* 'Elegans compacta' inserted on 15 June for 5 weeks. Statistically significant effects: light ($P<0.001$), wetting ($P<0.001$) and the interaction of wetting x light ($P<0.001$).

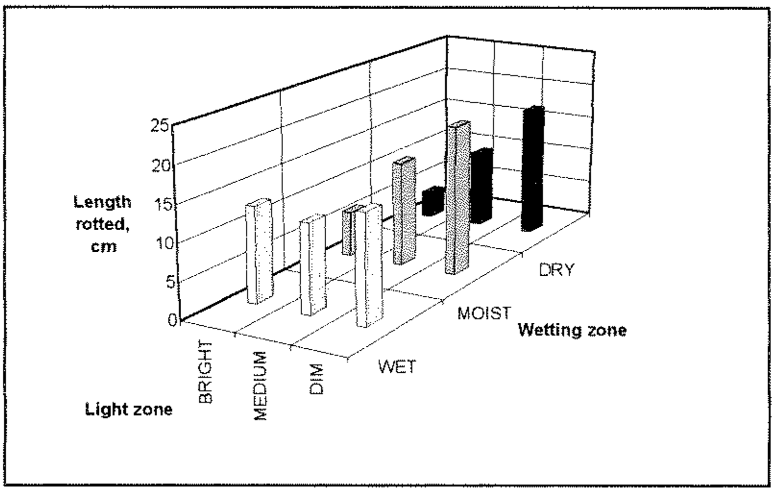


Figure 37. Average length of rotted stem on cuttings of *Cryptomeria japonica* 'Elegans compacta' inserted on 15 June for 5 weeks. Statistically significant effects: light ($P<0.001$), wetting ($P<0.01$) and the interaction of wetting x light ($P<0.001$).

Cuttings in the fog house

Of a sample of 16 cuttings in the fog house, just 1 rooted (i.e. 6%). On average, there was 5.7 mm of rotted stem tissue.

Effect of cutting size

The heaviest grade of cutting had significantly more roots per rooted cutting than the lighter grades (11.5 compared with 6.0 in the lightest grade) but there was no significant effect of grade on rooting percentage.

Experiment B: Effects of environment and cuttings size on final plant quality

The objective of this experiment was to determine whether there is any effect of propagation environment on the performance of *Cryptomeria japonica* 'Elegans Compacta' beyond the rooting stage. It also examined whether the size of cutting had any long-term effect. Details were as follows:

Cuttings inserted:	30 June, 1995.
Time in the G-CPE:	45 days.
Types of cutting:	Apical cuttings, divided into 4 grades on basis of overall size (see Table 30 for comparison of grades)
Replication:	Two cuttings of each grade per location.
Spacing:	9 x 9 cm in QP24 trays.
Weaning:	Weaned rapidly to an unshaded well-ventilated polytunnel over 10 days using mist controlled by an evapostat.
Liquid feeding:	Complete liquid feed (Peters Professional at 300 mg L^{-1}) applied on 3 occasions at two week intervals following weaning.
Potting:	Into 9 cm square pots on 16/1/96.
Overwintered:	In a polytunnel with base heating to provide frost protection to the roots (thermostat setting 2 °C)
Growing on:	A subsample of liners were potted-on into 2 L containers on 28 May, 1996. The medium was 70:30 (v/v) Peat : Bark (medium grade Irish moss peat : Cambark 100) with 3 kg m^{-3} Ficote 180 16-10-10 controlled release fertiliser, 1 kg m^{-3} magnesian limestone, 300 g m^{-3} fritted trace elements (WM255). They were placed on Mypex-covered soil under overhead irrigation, which was applied twice daily under timeclock control, supplemented by hand-watering when necessary.
Assessment:	Rooting was scored without disturbance when trays were moved from the G-CPE on 14 August, 1995. Survival recorded on 11 September and 6 December 1995. Plant height was recorded on 6 December 1995, 20 May and 21 August. 1996. Lateral spread of the head (the mean of two measurements at right angles) was recorded on 20 May and 21 August 1996.

Table 30. Measurements on a sample of 6 cuttings of each grade as inserted into the G-CPE.

	Grade		
	Light	Heavy	Mean
Length, cm	12.2	16.0	13.6
Diameter, mm	0.86	1.40	1.13
Number of laterals	1.3	6.2	3.7
Dry weight, g	0.201	0.684	0.442

Rooting and weaning

The rooting response was similar to that seen in Experiment A, except for a slight decline in rooting when high light was combined with the lowest level of wetting (W6), and a greatly reduced frequency of rooting under heavy wetting conditions (Figure 38). The period for rooting was extended by one week in this experiment and this may have resulted in the rooting of some cuttings under wet conditions that otherwise would not have rooted. This would imply that wet conditions slow down rooting rather than prevent it completely. It is certain that some of the heavily-wetted cuttings that were still unrooted at this stage retained the capacity to root, because the number which were still alive in December was greater than the number recorded as having been rooted at the start of weaning (Figure 39 compared with Figure 38). When survival was recorded 17 days after transfer to a normal growing environment, many more cuttings appeared healthy despite being still un-rooted.

Heavy cuttings developed roots sooner than light cuttings. When averaged over all environments, 52% of heavy cuttings had rooted after six weeks compared with 32% of light cuttings ($P<0.001$). However, the ultimate rooting percentages were not significantly different, as indicated by the percentage of cuttings which survived to December (i.e. 64% of heavy cuttings and 60% of light cuttings). There was no significant difference in the response to environment of the two grades of cutting.

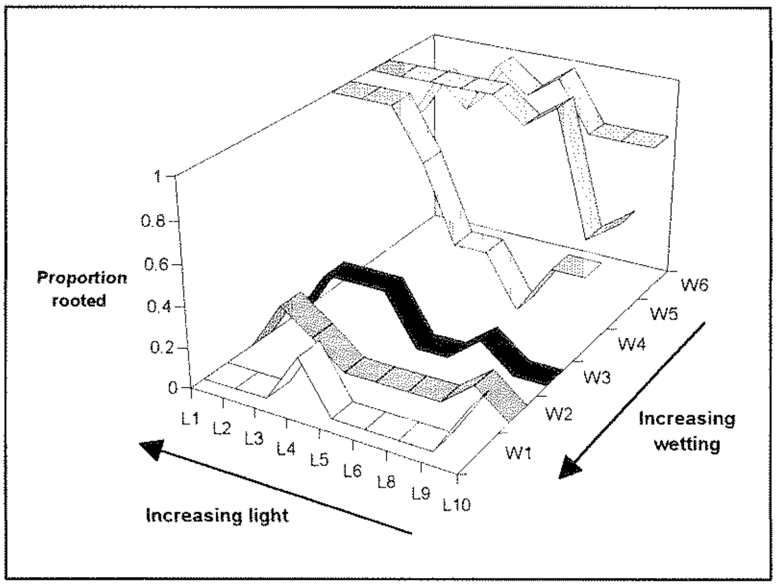


Figure 38. Rooting of cuttings *Cryptomeria japonica* 'Elegans compacta' inserted on 30 June for 6 weeks. Statistically significant effects: light ($P<0.001$), wetting ($P<0.001$) and the interaction of wetting x light ($P<0.001$).

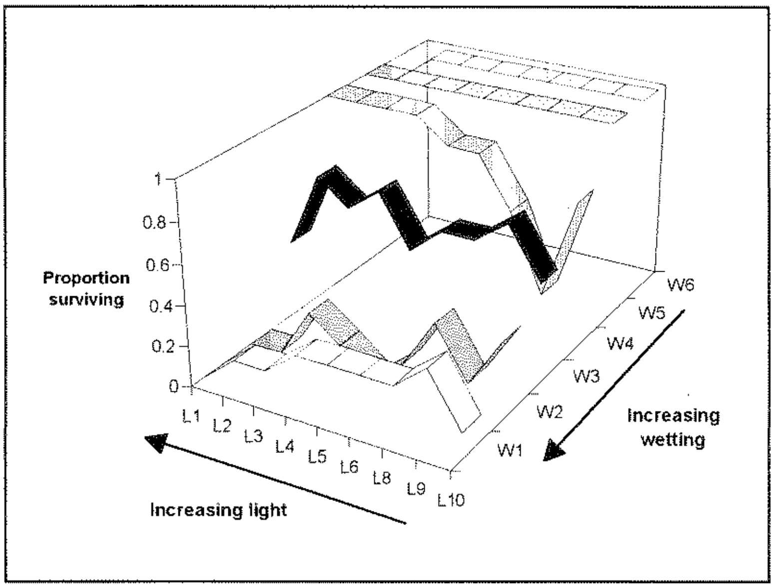


Figure 39. Survival of *Cryptomeria japonica* 'Elegans compacta' cuttings recorded on 6 December, 15 weeks after the end of weaning. Statistically significant effect of wetting only ($P<0.001$).

In December, the height of cuttings which remained alive showed a significant carry-over effect of the rooting environment, the largest rooted cuttings being those from the drier end of the wetting gradient and the high light end of the light gradient (Figure 42).

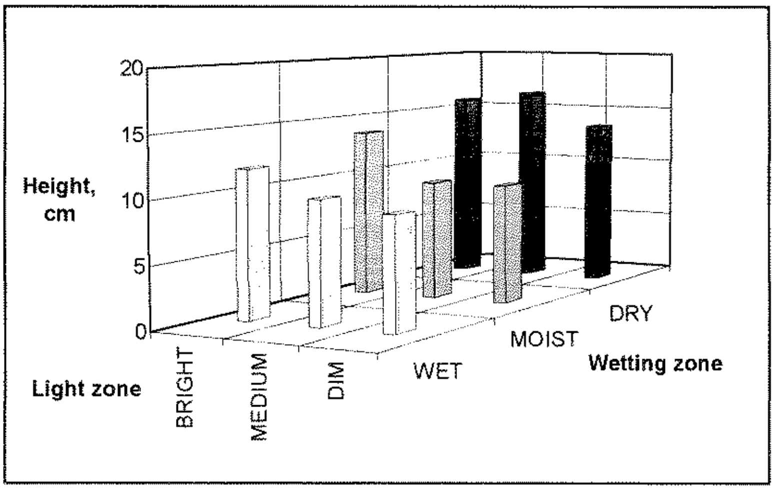


Figure 40. Average height of rooted cuttings of *Cryptomeria japonica* 'Elegans compacta' on 6 December, 15 weeks after the end of weaning. Statistically significant effects: wetting ($P<0.001$), light ($P<0.001$), and the light x wetting interaction ($P<0.001$).

Liners

Rooted cuttings were potted into 9 cm liner pots in January. Despite minimal heat input in a polytunnel, they made substantial growth overwinter; when reassessed on 20 May the effect of rooting environment on height of the liners was still clearly evident (Figure 41), and there was a comparable effect on lateral spread (Figure 42). Also, a difference in height between the 'heavy' and 'light' grades of cutting remained and was matched by a difference in spread of 2.2 cm ($P<0.001$, data not shown).

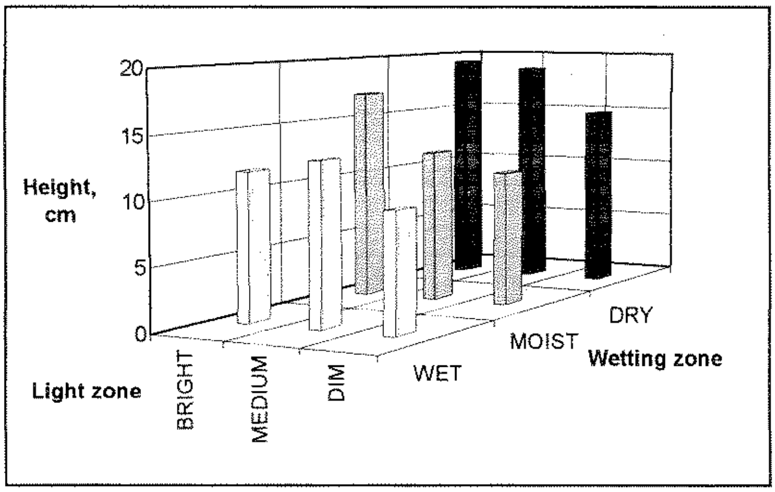


Figure 41. Average height of *Cryptomeria japonica* 'Elegans compacta' liners on 20 May, 1996. Statistically significant effects: wetting ($P<0.001$), light ($P<0.001$), and the light x wetting interaction ($P<0.001$).

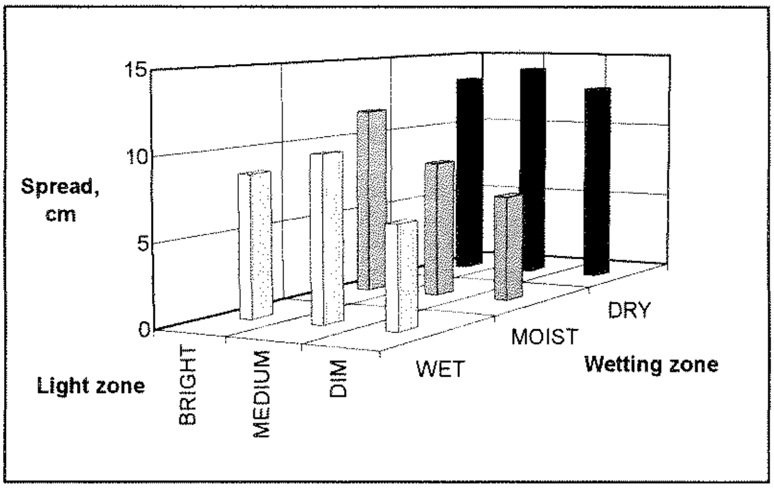


Figure 42. Average lateral spread of *Cryptomeria japonica* 'Elegans compacta' liners on 20 May, 1996. Statistically significant effects: wetting (P<0.001), light (P<0.001), and the light x wetting interaction (P<0.001).

Container plants

A subsample of liners was potted-on into 2 L containers to compare the performance of the relatively large liners derived from a favourable rooting environment, with the relatively small liners derived from rooting environments that were either too wet or too dark. The effect of the difference attributable to the size of the original cutting was also taken into account. Six liner plants were selected from each of grade of cutting rooted in the three environments tabulated below:

Rooting environment	Rooting percentage on 14 August 1995	Mean height of liners on 20 May 1996
W4/Bright (i.e. W4 x L1 to L3)	100 %	19.9 cm
W4/Dim (i.e. W4 x L8 to L10)	29 %	12.1 cm
W1/All (i.e. W1 x L1 to L10)	6 %	10.6 cm

Measurements made in late August showed that initial differences in liner quality were being maintained, with significant effects of rooting environment and size of cutting clearly visible (Figure 43). The effects of these factors on spread were similarly retained (data not shown). However, the amount by which height increased over the intervening three months did not differ significantly between treatments, and was actually greatest amongst the 'W1/All' plants (data not shown). It follows that the size of the differences was declining as a proportion of total plant height. For example, in May, the plants from the W4/Dim environment were on average 39% shorter than those from W4/Bright, but this had declined to 25% in August. In contrast to plant height, lateral spread increased more in the large plants than the small ones (Figure 44), which would tend to maintain the relative difference in this aspect of size.

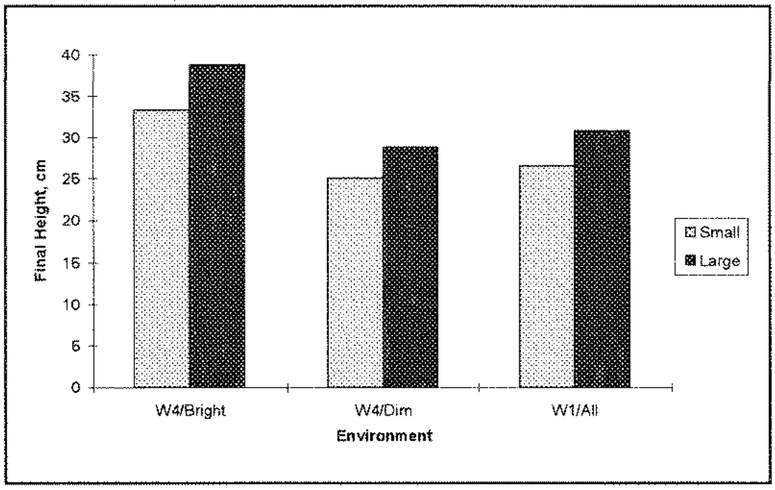


Figure 43. Average height of *Cryptomeria japonica* 'Elegans compacta' plants 14 months after taking cuttings, showing the residual effects of rooting environment and size of cutting. Statistically significant effects: environment ($P<0.001$), and grade ($P<0.001$); LSD = 4.2.

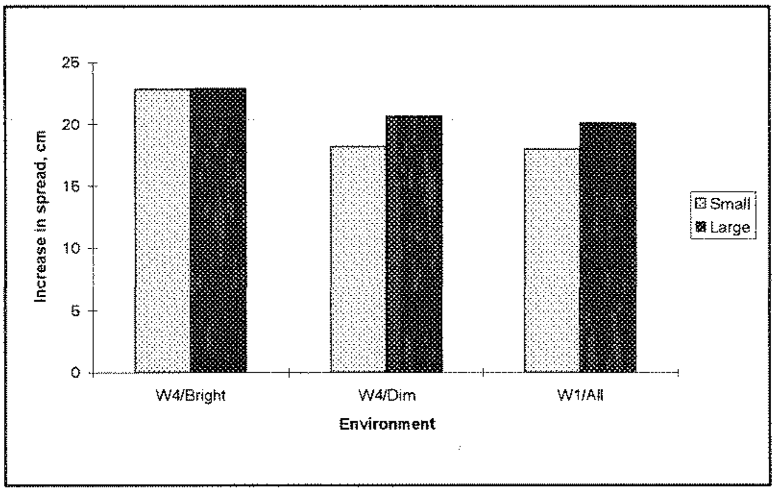


Figure 44. Increase in lateral spread of *Cryptomeria japonica* 'Elegans compacta' plants over 3 months in a container (20 May to 21 August) showing the residual effects of rooting environment and size of cutting. The effect of environment was significant ($P<0.01$) while that of grade approached significance ($P=0.08$); LSD =3.96.

Discussion

The results of both experiments illustrate that rooting of *Cryptomeria japonica* benefits from dry conditions. The level of wetting tolerated increased with increases in light level (Figure 36); this suggests that it may not be the wetting *per se* that has an adverse effect, but rather the resultant low transpiration rate. Increased light will increase evaporative demand and therefore tend to counteract the suppression of transpiration by wetting.

Incidence of rotting increased towards the wet end of the CPE. This was not sufficient to explain the suppression of rooting simply in terms of loss of the tissues in which rooting would normally occur. It may reflect some form of over-hydration of the basal tissues which simultaneously inhibited rooting and stimulated physiological breakdown. One possibility is that some of the internal air spaces may become filled with water when the transpiration demand is too low relative to the availability of water from the medium.

Alternatively, the effects on rooting and rotting may be unrelated. It is possible that some degree of water stress is required to stimulate the root initiation process in *Cryptomeria japonica* . Detailed physiological studies would be required to distinguish these two alternatives.

From the practical viewpoint, the results indicate that, for this plant, it is important to avoid highly 'supportive' environments, such as wet fog, because they are likely to suppress transpiration too much. The poor rooting obtained in the fog house is consistent with this conclusion. Instead, either an open mist system with minimal wetting but relatively low humidity, or a simple polythene system to raise humidity but without any wetting, are likely to be more suitable. In either case, moderate shade would be appropriate (i.e.60 - 80%, including shading by glass, etc.).

Experiment B showed that cuttings could root in sub-optimal conditions, but these were liable to produce weaker liners than those rooted under ideal conditions. For this subject the optimum environment for a high rooting percentage was also optimal for production of high quality liners. Exposure to high light levels during rooting increased the size of liners only where it helped counteract heavy wetting. The results also suggest that the effect of over-wetting may be to slow down rooting rather than to prevent it completely. Such a delay may be important in the reduction of the quality of the liners produced from those cuttings that eventually rooted.

In both experiments there was evidence of a considerable benefit from use of large cuttings with a number of developing lateral shoots. This benefit comes in terms of enhanced rooting and the quality of liner that is produced. However, in Experiment A, the benefit was only evident in the amount of root that was produced, not in rooting percentage.

From the subsample of liners that were grown-on in containers it was quite clear that, for *C. japonica* 'Elegans compacta', large liners offer a real advantage in achieving a saleable plant as quickly as possible, whether the large size is the result of starting with large cuttings, or the result of rooting under optimal conditions.

Daphne x *burkwoodii* 'Somerset'

Daphne x *burkwoodii* 'Somerset' was included as an example of a genus of specialist plants which are difficult to produce and for which there is probably a potentially larger market than at present. One difficulty is at the propagation stage, cuttings usually rooting poorly. This subject was suggested by Round Pond Nurseries, which kindly provided the cuttings.

Cuttings inserted:	31 July, 1996.
Time in the G-CPE:	29 days.
Types of cutting:	Apical cuttings, divided into 4 grades on basis of overall size (see Table 31 for comparison of grades)
Replication:	One cutting of each grade per location.
Spacing:	9 x 4.5 cm in QP96D trays.

Table 31. Measurements on a sample of 3 cuttings of each grade.

	Grade				
	1 (smallest)	2	3	4 (largest)	Mean
Length, cm	3.8	5.0	6.0	8.3	5.8
Diameter, mm	1.40	1.51	1.74	1.89	1.63
Number of leaves	11.0	13.7	17.7	23.0	16.3
Leaf area, cm^2	13.4	21.5	28.4	38.7	25.5

Rooting was almost entirely confined to the dry end of the wetting gradient and was also favoured by high light (Figure 45). In the Bright/Dry zone it averaged 63% but it is not clear from Figure 45 whether this is close to the optimum or whether the optimum lay outside the range of the G-CPE, under brighter and/or drier conditions. On average, rooted cuttings had 8.1 roots up to 4 cm long. It is unlikely that rooting percentage would have increased if the rooting period had been extended because leaves were yellowing and dropping in large numbers and there was rotting at the base of all non-rooted cuttings.

Despite the wide range of cutting sizes, there was no evidence that size influenced rooting or rotting (data not shown).

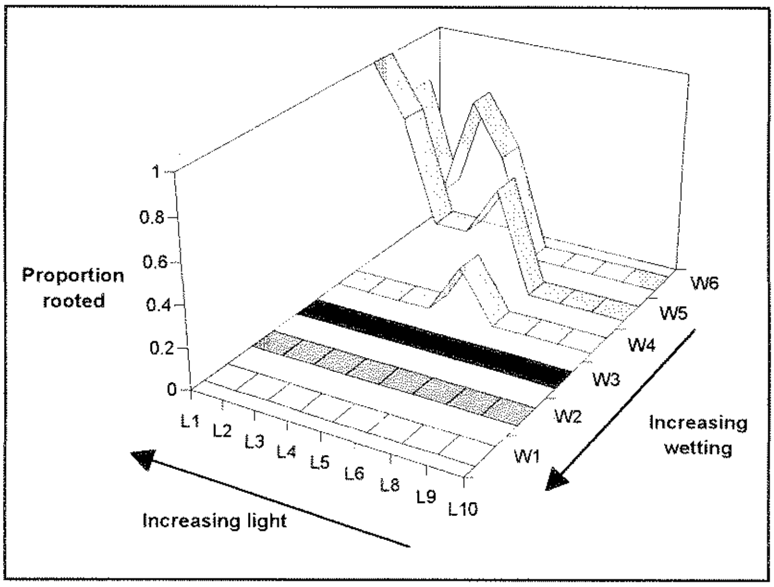


Figure 45. Rooting of cuttings of *Daphne* x *burkwoodii* 'Somerset' inserted on 31 July for 4 weeks. Statistically significant effects: light ($P<0.001$) and wetting ($P<0.001$).

Discussion

Rooting of *Daphne* was shown to be completely suppressed by the combination of high humidity and heavy wetting, and also by low light level. The highest rooting percentage was obtained by the combination of high light and minimal wetting, i.e., 63% in the Bright/Dry zone. It is not clear from the results whether this represented the full rooting potential of these cuttings or whether a further increase in light, or a reduction in humidity to increase evaporative demand, would have achieved closer to 100%. However, it is very possible that the physiological state of the cuttings was the limiting factor because the source of the cuttings was a mature garden specimen. This could explain the early senescence and abscision of leaves which would have tended to limit rooting and promote rotting.

The narrow range of environments in which rooting occurred indicates that environment is critical for success with this subject, but further work is required to see whether it is possible to identify a combination of cutting source and environment that consistently achieves close to 100% rooting.

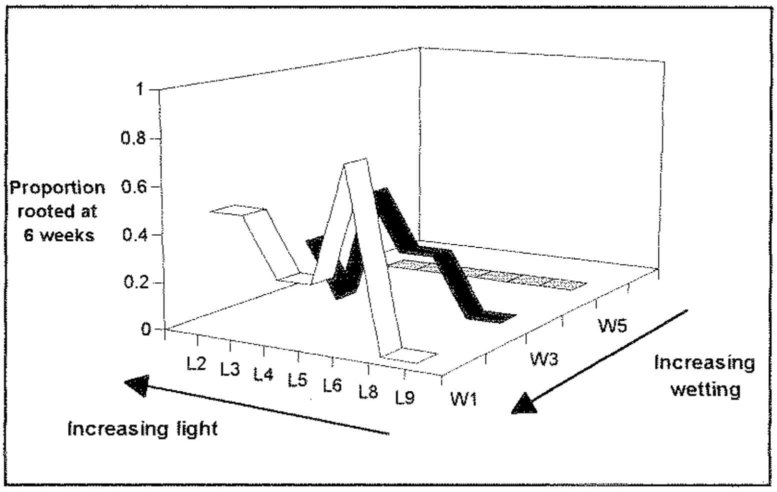
***Elaeagnus pungens* 'Maculata' EM86**

Previous attempts to root cuttings from field-grown stock plants at East Malling had not achieved high success, including an earlier experiment in the G-CPE with cuttings taken in September. The current experiment involved earlier propagation and incorporated a comparison of two concentrations of IBA.

Cuttings inserted:	16 June, 1995.
Time in the G-CPE:	42 days. At this stage cuttings were removed from the medium for detailed examination.
Extra rooting period:	Cuttings which were healthy but non-rooted after 42 days in the G-CPE were replanted and moved to a very wet location in the fog house for a further 8 weeks.
Types of cutting:	Apical cuttings from actively elongating shoots with soft, usually brown leaves near the tip, divided into 2 size grades (see Table 32)
Auxin treatments:	1.25 g L^{-1} and 5.0 g L^{-1} IBA in a 50:50 (v/v) mixture of acetone and water, applied as a 5 s dip.
Replication:	One cutting of each grade, at each IBA concentration, per location.
Environments excluded:	Shortage of cuttings made it necessary to omit alternate wetting levels (W2, W4, and W6), and two light levels (L1 and L10).
Spacing:	9 x 9 cm in 7 cm square pots.
Potting after rooting:	Cuttings which had rooted when examined after 42 days were potted up into 9 cm square pots and placed in a wet location in the fog house for 4 weeks to recover from the effects of severe root disturbance involved in recording rooting. Those which rooted later were left in 7 cm pots without disturbance.
Weaning:	Moved to the dry end of the fog house for at least one week. On 29 September all were moved to a lightly-shaded and ventilated polytunnel.
Container stage:	All surviving liners were potted on into 2 L containers on 2 April, 1996. The medium was 70:30 (v/v) Peat : Bark (medium grade Irish moss peat : Cambark 100) with 3 kg m^{-3} Ficote 180 16-10-10 controlled release fertiliser, 1 kg m^{-3} magnesian limestone, 300 g m^{-3} fritted trace elements (WM255). They were stood out on Mypex-covered soil under overhead irrigation, which was applied twice daily under timeclock control, supplemented by hand-watering when necessary. Growth was assessed on 21 August.

Table 32. Measurements on a sample of 10 cuttings of each grade.

	Grade		
	Small	Large	Mean
Length, cm	11.1	16.5	13.8
Diameter, mm	2.55	2.94	2.75
Number of leaves	5.6	8.5	7.1
Leaf area, cm^2	65.8	117.3	91.5



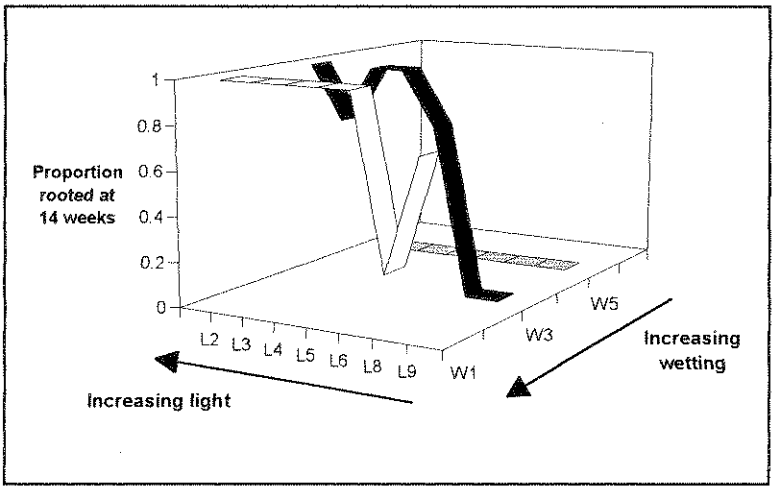


Figure 46. Rooting of *Elaeagnus pungens* 'Maculata' cuttings inserted on 16 June, after 6 weeks in the G-CPE (upper) and after a further 8 weeks in the fog house (lower). Significant effects: light (P<0.01), wetting (P<0.01).

Figure 46 shows that wetting was essential to rooting, and the highest rooting percentage was obtained at the heaviest wetting level (W1). This corresponds with observations of wilting which was seen soon after cuttings were inserted. After three days slight wilting was noted in W3 at L2 and L3, while in W5 wilting was progressively more severe from L5 up to L2. In W5 the wilting became more severe with time and eventually almost all leaves were lost. There was also moderate leaf drop in W3 and at low light in all wetting zones (Figure 47).

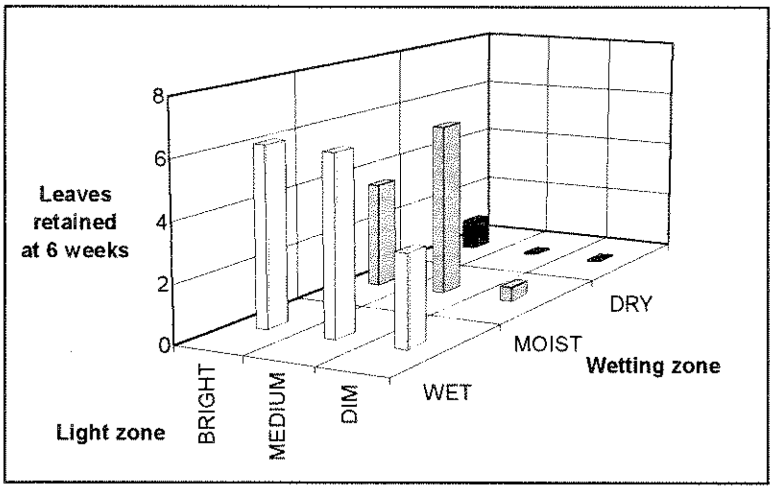


Figure 47. Number of leaves retained on cuttings of *Elaeagnus pungens* 'Maculata' cuttings, after 6 weeks in the G-CPE. Significant effects: light (P<0.001), wetting (P<0.01).

After 6 weeks in the G-CPE, rooted cuttings had, on average, 4.1 roots up to 1.5 cm long. Numbers and lengths of roots were greater at wetting level W1 than W3 but the difference was not significant. Rotting was mainly associated with the leaf loss that occurred both at low light (L8 and L9, i.e. Dim zone) and under dry conditions (W5).

The number of rooted cuttings more than doubled during the additional 8 weeks after the original recording, during which time they were all held in a very wet part of the fogger, roughly equivalent to W1 and a moderate light level in the G-CPE. From the trends evident at six weeks, it seems likely that there would have been less additional rooting of cuttings from W3, and from L8 and L9, had cuttings remained in their original locations in the G-CPE.

Size of cutting and IBA concentration

Application of IBA at four times our 'standard' concentration resulted in a significantly higher rooting percentage at six weeks (Figure 48). There was also twice as many large cuttings rooted at this stage as small cuttings, though this difference was not statistically significant. However, eight weeks later both of these differences had reduced to 5% and were non-significant.

The higher concentration of IBA increased the average length of rotted stem from 15 mm to 24 mm but the effect was not significant.

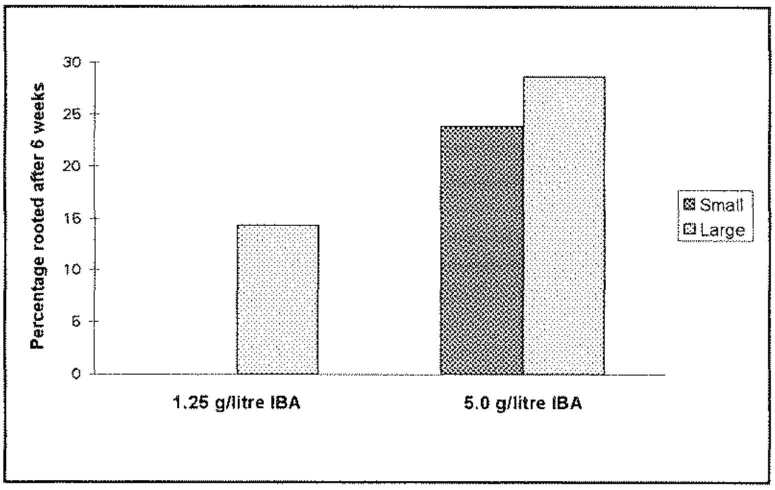


Figure 48. Effects of the size of cuttings used and the concentration of IBA applied on rooting of *Elaeagnus pungens* 'Maculata', after 6 weeks in the G-CPE, averaged over all environments. The effect of IBA was significant ($P<0.01$).

Growth after rooting

When the height and stem diameter of the rooted cuttings was measured, in January 1996, the diameter of cuttings which rooted in the 'Wet' zone was slightly (6%) greater than those from the 'Moist' zone ($P=0.05$). The initial difference between the two size grades was still evident.

In August, after four months in a container, a much larger effect of both wetting zone and size of the original cutting were evident in terms of total shoot growth (Figure 49). There were parallel effects on stem diameter and the number of lateral branches (data not shown).

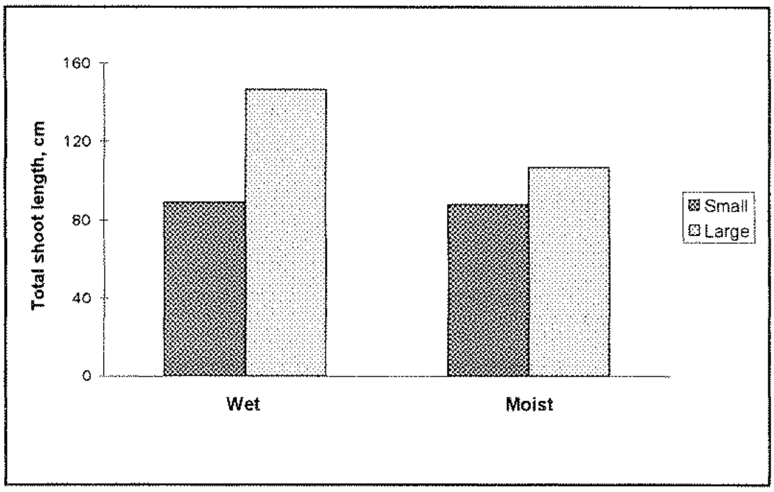


Figure 49. Effects of amount of wetting in the rooting environment, and the size of cuttings used on shoot length of *Elaeagnus pungens* 'Maculata' plants 14 months after propagation, averaged over all light levels. Statistical significance: wetting ($P<0.05$), size ($P<0.001$); LSD = 37.7.

Discussion

These results show that apical cuttings of *Elaeagnus pungens* 'Maculata' are highly sensitive to water stress and benefit from an environment that minimises evaporative demand, such as the wet end of the G-CPE and of the fog house. Although the rough surface of the leaves and stems that is characteristic of this plant gives the impression of tough resilient shoots, they wilted severely when wetting was insufficient to keep leaves visibly wet. In this experiment cuttings were collected in June when the stock plants were growing strongly so that the material was unusually soft. However, in an earlier experiment, more lignified cuttings taken in September also suffered severe stress in the Dry zone.

These results are surprising because this subject is not recognised as particularly difficult to root. For example, Lamb *et al.*(1985) indicate that, with cuttings taken in July, up to 100% rooting can be expected within two months using a simple contact polythene system. Such a system provides high humidity combined with a little wetting of leaves from water condensing on polythene but cannot be expected to cut down transpiration as effectively as the G-CPE results suggest is necessary.

On the basis of this work, high success rates can be expected using a very supportive system such as polythene enclosed mist or wet fog. Good results with simpler systems may be possible but any nursery that is having difficulty obtaining high success rates with this subject should try to reduce evaporative demand further, by raising humidity, increasing wetting, or increasing shade. No particular benefit of high light was detected but at very low light cuttings failed to root and many rotted. Shade should therefore be used to help limit evaporative demand but must not be excessive (e.g. > 80% shade during cloudy summer weather).

Further work is required to confirm that the material used in these experiments is more dependent on a supportive rooting environment than is typical of the cultivar generally and, if so, to try to identify which aspect of stock plant management is responsible.

Performance of the plant in the container was shown to be strongly influenced by factors that operated at the propagation stage. The combined effects of taking relatively large cuttings and using a favourable rooting environment increased by 68% the overall size and degree of branching of the plants 14 months later (Figure 49).

***Garrya elliptica* 'James Roof'**

Previous studies showed that *Garrya elliptica* 'James Roof' can be propagated from soft summer cuttings, instead of using 'ripe' cuttings in winter as is the usual approach, if a highly supportive environment such as a 'ventilated wet fog system' is used (Harrison-Murray *et al.* 1993). In any other environment such cuttings wilted severely and failed to root. It was therefore of interest to determine how this acutely sensitive subject would behave in the G-CPE.

Cuttings inserted:	11 June, 1996.
Time in the G-CPE:	36 days.
Types of cutting:	Apical cuttings, divided into 2 size grades (see Table 33 for comparison of grades)
Replication:	Two cuttings of each grade per location.
Spacing:	9 x 9 cm in QP24 trays.

Table 33. Measurements on a sample of 9 cuttings of each grade.

	Grade		
	Small	Large	Mean
Length, cm	11.3	16.3	13.8
Diameter, mm	3.27	4.01	3.64
Number of leaves	7.0	8.0	7.5
Leaf area, cm^2	54.4	87.2	70.8

Rooting was entirely confined to the two heaviest levels of wetting, and even there 100% rooting did not occur, in any location (Figure 50). There was no rooting at light levels below L6 but rooting was inhibited also by high light, particularly at W2. The few cuttings which rooted developed large numbers of roots, 21 on average, with an average maximum length of 3.6 cm. Roots were longer and more numerous in W1 than W2 and at L4 than at other light levels.

Cuttings started to wilt in the Bright/Dry zone within 24 hours of insertion and wilting became gradually more severe and extended to a wider range of environments over several days. A detailed inspection made after three weeks recorded marked drooping of the top of the stem from L1 to L6 even in W4 where wetting was sufficient to keep leaves visibly wet, and from L1 to L3 in W3. No wilting was noted in W1 and W2 at any light level. Many leaves had started to develop black rotten areas at the lowest light levels (L8 - L10) at all wetting levels.

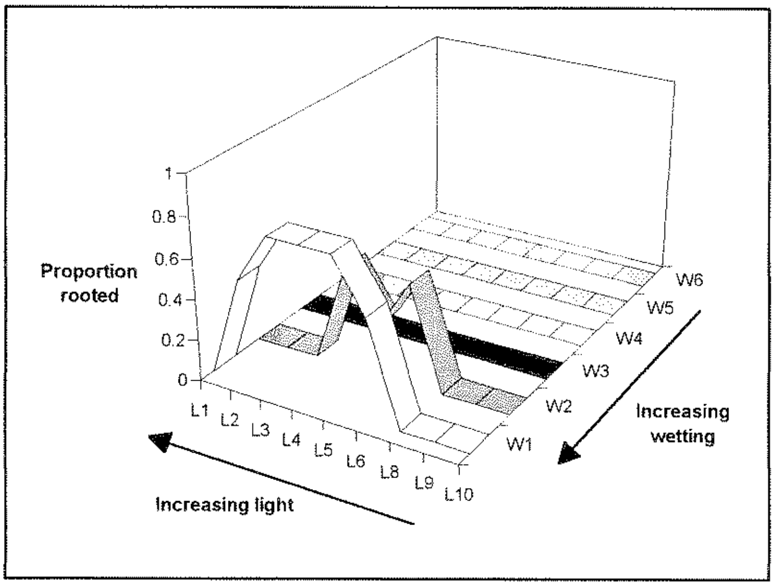


Figure 50. Rooting of *Garrya elliptica* 'James Roof' cuttings inserted on 11 June for 5 weeks. Statistically significant effects: light (P<0.001), wetting (P<0.001).

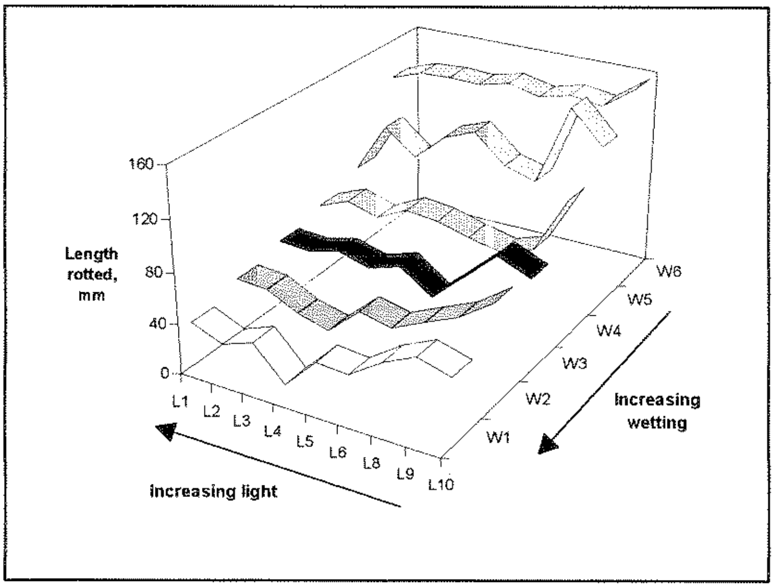


Figure 51. Average length of stem rotted on cuttings of *Garrya elliptica* 'James Roof' inserted on 11 June for 5 weeks. Statistically significant effects: light (P<0.001), wetting (P<0.001).

Rotting

All non-rooted cuttings had at least 20 mm of dead stem at the base, and even some of the rooted cuttings had a section of dead stem below the zone where the roots emerged. The extent of rotting increased as conditions became drier (Figure 51) eventually affecting the whole stem of all cuttings in W6. There was also a smaller but significant increase in rotting at low light (L8 to L10).

Size of cutting

The number of small grade cuttings which rooted was twice that of the large grade, and the difference was statistically significant ($P<0.05$).

Discussion

The results from the G-CPE are consistent with previous results comparing various conventional propagation environments, in which 100% rooting was obtained only from cuttings in the wettest part of the fog house, and under 80% shade. Failure to reach 100% rooting, even in the wettest part of the G-CPE where water deposition is comparable to the wettest part of the fog house, may reflect an advantage of the fan-assisted fogger used in the fog house. For cuttings within a few metres of the fogger the air current created by the fan is sufficient to force the fog laden air amongst the leaves of the cuttings, displacing warmer air and depositing a small amount of water on the undersurface of leaves, particularly on smaller leaves near the tops of cuttings.

Some basal rotting is common in *Garrya* cuttings and the results from the G-CPE show that it is more likely to be a sign that the environment is too dry or too dark than that it is too wet. However, further work is required to determine why there was a high level of rotting even at the heaviest level of wetting. Some rotting is commonly seen below the rooted zone and the presence of roots appears to halt further rotting. Any stock plant factor that influences the physiological condition of the cutting in a way that slows down the processes leading towards root initiation are therefore likely to appear as an increase in rotting at the expense of rooting.

Indeed, it is possible that the benefit of small cuttings observed in this experiment may operate in this way since it has been shown in other species that thinner cuttings tend to root faster than thicker ones from the same plant (Howard and Ridout, 1992). There may also be other environmental factors, such as base temperature, that influence the relative speed of the processes leading to rooting and rotting respectively.

In practical terms, it is clear that it is likely to be difficult to achieve consistently 100% success in rooting *Garrya elliptica* 'James Roof' from soft cuttings but success rates above 80% should be possible if cuttings are kept well wetted, relative humidity is kept at or very close to 100% and sufficient shade is used. For summer propagation a total of about 80% shade (including absorption by the glass or polythene) is acceptable, but this could probably be increased to 90% during sunny weather with advantage.

***Rhododendron* 'Gold Flimmer'**

A substantial proportion of Rhododendrons are now produced by micropropagation. However, variegated cultivars such as 'Gold Flimmer' often lose their variegation while in culture. This subject was suggested by Round Pond Nurseries who also kindly provided the cuttings. Details were as follows:

Cuttings inserted: 7 August, 1996.
Time in the G-CPE: 85 days.
Types of cutting: Apical cuttings divided into four grades as follows:
Elongating shoots (i.e. no terminal bud and some soft expanding leaves)
Terminated shoots (i.e. terminal bud present), thin
Terminated shoots, medium thickness
Terminated shoots, thick
(The differences amongst the grades are summarised in Table 34)
Replication: One cutting of each grade per location.
Spacing: 9 x 9 cm in QP24 trays

Roots were too fine to count but, after washing away as much of the rooting medium as possible, the amount of roots was quantified on a scale of 0 to 3 as follows:

0 = unrooted
1 = diameter of the washed root mass < stem diameter
2 = diameter of the washed root mass > stem diameter but no part of it so dense as to prevent washing out of peat:bark rooting medium
3 = substantial root ball with at least part of the rooting medium firmly bound by interwoven roots, many roots having reached the edge of the 240 cm^3 cell.

Table 34. Measurements on a sample of 3 cuttings of each grade.

	Grade				
	Elongating	Terminated Thin	Terminated Medium	Terminated Thick	Mean
Length, cm	5.7	9.2	8.0	6.5	7.3
Diameter, mm	4.30	3.62	4.64	6.42	4.75
Number of leaves	6.3	7.7	9.0	7.0	7.5
Leaf area, cm^2	79.6	89.0	117.1	126.4	103.0

The proportion of cuttings which rooted was highest when heavy wetting was combined with medium to high light (Figure 52), the average rooting percentage in the Bright/Wet zone being 79%. As wetting decreased, rooting was suppressed, especially at the highest light levels. Rooting was also suppressed completely at the three lowest light levels (L8 to L10) irrespective of the amount of wetting . Root score data indicated no benefit of high irradiance beyond its effect on rooting percentage (Figure 53 compared with Figure 52).

By careful examination it was found that even cuttings with a good root ball often had very few primary roots emerging from the stem: their root mass arose by prolific branching of a few main roots. It did not appear that roots were any more likely to emerge from the slice wound than any other part of the circumference of the stem. In contrast, callus was more often seen on the slice wound than the basal cut.

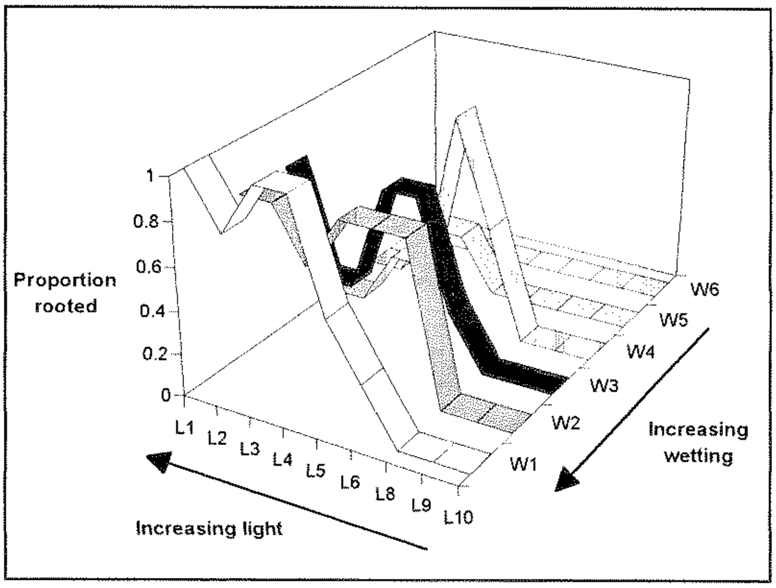


Figure 52. Rooting of *Rhododendron* 'Gold Flimmer' cuttings inserted on 7 August, for 12 weeks. Statistically significant effects: light ($P<0.001$), wetting ($P<0.001$) but not the interaction of wetting x light.

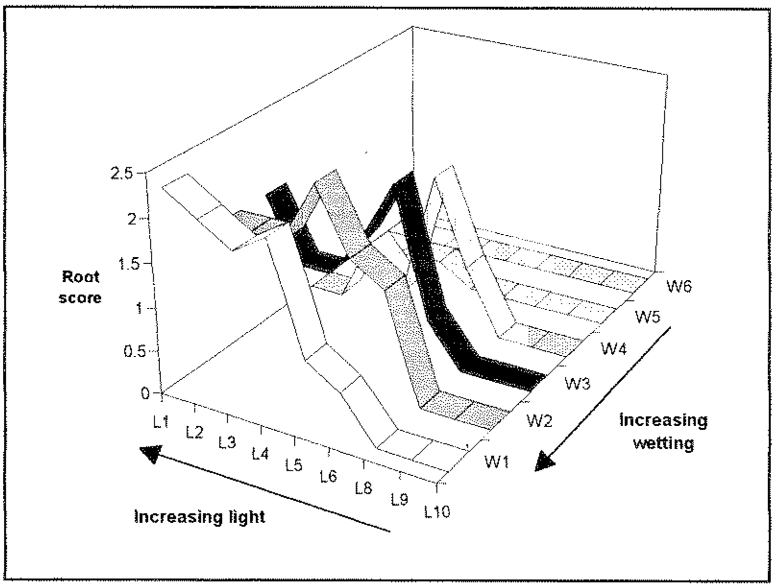


Figure 53. Average score for the amount of root on *Rhododendron* 'Gold Flimmer' cuttings inserted on 7 August for 12 weeks (on a scale of 0 to 3, where 0 = unrooted, 3 = substantial root ball). Statistically significant effects: light ($P<0.001$), wetting ($P<0.001$), and the interaction of wetting x light ($P<0.001$).

There was little or no callus on most cuttings, even under conditions which favoured rooting. Sixty one percent of cuttings suffered rotting of more than 5 mm of the stem base, much of it associated with the margin of the slice wound. The average length of stem that rotted increased as light level decreased (Figure 54). Compared to the major effect of light, wetting had little effect. However, amongst cuttings at high light there was evidence that the amount of stem which rotted was greater at the dry end of the G-CPE where cuttings wilted severely.

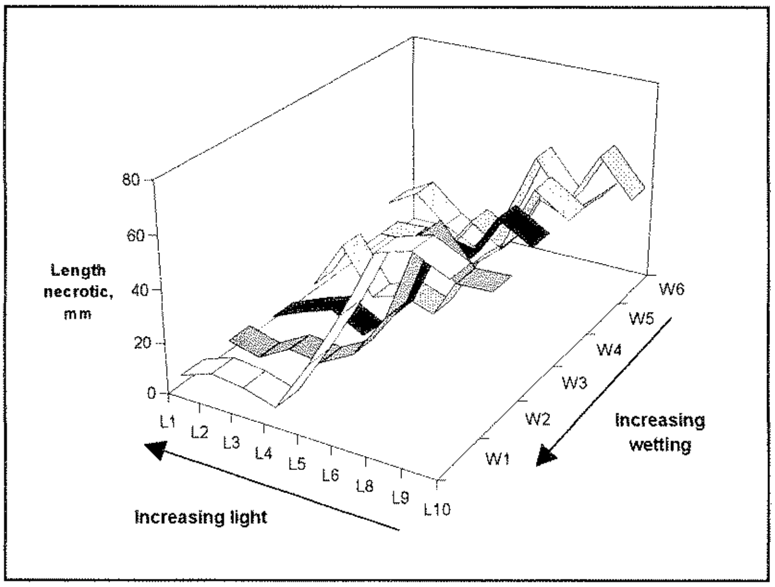


Figure 54. Average length of stem rotted on cuttings of *Rhododendron* 'Gold Flimmer' inserted on 7 August for 12 weeks. The effect of light was statistically significant ($P<0.001$).

Type of cutting

Despite the large differences in appearance amongst the grades of cutting, there were no significant differences in their rooting, or the way that they responded to environment.

Discussion

Rooting was favoured by generous wetting, and the combination of high light with heavy wetting appeared to be optimal but even under these conditions about 20% of cuttings failed to root in 12 weeks. Rooting was completely inhibited by very low light. In practical terms this means that this subject would require a highly supportive rooting environment, such as fog, or polythene-enclosed mist adjusted to run generously wet. There would be a benefit also from keeping shade to the minimum practicable (40 to 80%, depending on weather).

The plant material was highly variable in appearance but no relationship with rooting potential was detected. One grade of cutting was made from shoots which were in a growth flush at the time of collection and therefore had some soft apical leaves at their apex. These did not differ significantly in performance from those with a terminal bud. While this seemed surprising, it is worth noting that this was not the first flush of the season, and both the stem tissue and leaves at the base of these cuttings were well lignified.

***Rhododendron* 'President Roosevelt'**

Like *Rhododendron* 'Gold Flimmer', this is a variegated cultivar which was included in the G-CPE experiments on the suggestion of Round Pond Nurseries who also kindly provided the cuttings. Details were as follows:

Cuttings inserted:	1 August, 1996.
Time in the G-CPE:	91 days.
Types of cutting:	Apical cuttings divided into four grades on the basis of length and thickness. The differences amongst the grades are summarised in Table 35
Replication:	One cutting of each grade per location.
Spacing:	9 x 9 cm in QP24 trays

Roots were too fine to count but were scored in the same way as described for *R.* 'Gold Flimmer'.

Table 35. Measurements on a sample of 3 cuttings of each grade.

	Grade				
	Small	Medium, Thin	Medium, Thick	Large	Mean
Length, cm	5.2	6.6	7.3	7.7	6.71
Diameter, mm	2.97	2.99	3.70	4.21	3.47
Number of leaves	7.7	7.0	6.7	8.0	7.3
Leaf area, cm^2	89.4	79.9	93.4	107.5	92.5

Maximum rooting was obtained when heavy wetting was combined with medium irradiance (Figure 55); the percentage of cuttings which rooted in the Medium/Wet zone was 79%, compared to 54% in the Bright/Wet zone. Taking the volume of roots into account (Figure 56) provides additional evidence that high light levels had an adverse effect on this cultivar, even when heavily wetted, which was not evident in 'Gold Flimmer' (Figure 53). Another striking difference is that in this cultivar a small number of cuttings rooted at very low irradiance (L8 and L9). It is not obvious from the data that the proportion of rooted cuttings which had a very small root system, often based on just one primary root emerging from the stem, was notably greater in 'President Roosevelt' than 'Gold Flimmer'.

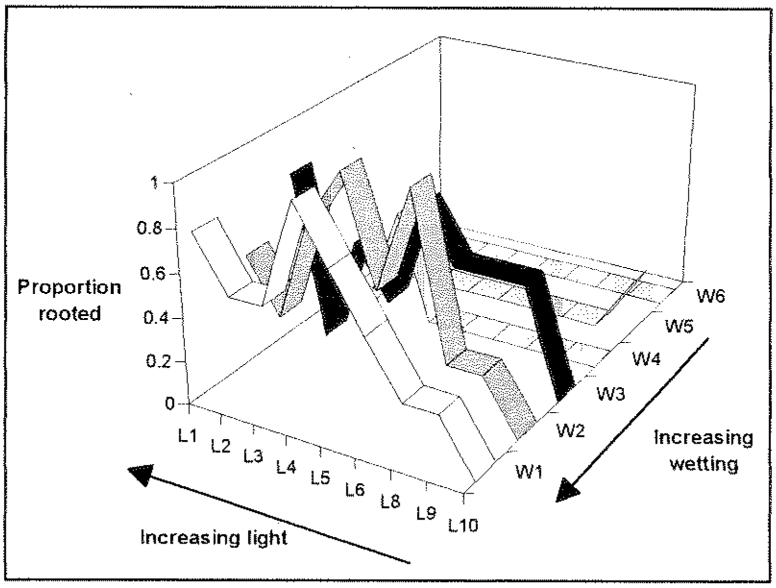


Figure 55. Rooting of *Rhododendron* 'President Roosevelt' cuttings inserted on 1 August for 13 weeks. Statistically significant effects: light ($P<0.001$), wetting ($P<0.001$) but not the interaction of wetting x light.

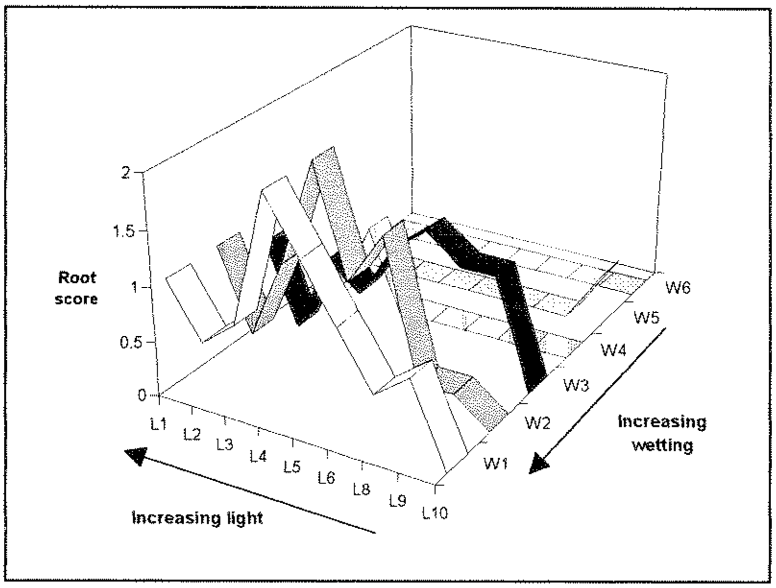


Figure 56. Average score for the amount of root on *Rhododendron* 'President Roosevelt' cuttings inserted on 1 August for 13 weeks (on a scale of 0 to 3, where 0 = unrooted, 3 = substantial root ball). Statistically significant effects: light ($P<0.001$), wetting ($P<0.001$), and the interaction of wetting x light ($P<0.01$).

As with *R.* 'Gold Flimmer' there was very little callus and most cuttings suffered some basal rotting, the length of stem which had rotted decreasing as the light level increased, except at the lowest level of wetting (Figure 57).

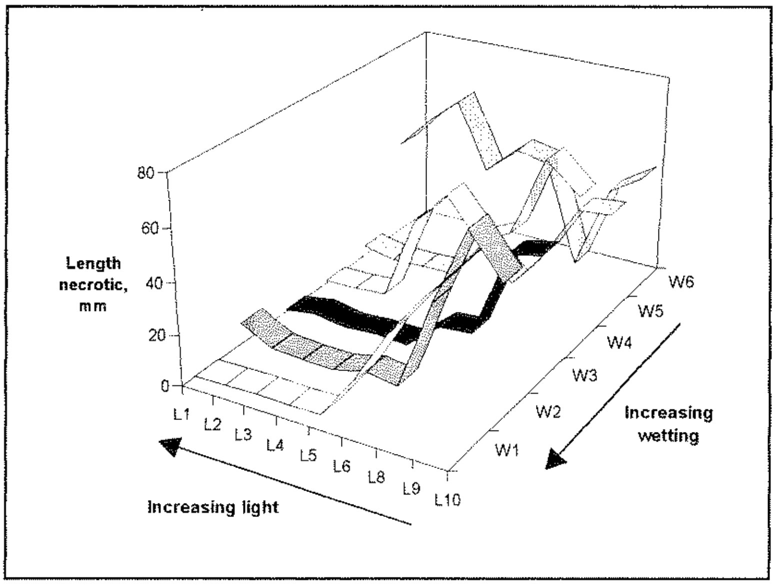


Figure 57. Average length of stem rotted on cuttings of *Rhododendron* 'President Roosevelt' inserted on 1 August for 13 weeks. Statistically significant effects: light ($P<0.001$), and the interaction of wetting x light ($P<0.01$).

Type of cutting

As for *R.* 'Gold Flimmer', there were no significant differences in rooting amongst the grades, or in the way that they responded to environment. Although there were too few elongating shoots of this cultivar to make a separate grade for such cuttings, no correlation between rooting and the presence of soft apical growth was evident.

Discussion

This cultivar behaved very similarly to *R.* 'Gold Flimmer', which was described in the previous section, except that it was more able to root at very low irradiance, and rooting was adversely affected by the highest irradiance levels, even in the most heavily wetted zone. Other points made in the discussion of 'Gold Flimmer' results therefore apply also to 'President Roosevelt'.

Acer palmatum 'Aureum'

Acer palmatum 'Aureum' was included in the G-CPE experiments as an example of a plant with a palmate leaf shape, and because it has previously been found to suffer from water-soaked and/or necrotic leaf spots under conditions of heavy wetting (Harrison-Murray, *et al.* 1996). Like most of the Japanese maples, it is currently produced almost entirely by grafting, the majority of plants being imported, but there is interest in production by cuttings if rooting, establishment and subsequent growth can be made more reliable.

Cuttings were taken from well-established stock plants growing in 10 L containers, which were overwintered in an unheated polythene tunnel but had been moved outside for the summer at the time that cuttings were collected.

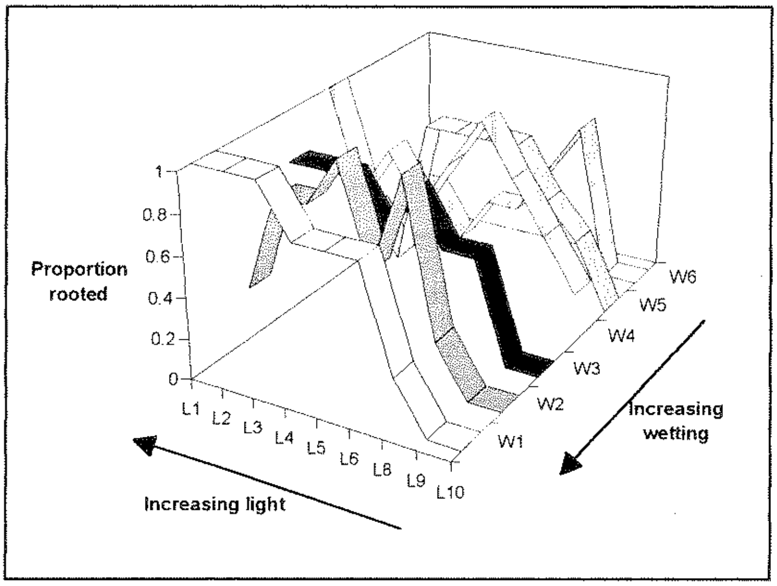
Details of the experiment were as follows:

Cuttings inserted:	25 July, 1996.
Time in the G-CPE:	34 days.
Types of cutting:	Tall apical, short apical, immature proximal (golden leaves), mature proximal (green leaves). Morphological differences between these types are summarised in Table 36.
Replication:	One cutting of each type per location.
Spacing:	9 x 4.5 cm in QP96D trays by leaving alternate cells in each row empty.

Table 36. Measurements on a sample of 6 cuttings of each type

	Type				
	Apical (tall)	Apical (short)	Proximal (immature)	Proximal (mature)	Mean
Length, cm	16.3	13.4	8.0	7.3	11.2
Diameter, mm	1.59	1.63	1.99	2.51	1.93
Number of leaves	4.7	4.3	2.0	2.3	3.3
Leaf area, cm^2	32.5	31.8	34.3	39.8	34.6

The only response that is immediately obvious from the fingerprint graph is the decrease in rooting at low light, but careful examination reveals that rooting also declined sharply where high light was combined with minimal wetting (Figure 58). In this Dry / Bright zone, 25% of cuttings rooted compared to a maximum of 79% which was obtained in both the Bright / Wet and Medium / Wet zones. Although most cuttings failed to root at the lowest light levels (i.e. the Dim zone, corresponding to L8 - L10), there was no evidence that high light stimulated rooting compared to medium light levels.



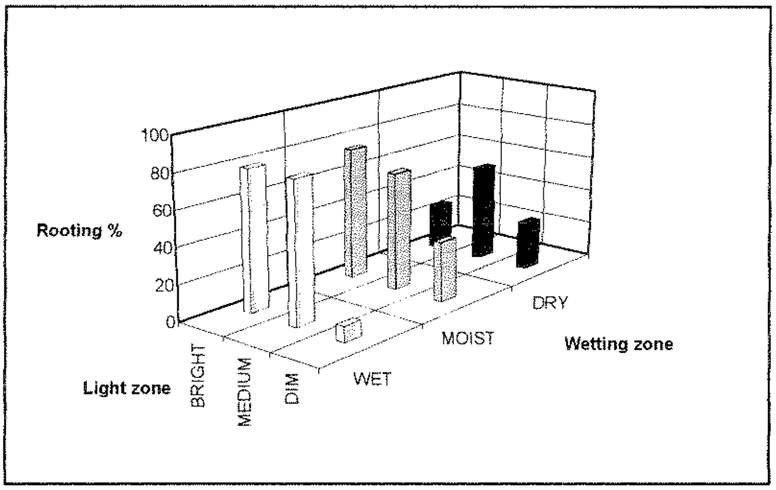


Figure 58. Rooting of *Acer palmatum* 'Aureum' cuttings inserted on 25 July for 5 weeks. Statistically significant effects: light ($P<0.001$), and the interaction of wetting x light ($P<0.05$). In the lower part of the figure the same results are averaged over larger zones as an aid to interpretation (mean LSD between zones = 22.8%).

The numbers of roots per rooted cutting reached a maximum at medium light levels, with a significant decline below this at both higher and lower levels (Table 37). Wetting had no significant effect on roots per rooted cutting. Similarly, the average maximum root length was greatest in the medium light zone (3.0 compared to an average of 2.5; other data not shown).

Table 37. The effect of environment on the number of roots per rooted cutting of *Acer palmatum* 'Aureum' inserted in the G-CPE on 25 July for 5 weeks. Statistically significant effect of light only (P<0.001). LSD = 2.86 for the body of the table, and 1.65 for means (italicised).

Light zone	Wetting zone			
	Wet	Moist	Dry	Mean
Bright	4.5	3.8	2.5	*3.91*
Medium	5.7	6.1	4.8	*5.58*
Dry	3.5	2.9	3.2	*3.07*
Mean	*5.03*	*4.51*	*3.84*	*4.55*

In this experiment leaves did not suffer severe leaf spotting in any environment but, using a scale of 0 to 4 to score the severity of leaf deterioration, the average score varied from 0.9 in the Dry / Medium zone to 2.3 in the Wet / Dim zone (data not shown). The effects of both light and wetting were significant (P<0.001).

There was generally little basal rotting except at the lowest light levels but it was also more frequent at high light than at medium light (Figure 59). Callus was produced at the base of some cuttings but in no environment was callusing heavy. On a scale of 0 to 3, the maximum average callus score was 1.0 which was obtained in the Bright / Wet zone. There was significantly less callus in the Dim and the Bright / Dry zones than in other environments (P<0.05; other data not shown).

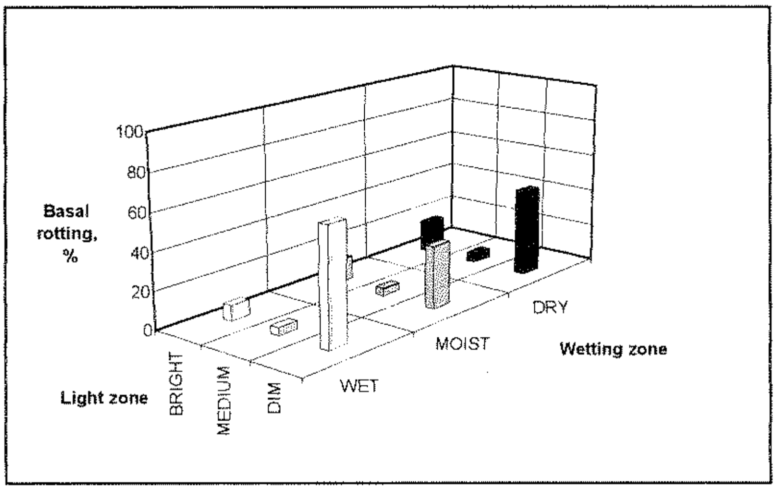


Figure 59. The frequency of basal rotting (affecting > 5 mm of stem) in cuttings of *Acer palmatum* 'Aureum' inserted in the G-CPE on 25 July for 5 weeks. Only the effect of light was statistically significant ($P<0.001$); mean LSD = 16.5.

Type of cutting

There were a number of large differences amongst the different types of cutting, as summarised in Table 38. Proximal cuttings produced more basal callus, and suffered less from basal rotting and leaf deterioration than apical cuttings. Amongst those referred to as 'mature', whose leaves had lost there golden colour, rooting percentage was significantly lower than that of the apicals ($P<0.05$). Amongst cuttings bearing golden leaves, a higher percentage of proximal than apical cuttings rooted. However, both types of proximal cutting produced fewer roots per rooted cutting than apical cuttings.

There were differences also in the way that the types of cutting responded to environment. Rooting of proximal cuttings was relatively insensitive to the combination of high light and minimal wetting, 42% rooting in the Bright / Dry zone compared with only 8% of apical cuttings. Proximal cuttings were also less prone to rotting under low light conditions than apical cuttings, 25% rotting compared with 69%.

Table 38. Summary of the significant differences in behaviour amongst the types of cutting, averaged over all environments

	Grade				
	Apical (tall)	Apical (short)	Proximal (immature)	Proximal (mature)	LSD
Rooting %	53.7	46.3	63.0	35.2	15.0
Roots per rooted cutting	6.2	5.2	3.2	3.5	0.96
Callus score (0 - 3)	0.35	0.24	0.87	0.65	0.27
Leaf deterioration score (0 - 4)	2.03	2.05	1.51	0.96	0.25
Basal rotting (>5 mm), %	33.3	22.2	9.3	20.4	11.3

Discussion

A high rooting percentage (67 to 80%) was achieved throughout the wide range of conditions covered by L1 to L6 / W1 to W4. This was also the area in which the most callus was produced and basal rotting was least. The size of the root system produced, both in terms of number and length of roots, was greater at medium than at high light level.

The results obtained with different types of cutting suggest that the transition from golden to green leaves with distance from the shoot apex may be a useful marker of a substantial loss of rooting potential in older tissues. With smaller leaf area and thicker stems, proximal cuttings showed greater tolerance of low light and of dry conditions than apical cuttings though no difference in optimal environment was detected. Previous studies showed that proximal cuttings are also more tolerant of harsh weaning than apical cuttings (Harrison-Murray *et al.* 1996).

Berberis* x *stenophylla

Berberis x *stenophylla* was included as an example of a commercially important group of evergreen plants with small leaves and thorns. In this particular species the leaves are very narrow (2 - 3 mm) and curl down strongly at the edges so as to almost form a cylinder. In commercial production it is generally rooted under mist from well lignified shoots and success rates are usually high but rather variable. One objective of this experiment was to determine whether some of this variability may be associated with the length or thickness of the shoots from which cuttings are prepared.

Cuttings inserted:	21 June, 1994.
Time in the G-CPE:	34 days.
Types of cutting:	Non-apical cuttings, approximately 15 cm long, divided into 4 grades based on the length and thickness of the shoot from which they were prepared (Table 39).
Replication:	One cutting of each grade per location.
Spacing:	9 x 9 cm in pots (4 cuttings per 11 x 11 cm pot)
Additional environment:	Relatively dry location in the fog house (about 11 m from the fogger).

Table 39. Measurements on a sample of 3 cuttings of each grade. All cuttings were prepared to a length of 15 ± 1 cm; 'long' and 'short' refer to the length of the entire shoot, which ranged from 30 to 80 cm. Leaf area was estimated from the leaf dry weights.

	Grade				
	Thin-Short	Thin-Long	Thick-Short	Thick-Long	Mean
Diameter, mm	2.27	3.06	3.43	4.08	3.21
Leaf area, cm^2	12.6	9.2	11.6	14.5	12.0
Leaf dry weight, g	0.225	0.164	0.207	0.259	0.214
Total dry weight, g	0.501	0.530	0.743	0.945	0.680

Responses to environment

Figure 60 shows that the rooting was affected most by light level, no rooting at all being recorded below L5. The response to wetting is much less clear but, using a statistical curve-fitting procedure, an optimum was identified at W3-4, with a decline towards both wetter and drier conditions. As well as the decline in rooting at the dry end, there was substantial leaf drop in W6, especially at high light (L1 to L4), which suggests the cuttings were suffering water stress under these conditions. At the other extreme, under heavy wetting in W1, leaves were retained but growth of lateral shoots was suppressed compared with less heavily wetted zones (Figure 61).

Amongst the rooted cuttings, the number and length of roots was not significantly influenced by environment, averaging 5.1 roots, up to 6.1 cm long.

Nowhere was rooting consistently close to 100%, indeed the maximum percentage rooting that was predicted from the curve-fitting procedure was only 65%. This indicates that either some of the cuttings did not have the potential to root or that the optimum environment for their rooting lay outside the range tested. For example, from the evidence in Figure 60, it seems possible that by extending the range of light levels above the maximum used here further improvement in rooting would result, especially when combined with moderate to heavy wetting. On the other hand, the rooting potential of the cuttings used in this experiment may have been inherently low. Cuttings were collected earlier than is usual in order to see whether it would be possible to move the propagation date forward by providing a suitable environment for softer cuttings. The stems were pale green and rather flexible, and discussions with nurserymen indicate that rooting is more reliable when shoots have become more 'ripe' (i.e. woody and brown coloured) than this. At low light (L8 - 10) most cuttings rotted completely. As light level increased the average length of rotted stem decreased but it never reached zero, (Figure 62) and virtually every cutting was affected.

Type of cutting

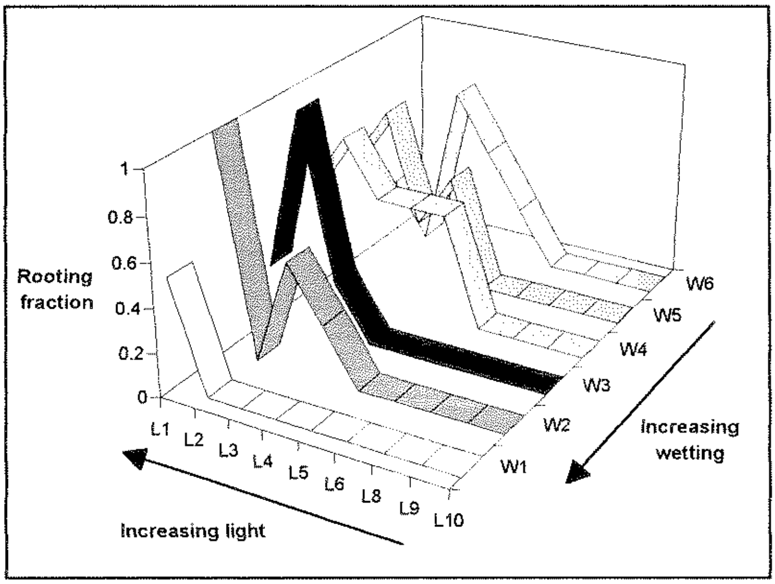
Table 40 shows the percentage rooting, and the extent of rotting, in each grade averaged over all environments. The thickest cuttings (Thick-Long grade) rooted significantly less well, and suffered more extensive rotting, than the thinnest (Thin-Short type); the other two types of cutting were intermediate in all respects. The differences between the two intermediate thickness types suggest that cuttings from short shoots had an advantage independent of their being thinner, but the difference between them was not significant.

Table 40. Effect of shoot type from which cuttings were prepared on rooting and basal rotting of *Berberis* x *stenophylla*. Results have been averaged over all levels of wetting and light, there being no significant interaction with environment.

	Grade				
	Thin-Short	Thin-Long	Thick-Short	Thick-Long	LSD
% rooting	31	17	22	6	11
% severely rotted (> 10 mm)	59	81	69	83	11

Cuttings in the fog house

Of a sample of 16 cuttings in the fog house, 44% rooted with, on average, 5.0 roots up to 3.9 cm long. These are similar to the average values for the Bright zone of the G-CPE, as were also the means for rotting and lateral shoot development.



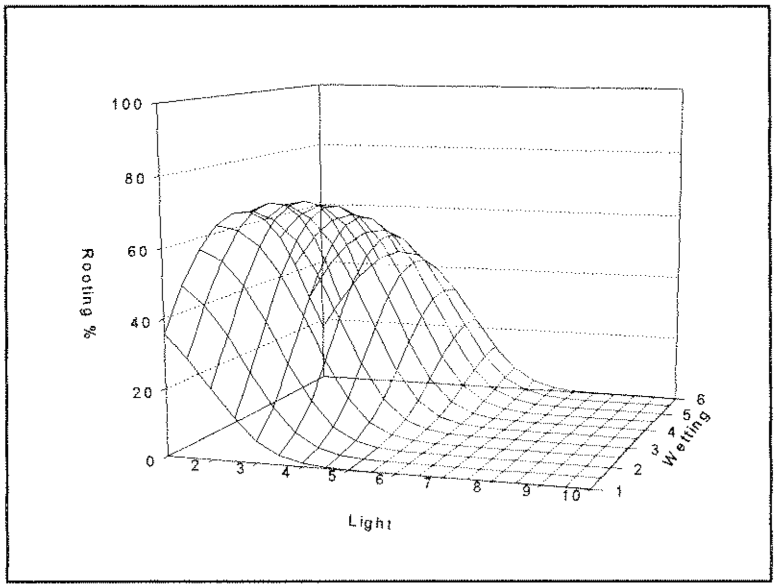


Figure 60. Rooting of *Berberis* x *stenophylla* cuttings inserted on 21 June for 5 weeks. The effect of light, but not wetting, was statistically significant (P<0.001). Upper figure shows the actual data; the lower figure shows the result of a statistical curve-fitting procedure.

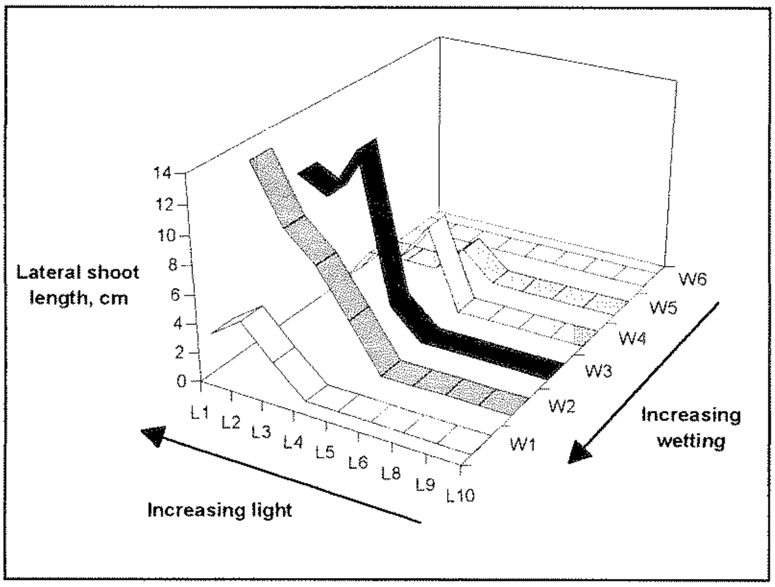


Figure 61. The length of new lateral shoots that developed during 5 weeks rooting of *Berberis* x *stenophylla* cuttings inserted on 21 June. Significant effects of light ($P<0.001$), wetting ($P<0.01$), and the interaction of wetting x light ($P<0.05$).

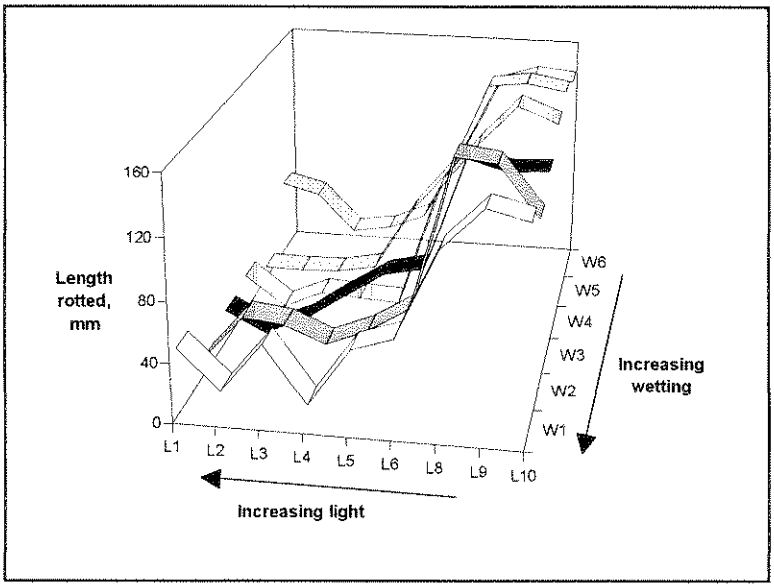


Figure 62. Average length of stem rotted on cuttings of *Berberis* x *stenophylla* inserted on 21 June for 5 weeks. The effect of light, but not wetting, was statistically significant ($P<0.001$).

Discussion

The results from the G-CPE indicate that rooting of *Berberis* x *stenophylla* cuttings requires a higher light level than any other plant which has been tested so far. This may be because they have very little photosynthetic leaf area from which to generate the carbohydrates required to maintain the relatively large volume of stem tissues. This explanation is consistent with the high levels of rotting that were observed, and the sharp increase in rotting which occurred at light levels below L4. By comparison the amount of wetting had virtually no effect on the extent of rotting.

Further work is required to clarify whether the optimum light level of the type of cutting used in this experiment is above the maximum provided by the current configuration of the G-CPE, and whether there is a decrease in the requirement for light as shoots 'ripen'. The term 'ripening' of shoots is not clearly defined but involves additional lignification so that stems become less flexible and often also a change in colour of the stem from green to yellow, red or brown. Amongst the physiological changes that might coincide with these visible changes is the start of accumulation of carbohydrate reserves which would make cuttings less dependent on generating carbohydrate by photosynthesis during rooting and therefore might reduce their light requirement compared to the soft green cuttings used here.

By comparison with light, the level of wetting had little effect on rooting, but the evidence suggests that, while the cuttings are too lignified to wilt visibly, rooting can be suppressed by water stress at high light if there is no wetting, whereas moderate to heavy wetting has no adverse effect if the light level is high.

The practical conclusion is that an open mist system is likely to be more appropriate for this subject than fog or any other high humidity system because shading needs to be kept to a minimum. If little shade is used on any system which is closed to retain humidity, extremely high temperatures tend to develop. The combination of lower humidity and higher light is expected to shift the wetting response seen under G-CPE conditions towards heavier wetting, so that adverse effects of heavy wetting are unlikely unless inadequate drainage results in the medium becoming excessively wet.

The results from the small sample of cuttings placed in a relatively dry part of the fog house were consistent with the responses observed in the G-CPE.

Ceanothus impressus

Ceanothus impressus was included in the G-CPE experiments because nurseries report variable success with this subject and because its environmental response might reflect its distinctive leaf morphology and highly branched habit. The leaves are very small, on average about 5 mm across, almost round and very deeply veined. Details of the experiment were as follows:

Cuttings inserted:	27 June, 1996.
Time in the G-CPE:	36 days.
Types of cutting:	Apical cuttings divided into 2 size grades. The differences between the two grades are summarised in Table 41.
Replication:	2 cuttings of each grade per location.
Spacing:	4.5 x 4.5 cm in QP96D trays.

Table 41. Measurements on a sample of 12 cuttings from each grade.

	Grade		
	Small	Large	Mean
Length, cm	11.9	14.7	13.3
Diameter, mm	1.74	1.92	1.83
*Leaf area, cm^2	4.13	9.05	6.59

* Leaf area estimated from the dry weight of the leaves using the ratio of leaf area to dry weight determined on a single cutting of each grade

Despite regular spays of fungicide, after three weeks cuttings at the three lowest light levels had become seriously infected with *Botrytis* and were removed.

Little rooting was observed in any environment, but the results in Figures 63 and 64 suggest that high light, and to a lesser extent generous wetting, favoured rooting. There was virtually no callus formation, and basal rotting affected all cuttings. The average length of rotted stem decreased with increasing light, but even amongst many rooted cuttings, rotting extended to more than 5 mm from the base (Figure 65).

Cutting size

Cutting size had no significant effect on either rooting or the problem of basal rotting.

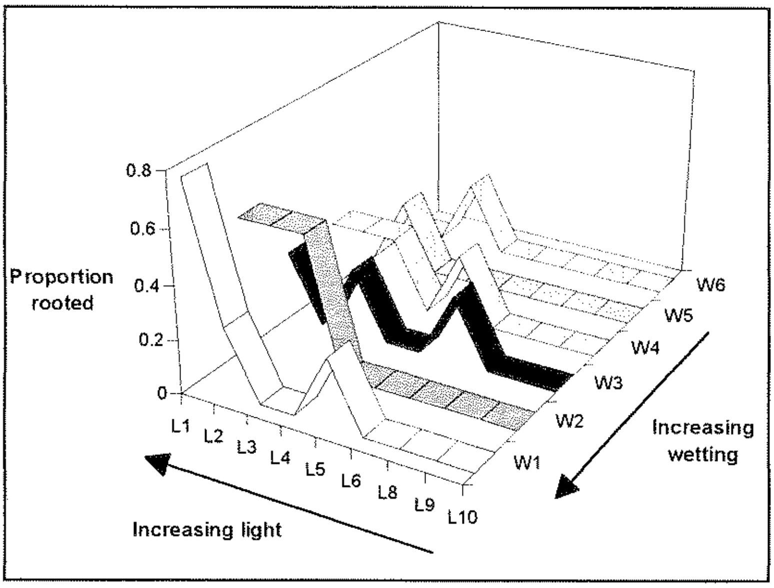


Figure 63. Rooting of *Ceanothus impressus* cuttings inserted on 27 June for 5 weeks. Statistically significant effects: wetting ($P<0.05$), light ($P<0.001$), but not the interaction of wetting x light.

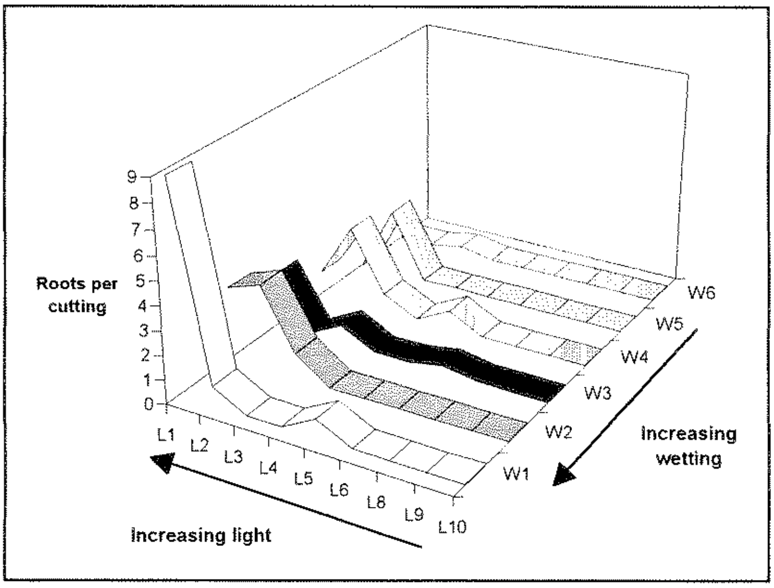


Figure 64. Effect of environment on the number of roots per cutting of *Ceanothus impressus* inserted on 27 June for 5 weeks. Only the effect of light was statistically significant ($P<0.001$).

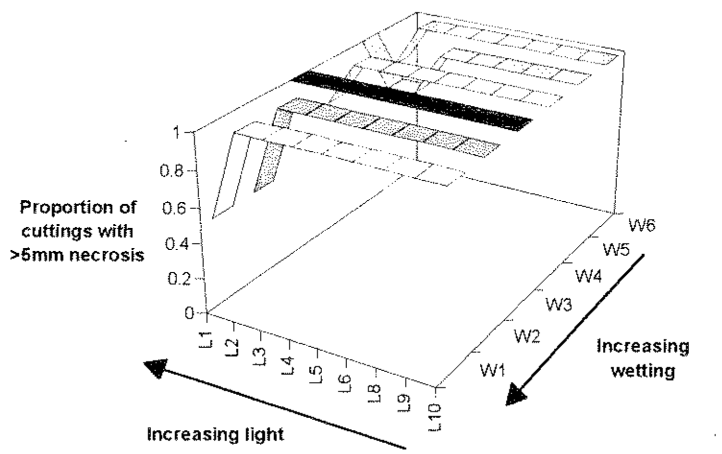


Figure 65. Basal rotting of *Ceanothus impressus* cuttings inserted on 27 June for 5 weeks. Only the effect of light was statistically significant ($P<0.001$).

Discussion

None of the environments in the G-CPE were suitable for this species. The results showed some benefit from high light, both in terms of rooting and limiting the problem of basal rotting, and it is possible that higher rooting percentages might have been obtained if the maximum light level had been greater. However, 83% rooting has been recorded previously from the same clone, in a fog house in which cuttings were kept lightly wetted, and in which the average light level would have been approximately equivalent to that in L4 (Harrison-Murray *et al.* 1993). It may be relevant that those cuttings were propagated much later in the year (early September), but results obtained with *C. impressus* 'Puget Blue' (see next section) suggest that there is some factor common to all the G-CPE environments that adversely affects cuttings of this species.

Ceanothus impressus **'Puget Blue'**

This cultivar of *C. impressus* was included in the G-CPE experiments partly because it is a more desirable form and partly because it has larger leaves which might alter the response to propagation environment. Cuttings were kindly supplied by Round Pond Nursery. Details of the experiment were as follows:

Cuttings inserted:	8 August, 1996.
Time in the G-CPE:	89 days.
Types of cutting:	Apical cuttings divided into 4 size grades
Replication:	One cutting of each grade per location.
Spacing:	9 x 4.5 cm in QP96D trays.
Additional environment:	Towards the drier end of the fog house, at about 11 m from the fogger.

The material received from Round Pond Nurseries was very uniform and the differences between the grades were therefore negligible. Table 42 provides a description of the cuttings based on the mean of all grades.

Table 42. Measurements on a sample of 12 cuttings (3 from each grade)

Length, cm	9.57
Diameter, mm	1.65
Number of leaves	40.7
Leaf area, cm^2	6.22

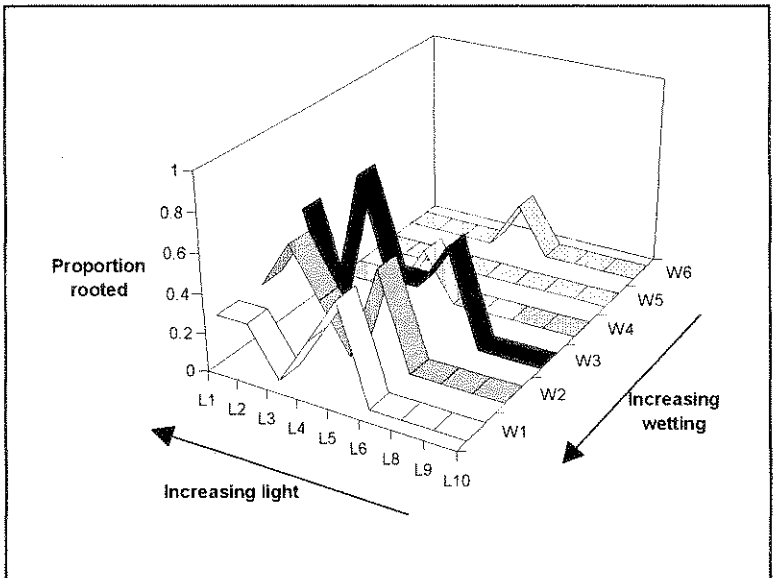


Figure 66. Rooting of *Ceanothus impressus* 'Puget Blue' cuttings inserted on 8 August for 13 weeks. Statistically significant effects: wetting (P<0.01), light (P<0.001), but not the interaction of wetting x light.

The rooting results showed that rooting was favoured by moderate to heavy wetting but in no environment was a high percentage rooting obtained (Figure 66). Rooting was inhibited completely at the three lowest light levels. Averaged over larger zones, the highest rooting percentage was 25% which occurred in the Bright/Wet zone. Despite allowing 13 weeks for roots to develop before removing cuttings for assessment, the average number of roots per rooted cutting was only 4.1 and the maximum root length per cutting was only 1.6 cm.

As in the case of the species (see previous section), there was little callus formation and all but one cutting had more than 5 mm of rotted stem at the base. Averaged over the larger zones, the minimum length of rotted tissue was 40 mm which was observed in the Bright/Wet zone.

Cuttings in the fog house

Out of 27 cuttings placed towards the drier end of the fog house, 93% rooted, with an average of 10.6 roots per rooted cutting and an average maximum root length per cutting of 8.9 cm.

Discussion

The much better performance of cuttings in the fog house suggests that this subject was sensitive to some factor that was common to all the environments in the G-CPE. The most likely candidate is the quality of the light provided by high pressure sodium lamps, which differs substantially from natural light.

The rooting obtained in the fog house, combined with the trends seen in the G-CPE, suggest that the optimal environment for rooting *C. impressus* 'Puget Blue' is probably one in which moderate to heavy wetting is combined with moderate to high light level. In a previous project, *C. impressus* cuttings failed to root in the *wettest* part of the fog house (Harrison-Murray *et al.*, 1993), indicating that it is sensitive to excessive wetting . It is probably important that in that part of the house, close to the fan assisted fogger, some water is deposited on the undersurface of leaves.

***Ceanothus* 'Autumnal Blue'**

This cultivar of *Ceanothus* was included in the G-CPE experiments for comparison with the two forms of *C. impressus* both of which have much smaller but otherwise similar leaves. Details of the experiment were as follows:

Cuttings inserted:	8 August, 1996.
Time in the G-CPE:	90 days.
Types of cutting:	Apical cuttings, divided into 2 grades on stem thickness. The differences between them are summarised in Table 43.
Replication:	2 cuttings of each grade per location.
Spacing:	9 x 9 cm in QP96D trays by leaving alternate cells empty.
Additional environment:	Towards the drier end of the fog house, at about 11 m from the fogger.

Table 43. Measurements on a sample of 6 cuttings from each grade.

	Grade		
	Thin	Thick	Mean
Length, cm	12.28	13.47	12.87
Diameter, mm	2.15	2.29	2.22
Number of leaves	8.5	11.8	10.2
Leaf area, cm^2	24.5	31.7	28.1

As can be seen from the results in Figure 67, close to 100% rooting was obtained over the broad range of locations in which there was at least light wetting combined with moderate to high light, the optimum light level increasing as wetting increased. Root number data showed that additional light, above that required to achieve 100% rooting, did not result in any increase in root number (Figure 68 compared with Figure 67). The maximum root length per cutting averaged over the whole experiment was 6.6 cm, with no significant effect of environment.

There was no difference in rooting percentage between the two grades of cutting but thick cuttings had significantly more roots per rooted cutting (17.2 compared with 13.6, $P<0.05$).

Almost all cuttings had a few millimetres of rotted tissue at the base of the cutting but more extensive rotting was largely confined to the lowest light levels (L8 to L10) (Figure 69). Rotting was not influenced by the thickness of cuttings.

Many cuttings showed some production of callus, though it was rare for a complete ring to be formed. Callus production was greatest at high light and intermediate wetting (Figure 70), a combination in which water stress prevented maximum rooting (Figure 67).

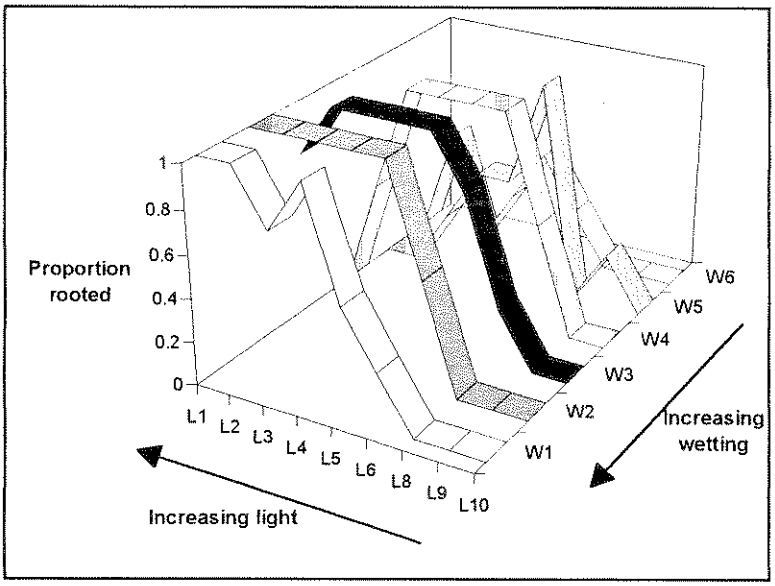


Figure 67. Rooting of *Ceanothus* 'Autumnal Blue' cuttings inserted on 8 August for 13 weeks. Statistically significant effects: wetting (P<0.001), light (P<0.001), and the interaction of wetting x light (P<0.01)

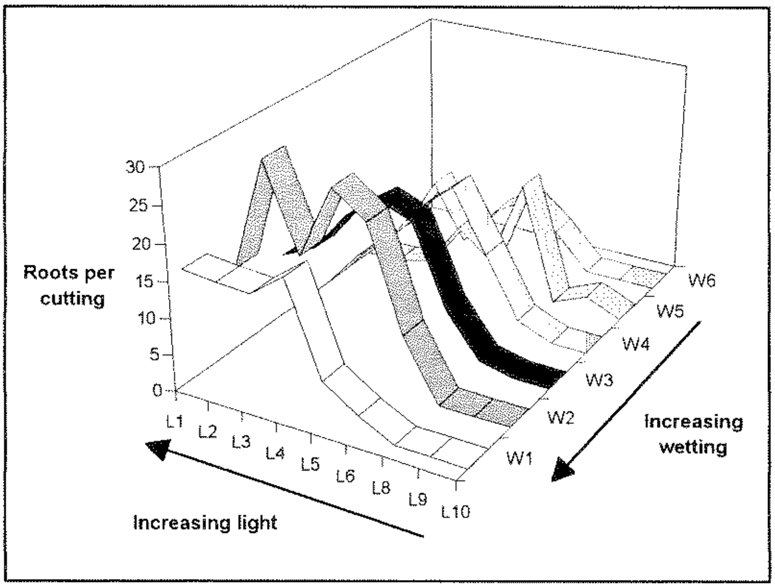


Figure 68. The number of roots per cutting of *Ceanothus* 'Autumnal Blue' inserted on 8 August for 13 weeks. Statistically significant effects: wetting (P<0.001), light (P<0.001), and the interaction of wetting x light (P<0.01)

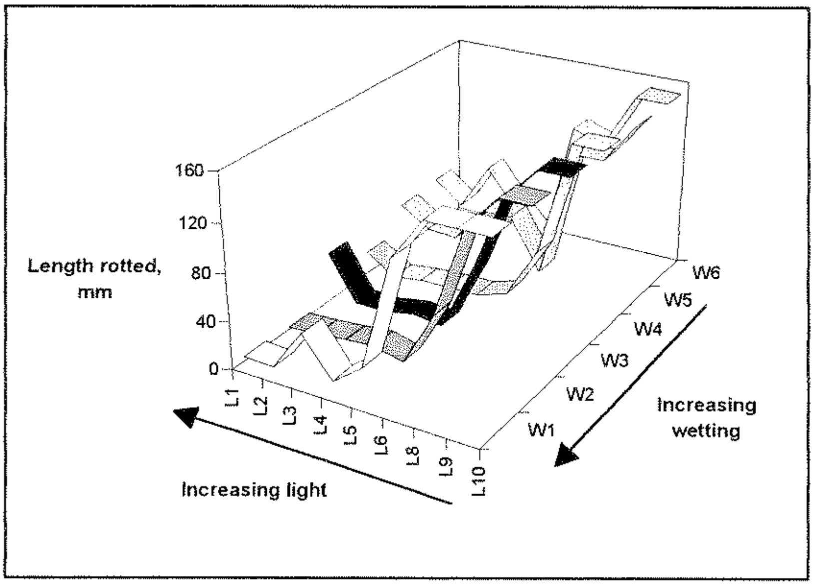


Figure 69. The extent of rotting in cuttings of *Ceanothus* 'Autumnal Blue' inserted on 8 August for 13 weeks. Only the effect of light was statistically significant ($P<0.001$).

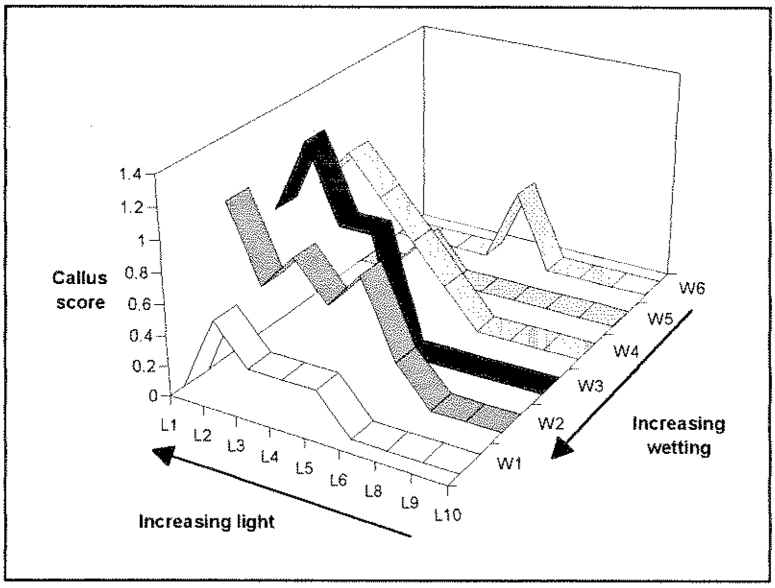


Figure 70. Extent of basal callus production in cuttings of *Ceanothus* 'Autumnal Blue' inserted on 8 August for 13 weeks (scored 0 to 3 where 3 = a complete ring of callus). Statistically significant effects: wetting ($P<0.001$), light ($P<0.001$), and the interaction of light x wetting ($P<0.001$).

Cuttings in the fog house

Of 28 cuttings placed in the fog house 27 rooted (96%), with an average of 16.6 roots per cutting, an average maximum root length of 10.2 cm, and an average callus score of 1.54, all of which are broadly similar to those observed in the optimal zones within the G-CPE matrix.

Discussion

Ceanothus 'Autumnal Blue' rooted well over a wide range of conditions though it could not tolerate very low light nor very dry conditions. High light did not increase the number or length of roots compared to moderate light but increased the need for heavy wetting to avoid drought stress.

In practical terms this means that reliably high success rates are likely to be achieved by aiming for moderate light levels combined with moderate to heavy wetting. This is little different from that proposed for the smaller leaved *C. impressus* and *C. impressus* 'Puget Blue'. In contrast to those subjects, there was no evidence that *C.* 'Autumnal Blue' cuttings were adversely affected by the light from the high pressure sodium lamps, or some other factor common to all locations in the G-CPE matrix.

Convolvulus cneorum

Convolvulus cneorum was included in the G-CPE experiments as an example of a plant with densely hairy grey leaves. It is currently popular with the gardening public and in trying to meet the resultant high demand for it some nurseries have reported highly variable success rates. Material from this experiment came from two sources: well lignified cuttings from field grown stock plants at East Malling; softer cuttings from young container plants (kindly supplied by Round Pond Nursery).

Cuttings inserted:	1 August, 1996.
Time in the G-CPE:	28 days.
Types of cutting:	Apical cuttings, from two sources (see above) each divided into 2 size grades (see Table 44 for comparison of grades)
Replication:	One cutting of each grade per location.
Spacing:	9 x 4.5 cm in QP96D trays

Table 44. Measurements on a sample of 3 cuttings of each grade.

	Container source		Field source		
	small	large	small	large	Mean
Length, cm	9.0	11.7	13.2	13.3	11.8
Diameter, mm	1.56	1.57	1.65	1.71	1.62
Number of leaves	8.0	10.3	10.7	12.0	10.3
Leaf area, cm^2	13.8	20.5	19.9	26.3	20.1

Rooting occurred only at the drier end of the wetting gradient; the results in Figure 71 suggest that the optimal conditions are a combination of moderately high light with minimal wetting. The data are not conclusive but it appears that rooting may be suppressed by high light if there is no wetting (i.e. in W6 but not W5). Most of the cuttings which rooted were from the container plant source. Under the most favourable conditions (i.e Bright/Dry and Medium/Dry zones combined) 67% of cuttings from the container plant source rooted compared to 25% from the field source. There was no significant difference between cuttings in different size grades.

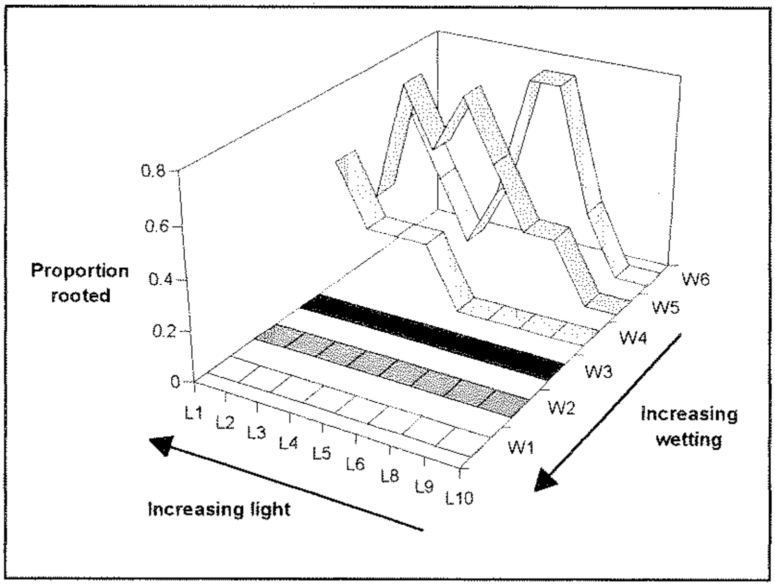


Figure 71. Rooting of cuttings *Convolvulus cneorum* inserted on 1 August for 4 weeks. Statistically significant effects: light ($P<0.01$), and wetting ($P<0.01$).

The decision to record rooting after 28 days was based on the appearance of a few long roots out of the base of the trays. Following removal of the cuttings from the medium it was clear that many cuttings had only just rooted, having roots only a few millimetres long. It is very likely that more cuttings would have rooted in time but unlikely that many cuttings would have rooted under very wet or low light conditions because rotting was a extensive under these conditions (Table 45). The softer cuttings from the container source were particularly susceptible to rotting at low light (data not shown).

Table 45. Average length of rotted stem at the base of cuttings of *Convolvulus cneorum* inserted in the G-CPE on 1 August for 4 weeks. Statistically significant effects: light ($P<0.001$), and wetting ($P<0.001$); LSD = 15.2 for the body of the table and 8.79 for comparisons between wetting or light zone means (italicised).

Light zone	Wetting zone			
	Wet	Moist	Dry	Mean
Bright	14.1	6.5	1.8	*7.5*
Medium	19.2	9.0	3.4	*10.5*
Dim	25.1	23.5	15.0	*21.2*
Mean	*19.5*	*13.0*	*6.7*	

Discussion

These results show that cuttings of *C. cneorum* require relatively dry conditions because they are adversely affected by wetting, as well as by low light. There was some evidence that high light was able to offset the adverse effect of moderate wetting on rooting. This suggests that excessive suppression of transpiration may be injurious, rather than wetting *per se*. There was also some evidence that high light in the absence of any wetting reduces rooting, but further work would be required to confirm this. In retrospect, it is clear that rooting was recorded before rooting potential had been expressed fully and it is likely that a future experiment would identify an environment in which rooting would approach 100%.

Relatively soft cuttings from young plants growing in containers rooted in greater numbers than more lignified cuttings from a field source. In view of the early recording of rooting, this result must be interpreted with caution because it is possible that the difference is in speed of rooting rather than ultimate rooting potential.

Further work would be required to identify more precisely the combination of cutting source and environment to ensure high success rates.

***Pieris japonica* 'Little Heath'**

This subject was suggested and cuttings were kindly provided by Round Pond Nurseries. Details were as follows:

Cuttings inserted:	7 August, 1996.
Time in the G-CPE:	31 days.
Types of cutting:	Apical cuttings divided into three grades on stem thickness. The differences between the three grades are summarised in Table 46.
Replication:	2 thin, 1 medium, and 1 thick grade cutting per location.
Spacing:	9 x 9 cm in QP96D trays (by leaving alternate cells unused).

Table 46. Measurements on a sample of each grade of cutting.

	Grade			
	Thin (n = 6)	Medium (n = 3)	Thick (n = 3)	Mean (n = 12)
Length, cm	4.08	4.67	6.33	4.79
Diameter, mm	1.39	1.56	1.93	1.57
Number of leaves	15.1	13.6	24.6	17.1
Leaf area, cm^2	12.8	14.7	16.3	14.1

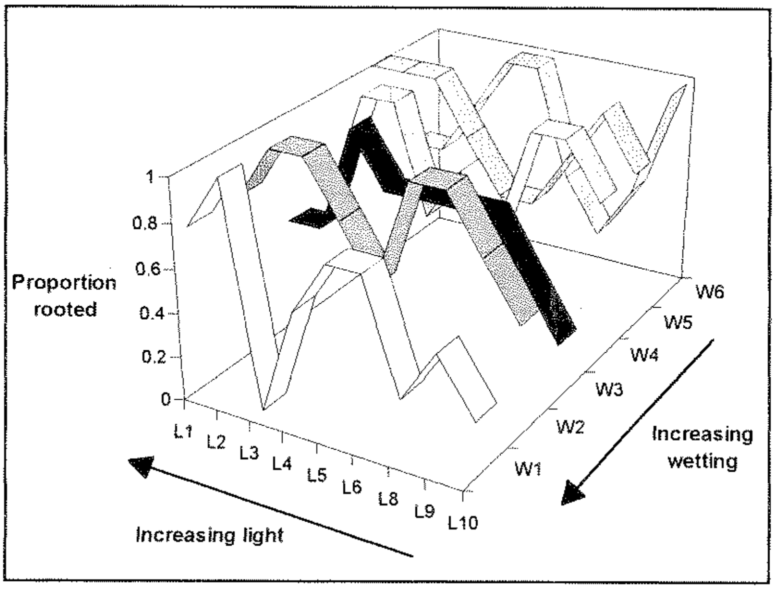


Figure 72. 'Environmental fingerprint' for *Pieris japonica* 'Little Heath'. There were no statistically significant effects.

On average 70% of all cuttings rooted but there was no evidence of there being any effect of environment on this percentage (Figure 72). However, the number of roots increased with light level and decreased with wetting (Table 47). Similar trends applied to root length which averaged 4.3 cm (data not shown). The proportion of cuttings showing new shoot growth at the end of the rooting period was significantly greater in the 'Bright' and 'Medium' zones than in the 'Dim' zone.

The grade of cutting had no effect on rooting percentage or root number but the thin cuttings were better callused and suffered significantly less basal rotting (an average of 1.7 mm compared to 5.7; $P< 0.001$).

Table 47. Roots per rooted cutting of *Pieris japonica* 'Little Heath' inserted in the G-CPE on 7 August for 31 days. Statistically significant effects: light ($P<0.05$), wetting ($P<0.001$); LSD = 1.96 for the body of the table, and 1.14 for comparisons between light or wetting zone means (italicised).

Light zone	Wetting zone			
	Wet	Moist	Dry	Mean
Bright	3.06	3.06	4.95	*3.71*
Medium	2.65	2.87	4.06	*3.20*
Dim	2.39	2.94	3.29	*2.91*
Mean	*2.73*	*2.96*	*4.13*	

Discussion
This subject was tolerant of a very wide range of environments but failed to reach 100% rooting in any environment. It showed no signs of suffering water stress under 'Bright' / 'Dry' conditions, indeed it was these conditions in which the greatest root numbers were produced and cuttings suffered the least necrosis.

Roots were quite short, and root numbers small when cuttings were examined, so that it is possible that many of the unrooted cuttings would have rooted given more time. Except under very low light conditions, basal rotting was not extensive and is unlikely to be a limiting factor.

***Pieris* 'Flaming Silver'**

This subject was suggested and cuttings kindly provided by Round Pond Nurseries. Details were as follows:

Cuttings inserted:	6 August, 1996.
Time in the G-CPE:	57 days.
Types of cutting:	Apical cuttings divided into three size grades. The differences are summarised in Table 48.
Replication:	1 cutting of each grade per location.
Spacing:	9 x 9 cm in QP24 trays (one in every four cells empty because of shortage of material).

As can be seen from Table 48 the difference in size between the grades was substantial.

Table 48. Measurements on a sample of 3 cuttings from each grade.

	Grade			
	Small	Medium	Large	Mean
Length, cm	3.83	5.33	7.83	5.67
Diameter, mm	1.83	2.17	2.31	2.10
Number of leaves	9.0	12.3	13.7	11.7
Leaf area, cm^2	37.6	50.2	59.9	49.2

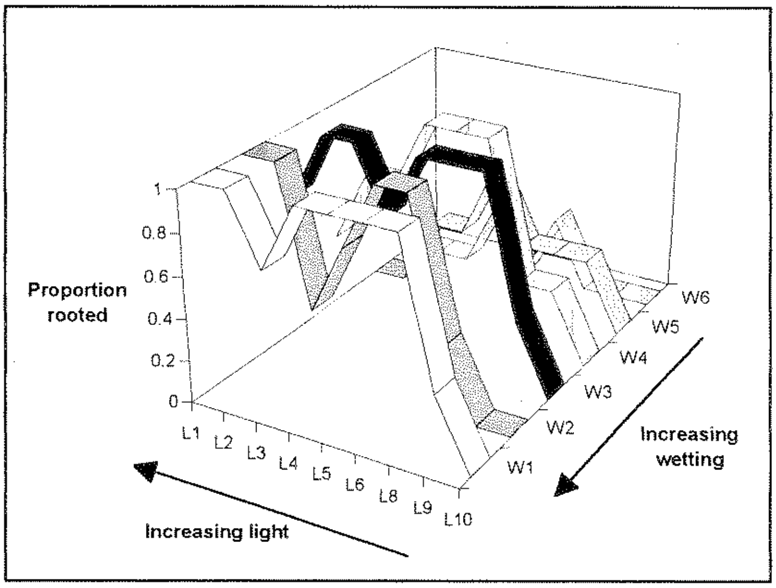


Figure 73. Rooting of *Pieris* 'Flaming Silver' inserted on 6 August for 8 weeks. Statistically significant effects: wetting ($P<0.001$), light ($P<0.001$), but not the interaction of wetting x light.

The results shown in Figure 73 indicate that the proportion of cuttings which rooted decreased rapidly where wetting was minimal, i.e. in W5 and W6. The response to light was less marked: some rooting occurred at all but the lowest light level (L10) though moderate light (L6) was required to ensure maximum rooting. Where there was little leaf wetting (W4 to W6) high light reduced rooting, though the interaction between light and wetting was much weaker than in most subjects and not statistically significant. Similarly, neither light nor wetting significantly affected either the length or the number of roots per rooted cutting (data not shown), which averaged 3.1 cm and 4.0 respectively.

The development of basal callus responded to environment in a way that paralleled the rooting response, even though some individual cuttings rooted but did not callus, and others callused but did not root (data not shown). Absence of callus was often associated with rotting of the stem tissues at the base of cutting being sufficiently severe and extensive to eliminate any possibility that the cutting would root. This was reflected in measurements of the average length of rotted stem which showed significant effects of both light and wetting (Table 49).

Table 49. The effect of environment on the extent of rotting at the base of cuttings of *Pieris* 'Flaming Silver' inserted in the G-CPE on 6 August for 8 weeks. Statistically significant effects: wetting ($P<0.05$), light ($P<0.001$). LSD = 24.1 for the body of the table, and 13.9 for comparisons of wetting or light zone means (italicised).

Light zone	Wetting zone			
	Wet	Moist	Dry	Mean
Bright	6.0	2.4	10.6	*6.3*
Medium	6.8	3.6	12.4	*7.6*
Dry	31.0	35.8	49.7	*38.8*
Mean	*14.6*	*13.9*	*24.2*	

Cutting size

Small cuttings rooted in significantly greater numbers than large ones, the difference becoming more marked as wetting decreased (Table 50). However, cutting size had no influence on the number or length of roots per rooted cutting.

Small cuttings were also less susceptible to rotting than larger cuttings (Table 51). Over all environments, the proportion of cuttings with more than 5 mm of rotted stem was 20% of the small grade cuttings compared with 54% of the large grade, the latter increasing to 72% in the Dry zone.

Table 50. Rooting percentage of *Pieris* 'Flaming Silver' cuttings inserted in the G-CPE on 6 August for 8 weeks as affected by cutting grade and wetting level. Values in the table are averaged over all light levels. The effect of size was statistically significant (P<0.05) and the interaction with wetting level approached significance (P=0.07).

Wetting zone	Grade			
	Small	Medium	Large	Mean
Wet	72.2	66.7	66.7	68.5
Moist	88.9	61.1	50.0	66.7
Dry	22.2	27.8	0	16.7
Mean	61.1	51.9	38.9	

Table 51. Incidence of basal rotting (%) amongst *Pieris* 'Flaming Silver' cuttings inserted in the G-CPE on 6 August for 8 weeks, as affected by cutting size and wetting level. Values are the percentage of cuttings in which >5 mm had rotted, averaged over all light levels. The effect of size was statistically significant (P<0.001).

	Grade			
	Small	Medium	Large	Mean
Wet	22.2	50.0	50.0	40.7
Moist	11.1	22.2	38.9	24.1
Dry	27.8	27.8	72.2	42.6
Mean	20.4	33.3	53.7	

Discussion

In contrast to *Pieris japonica* 'Little Heath', this subject responded strongly to environment. In particular it showed a marked benefit from leaf wetting that was not evident in 'Little Heath'. The difference may well be related to the much larger leaves, less dense habit, and greater total leaf area per cutting in 'Flaming Silver'. The average leaf area per cutting on 'Flaming Silver' was more than three times that of 'Little Heath', which would clearly have increased its potential to lose water.

A high level of rooting was obtained over a broad range of conditions in which moderate to heavy wetting was combined with moderate to high light. However, despite allowing eight weeks for rooting to occur, some cuttings remained healthy but unrooted whilst others in essentially identical environments had developed roots up to 5 cm long. This is likely to reflect inherent differences in the rooting potential amongst cuttings. Some differences in rooting potential were shown to be related to the size of the cutting, and it is probable that rooting of individual cuttings was influenced by less readily identified factors, such as the cutting's position within the stockplant. The alternative is that the variation in rooting between adjacent cuttings results from minor differences in the environment of individual cuttings, such as the degree of compaction of the rooting medium around the cutting base.

The practical conclusion is that *Pieris* 'Flaming Silver' cuttings root best under wet conditions and are tolerant of a wide range of light intensity. However, cuttings can vary considerably in their rooting potential and, within the material used for this experiment, small cuttings had the highest rooting potential.

Cornus alba 'Sibirica'

Cornus alba 'Sibirica' is the first of four readily-rooted subjects to be described. The purpose of including some easy-to-root plants in the G-CPE experiments was to compare their response to environment with that of the more difficult subjects.

This subject, together with *Forsythia* and *Weigela*, was tested in G-CPE using a rather different approach from that adopted for all other subjects. In the expectation that in most environments almost all cuttings would root, just one cutting of each species was placed in each location.

Apical cuttings, with two pairs of fully expanded leaves, were inserted on 23 August, 1994, for 35 days. Detailed measurements were not made but a typical cutting was 18 cm long, with a leaf area of 85 cm^2 and a stem diameter of 2.9 mm. They were planted at 9 x 9 cm spacing in 11 cm square pots.

Responses to environment

Within a few days of insertion, cuttings wilted in the Bright/Dry zone, and although many later appeared to recover, rooting was suppressed severely (Figure 74) and many leaves were permanently 'scorched', even on those which rooted. Unexpectedly, out of the six cuttings in each major zone, some failed to root in almost all zones. Rooting was suppressed also where low light was combined with heavy wetting.

The adverse effects of water stress and low light on root growth and development after rooting was very evident from the average length of the longest individual root on each cutting, and dry weight of roots (lower sections of Figure 74). There was no significant effect on root numbers, which averaged 15 roots per rooted cutting, and there was little rotting and no new shoot growth in any environment (data not shown).

Discussion

This experiment showed that, even in this relatively easy-to-root plant, rooting could be inhibited by water stress, in situations where high light was combined with minimal wetting to create high evaporative demand. However, some cuttings failed to root in all parts of the G-CPE, indicating that the rooting potential of this particular batch of cuttings was less than expected, probably because shoots had almost terminated growth when cuttings were collected. In a separate experiment with cuttings taken from strongly growing shoots at the end of June, failures were confined to the 'Dim' and 'Dry' zones. The responses of this subject can therefore be seen to have something in common with morphologically similar difficult-to-root subjects, such as *Cotinus coggygria*, but the degree to which rooting is inhibited by low light or by high evaporative demand is much less.

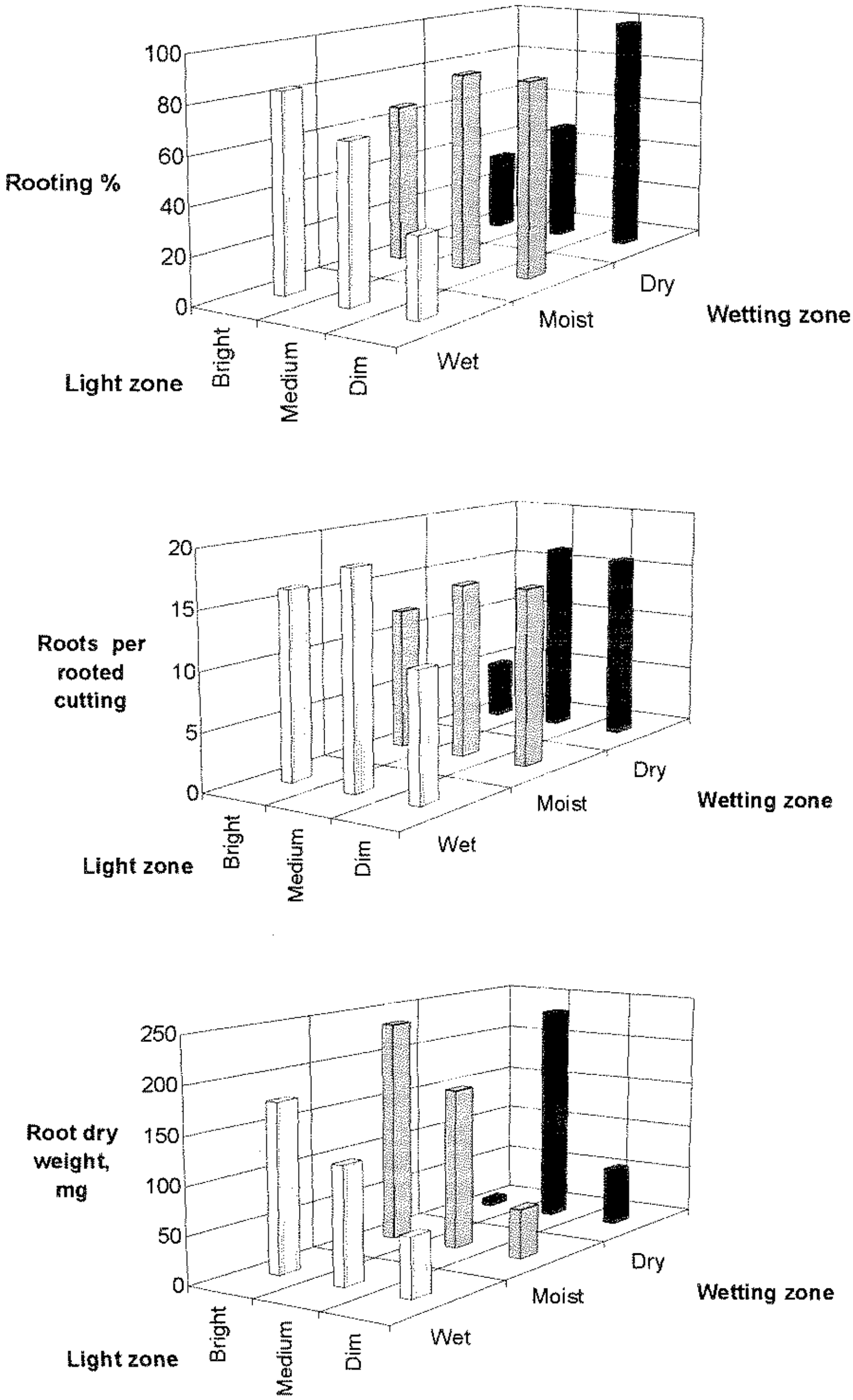


Figure 74. Rooting percentage, length of the longest root, and root dry weight per rooted cutting of *Cornus alba* 'Sibirica' cuttings inserted on 23 August for 5 weeks. Significant effects: the interaction of wetting x light on rooting ($P<0.05$) and the effect of light on length and dry weight of roots ($P<0.05$).

***Forsythia* x *intermedia* 'Lynwood'**

This was the second of the three easy-to-root subjects that were tested together in the G-CPE using a rather different approach from that adopted for all other subjects. In the expectation that in most environments almost all cuttings would root, just one cutting of each species was placed in each location.

Apical cuttings, with four pairs of leaves, were inserted on 23 August, 1994, for 35 days. Detailed measurements were not made but a typical cutting was 18 cm long, with a leaf area of 60 cm^2 and a stem diameter of 2.3 mm. They were planted at 9 x 9 cm spacing in 11 cm square pots.

Responses to environment

Within a few days of insertion, slight wilting was observed in the Bright/Dry zone but neither in this, nor any other environment did any cutting fail to root.

The length of roots increased in response to both light and wetting and this was reflected in the dry weight of roots (Figure 75). In contrast to two other easy-to-root subjects, *Weigela florida* 'Variegata' and *Cornus alba* 'Sibirica', the number of roots per rooted cutting was also influenced by environment, increasing in response to light, from 18 in the 'Dim' zone to 36 in the 'Bright' zone ($P<0.001$; full data not shown).

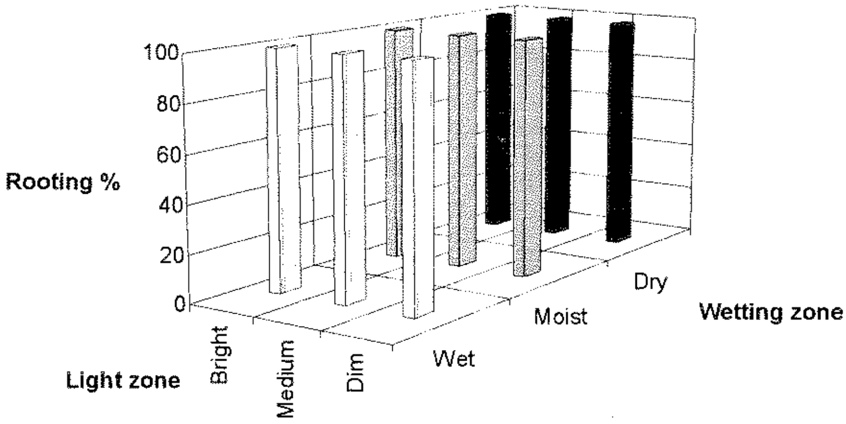
There was little rotting and virtually no development of lateral shoots in any environment. Extension growth of the original shoot averaged 4.5 cm and was not significantly affected by environment (data not shown).

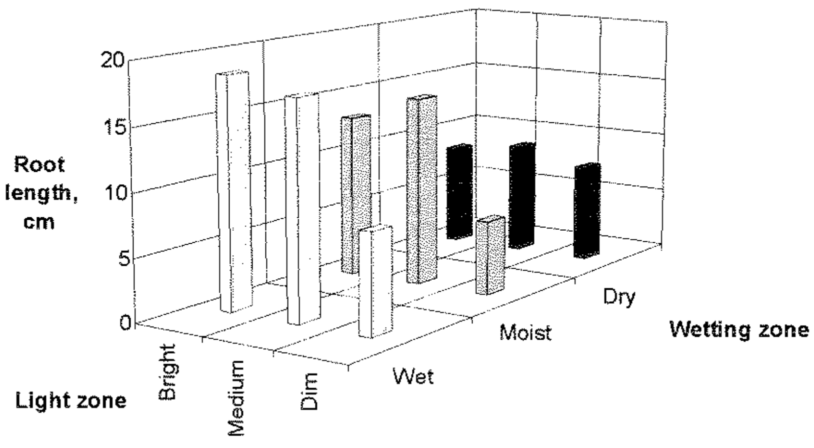
Discussion

Forsythia was the only subject examined in which 100% rooting was obtained throughout the very wide range of conditions provided by the G-CPE. These results demonstrate how the concept of 'ease of rooting' is closely related to wide environmental tolerance. This included tolerance of the water stress that was evident, prior to rooting, in the Bright/Dry zone and also light levels so low that many other species simply die and rot.

However, in a separate experiment using softer cuttings taken at the end of June, a few cuttings failed to root in the 'Dim' and 'Dry' zones. This illustrates that even for the most readily rooted species, performance of cuttings is subject to the influence of factors such as stockplant growing conditions, pruning, and season, that influence the physiological status of the material from which cuttings are prepared.

The results also show that light and evaporative demand can have a large influence on the size of the root system which develops, particularly if cuttings remain in the rooting environment for some time after the roots first emerge. This is likely to influence how quickly cuttings can be weaned and resume normal growth and thus the length of the production cycle. In the case of *Forsythia*, which requires pruning to develop a well-branched plant, it is also likely to influence the number of branches that develop and grow strongly in response to pinching and pruning.





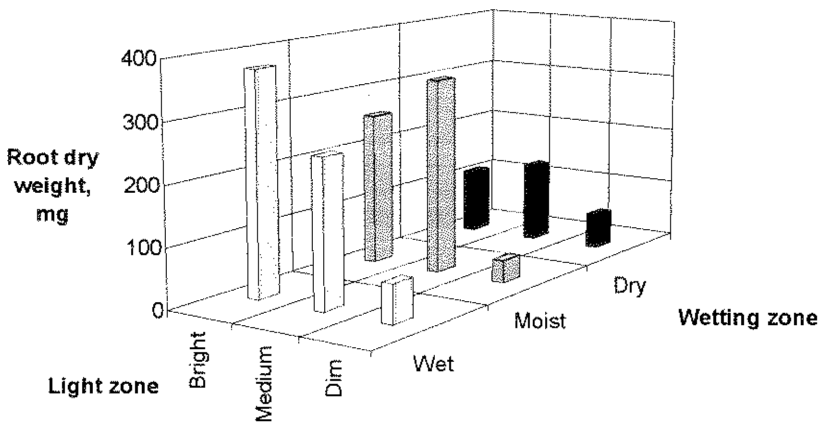


Figure 75. Rooting percentage, length of the longest root, and root dry weight per rooted cutting of *Forsythia* x *intermedia* 'Lynwood' cuttings inserted on 23 August for 5 weeks. Significant effects: of light ($P<0.001$), wetting ($P<0.01$) and the interaction of light x wetting ($P<0.05$) on length and dry weight of roots.

***Potentilla fruticosa* 'Tangerine'**

Potentilla fruticosa was included in the G-CPE experiments because it has small leaflets that it was thought might tend to become wetted on *both* surfaces in the dense fog at the wet end of the wetting gradient, with possible adverse effects. If leaves are completely covered with water stomatal pores are likely to be blocked which would interfere with the carbon dioxide uptake required for photosynthesis and could stop transpiration completely.

Cuttings inserted:	24 June, 1994.
Time in the G-CPE:	25 days.
Types of cutting:	Apical cuttings, divided into 2 size grades (see Table 52 for comparison of grades).
Replication:	Two cuttings of each grade per location.
Spacing:	9 x 4.5 cm in QP96D trays.

Table 52. Measurements on a sample of 6 cuttings of each grade.

	Grade		
	Small	Large	Mean
Length, cm	5.7	7.7	6.7
Diameter, mm	0.98	1.24	1.11
Number of leaves	4.3	3.7	4.0
Leaf area, cm^2	4.1	5.6	4.9

Virtually 100% of rooting occurred in the moderate to high light zone, irrespective of the level of wetting (Figure 76). At very low light (L9 and L10) no rooting occurred, and proportion of cuttings which rooted started to decline at L6. Above this threshold, additional light increased the length but not the number of roots (Figures 77 and 78). In contrast, reducing the amount of wetting increased the number but not the length of roots. The overall size of the root system was therefore greatest where high light and minimal wetting were combined (i.e. the Bright/Dry zone).

Almost all cuttings had a few millimetres of dead tissue at their bases but significant rotting was only observed at low light levels (Figure 79). Apart from the slight reduction of root number, the only other adverse effect associated with heavily wetted conditions was more frequent rotting or abscission of the shoot tip, and a water-soaked or 'vitrified' appearance of leaves on developing lateral shoots. Close inspection revealed that most wetting of the original leaves was confined to the upper leaf surfaces even in the wettest zone, but this would not have been the case as new leaves emerged at the apex because at that stage the developing leaf is held almost vertically.

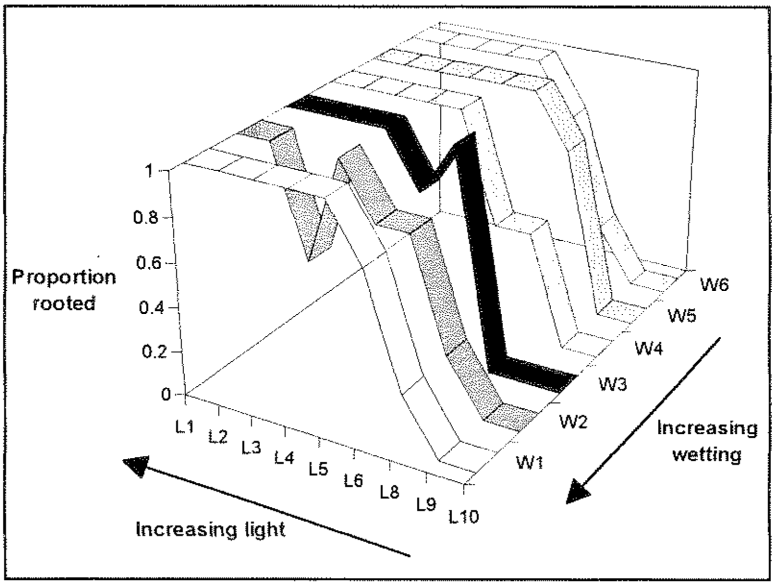


Figure 76. Rooting of *Potentilla fruticosa* 'Tangerine' cuttings inserted on 24 June for 25 days. Statistically significant effect of light only (P<0.001).

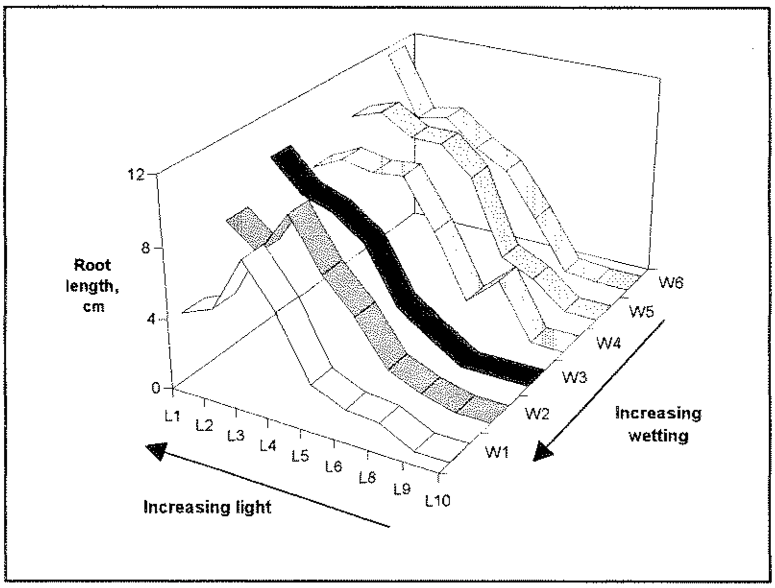


Figure 77. The average maximum root length on cuttings of *Potentilla fruticosa* 'Tangerine' inserted on 24 June for 25 days. Statistically significant effects of light (P<0.001) and wetting (P<0.05).

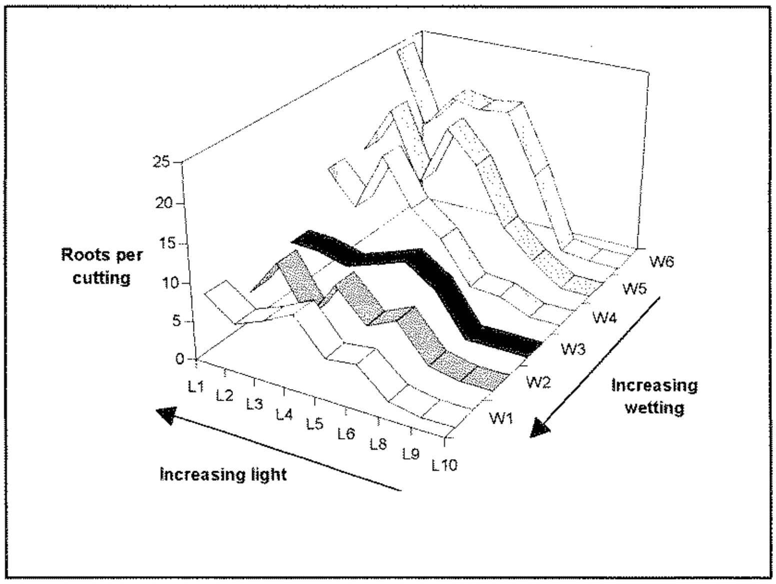


Figure 78. The number of roots per cutting of *Potentilla fruticosa* 'Tangerine' inserted on 24 June for 25 days. Statistically significant effects: light ($P<0.001$) and wetting ($P<0.001$) and the interaction of light x wetting ($P<0.01$).

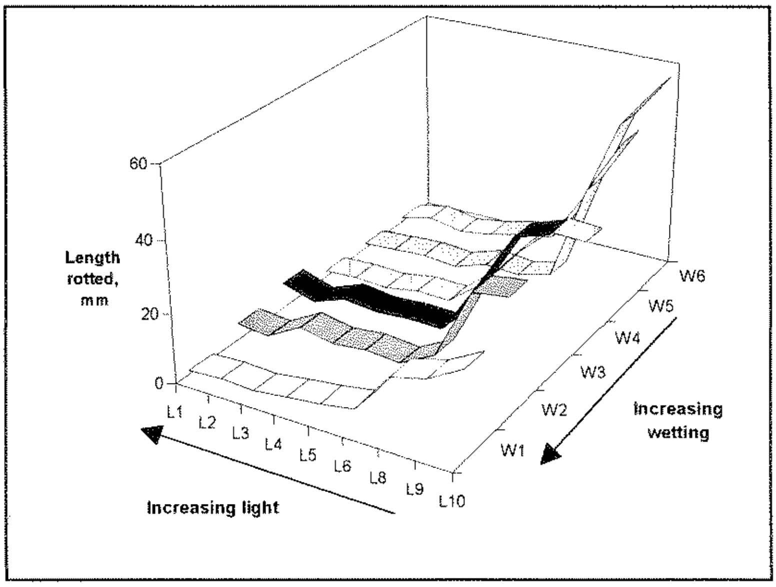


Figure 79. Average length of rotted stem on cuttings of *Potentilla fruticosa* 'Tangerine' inserted on 24 June for 25 days. Statistically significant effect of light alone ($P<0.001$).

Size of cutting

The percentage of thick-grade cuttings which rooted was significantly less than that of the thin grade, being 61% compared with 71%, averaged over all environments ($P<0.01$). At light levels above L6, the percentages were 95% and 98% respectively. Size of cutting had no effect on the length or number of roots per rooted cutting nor was any other difference between the size grades detected.

Discussion

The ease of rooting of *Potentilla fruticosa* 'Tangerine' was reflected in its ability to root well in a very wide range of environments though this did not extend to tolerance of very low irradiance. The minimum light level at which virtually 100% rooting was achieved was L5, which corresponds to approximately 60 μmol m^{-2} s^{-1} of photosynthetically active radiation. This is close to what cuttings will receive in a propagation unit with a total of 80% shade (i.e. including light absorption by the glass or polythene structure, and reflection by any condensation) averaged over a cloudy spell of weather in summer.

Heavy shade should therefore be avoided, especially since extra light improved the size of the roots produced. Similarly, heavy wetting, especially if combined with high humidity, should be avoided because a greater number of roots were produced under the high evaporative demand at the dry end of the G-CPE.

Contrary to expectations no wetting of the undersurface of the leaves was observed even in the dense fog at the wet end of the G-CPE, at least not on the fully expanded older leaves which are held almost horizontal. In a fog system in which there is more air movement, such as our own 'fog house' (see Materials and Methods section), wetting of the undersurface of leaves does tend to occur and might lead to more serious adverse effects of heavy wetting.

Weigela florida **'Variegata'**

This is the last of the three easy-to-root subjects that were tested together in G-CPE using a rather different approach from that adopted for all other subjects. In the expectation that almost 100% rooting was likely to be obtained in the majority of locations, only one cutting of each species was placed in each location.

Apical cuttings, with three pairs of leaves, were inserted on 23 August, 1994, for 35 days. Detailed measurements were not made but a typical cutting was 15 cm long, with a leaf area of 80 cm^2 and a stem diameter of 2.2 mm. They were planted at 9 x 9 cm spacing in 11 cm square pots.

Cuttings wilted slightly in the Bright/Dry zone, within a few days of insertion and one cutting failed to root in that zone. There were also three rooting failures at very low light (i.e.17% of cuttings in the Dim zone) but otherwise all cuttings rooted (Figure 80). There was no effect of environment on root numbers (data not shown) but the length and weight of roots increased with light level (Figure 80). As light level increased, the amount of new shoot growth increased also, both extension of the original shoot and the development of lateral branches; in contrast, heavy wetting strongly suppressed shoot growth (data not shown).

Discussion

The ease of rooting of *Weigela* was reflected in its tolerance of both high evaporative demand and, perhaps more remarkably, extremely low light levels. The size of the root system that was produced on cuttings increased with light level. Such differences would have been magnified by holding the cuttings in the G-CPE for about three weeks beyond the time required for the first roots to be formed. Dry conditions and high light enhanced shoot growth and lateral branching so that cuttings should be moved to drier and less shaded conditions as soon as they are sufficiently well rooted.

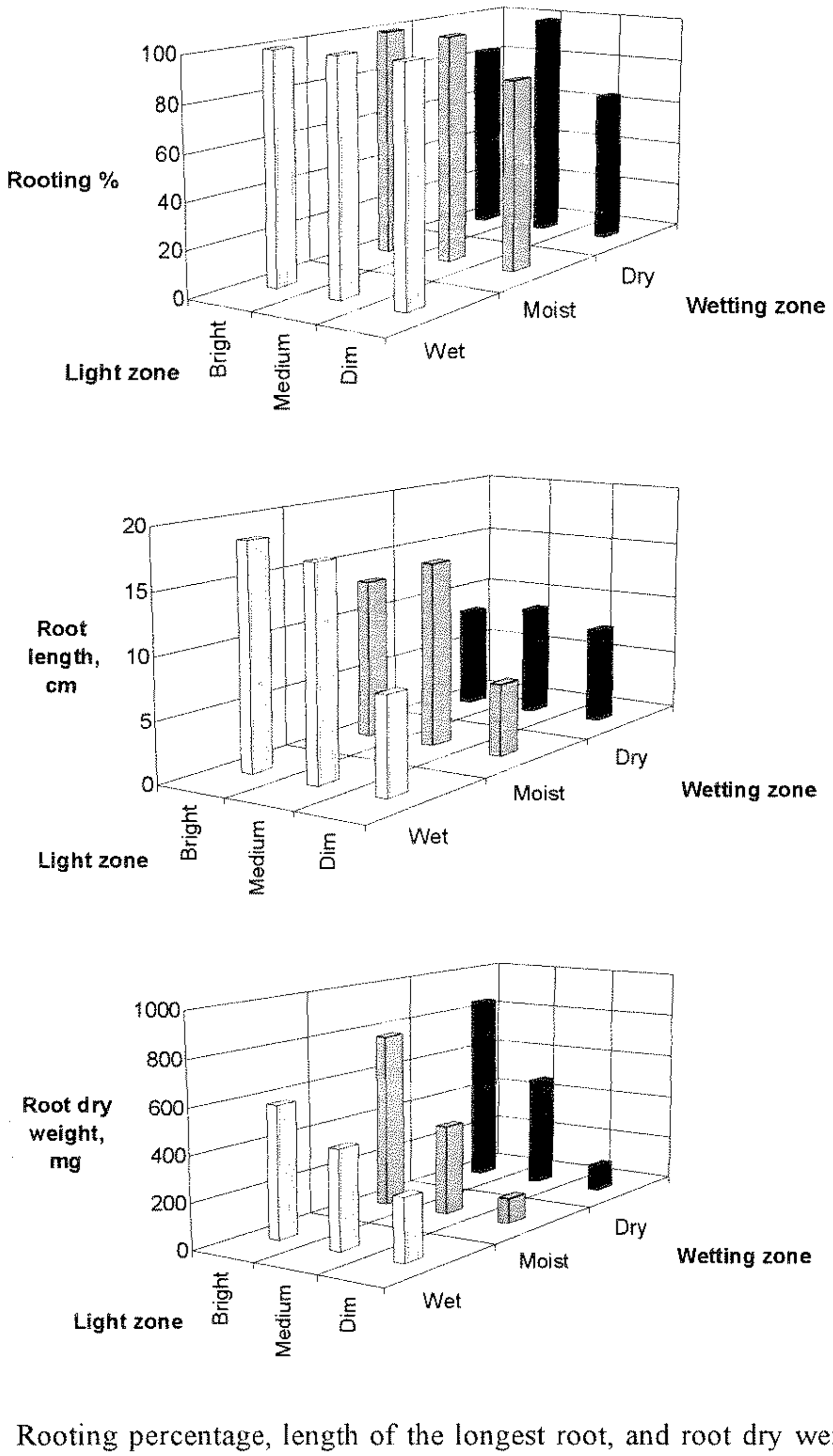


Figure 80. Rooting percentage, length of the longest root, and root dry weight per rooted cutting of *Weigela florida* 'Variegata' cuttings inserted on 23 August for 5 weeks. Significant effects: light and wetting on root length ($P<0.001$), and light on root dry weight ($P<0.001$).

Overview and Conclusions

The G-CPE tests the response of cuttings to a wide range of rooting environments in a reproducible and efficient manner. One important aim of this project was to use this unique facility to establish general principles that would apply to most cuttings and to see whether any readily observable features are useful as indicators of the requirements of particular cuttings. Species and cultivars were therefore selected which provided a wide range of shapes and sizes of cuttings. In this section the evidence from all the subjects is collated and conclusions are drawn.

To summarise the data from so many 'environmental fingerprints' it was necessary to characterise the response in the form of a few key indices. The most useful indices are presented in Table 53, while the morphological data are shown in Table 54. The derivation of the indices is explained in the appropriate subsection below.

Interaction of light and moisture

An explanation of the interaction

The responses of plants to their environment are complicated by interactions between the many separate environmental factors. For stem cuttings, the most important interaction is that between light and moisture, which is why these two factors were chosen for the gradients in the G-CPE. The reason why they interact is that although light may benefit wound healing and rooting through the supply of assimilates from photosynthesis, it may also hinder rooting if, by increasing transpiration, it results in water stress. The response to increasing light is therefore affected by all the other factors that influence transpiration, the most important of which are the humidity of the air around the leaves and the amount of leaf wetting (i.e. the extent to which the surface of the cutting is kept wet by deposition of mist or fog droplets).

The 'moisture' environment

The combination of wetting and humidity can conveniently be referred to as the 'moisture' environment. In the G-CPE, the air was close to 100% relative humidity throughout, so that variation in the suppression of transpiration by 'moisture' was mainly due to the large variation in wetting shown in Figure 3. Measurements with an evaporation sensor demonstrated how light and wetting interacted to determine the potential for a cutting to lose water (Figure 6), such that it was approximately constant along a diagonal line across the G-CPE from L1/W3 to L10/W6.

A band of optimal environments

The 'environment fingerprints' of many of the plants tested reveal the effect of this interaction, similar rooting percentages being obtained along a diagonal across the G-CPE, from relatively low light at the dry end to relatively high light at the wet end. That for *Cotinus coggygria* 'Royal Purple' (Figure 32) shows it particularly clearly. The occurrence of this sort of interaction means that it is often not possible to identify a single optimum

.evel of wetting and another of light. Instead, there is a band of optimal environments running diagonally across the G-CPE, representing a range of different combinations of wetting and light. The subjects varied greatly in both the position and breadth of this band (e.g. compare *Corylus maxima* 'Purpurea', trimmed proximal cuttings, Figure 20, with *Ceanothus* 'Autumnal Blue', Figure 6).

Responses to light

Some generalisations

Most subjects rooted poorly, or not at all, below light level L6, irrespective of the amount of wetting (Table 53). This was often accompanied by extensive death and rotting of stem tissue, sometimes involving the entire cutting. To achieve maximum rooting in most subjects, L5 was sufficient, which corresponds to about 60 µmol m^{-2} s^{-1} (PPFD), or the equivalent of the average amount of light reaching cuttings in a conventional propagation house with 80% shade, over the course of a cloudy day in summer. It also corresponds approximately to 1.0 MJ m^{-2} day^{-1}, consistent with the results of Loach and Whalley (1978) who suggested 1.5 MJ m^{-2} day^{-1} as at target for the minimum daily solar radiation level . Their recommendation was based on shading experiments in conventional facilities and the similarity of the threshold observed in the G-CPE gives reason for confidence that results from the G-CPE should be applicable to naturally illuminated facilities.

Tolerance of low light conditions

A few subjects could tolerate lower light levels: easy-to-root subjects such as *Forsythia* and *Weigela*, and also the less easy *Pieris japonica* 'Little Heath'. Although, in these cases, rooting percentage was not substantially affected, the quantity of roots produced was reduced at low light level.

Plants which require higher light conditions

A few subjects required more light (L3 to L4), irrespective of wetting level, to achieve their maximum potential rooting. This was clearly the case with *Berberis* x *stenophylla*, but may also apply to *Fremontodendron* 'California Glory', *Daphne* x *burkwoodii* 'Somerset' and *Ceanothus impressus*. The uncertainty reflects difficulty in identifying a precise threshold from the environmental fingerprints, particularly when maximum rooting percentage was less than 100%. L3 to L4 corresponds to about 150 µmol m^{-2} s^{-1} (PPFD) and, in conventional facilities, would require that at least 50% of outside light should reach the cuttings during a period of cloudy weather in the middle of summer. Taking into account that about 30% of incoming light is usually absorbed by the structure of the propagation house, this is equivalent to little or no shade under such weather conditions.

Benefits of higher light conditions

For the many subjects which were capable of 100% rooting at intermediate levels of light, many could also root at high light level, often requiring additional wetting to do so for the reasons explained above. In some cases this extra light increased the size of the root system produced (e.g. *Cotinus coggygria* 'Royal Purple', Figure 33), but in many it did not (e.g. *Rhododendron* 'President Roosevelt').

Differences in sensitivity to environment

Nine major zones

For each subject, the range of rooting percentage observed amongst the nine major zones within the G-CPE (e.g. Figure 5) was taken as a guide to the overall sensitivity to environment. Because they are based usually on 24 cuttings, the rooting percentages for these zones are more reliable than those obtained for each of the 54 locations shown in the full 'environmental fingerprint'. In many cases, the true maximum may be higher than that shown because the optimum conditions did not cover the *whole* of any of the major zones (e.g. *Cotinus coggygria* 'Royal Purple').

Most subjects failed to root at all in at least one zone. Rooting percentages for *Aubrieta* 'Red Carpet', *Cryptomeria japonica* 'Elegans Compacta' and *Elaeagnus pungens* 'Maculata' spanned the full range from 0 to 100%. Similarly, ten other subjects exhibited a range from 0 to 75% or greater (see the pair of columns headed 'Range of rooting %' in Table 53).

Less responsive subjects

Some of the less responsive subjects failed to achieve high rooting in any environment. In most of these it is believed that the plant material used in the experiment was of inherently low rooting potential (e.g. *Daphne* x *burkwoodii* 'Somerset', of which cuttings were provided from a mature garden specimen). In others, the range of conditions in the G-CPE may not have included the optimum for that species (e.g. *Berberis* x *stenophylla*, which appears to have an unusually high light requirement).

Easy-to-root subjects

Because all cuttings of *Forsythia* x *intermedia* 'Lynwood' rooted, irrespective of environment, it was the least responsive to the range of G-CPE conditions. With other easy-to-root subjects, such as *Weigela florida* 'Variegata', 100% rooting occurred in most zones but a few cuttings failed where the evaporative demand was highest or the light level lowest. These observations suggest that the concept of 'ready-rooting cuttings' is almost synonymous with 'cuttings of wide environmental tolerance'.

A special case

One subject which was insensitive to environment but not particularly 'ready-rooting' was *Pieris japonica* 'Little Heath', in which the range of rooting percentage was from 54 to 79%. The most likely explanation of this sort of result is that a proportion of the cuttings are incapable of rooting under any conditions, whereas those that are capable of rooting are not very sensitive to environment. Further work would be required to see if the barrier to rooting in some cuttings is associated with the origin of the cutting (e.g. differences between mother plants or the position from which the cutting is taken). The variation in rooting amongst the cuttings was not related to the thickness of their stem.

Responses to wetting

Characterising the response

The optimum amount of leaf wetting is liable to vary depending on the level of light because of the interaction referred to earlier. To compare the requirement for wetting of different subjects, it was therefore necessary to adopt a standard light level. The zone from L4 to L6 (i.e. the 'Medium' light zone) was chosen because it corresponds to the range of conditions most likely to be found in commercial propagation facilities, and provides enough light for the majority of cuttings to root. The environmental fingerprint for each subject was used to estimate the optimum range of wetting levels in the 'Medium' light zone. The lowest wetting level at which any rooting occurred was also noted.

An additional level of wetting, W0, was included where trends in the environmental fingerprint indicated that the optimum probably extended beyond the maximum wetting level in the G-CPE. Although the amount of water deposited in W1 was enough to maintain a complete layer of water over the leaves at all times, evidence from a number of subjects (e.g. *Garrya elliptica* 'James Roof') indicated that further benefit from wetting is achieved when fog droplets are blown amongst the foliage, as occurs close to a fan-assisted fogger (e.g. the Agritech machine in the fog house used for these studies). The adverse effect of wetting on some subjects was also more severe under such conditions (e.g. *Fremontodendron* 'California Glory') despite the amount of water deposited in measuring dishes being very similar.

The range of requirements

The range of wetting levels required by different subjects was very wide, from those subjects that required very heavy wetting to achieve their potential (e.g. *Garrya elliptica* 'James Roof'), to those in which rooting was suppressed if there was more than a trace of leaf wetting (e.g. *Cryptomeria japonica* 'Elegans Compacta'). In some cases the optimum range was narrow (e.g. trimmed proximal cuttings of *Corylus maxima* 'Purpurea') while in many it was wide, particularly those that would be recognised as easy-to-root (e.g. *Potentilla fruticosa* 'Tangerine', or *Forsythia* x *intermedia* 'Lynwood'). The range of wetting over which rooting occurred was usually much wider than the optimal range, as shown by the last column in Table 53.

Table 53. Responses to environment in all 26 subjects tested in the G-CPE, arranged in order of decreasing requirement for wetting.

	Type of cutting	[2] Range of rooting %		[1] Minimum light level for :		[1] Wetting levels required :		
				Maximum rooting %	Any rooting	Range for maximum rooting %		Driest for any rooting
				L	L	W	W	W
Garrya elliptica 'James Roof'	Apical	0	54	5	6	1	0	2
Acer cappadocicum 'Rubrum'	Apical	0	75	6	8	1	0	4
Ceanothus impressus	Apical	0	42	3	6	2	1	6
Rhododendron 'President Roosevelt'	Apical	0	79	6	9	3	1	4
Cotinus coggygria 'Royal Purple'	Apical	0	96	6	10	3	1	5
Ceanothus impressus 'Puget Blue'	Apical	0	25	5	6	3	1	6
Corylus maxima 'Purpurea'	Apical	0	83	6	10	3	1	6
Elaeagnus pungens 'Maculata'	Apical	0	100	6	6	3	0	3
Ceanothus 'Autumnal Blue'	Apical	0	96	6	9	4	3	6
Rhododendron 'Gold Flimmer'	Apical	0	79	5	6	4	2	5
Aubrieta 'Red Carpet'	Apical	0	100	6	9	4	2	6
Cornus alba 'Sibirica'	Apical	33	100	8	10	4	2	6
Pieris 'Flaming Silver'	Apical	6	95	7	9	4	1	6
Corylus maxima 'Purpurea'	Proximal (trimmed)	0	88	5	10	5	4	6
Corylus maxima 'Purpurea'	Proximal (non-trimmed)	0	83	6	10	5	3	5
Acer palmatum 'Aureum'	Apical + proximal	8	79	6	9	5	1	6
Cryptomeria japonica 'Elegans Compacta'	Apical	0	100	6	9	6	6	6
Convolvulus cneorum	Apical	0	54	6	8	6	5	6
Daphne x *burkwoodii* 'Somerset'	Apical	0	63	3	5	6	5	6
Fremontodendron 'California Glory'	Single node	0	96	4	6	6	5	6
Berberis x *stenophylla*	Proximal	0	54	3	5	6	4	6
Potentilla fruticosa 'Tangerine'	Apical	8	100	5	8	6	3	6
Aubrieta 'Greencourt Purple'	Apical	0	83	6	9	6	2	6
Pieris japonica 'Little Heath'	Apical	54	79	10	10	6	1	6
Forsythia x *intermedia* 'Lynwood'	Apical	100	100	10	10	6	1	6
Weigela florida 'Variegata'	Apical	67	100	9	10	6	1	6

[1] Levels of light and wetting relate to absolute units as shown in Figure 3. Wetting level 0 extends the wetting range beyond that maintained in the G-CPE; see p. 156 for further details. Wetting optima are for cuttings at light levels between L4 and L6.

[2] Based on rooting in the nine major zones.

Table 54. Comparison of the morphology of the cuttings of all 26 subjects tested in the G-CPE. 'Leaf : Stem area ratio' is the ratio of leaf area to cross-sectional area of the stem at the base of the cutting. Subjects are arranged in order of decreasing moisture requirement, to match that in Table 53.

Subject	Type of cutting	Leaf width, mm	Leaf area, cm^2	Stem diameter, mm	Leaf : Stem area ratio
Garrya elliptica 'James Roof'	Apical	30	70.8	3.6	680
Acer cappadocicum 'Rubrum'	Apical	80	76.0	3.0	1112
Ceanothus impressus	Apical	5	6.6	1.8	251
Rhododendron 'President Roosevelt'	Apical	30	92.5	3.5	978
Cotinus coggygria 'Royal Purple'	Apical	30	70.7	3.5	735
Ceanothus impressus 'Puget Blue'	Apical	5	6.2	1.7	291
Corylus maxima 'Purpurea'	Apical	60	111.0	2.9	1680
Elaeagnus pungens 'Maculata'	Apical	30	91.5	2.8	1540
Ceanothus 'Autumnal Blue'	Apical	10	28.1	2.2	726
Rhododendron 'Gold Flimmer'	Apical	30	103.0	4.8	581
Aubrieta 'Red Carpet'	Apical	8	9.0	1.0	1146
Cornus alba 'Sibirica'	Apical	50	85.0	2.9	1287
Pieris 'Flaming Silver'	Apical	15	49.2	2.1	1420
Corylus maxima 'Purpurea'	Proximal (trimmed)	40	91.0	4.1	689
Corylus maxima 'Purpurea'	Proximal (non-trimmed)	100	249.0	4.1	1886
Acer palmatum 'Aureum'	Apical + proximal	50	34.6	1.9	1183
Cryptomeria japonica 'Elegans Compacta'	Apical	2	16.7	1.7	781
Convolvulus cneorum	Apical	5	20.1	1.6	975
Daphne x *burkwoodii* 'Somerset'	Apical	5	25.5	1.6	1222
Fremontodendron 'California Glory'	Single node	40	30.0	4.7	174
Berberis x *stenophylla*	Proximal	3	12.0	3.2	148
Potentilla fruticosa 'Tangerine'	Apical	3*	4.9	1.1	506
Aubrieta 'Greencourt Purple'	Apical	7	7.3	1.2	645
Pieris japonica 'Little Heath'	Apical	8	14.1	1.6	728
Forsythia x *intermedia* 'Lynwood'	Apical	20	60.0	2.3	1444
Weigela florida 'Variegata'	Apical	30	80.0	2.2	2104

* width of leaflets rather than whole leaf

Morphological indicators of environmental requirements

Leaf area : stem area ratio

In order to test for links between the requirement for wetting and the morphology of the cutting, the relation between various morphological indices and the mid-point of the wetting range was analyzed graphically and statistically. Plants with a very wide optimal range were excluded from the analysis. In the second annual report on this project it was proposed that a high ratio of leaf area to stem cross-sectional area (i.e. the area for water loss relative to the area for water uptake) tends to be associated with a need for heavy wetting. The same trend is evident in Figure 81, which includes results from many additional subjects, but the correlation is poor and not statistically significant. The correlation with leaf area alone was much closer and significant ($P<0.01$), but only if the results for the non-trimmed proximal cuttings of *C. maxima* 'Purpurea', which had by far the greatest leaf area per cutting, were excluded from the data (Figure 82). No other correlations were significant. The conclusion is, therefore, that cuttings with a large leaf area tend to require a more moist environment than those with less leaf but the inconsistencies in the relationship limit its practical value.

Hairiness and greyness

Hairiness and grey-coloured leaves are two features that are commonly held to indicate a need for relatively dry conditions. The leaves of *Corylus maxima* and *Garrya elliptica* are hairy on their undersurface while *Convolvulus cneorum* leaves are covered with fine hairs that make the leaves appear grey. Of these subjects, only *C. cneorum* favoured dry conditions, but as this was in keeping with its small leaf area per cutting it does not provide strong evidence in either direction. Since the project ended, two other plants with grey-green densely hairy leaves have been tested (*Phlomis fruticosa* and *Cistus* 'Silver Pink') neither of which showed a preference for dry conditions, especially at high light. Therefore, it seems unlikely that either of these features is of great predictive value.

Stem volume

The three subjects with conspicuously low leaf : stem-cross-section area ratios (*Berberis* x *stenophylla*, *Fremontodendron* 'California Glory' and *Ceanothus impressus*) were all amongst the four subjects identified as having an unusually high requirement for light (Table 54). For a given length of stem, its volume is approximately proportional to cross sectional area so that this ratio provides a measure of the relative size of the 'photosynthetic factory' for carbohydrates (i.e. the leaves) and the mass of tissue in the stem which depends on a supply of carbohydrates for its maintenance. The amount of carbohydrate produced per unit of leaf area depends on the light level so that high light levels would tend to compensate for a small leaf area. There is therefore a physiological basis for a correlation between the leaf : stem area ratio and light requirement. The increase in light requirement caused by trimming the leaves of *Corylus maxima* 'Purpurea' proximal cuttings adds weight to this suggestion.

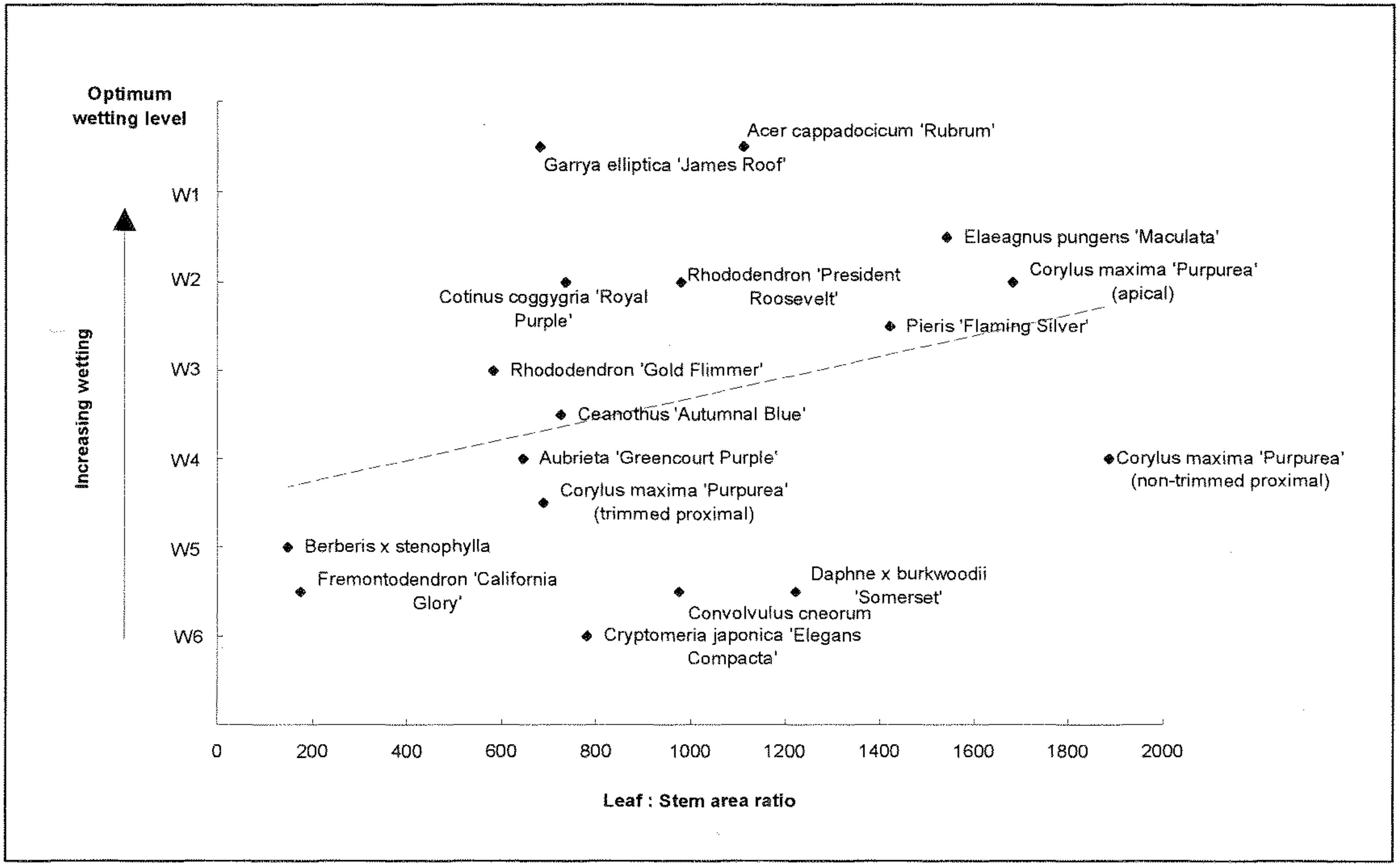


Figure 81. Relationship between the optimum wetting level for rooting and the ratio of leaf area to stem cross-sectional area. The plotted values indicate the mid-point of the optimal range at 'Medium' light (L4 to L6). Subjects which rooted almost equally well at all wetting levels were excluded. Line fitted by linear regression (R^2 = 0.103; not significant).

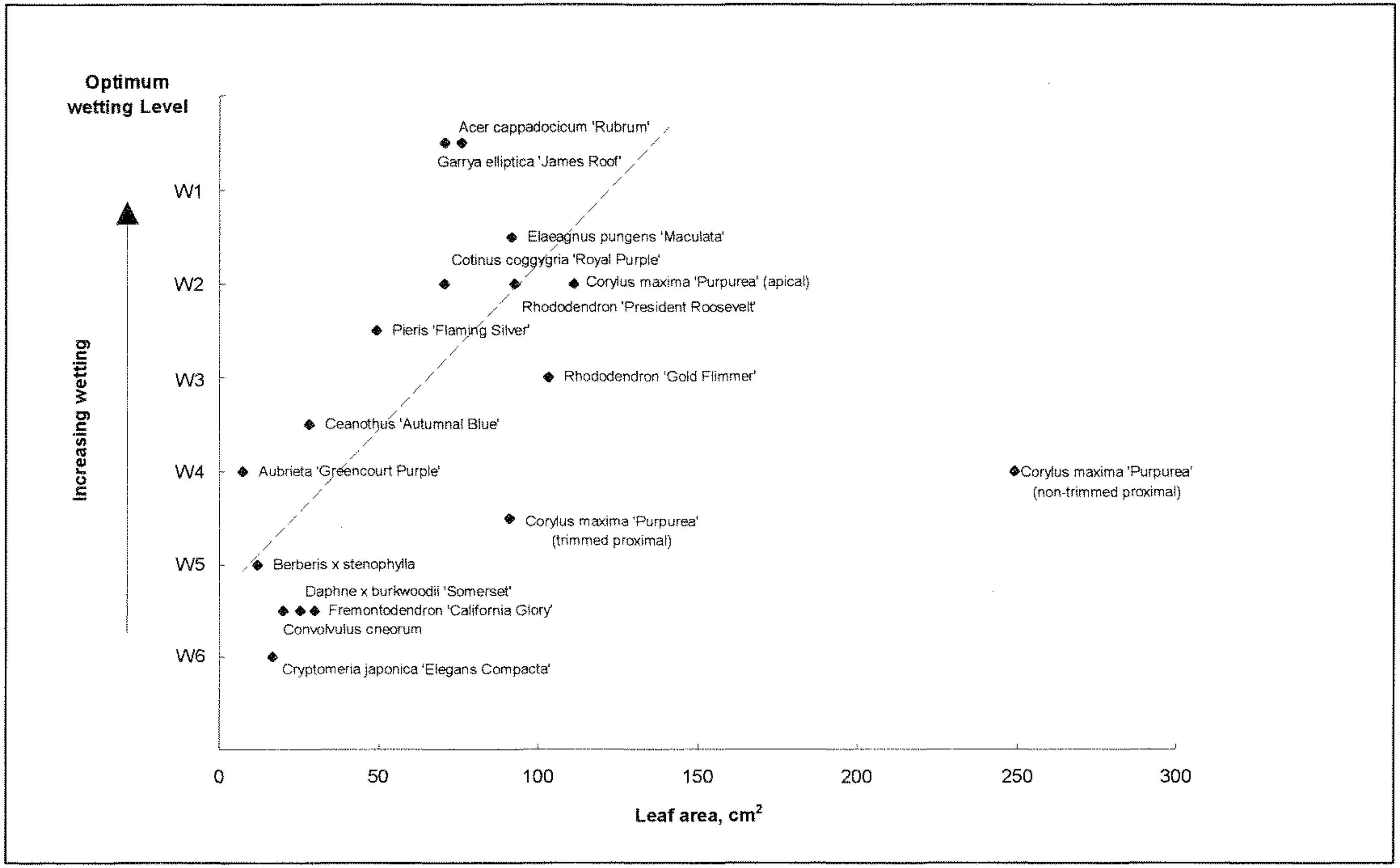


Figure 82. Relationship between the optimum wetting level for rooting and the leaf area per cutting. The plotted values indicate the mid-point of the optimal range at 'Medium' light (L4 to L6). Subjects which rooted almost equally well at all wetting levels were excluded. Broken line fitted by linear regression, omitting non-trimmed proximal cuttings of *C. maxima* 'Purpurea' (R^2 = 0.476, P<0.01).

Practical application of G-CPE results

The results of this project show that an 'environmental fingerprint' from the G-CPE will usually provide valuable insight, into problems that are being experienced in the propagation of a particular plant. It will indicate whether the plant material has the potential to root well given a more appropriate aerial environment and, if so, what sort of environment is appropriate. In many cases, this alone will be enough to indicate how the existing propagation environment should be changed to improve success rates, potentially saving much wasted time and effort on a 'trial and error' approach to improving the environment.

What is less clear is whether the optimum conditions identified in the G-CPE can be translated into advice on achieving optimum conditions in a conventional propagation facility. There are two components of the problem: first, whether the behaviour of cuttings is substantially altered by unnatural features of the G-CPE (e.g. light quality) and second, whether there are suitable instruments to relate conventional environments to those in the G-CPE. Of the species tested, in only one case (*Ceanothus impressus*) was any evidence obtained that behaviour in the G-CPE differed substantially from comparable conditions in conventional facilities. There are probably subtle effects in many other species, but subtle differences are unlikely to be of practical importance.

With regard to the instrumentation, equipment is available to measure light levels and average them over a 24 hour period. Averaging is necessary to enable the fluctuating light levels of a conventional propagation house to be compared meaningfully with the stable light levels of the G-CPE.

Instrumentation which would allow growers to relate their conditions to the information on the response to wetting is less straightforward. Measuring wetting, using dishes to collect and weigh the deposited water, is not difficult, if a balance is available which reads to 0.01 g or better. However, the wetting optima identified in the G-CPE can only be expected to apply in other environments if the humidity is as close to saturation (i.e 100% rh) as it is in the G-CPE. Humidity can also be measured but is prone to large errors, especially where the sensor is exposed to liquid water as is usually the case in propagation environments. A more fundamental difficulty is that there is no straightforward way of combining the wetting and humidity data into a single 'moisture' value that could be related to the wetting optima identified in the G-CPE.

A more promising approach is to use the **HRI - East Malling EVAPO-SENSOR** (see page 24) to measure the total evaporative demand and then relate this to similar measurements in the G-CPE (Figure 6). The evapo-sensor is awaiting funding that is required prior to commercial development. When a commercial version is available, it will be necessary to characterise the G-CPE in terms of readings from the *new* evapo-sensor and then use existing 'environmental fingerprint' data to identify optimal evapo-sensor readings for each subject. Nurserymen would then be able to use the evapo-sensor to evaluate existing environments in relation to subjects they are interested in propagating, and to monitor the effect of changes in those environments. This would apply equally to all propagation units, whether the existing system was a simple polythene tunnel, or computer controlled fog house. For fog and mist units, the evapo-sensor could also be used to control the system, with the set point of the controller being adjusted to the optimal evaporative demand.

Some growers have expressed interest in applying the CPE concept to commercial propagation. The results do not suggest that this sort of facility offers any improvement in rooting compared with an appropriate conventional facility, so that the potential benefit must be weighed in terms of much greater reproducibility and the potential for out-of-season propagation.

Future use of the G-CPE

The CPE facilities were designed to provide maximum flexibility in their use, and the G-CPE could be readily modified to look at other factors (e.g. wetting x humidity at uniform light) but it is likely to remain in its current configuration for at least two years to meet the needs of other projects. There will therefore be opportunities for further 'environmental fingerprinting' and HRI - East Malling would welcome approaches from growers to discuss subjects which they would like to see tested, either under confidential commercial contract terms or in possible future projects funded by HDC or others.

Many opportunities for more detailed studies with particular subjects are mentioned in the sections concerned with individual plant subjects. There is also a need to determine, for a small range of representative plants, how light and wetting interact with other factors such as rooting medium, drainage, planting density and base heating. Whilst it is impossible to attempt to study all possible interactions between environmental factors, these are all factors that are likely to interact with light and/or wetting with important practical implications for the design and management of propagation facilities.

Summary and conclusions

- 'Environmental fingerprints' provide a unique overview of the needs of a particular plant that can guide improvement of conventional facilities.

- The following response-types were identified amongst the subjects studied:

  - High moisture requirement:
    - *Acer cappadocicum* 'Rubrum'
    - *Corylus maxima* 'Purpurea' apical cuttings
    - *Corylus maxima* 'Purpurea' non-trimmed proximal cuttings
    - *Cotinus coggygria* 'Royal Purple'
    - *Elaeagnus pungens* 'Maculata'
    - *Garrya elliptica* 'James Roof'
    - *Pieris* 'Flaming Silver'
    - *Rhododendron* 'Gold Flimmer'
    - *Rhododendron* 'President Roosevelt'

  - Moderate moisture requirement:
    - *Acer palmatum* 'Aureum'
    - *Aubrieta* 'Red Carpet'
    - *Aubrieta* 'Greencourt Purple'
    - *Cornus alba* 'Sibirica'
    - *Corylus maxima* 'Purpurea' leaf-trimmed proximal cuttings
    - *Ceanothus* 'Autumnal Blue'

  - Low moisture requirement:
    - *Cryptomeria japonica* 'Elegans Compacta'
    - *Convolvulus cneorum*
    - *Daphne* x *burkwoodii* 'Somerset'
    - *Potentilla fruticosa* 'Tangerine'

  - High light requirement
    - *Berberis* x *stenophylla*
    - *Fremontodendron* 'California Glory'

  - Tolerant of almost all conditions:
    - *Forsythia* x *intermedia* 'Lynwood'
    - *Pieris japonica* 'Little Heath'
    - *Weigela florida* 'Variegata'

Results for *Ceanothus impressus* and *C. impressus* 'Puget Blue' would place them in the second group above but there is evidence that these subjects were adversely affected by the light quality, or some other feature of the G-CPE environments, which may have altered their response to light quantity and moisture.

- Most cuttings fail if the light level, averaged over daylight hours, is less than about 40 μmol m^{-2} s^{-1} (PPFD) (approximately equivalent to 16 W m^{-2}, 2150 lux, and 0.7 MJ m^{-2} day^{-1} in natural light).

- Most subjects show no further increase in rooting percentage of light levels above 60 μmol m^{-2} s^{-1} (approximately equivalent to 24 W m^{-2}, 3250 lux, and 1.0 MJ m^{-2} day^{-1}).

- A few subjects have high light requirements - in this study, up to at least 150 μmol m^{-2} s^{-1} for *Berberis* x *stenophylla* (approximately equivalent to 60 W m^{-2}, 8100 lux, and 2.6 MJ m^{-2} day^{-1}).

- Cuttings with a small amount of leaf area relative to the thickness of the stem tend to have a higher light requirement. As a guide, higher than average light may be needed when the ratio of leaf area to stem cross-sectional area is less than 300. The area of most leaves can be estimated reasonably accurately from the formula: length x breadth x 0.67. The cross sectional area of the stem = 3.14 x $(diameter/2)^2$.

- As light levels increase, more moisture (i.e. wetting and/or elevated humidity) is required to avoid reduction of rooting due to water stress.

- In conventional facilities, light is difficult to control within tight limits. It is therefore wise to aim for higher light levels than the minimum acceptable, and to provide correspondingly more moisture to avoid water stress.

- The fluctuations in natural light require that fog / mist controllers must increase output as light level increases if water stress is to be minimised. Timers are unsuitable; 'Solarmist' systems are suitable but take no account of other factors; the **evapo-sensor** developed at HRI - East Malling is potentially the best instrumentation but is not yet available commercially.

- The **evapo-sensor**, as a measuring device, will help translate results from the G-CPE to all types of conventional facilities (i.e. including simple polythene tunnel, etc.).

- At a given light level, subjects vary greatly in their moisture requirement. The larger the leaf area per cutting the greater the moisture requirement tends to be, but the correlation is not very close (Figure 82).

- Rotting is not a reliable symptom of overwetting : rotting can occur when there is too little moisture, and almost always occurs when there is not enough light.

- Many 'difficult-to-root' subjects (e.g. *Cotinus coggygria* 'Royal Purple') have high rooting potential but a narrow range of environments in which that potential is expressed.

- 'Easy-to-root' subjects are those which tolerate an unusually wide range of environments, often including very low light.

- Some subjects failed to approach 100% rooting percentage in any environment (e.g. *Rhododendron* 'President Roosevelt'), suggesting that some cuttings did not have the potential to root or that another factor was sub-optimal (e.g. temperature or amount of auxin applied).

- The rooting environment can affect subsequent growth and thus the quality of liners and container plants, especially in slower growing plants which do not require much pruning to create a desirable shape.

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Glossary of terms, abbreviations and products used

Agritech fogger - a machine in which large quantities of water (up to 135 L h^{-1}) are atomised by nozzles mounted on the ends of a pair of rotating arms, and which incorporates a powerful fan to distribute the resulting fog. It produces a mixture of droplet sizes, ranging from mist-sized drops to fine fog droplets. It is no longer manufactured but alternatives are available.

apical cutting - one which includes the shoot tip.

Benlate - a fungicide containing 50% (by weight) benomyl, supplied by DuPont (UK) Ltd, Stevenage.

'Bright' zone - the combination of light levels L1, L2 and L3 (see pages 16 and 20 for further details).

closed mist - a mist propagation bed enclosed within some form of polythene tent to prevent exchange of air with the rest of the house so that the air around the leaves remains at high humidity between mist bursts. Compare *open mist.*

CPE - a 'Controlled Propagation Environment'. See 'Materials and Methods', page 14, for further details.

CRF - controlled release fertilizer.

'Dim' zone - the combination of light levels L8, L9 and L10 (see pages 16 and 20 for further details).

'Dry' zone - the combination of wetting levels W5 and W6 (see pages 16 and 20 for further details).

'environmental fingerprint' - term coined for a 3D graph summarising the response of rooting to environment, in a particular species, cultivar, or type of cutting, based on results from the G-CPE (e.g. Figure 4 or 5).

evaporative demand - an imprecise term referring to the power of an environment to evaporate water. It differs from humidity in that it takes account of the many other factors which influence evaporation, such as irradiance. For a more precise definition it is necessary to specify a particular evaporative surface e.g. a leaf - see also potential transpiration.

evapo-sensor - an instrument invented at HRI - East Malling which provides an electrical signal approximately proportional to potential transpiration from a model leaf. As such it is sensitive to the effects of humidity, light, temperature, wind, and leaf wetting. It can be used to improve control of mist and fog compared to existing commercially available sensors (see Harrison-Murray, 1996) and to monitor how effectively any kind of propagation environment is restricting water loss from cuttings (e.g. refer to Part 1 of

'Results and Discussion'). It also has potential in irrigation control (Harrison-Murray, 1995).

evapostat - a control system which regulates the output of fog or mist on the basis of the signal from an HRI - East Malling **evapo-sensor**, such that the system seeks to maintain evaporative demand at or below a user-adjustable set point. (Not currently available commercially).

Ficote 140 16-10-10 and **Ficote 180 16-10-10** - controlled release fertilizers supplied by Fisons Horticulture Division, Bramford, Ipswich. '140' or '180' relates to the expected release period of the product. '16-10-10' indicates the percentage by weight of the major nutrients in the order N - P - K. The value for N is in terms of pure nitrogen but, by convention, the values for P and K relate to the equivalent weight of their oxides P_2O_5 and K_2O.

G-CPE - the 'Gradient - Controlled Propagation Environment' in which gradients of two environment factors (currently light and wetting) interact to create a matrix of different environmental conditions. See the 'Materials and Methods', page 14, for further details.

g L^{-1} - grammes per litre.

IBA - indolyl butyric acid. This is a synthetic auxin used to stimulate rooting in cuttings and the active ingredient in Seradix rooting powders.

internodal cutting - one without a node immediately above the base (see also *nodal cutting*).

irradiance - a scientific term to describe the quantity of light, or other form of radiant energy, falling on unit area of a flat surface per unit of time, which in this report has usually been replaced by the lay person's term **light level**. The scientific term *light intensity* is often used incorrectly in place of irradiance. (Intensity refers to the quantity of light emitted by a source of radiation per unit solid angle.)

'Medium' zone - the combination of light levels L4, L5 and L6 (see pages 16 and 20 for further details).

'Moist' zone - the combination of wetting levels W3 and W4 (see pages 16 and 20 for further details).

morphology - information about the form of an object. In the context of this report it refers to all aspects of the external appearance of plant shoots and leaves.

nodal cutting - one with a node (i.e. point of attachment of a leaf and lateral bud) immediately above the base.

necrosis - tissue death. Used in this report to refer to darkening of external tissues of the stem of a cutting that indicates that the cells have probably died so that the tissues will eventually break down.

NS - not statistically significant, i.e. the probability that the observed difference(s) were due to chance is greater than 5%.

open mist - a mist propagation system operating in a glass or polythene house with free exchange of air between the mist area and the rest of the house. As a result, the humidity of the air around the leaves falls substantially between mist bursts. Compare *closed mist*.

Osmocote Mini 18-6-12 - a controlled release fertilizer supplied by Scotts, Nottingham, NG2 7LA. The granules of this product are much smaller than standard CRF so that small quantities can be distributed evenly between the small cells of propagation trays.

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

Perlite - granules of expanded volcanic rock, supplied under the trade name Silvaperl by William Sinclair Horticulture, Lincoln, LN6 7AH.

potential transpiration - the maximum rate at which leaves could be losing water under prevailing environmental conditions. To achieve this maximum rate, water supply would be unrestricted and stomata would be fully open. Since leaf shapes and stomatal frequency vary considerably, it can only be given a precise value for a particular leaf. It is nonetheless a useful term for conceptually separating the effect of environment on transpiration rate from the influence of stomatal regulation.

PPFD - Photosynthetic Photon Flux Density. A measure of irradiance confined to the wavelengths of light that are active in photosynthesis (i.e. 400 to 700 nm) and in the units that relate to its action in photosynthesis (i.e. quantum units).

Proportion rooted - see *rooting fraction* below.

proximal cutting - one prepared from the lower part of the shoot (i.e. from that part of the shoot which is in closer *proximity* to the main body of the plant).

QP24 and **QP96D** - 'Quick Pot' propagation trays supplied by PG Horticulture, Eye, Suffolk, IP23 8HB. The dimensions are 330 x 520 mm, and they have 24 and 96 cells respectively.

rooting fraction - is synonymous with **proportion rooted** and means the number of cuttings rooted divided by the total number of cuttings. They are alternatives to *rooting percentage* as a means of expressing the degree of success in rooting cuttings. Multiply by 100 to convert to percentage.

Rovral - a fungicide containing 50% (by weight) iprodione, supplied by Hortichem, Salisbury, Wilts, SP2 7NU.

specific leaf area - the area : dry weight ratio of a sample of leaves. Thin leaves tend to have larger ratios than thick leaves.

Seradix No. 2 - rooting hormone powder containing 0.3% by weight of indolyl butyric acid, supplied by Hortichem, Salisbury, Wilts, SP2 7NU.

'Wet' zone - the combination of wetting levels W1 and W2 (see pages 16 and 20 for further details).

WM255 - Sintered silicate granules, supplied by Munro South Horticulture, Maidstone, containing the following elements (with minimum percentages, by weight, in brackets) : Fe (18.8%), Mn (5.4%), Zn (4.3%), Cu (4.3%), Mo (1.0%), B (1.0%), K (1.2%).