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PRACTICAL SECTION FOR GROWERS

This project is investigating the way that cuttings respond to conditions in the rooting medium. The objective is to provide guidelines to growers for the selection and management of rooting media and arrangements for their drainage.

Commercial benefits of the project

Progress in this project is expected to have the following commercial benefits:

- Reduced wastage: about 200 million HNS cuttings are taken every year and while failure rates vary from nursery to nursery and from crop to crop, it has been estimated to be at least 25% overall. Optimising the rooting environment could contribute to reducing this wastage.
- Cost savings: See cost benefit analysis below.
- Reduced management costs: by identifying media that are easier to manage, and that avoid the need for hard-to-manage drainage materials (e.g. sand base).
- Reduced need to import liners, that are often of uncertain quality, from abroad.
- Increased ability to respond to any future pressure to avoid the use of peat.

Background and objectives

The purpose of this project is to understand how the rooting medium contributes to successful rooting of cuttings so as to be able to recommend how growers should select and manage the medium for different types of cutting and different types of propagation environment.

Little is known about what constitutes a satisfactory rooting medium from the cuttings viewpoint, with most of the literature simply reporting comparisons of alternative media in a specific context. From first principles it is clear that it should be able to supply water to the base of the cutting as fast as the cutting can take it up, otherwise it will contribute to the development of water stress. This is only likely to be achieved if the water content is very high, perhaps as high as 70% by volume in the case of peat.

What is less clear is how wet the medium can be before it starts to suppress rooting. Indeed, it is not known whether this depends on the volume of pores that remain filled with air, or the water content, or the tension with which the water is held. Available evidence suggests that the response to the wetness of the medium varies depending on the transpiration demand of the cuttings. Therefore a medium which is too wet on a cloudy day may be ideal during fine weather!

Despite these many uncertainties, nurserymen have no doubt that the rooting medium, and the management of its water content, can have a profound influence on rooting failure rates. As a result they modify their media in an attempt to reduce losses but readily admit that there is little rationale behind these adjustments because useful basic principles and practical guidelines are lacking. This project addresses this need.

This project is timely because two factors are putting pressure on the properties of the medium:

- Many growers want to achieve more supportive aerial environments, which usually involves generous wetting of the foliage and hence increased danger of overwet media.
- There is a move away from sand under propagating trays, towards cleaner and more hygienic surfaces such as concrete which do not provide ‘positive’ (i.e., capillary) drainage.

Summary of results and conclusions

The first year of the project was largely concerned with establishing appropriate techniques, especially for studying the drainage (or 'water release') characteristics of a wide variety of media, many of which pose special technical problems. The main results and conclusions were:

- A method has been developed for studying the water release characteristics, which meets the main requirements of the project.
- Media samples must be pre-wetted for a least a week under conditions relevant to nursery practice to allow a stable value of total porosity to be established without modifying the structure of the medium (as would occur if the media were stood in water to wet up the particles).
- Three replicate samples gives acceptable statistical precision with most media.
- Under conditions equivalent to placing propagation trays on a solid floor, Mypex, or other non-capillary surface, few media contained more than 10% air, and those with a high proportion of peat contained less than 5%.
- Placing trays on a 5 cm-deep layer of sand to provide capillary drainage increased the air content of all media substantially and of pure peat to 12%.
- Addition of perlite or vermiculite to fine grade sphagnum peat greatly increased the air content of the medium but only if the proportion of additive was 50% or more.
- The grade of perlite or vermiculite added had no effect on the increase in air content achieved.
- Addition of Melcourt Propagating Bark to fine grade peat was particularly efficient at increasing the air content of the mix. It seems likely that this is because fine particles and fibrous material are screened out during production.
- Rooting and basal rotting of *Fremontodendron* 'California Glory' cuttings were significantly affected by whether the propagation trays were in contact with a layer of sand to provide capillary drainage. Such 'positive' drainage increases tension in the media with a corresponding decrease in water content and increase in air content, providing better conditions for establishment.
- Further work is required to determine whether increased tension affects the cuttings directly or whether it is due to the indirect effect of reduced water content and/or improved aeration.
- Future work will need to take account of the localised compaction that occurs around the base of the cutting during sticking.

Action points for growers

- It is too early in the project to make any firm recommendations but the results achieved to date clearly highlight the potential dangers of dispensing with the traditional sand layer in the propagation bed.
- A solid floor, or a covering of a woven material such as Mypex, clearly has advantages from the hygiene and management viewpoints but aeration of the rooting medium is reduced.
- Where rooting results are disappointing, particularly if there is extensive rotting at the base of the stem, it may be worth testing whether capillary drainage would improve matters.
- A large tray filled with sand, placed underneath the propagation tray, provides a simple means of doing a small scale test.

Anticipated practical and financial benefits

Cost benefit analysis

Estimate of number of cuttings which fail to make saleable liners

= 25% of 200M cuttings p.a.

= 50M cuttings p.a.

At an average price of £0.20, the value of this lost production

= 50M x 0.2 = £10M

Making the conservative estimate that improving rooting media could increase overall rooting percentage by 0.5%, that would be equivalent to reducing losses by 2% and the value of lost production saved

= 2% of £10M= £200K *per annum*

Total cost of the project is approximately £108K, therefore the ratio of *annual* benefit to total cost

= 200 / 108 = 1.9

SCIENCE SECTION

Introduction

Purpose

The purpose of this project is to understand how the rooting medium contributes to successful rooting of cuttings so as to be able to recommend how growers should select and manage the medium for different types of cutting and different types of propagation environment.

This project is timely because three factors are putting extra demands on the 'free-draining' properties of rooting media:

- Many growers want to achieve more supportive aerial environments, which usually involves generous wetting of the foliage and hence increased danger of overwet media.
- There is a move away from sand under propagating trays, towards cleaner and more hygienic surfaces such as concrete which do not provide ‘positive’ (i.e. capillary) drainage.
- With increased use of shallow modular rooting trays, the depth of rooting medium below the base of the cuttings has decreased. This decreases the water tension and increases compaction of the medium at the base of the cutting, both of which tend to decrease aeration.

Basic requirements of a rooting medium

Little is known about what constitutes a satisfactory rooting medium from the cuttings viewpoint. Most of the literature reports comparisons of alternative media under a single set of circumstances. What is needed is a set of general principles which can be applied under all conditions.

To help direct us towards these principles, we may ask 'What does the medium have to do?' The basic requirements are:

- to hold the cutting upright

- to supply water
- to supply O_2 (oxygen) and remove CO_2 (carbon dioxide)

Therefore, mechanical strength, **water content**, and **air content** are likely to be the important properties. This helps us focus on the properties that determine air and water contents:

- Water and air content clearly depend partly on the total volume of pores accessible to air and water (i.e. excluding closed air pockets that exist in materials such as pumice and perlite), known as the total porosity.
- They also depend on the proportion of pores that are filled with water.
- This in turn depends on the size of the pores: the larger the pore the smaller the force required to pull the water out of it (as in a glass capillary tube).
- In a rooting medium, gravity provides the force pulling water out of the pores in the medium. This depends on the presence of a series of continuous water-filled pores to contain a hanging water column, analogous to the operation of a syphon.
- The size of this suction force depends on the height of the hanging water column.
- The hanging water column ends where it reaches a "water table", an impermeable surface where the water is forced to move laterally (e.g. a solid floor), or a break in the continuity of the pores, as may occur even on sand if trays are not carefully worked into the surface.
- The proportions of air and water in any rooting medium therefore vary depending on the drainage arrangements. Something that works well on sand might be disastrously wet on concrete because there is not enough suction to drain the majority of the pores.

Previous studies

To minimise the danger of drought stress, it is reasonable to suggest that the medium should be able to supply water to the base of the cutting at least as fast as the cutting can lose water by transpiration. There is evidence that this is only likely to be achieved if the water content is very high, perhaps as high as 70% by volume in the case of peat (Thomas and Harrison-Murray, 1995). However, the benefit of ready availability of water at the cutting base is cast into doubt by the evidence of partial blockage of the stem over the first few days after sticking (Grange and Loach, 1983). Furthermore, in a hydroponic system, the rate of blockage was affected by the nature of the medium (Anon, 1998). The benefit of high water availability in the medium needs to be examined further.

The most important area of uncertainty is how wet the medium can be before it starts to suppress rooting. Indeed, it is not known whether this depends on the volume of pores that remain filled with air, or the water content, or the tension with which the water is held. Loach (1985) identified many of the complexities involved including differences between species and interactions with evaporative demand of the aerial environment. If true, then a medium which is too wet on a cloudy day might be ideal during fine weather when cuttings are taking up more water. Investigating the performance of media over a range of aerial environments is therefore central to this project.

Some of the main interactions with the physical properties of the medium that we can envisage are summarised diagrammatically in Figure 1.

As well as the influence of the drainage arrangements referred to earlier, a second interacting factor shown in Figure 1 is the rate of water application. In propagation systems, mist or fog is constantly adding water to the medium so that the water and air content depend on a ***dynamic equilibrium*** between water deposition and drainage. This is very different from the *static* equilibrium conditions used in conventional methods of determining soil water release characteristics.

A third, and probably most important, interacting factor is the transpiration demand for water uptake - partly determined by the evaporative demand of the aerial environment, and partly by the area and stomatal conductance of the leaves on the cuttings. If transpiration demand is high then it is likely that the cutting will benefit from a high water content, to maximise supply of water to the small area of the cut base. However, if it is low, there is perhaps more chance that water will move from the medium into intracellular air spaces exposed by the basal cut. If this happens it would impede gas exchange within the tissues, effectively ‘drowning’ the tissues so that cells die from O_2 starvation.

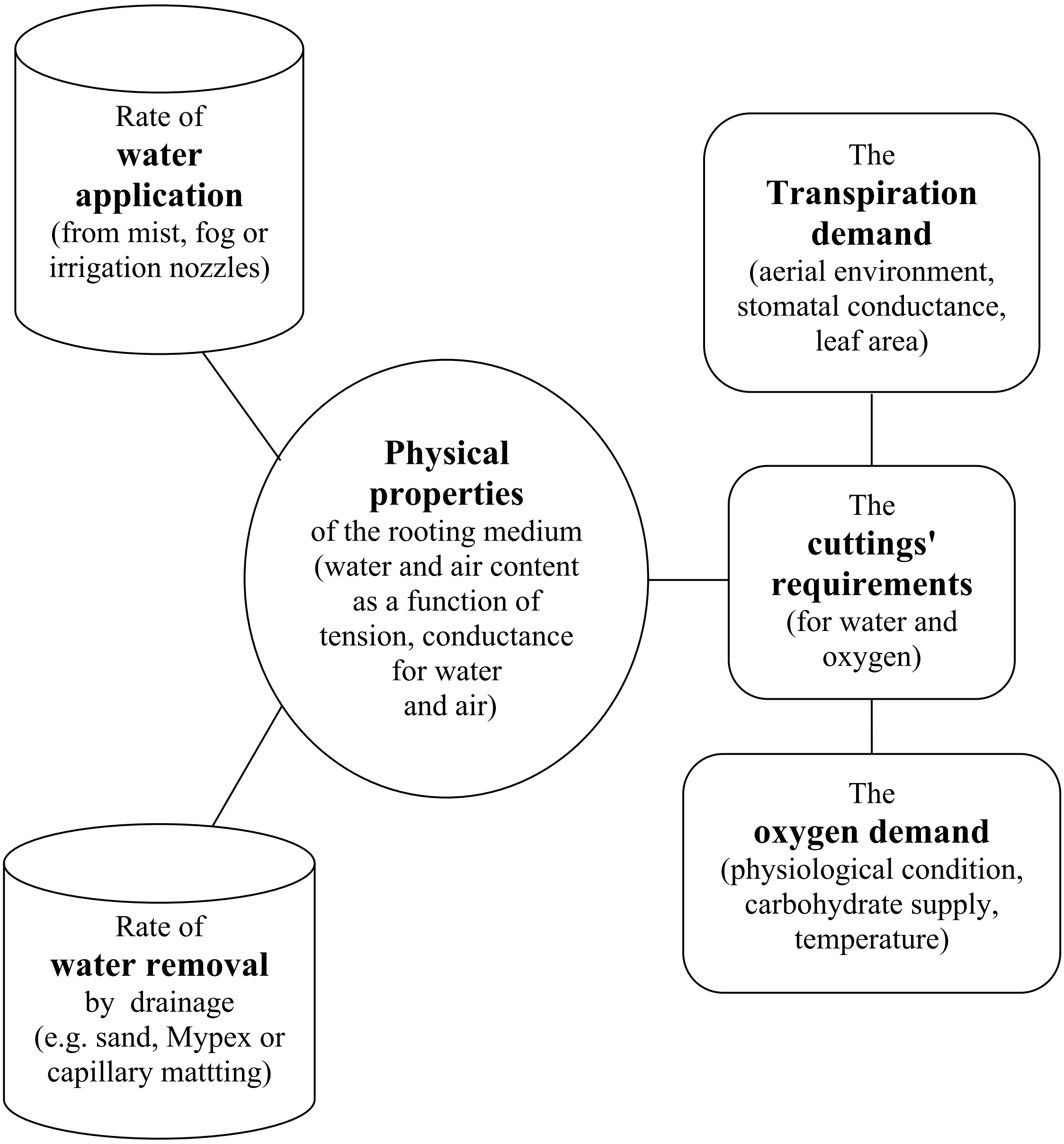


Figure 1. Model of the ways in which the influence of the physical properties of the rooting medium are likely to be affected by other aspects of the propagation environment and by physiological differences between cuttings (between cultivars, stockplants, time of year, etc.)

Despite such interactions, nurserymen have no doubt that the rooting medium, and the management of its water content, can have a profound influence on rooting failure rates. As a result they modify their media in an attempt to reduce losses. However, most recognise that there is little rationale behind these adjustments because useful basic principles and practical guidelines are lacking. This project addresses these needs.

Approach adopted

A two-strand approach to the problem has been adopted. The first strand is ‘systematic’ and is investigating how the rooting and rotting of cuttings is influenced by the water and aeration status of a range of media, and how that relationship is altered by aerial environment and the drainage arrangements. The Controlled Propagation Environment (CPE) facilities at East Malling are ideally suited to this purpose.

A second more ‘exploratory’ strand will challenge some basic assumptions and pre-conceptions in a series of small scale experiments, and may thus open up radically new practical opportunities. For example, are we right to assume that water uptake occurs mainly through the cut base? Existing evidence is inconclusive and the occurrence of stem blockage raises some doubt. It is possible that uptake through wetted leaves and lenticels on the stem may be more important than has previously be supposed. This is being tested by sealing the cut base with waterproofing materials before placing the cuttings in a highly supportive wet fog environment.

Work in Year 1

During the first year of the project, most of the work has been directed to adapting established methods of studying soil water release characteristics to the special needs of rooting media and the objectives of the project. Water release characteristics are usually presented as curves (water release curves) which show how the water content decreases (and the air content increases) as the forces drawing water out of soil increase. From a water release curve it is possible to predict the air and water contents under different drainage conditions. For this project a method would ideally provide:

- Tension range of 0 to 10 cm of water (0 to 0.1 kPa)
- Small range of tension within a single sample (i.e. minimise the depth of samples)
- Accurate estimation of air content in media close to saturation
- Relate closely to nursery practice regarding wetting up and packing of media
- Take account of the fact that the particles of many media continue to absorb water over a long period (e.g. months for perlite)
- High statistical precision (i.e. low standard errors)
- High throughput

A method was developed which meets most of these requirements. It is based on the use of 7 cm square pots, containing a 2 cm thick layer of medium, placed on a series of four tension tables which applied tensions of 2.5, 5.0, 7.5 and 10.0 cm. It is described in detail in the Material and Methods section. Results are presented for 24 different media including a range of peat and perlite mixtures. These show that the addition of perlite can 'open up' the medium as believed by many growers, but only if the proportion of perlite is high enough.

Also included in this report are results of the first rooting experiments. One compared five different media under a range of aerial environments and drainage arrangements. Another explored the importance of water uptake through the base of the cutting using a variety of different sealing materials applied to the base of the cuttings.

Materials and Methods

Water release characteristics of rooting media

Tension tables

A 'tension table' is a tank filled with a bed of porous material, such as fine sand, saturated with water connected to a hanging water column to apply a known tension. The hanging water column is achieved by connecting a flexible plastic tube to a system of drainage channels in the base of the tank. If the open end of the tube is below the surface of the bed then a tension is applied to samples placed in contact with the surface of the bed. The tension is equal to the vertical difference between the surface of the bed and the surface of the water in the tube. In practice, to maintain a constant tension, the tube is U-shaped and is connected to an overflow device which maintains a constant level when water is draining from the system. The same device provides a reservoir of water when water is moving up into the sand (e.g. to wet up samples or to compensate for evaporation) which can readily be topped up by hand or connected to a automatic water feed (e.g. Mariotte bottle).

Four such tanks were constructed from perspex sheet (10 mm thick base, with 8 mm thick sides). External dimensions were 450 x 300 x 95 mm (L x W x H). Channels cut in the base provided a system of drainage channels. A layer of glass fibre filter paper was laid over the base to separate the channels from the sand. The sand was Medium Classified Sand from the Aylesford Quarry of Hall Aggregates (South East) Ltd, Maidstone. The sieve analysis is shown in Table 1. This is the sand that is used to provide drainage in our propagation beds. It starts to drain at a tension of about 150 mm of water and is therefore suitable for tensions up to 100 mm, the maximum that is relevant to the rooting of cuttings. Because it is coarser than the materials used for higher tensions, water can drain through it rapidly, ensuring the maximum throughput of samples.

Table 1. Sieve analysis of sand used in the tension tables

Sieve size, µm	% retained
1000	0
710	0
500	0.4
355	4.3
300	10.4
250	31.8
212	26.6
180	21.3
150	3.9
125	1.0
90	0.3
63	0
pan	0

The layer of sand in the tension tables was about 20 mm deep and was initially wetted carefully to achieve a well consolidated layer with little entrapped air. A combination of wetting up from below, via the water reservoir and overhead from a can with rose attachment or sprayer on mist setting, proved best. To adjust the tension in the four tables, the overflow devices were adjusted to bring the level of water to the surface of the sand. A ruler was fixed to the side of each table with the zero line level with its overflow tube. The overflow tube was then lowered to the position on the ruler corresponding to the required tension. In early tests it was found that the surface of the sand was not sufficiently firm to support the sample until some tension was applied. The minimum tension that could be used in practice was found to be 5 mm at the sand surface.

The tension tables were set up in a constant temperature room at 20 ± 2 ºC. A perspex cover over each tension table minimised evaporation from the sand and the upper surface of the samples.

Variation in tension within the depth of the samples

Within a sample of rooting medium on the tension table, the height above the sand surface adds to the tension applied. The tension increases towards the top of the sample and the results obtained therefore relate to a range of tensions determined by the depth of the sample. A depth of 20 mm was chosen for this project, so that the tension at the top of the samples equilibrated on the table with a tension of 5 mm at the sand surface was 25 mm (5 + 20 = 25) and the range of tensions within the sample was 5 to 25 mm. Shallower samples may be used in future for specific investigations but lead to greater errors in the determination of the weights and volumes from which the water content of the samples is calculated.

Meaning of zero tension

Throughout this report, tension values are those at the upper surface of the samples. This convention has the advantage that, irrespective of the depth of sample, a tension of zero corresponds to the completely saturated condition. Complete saturation is difficult to achieve in practice, because of entrapped air, and can change the structure of some media due to slumping. However, when a medium is saturated, the water content is by definition equal to the total porosity. A value for total porosity, determined by an indirect method that does not require complete saturation, can therefore substitute for the saturated water content on a water release curve. That is the approach adopted in this project.

Sample preparation

Sample holders were made from 70 mm square plastic pots (Thovadec 0.3 L square pots) which have four drainage holes, 5 mm in diameter. The pots were cut down to a height of 5 cm so that a lid could be placed over the tension table. Samples were packed into these holders to a depth of about 20 mm, the actual depth achieved being determined with callipers at the end of the water release curve process. The quantity of material in a sample was set by filling a 50ml glass Pyrex beaker to the lip and settled by tapping the base on a solid surface. The sample was then tipped into a sample holder, levelled by tapping the sides, and firmed gently using the base of another pot. At this stage the material was slightly moist, as sold.

The samples were then wetted up in a way that simulated the first week under generous misting. Sample holders were placed in a rigid plastic tray, with drainage holes, and transferred to a generously wetted propagation environment (wet / low light part of the Gradient Controlled Propagation Environment (G-CPE)) and watered lightly using a can with rose attachment.

Use of the tension tables

One week later the samples were removed from the G-CPE, wiped dry inside and out, weighed and then placed on the 25 mm tension table, working the sample holders into the suffice of the sand to ensure good contact. Preliminary tests with pure peat showed that 24 hours was sufficient to reach equilibrium after a 25 mm increase in tension. Samples were therefore moved from one tension to the next at 24 hour intervals. Sand adhering to the base of the sample holders was brushed off before weighing.

To determine the water content at each tension the dry weight of the medium and sample holder is required. However, before the samples were dried it was necessary to estimate the total porosity.

Estimating total porosity

Many different approaches for the direct measurement of total porosity were attempted but none achieved sufficient accuracy for the present project. Most were modifications of the methods used for estimating total porosity of container growing media as part of the determination of 'Air Filled Porosity' (AFP). None gave sufficiently reproducible results for the determination of air content in media close to saturation.

Since air content has to be estimated as the difference between water content and total porosity, errors in both these measurements are combined in the air content estimates. Furthermore, with many of the materials used in rooting media (especially Perlite) total porosity varies not only between subsamples but also with time as water penetrates further into the micropores within the particles.

To overcome this difficulty an indirect method of estimating total porosity was adopted. If both the bulk density and the particle density are known, total porosity can be determined from the equation:

$$TP = 100\,(1 - BD/PD)$$

where TP = total porosity, %
PD = particle density, kg m^{-3}
BD = dry bulk density, kg m^{-3}

Dry bulk density is simply the mass of the dried medium divided by the volume that it occupied in the sample holder (i.e. before drying). To determine particle density the volume of the particles is needed in place of the volume of the medium (i.e. excluding the pores). For minerals such as sand this volume is readily determined using a specific gravity bottle to measure the mass of water displaced by a sample of particles. Many of the materials used for rooting media float on water which makes it impossible to use a conventional specific gravity bottle. To overcome the difficulty of floating material, a measuring cylinder with a special plunger was developed to use in place of a specific gravity bottle. The plunger consisted of a disc of fine stainless steel gauze mounted on a glass rod which forced floating material below the surface. As such, it was like a miniature version of a 'cafetiere' jug for making coffee. To ensure that the plunger displaced a consistent volume of water, the top of glass rod was bent back to form a hook which engaged with the lip of the measuring cylinder.

Details of the particle density technique for materials less dense than water:

A 100ml measuring cylinder with ‘cafetiere’ style plunger (to hold down media particles less dense than water) was used in place of a specific gravity bottle. It was filled to about the 80 ml mark with distilled water. The plunger was inserted until the hook reached the lip of the cylinder, the water topped up to the100ml level exactly, and then the whole assembly was weighed on a milligram balance to obtain a ‘blank’ reading.

To determine the particle density of the material used for the water release curves, about half the sample was scooped out of the sample holder into the measuring cylinder with about 60 ml of distilled water. The sample was stirred to encourage entrapped air to rise to the surface, the plunger was inserted gently, the water level was topped up to 100 ml mark exactly and the assembly was weighed.

The sample was then rinsed from the cylinder into a filter funnel, allowed to drain and then oven-dried at 80 ºC. Using filter papers whose dry weight had been determined in advance, the dry weight of the recovered sample could be calculated. The other half of the sample from the water release curve process was also dried and weighed. The water content of the samples at each tension could then be calculated by subtraction of the dry weight and the weight of the sample holder.

The method is sensitive to temperature because the density of water and the volume of measuring cylinder change with temperature due to expansion. By running a series of blanks at different temperatures a calibration graph was obtained which made it possible to allow for small differences in temperature between samples. To enable this correction to be applied, the temperature of the water in the cylinder was measured after filling to the 100 ml mark with the sample in the cylinder.

Using this method to determine particle density, the main source of error in the estimation of total porosity became the volume of medium in the sample holder. Alternative sample holders are being sought which would increase the precision of the sample volume without losing the link to normal nursery practice provided by the use of a standard liner pot as a sample holder.

Experiment to monitor changes in apparent particle density

In order to assess the importance of the slow penetration of water into the particles of peat and of perlite, two of the most important materials used in rooting media, samples were analysed after 1, 24 and 168 hours. In this case, samples proceeded directly to the particle density stage at the end of the pre-wetting stage in the G-CPE.

Media analysed

Media were tested in groups of four as follows:
(throughout the report, media mixes are defined on a volume basis):

Group1	Mixtures of: **fine peat** (Shamrock Irish sphagnum peat) **perlite** (Silvaperl standard grade) (0, 25, 50 and 75 % perlite)
Group 2	Mixtures of: **fine peat** (Shamrock Irish sphagnum peat) **vermiculite** (Pro Gro medium grade) (25, 50, 75, and 100% Vermiculite)
Group 3	Mixtures of: **fine peat** (Shamrock Irish sphagnum peat) **perlite** (Silvaperl special seed grade) (25, 50, 75, and 100% Perlite)
Group 4	Mixtures of: **fine peat** (Shamrock Irish sphagnum peat) **vermiculite** (Pro Gro fine grade) (25, 50, 75, and 100% Vermiculite)
Group 5	**Bulrush Plug-Its** (sphagnum peats with nutrient and wetter contained in a biodegradable tube); plugs broken down and packed into sample holders **Elle Pots** (55% Baltic peat, 15% Vapo Peat, 30% medium perlite, with nutrients and wetter contained in a biodegradable tube); plugs broken down and packed into sample holders **Agrimedia Oasis** rootcube cylinders (35mm diameter x 35mm deep); cylinders cut down to the standard depth of 20 mm for water release curve and cut into random small pieces for particle density determination **Grodan Rockwool** cubes (SBS 36/77) 36 x 36 x 40 mm (L x W x H); cut down to the standard depth of 20 mm for water release curve and cut into random small pieces for particle density determination

Group 6	**fine peat:fine bark mix** (50:50 mix of fine grade Shamrock Irish sphagnum peat and fine grade Cambark) **medium peat:fine bark mix** (50:50 mix of medium grade Shamrock Irish sphagnum peat and fine grade Cambark) **fine peat:'propagating' bark** (50:50 mix of fine grade Shamrock Irish sphagnum peat and Melcourt Propagating Bark) **Bulrush seeding propagation compost** (a fine screened peat with a small proportion of vermiculite)

Replication

Each medium was replicated three times within the above groups.

Rooting experiments

Plant material

Cuttings of Fremontodendron 'California Glory' were collected on 26 June, 2000, from well established container-grown stockplants in an unheated polythene tunnel. Cuttings were obtained from the current season's main shoots and the larger laterals. Cuttings were cut just above a node so that there was no node near the base (i.e. they were internodal cuttings). Half were apical, with a few nodes bearing expanding leaves and the shoot tip. Half were non-apical, with a single node bearing a fully expanded leaf and, in some cases, a small lateral shoot. Apical and non-apical cuttings were allocated to separate blocks.

All the plant material was kept well wetted during preparation of cuttings to minimise exposure to the irritant hairs borne on this plant.

All cuttings were dipped for 5 s, to a depth of about 8 mm, in a solution of 1 g L^{-1} of IBA in a 50:50 (v/v) mixture of acetone and purified water.

The treatments

The treatments were all possible combinations of the following three factors (i.e. a multifactorial experiment).

The rooting media

- Bulrush Plug-Its
- Elle Pots
- Grodan Rockwool cubes (SBS 36/77)
- Agrimedia Oasis rootcube cylinders (35mm diameter x 35mm deep)
- fine peat:fine bark mix (50:50 mix of fine grade Shamrock Irish sphagnum peat and fine grade Cambark). This is our standard propagation medium as used in previous HDC projects such as HNS 55.

The aerial environments

- Open mist, evapo-sensor controlled, with a polythene curtain around the edge of the bed to reduce air movement but not enclosed.
- Fog (Agritech), evapo-sensor controlled, in a tightly closed polythene tunnel with fan ventilation when temperature exceeded 32 ºC.

Both environments were shaded to reduce solar radiation at cutting level to about 20% of ambient, using external reflective shade (Ludvig Svensson OLS 60, Hortisystems UK, Pulborough). Electrical heating maintained the medium at a minimum temperature of 20 ºC.

Drainage

- Capillary drainage: trays worked into the surface of a layer of sand, approximately 10 cm deep, to provide capillary drainage.
- No capillary drainage: trays separated from the sand bed by a layer of polythene so that there was no capillary drainage.

Experimental design

There were 24 replicate cuttings per treatment combination in four plots of six cuttings. Plots were arranged in four completely randomised blocks.

A plot consisted of a row of six cuttings across a 6 x 10 cell tray. The trays used were of the type supplied with Elle Pots and Bulrush Plug-Its, so that the Rockwool cubes and Oasis cylinders did not fit as snugly as in the trays supplied for them.

Root inspection and other assessments

On 24 July, 2000, four weeks after sticking, cuttings were removed and detailed records made. In the case of Oasis and Rockwool, the material was carefully cut away to enable accurate observation. Records were made of the number of roots or, the presence of callus, the length of stem with evidence of tissue death (e.g. blackened), and a subjective score of root quality which took account of the length as well as the number of roots.

Physical measurements

The rate of water deposition in the two aerial environments was measured on two occasions. In each environment, six petri dishes were placed at representative locations around the trays of cuttings on special stands which reduce the influence of radiation on evaporation of the deposited water. The measurements are summarised in Table 2:

Table 2. Rates of water deposition recorded in the mist and fog environments on two separate days.

Date	Fog	Mist
28 June	21.3 $\mu m\ h^{-1}$	152 $\mu m\ h^{-1}$
30 June	28.9 $\mu m\ h^{-1}$	374 $\mu m\ h^{-1}$

Results and Discussion

Water release characteristics

Changes in total porosity associated with wetting of peat and perlite

The particle densities of both peat and perlite, determined as described above, increased with duration of wetting. Since their dry weight is constant, this implies that their volume was decreasing and total porosity was increasing, as shown in Figure 2.

The most likely explanation of this phenomenon is that the particles (in the case of peat the term particle refers to individual fibres and tight clumps of fibres) contain pores within them that are *almost* completely enclosed and therefore isolated from the pore space between the particles. As a result, water penetrates these pores extremely slowly. Since the volume of the particles is determined by water displacement, as these pores fill with water they cease to be considered as part of the particle, the apparent volume of particles decreases and therefore their apparent density increases.

The results in Figure 2 show that the total porosity of Perlite was initially about 66% but had increased to 80% after a week. This change accounted for all of the increase in water content seen over the same period, so that there was no change in the estimate of air content (because air content is estimated from the difference between total porosity and water content). In comparison, the total porosity of peat was initially much greater than that of perlite (88%) but increased relative little over the course of one week (to 90%). However, in contrast to perlite, the estimated air content declined dramatically over the same period as pores between the particles wetted up. This probably reflects the hydrophobic nature of peat fibres which is absent from perlite. Hydrophobicity is very obvious when peat is extremely dry but these results suggest that it also slows up absorption of water into the finer pores of peat that already appears moist (e.g. at 60% water content, as measured after one hour).

The particle density of peat after wetting for a week was 1.22 g cm^{-3}. This is still well below the typical particle density of peat which is about 1.5 g cm^{-3}, suggesting that further slow change is likely to occur over many weeks in a propagation environment.

These results make it clear that the nature of the materials used in rooting media make it difficult to estimate accurately the air content from the water content. Compared with the mineral particles in a normal soil, they lack a sharp distinction between the solid particles and the pores between them.

On the basis of this experiment, it was decided to wet up all samples for one week before analysing their water release characteristics. Any further change in total porosity over the four days required to equilibrate the samples on four tension tables would then be small. It was also decided that the particle density needed to estimate total porosity should be determined on the same sample used for the water release curve. In this way, any variation in the wetting up process would not lead to errors in estimation of air content.

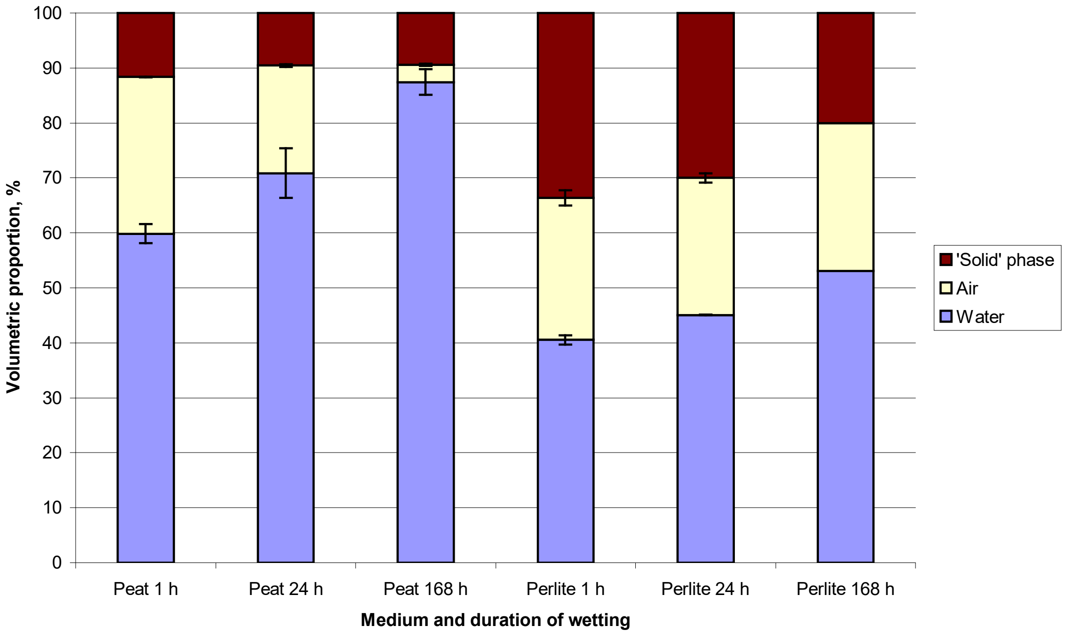


Figure 2. Changes in water and air content, and the apparent volume of the solid 'particles' of peat and perlite, over the course of wetting-up under wet fog, without capillary drainage. The sum of the water and air contents is the total porosity. (The 'apparent' volume is the volume of water displaced. Air content was determined by difference; SE bars are for the water and solid phase volumes; n=3)

Water release characteristics: peat and perlite mixtures

The first group of media examined the effect of incorporating coarse granules of perlite (i.e. what is sold as 'standard' grade) into a peat based rooting medium. This is often done to 'open up' the medium with the intention of reducing the water content and thus increasing aeration. However, while coarse perlite is itself very free draining, as reflected in the high air content seen in Figure 2, adding it to peat or other finer textured material will not necessarily improve drainage. If the proportion of perlite is too small then the perlite particles will tend to become separated from each other, embedded in a matrix of peat. In this situation the water release characteristics would continue to be dominated by the peat, and the effect of the perlite would be mainly to reduce total porosity. In pure perlite, the pore space between the granules is about 60% of the total volume (from the 1 h data in Figure 2). Therefore, there are theoretical grounds to expect that if the proportion of peat in peat:perlite mixture exceeds about 60% then the perlite granules will start to lose contact with each other and the effect of the perlite on aeration of the medium may decrease sharply. In practice, the interaction between the peat and perlite is likely to be much more complex.

The results obtained when 0, 25, 50 and 75% perlite was mixed with fine sphagnum peat (Figures 3 and 4) were consistent with this theoretical analysis. Compared to pure peat, the addition of 25% perlite resulted in slightly lower air contents at all tensions (not significant), whereas 50 or 75% perlite substantially increased air content at all tensions. The addition of 50% perlite increased air content at all tensions by about 6-7% and an addition of 75% perlite increased air content by 11-14%.

The potential practical benefit of adding perlite was particularly large at a tension of 2.5 cm because even 50% perlite increased air content almost 3-fold. A tension of 2.5 cm is approximately what would be expected at the base of a cutting stuck in a tray placed on a solid floor or other non-capillary drainage system. It seems likely that the increase in air content, from 3.6% to 10.5%, achieved by the addition of 50% perlite would be enough to have a marked effect on oxygen supply to the cuttings and thus on survival and rooting of many subjects. The increase in air content achieved by 50% perlite was the same as that achieved by increasing the tension to 7.5 cm, which could be achieved by placing trays on a 5 cm deep layer of sand.

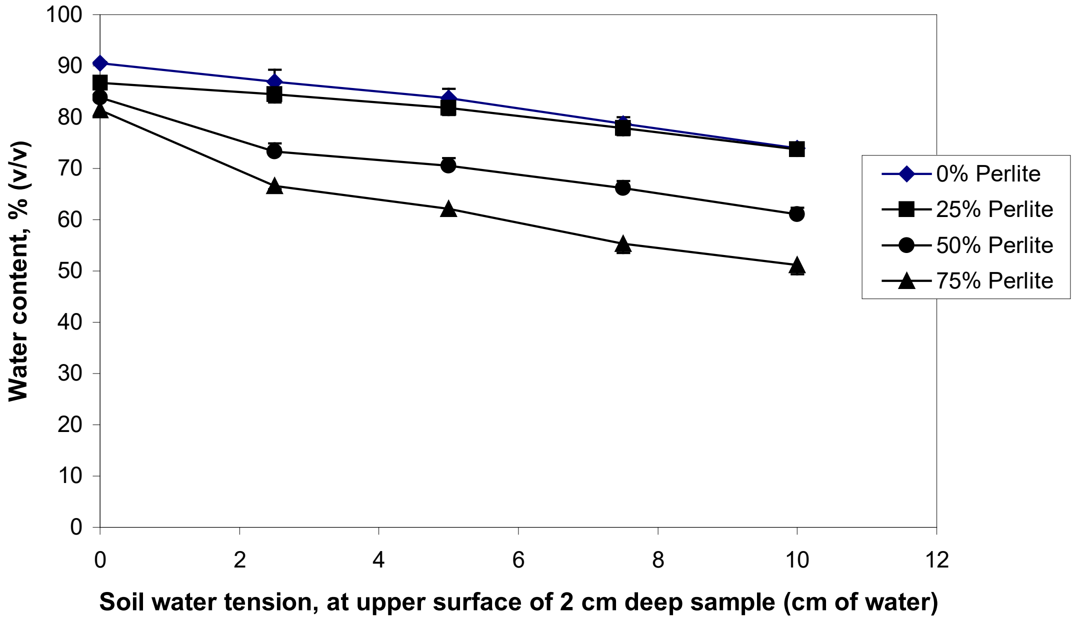


Figure 3. Water release curves for peat:perlite mixtures (fine peat:standard perlite) of media group 1. Vertical bars indicate the standard error of the mean (n=3).

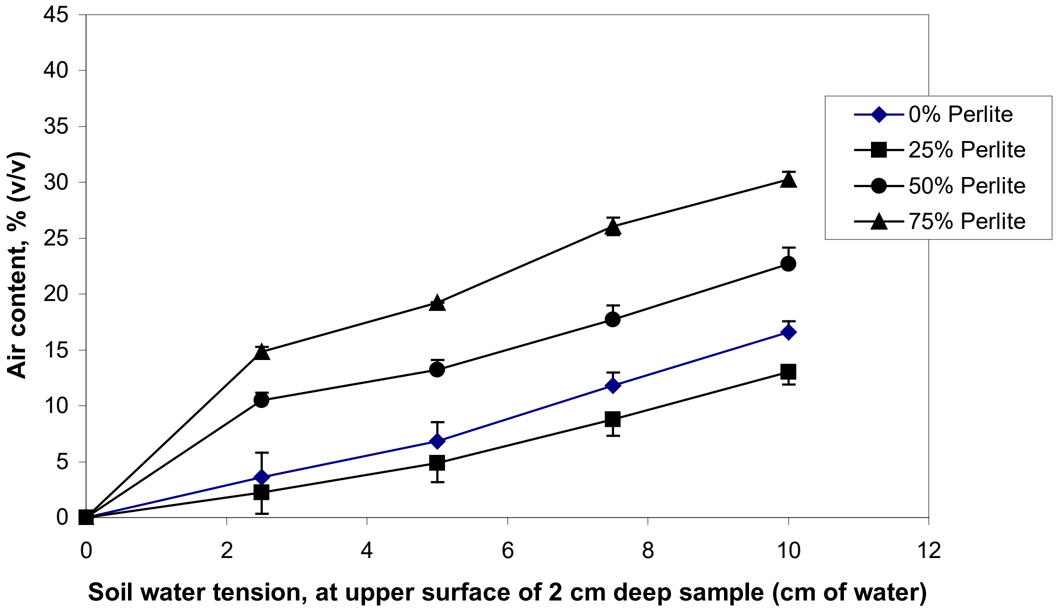


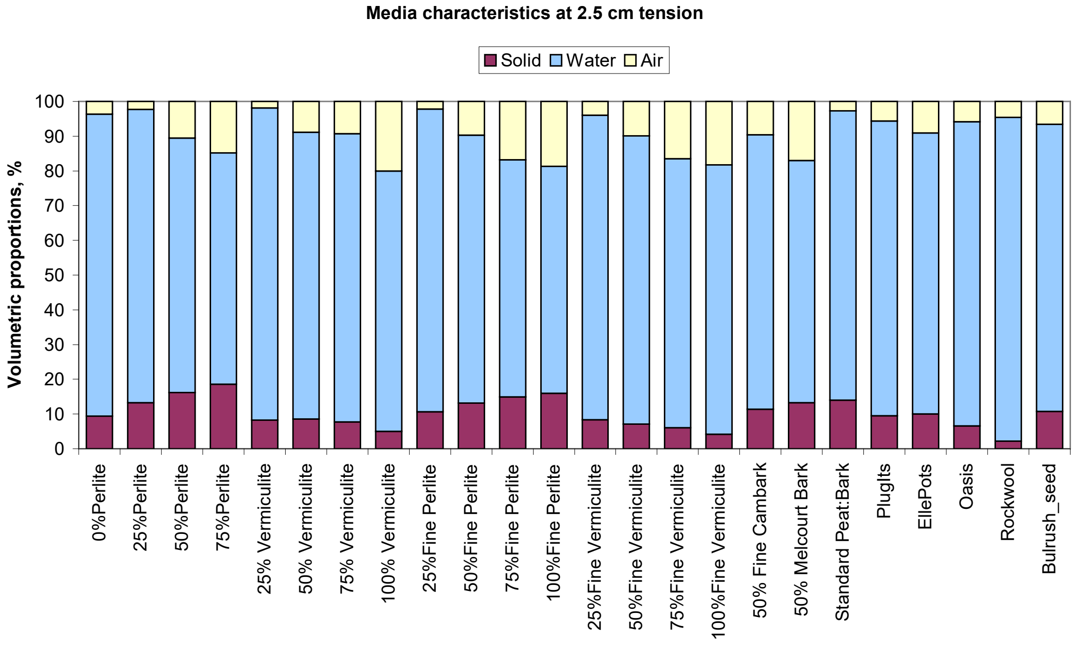
Figure 4. Air contents in peat:perlite mixtures (fine peat:standard perlite) of media group 1. Air content was estimated from the water release curve data, combined with a value of total porosity derived from particle and bulk densities. Vertical bars indicate the standard error of the mean (n=3).

Water release characteristics of other mixes

Water release curves for all the other media groups examined to date are included in an appendix. To provide an overview of the results, the data are summarised in Figure 5, which shows the proportion of each mix occupied by the solid particles, water and air at tensions of 2.5 cm and 10 cm.

The results show that there was remarkably little difference between the effects of adding vermiculite or perlite to peat. Even more surprising is that there was little difference between the effects of fine and coarse grades of these materials. An addition of 50% of fine grade Cambark had a very similar effect to 50% perlite, but Melcourt Propagating bark, that is largely free of any fine fibrous material, increased the air content by an extra 7% of total volume, to 17% at 2.5 cm tension and 36% at 10 cm tension. This was comparable to the effect of adding 75% of other additives such as perlite.

Conspicuously less well aerated was the mix which we use as a standard consisting of 50:50 medium Shamrock peat:fine Cambark. The reason for this is unclear but probably relates to it having a bulk density that was about 30% greater than that of the fine peat:fine bark mix (0.1845 and 0.1412 g cm^{-3} respectively). This implies that it was more densely packed, which would reduce the size of the pores and increase the tension required to remove water. This emphasises how sensitive these readily compressible media are to compaction and the dramatic effect that it can have on their water release characteristics. Since the action of sticking a cutting causes local compaction around the base of the cutting, this is an area that will have to be examined more closely in future.



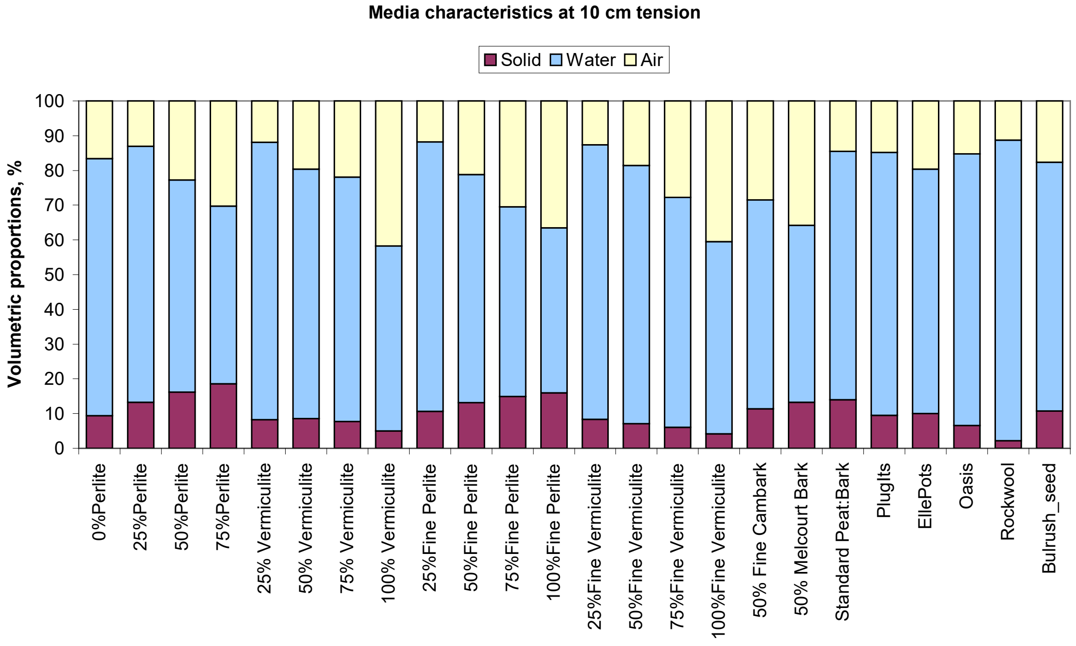


Figure 5. Summary of the water release characteristics of all media studied to date in simplified form. The bars show the volume occupied by solid particles, water and air as cumulative percentages of the total volume. The upper and lower graphs are for tensions of 2.5 cm and 10 cm respectively. These tensions correspond to the conditions that would exist around the base of a cutting 2.5 cm above the base of a tray placed either on a non-capillary surface (e.g. solid floor) or a 7.5 cm thick layer of sand respectively. Except for the last 6 media to the right of the graph, mixes are identified by the percentage of the material used as an additive to fine peat (Shamrock). 'Bulrush_seed' = Bulrush Seeding Propagation Compost. 'Standard peat:bark' refers to a 50:50 medium grade peat:fine grade Cambark mix used as standard in Propagation Science research group at East Malling.

Rooting experiment

The air and water content of the media around the base of the cuttings were estimated from the water release data. Data for the samples at the end of the pre-wetting period in the G-CPE, just before equilibration on the first tension table, were considered to relate closely to the non-capillary drainage treatment of this experiment. Estimates of the air and water contents are summarised in Table 3.

Table 3. Air and water contents of the media used in the rooting experiment, estimated from the water release curve data.

	Non-capillary drainage		Capillary drainage	
Medium	Water, %	Air, %	Water, %	Air, %
Peat:Bark	85.1	1.0	71.6	14.5
Plug-its	85.7	4.8	75.6	14.9
Elle Pots	81.5	8.4	70.3	19.6
Oasis	87.1	6.3	78.2	15.2
Rockwool	91.0	6.8	86.1	11.7

Rooting and other assessments on the cuttings are summarised in Figures 6 to 9. Salient features are listed below:

- There were large and significant effects of all factors on rooting.
- The largest effect was the increase in rooting from capillary drainage.
- The extent to which rooting was suppressed in the absence of capillary drainage showed no relation to the differences in air content indicated in Table 3.
- This could imply that the cuttings were adversely affected by the low tension itself.
- Alternatively, compaction of the medium in contact with the cut base, caused by process of sticking the cuttings, might have reduced air content in that critical region to damaging levels in all the media tested.

- A free-draining compaction-resistant material such as pure coarse perlite will need to be included in future experiments to distinguish between the two explanations.
- Rooting was suppressed in both the non-organic materials, i.e., Grodan Rockwool cubes and Agrimedia Oasis cylinders.
- Although the water release characteristics of Rockwool and Oasis were not distinctively different from the other media, these materials tended to become visibly dry, even in the absence of capillary drainage.
- There were no significant differences amongst the peat-based media.
- There was no significant interaction between media and aerial environment despite large differences in rates of water deposition (see Table 2)
- Rooting percentage was greatest in Mist + capillary drainage.
- The reduced rooting in fog probably reflects that the cuttings were placed in a relatively dry part of the fog house to maximise the contrast with open mist. This probably imposed too great an evaporative demand on the cuttings leading to suppression of rooting by drought-stress.
- Amongst non-rooted cuttings, more callus was observed in non-capillary drainage, but was mainly superficial callus developing on the epidermis rather than across the cut surface. Such callus develops from lenticels , is characteristic of overwet conditions, and is not associated with rooting.
- Basal rotting was greater amongst cuttings without capillary drainage and was particularly frequent in the Rockwell cubes. In contrast, there was little rotting in Oasis.

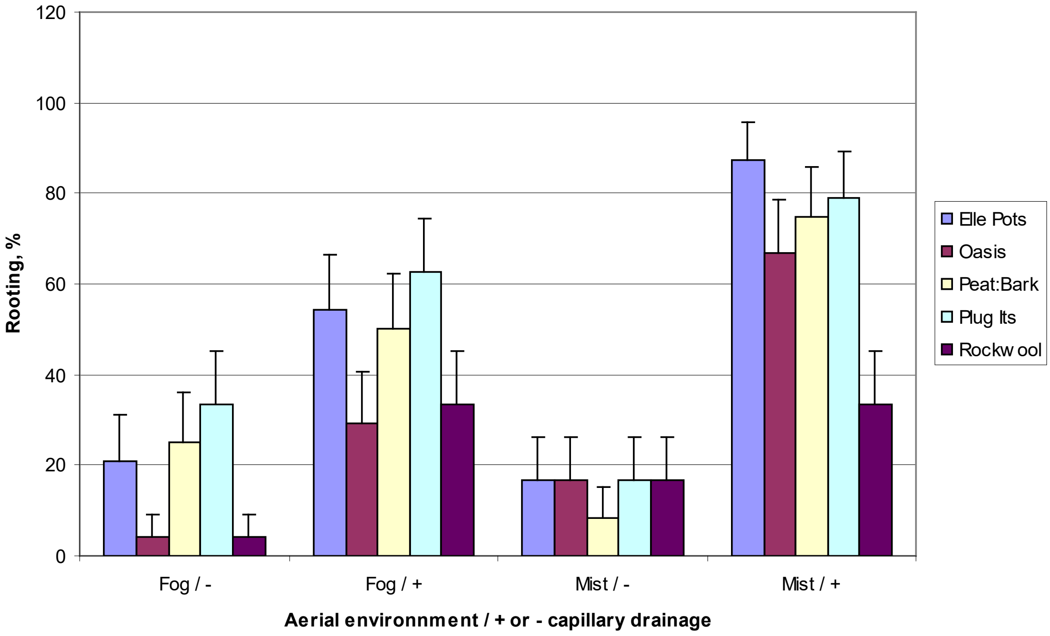


Figure 6. Rooting percentage of *Fremontodendron* 'California Glory' cuttings as influenced by rooting medium, aerial environment and drainage arrangement. Propagation trays were either in contact with a 10 cm-deep layer of sand to provide capillary drainage (+) or separated from the sand by a polythene sheet (-). Vertical bars indicate the standard error of the mean.

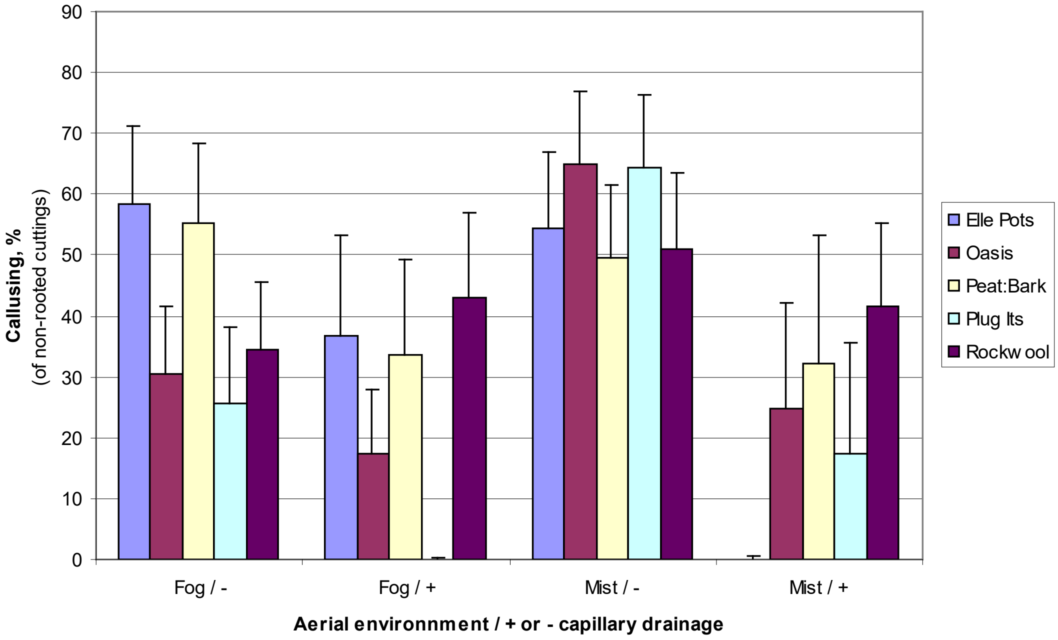


Figure 7. The percentage of non-rooted *Fremontodendron* 'California Glory' cuttings with visible callus, and the influence of rooting medium, aerial environment and drainage arrangement. Propagation trays were either in contact with a 10 cm-deep

layer of sand to provide capillary drainage (+) or separated from the sand by a polythene sheet (-). Vertical bars indicate the standard error of the mean.

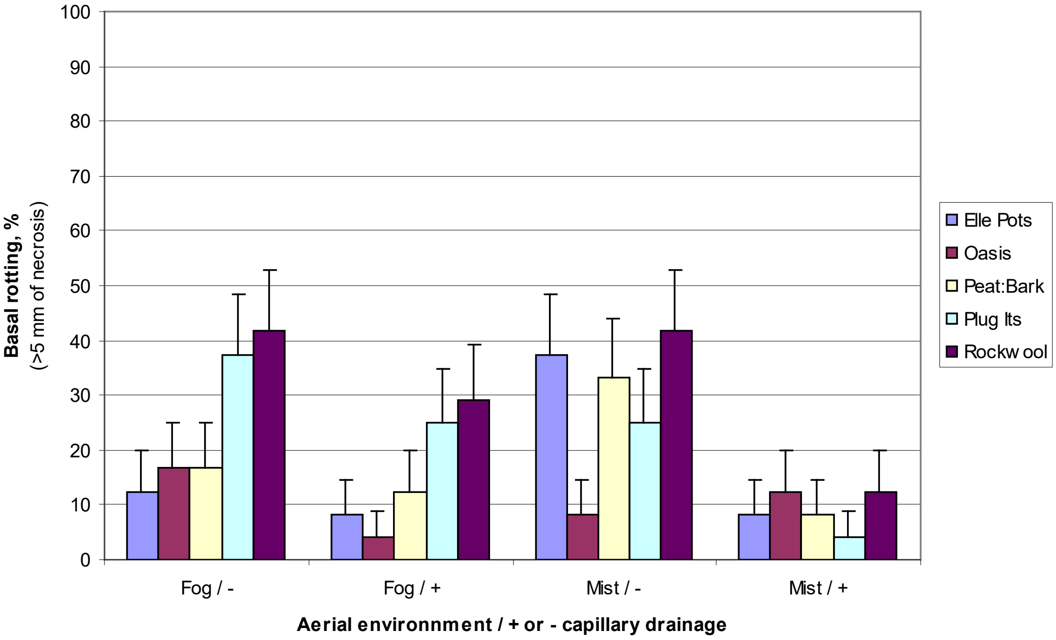


Figure 8. The percentage of *Fremontodendron* 'California Glory' cuttings with more than 5 mm of dead tissue at the base of the stem, and the influence of rooting medium, aerial environment and drainage arrangement. Propagation trays were either in contact with a 10 cm-deep layer of sand to provide capillary drainage (+) or separated from the sand by a polythene sheet (-). Vertical bars indicate the standard error of the mean.

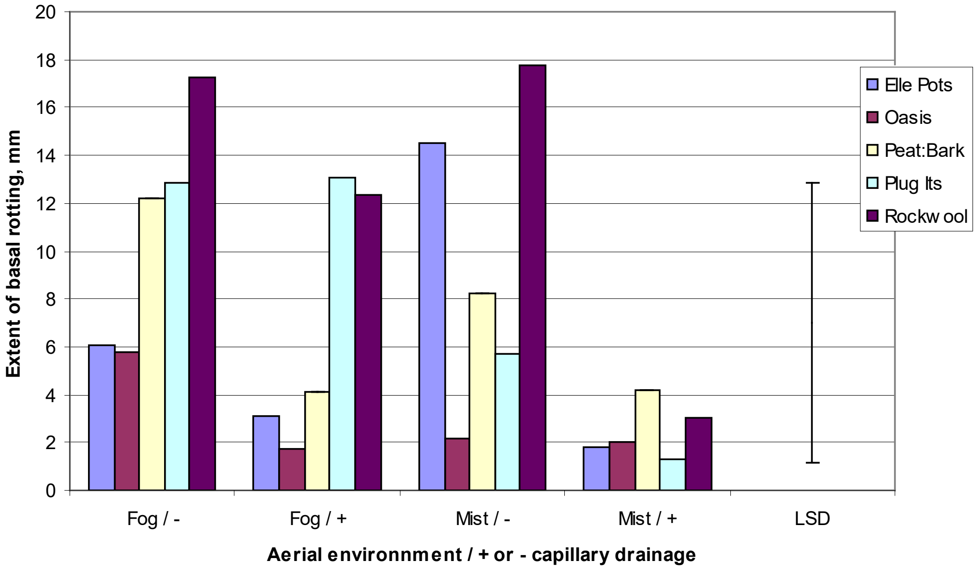


Figure 9. The extent of visible tissue death (necrosis) at the base of *Fremontodendron* 'California Glory' cuttings, and the influence of rooting medium, aerial environment and drainage arrangement. Propagation trays were either in contact with a 10 cm-deep layer of sand to provide capillary drainage (+) or separated from the sand by a polythene sheet (-). Vertical bars indicate the standard error of the mean.

Conclusions

The main conclusions at the end of the first year of this project are as follows:

- A method has been developed for studying the water release characteristics which meets the main requirements of the project.
- Media samples must be pre-wetted for a least a week under conditions relevant to nursery practice to allow a stable value of total porosity to be established without modifying the structure of the medium (as would occur if the media were stood in water to wet up the particles).
- Three replicate samples give acceptable statistical precision with most media.

- Under conditions equivalent to placing propagation trays on a solid floor, Mypex, or other non-capillary surface, few media contained more than 10% air, and those with a high proportion of peat contained less than 5%.
- Placing trays on a 5 cm-deep layer of sand to provide capillary drainage increased the air content of all media substantially and of pure peat to 12%.
- Addition of perlite or vermiculite to fine grade sphagnum peat greatly increased the air content of the medium but only if the proportion of additive was 50% or more.
- The grade of perlite or vermiculite added had no effect on the increase in air content achieved.
- Addition of Melcourt Propagating Bark to fine grade peat was particularly efficient at increasing the air content of the mix. It seems likely that this is because fine particles and fibrous material are screened out during production.
- Rooting and basal rotting of *Fremontodendron* 'California Glory' cuttings was significantly affected by whether the propagation trays were in contact with a layer of sand to provide capillary drainage. Such 'positive' drainage increases tension in the media with a corresponding decrease in water content and increase in air content.
- The benefit of capillary drainage was evident irrespective of the nature of the rooting medium.
- Further work is required to determine whether increased tension affects the cuttings directly or whether it is due to the indirect effect of reduced water content and/or improved aeration.
- An anomalous result for the water release characteristic of one peat:bark mix suggests that, in future work, the effect of compaction on the behaviour or rooting media needs to be examined critically.
- This approach will need to take account of the localised compaction that occurs around the base of the cutting during sticking.

TECHNOLOGY TRANSFER

This project was outlined to growers at the Propagation Workshops held at HRI East Malling on 22-23 September, 1999. Aspects of the work were discussed in workshops on grower holdings in 2000.

GLOSSARY : terms, abbreviations and products used

Bulk density - the density of the medium as a whole, including the pore space, i.e. the mass of a sample of the medium divided by its volume.

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

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

particle density - the density of the solid material making up the ‘particles’ of the solid in the rooting medium.

stomatal conductance – A measure of the ease with which water vapour can diffuse out of the lower surface of a leaf, and a function of the size of the stomatal apertures.

tension (or soil water tension) - a measure of the capillary forces holding water in the soil (or rooting medium), and therefore the force required to remove water from it. It is synonymous with ‘soil moisture suction’ and numerically equal to the soil matric potential (though of opposite sign). In the present context it is convenient to express it in centimetres of water, i.e. the height of a column of water which would create the same tension.

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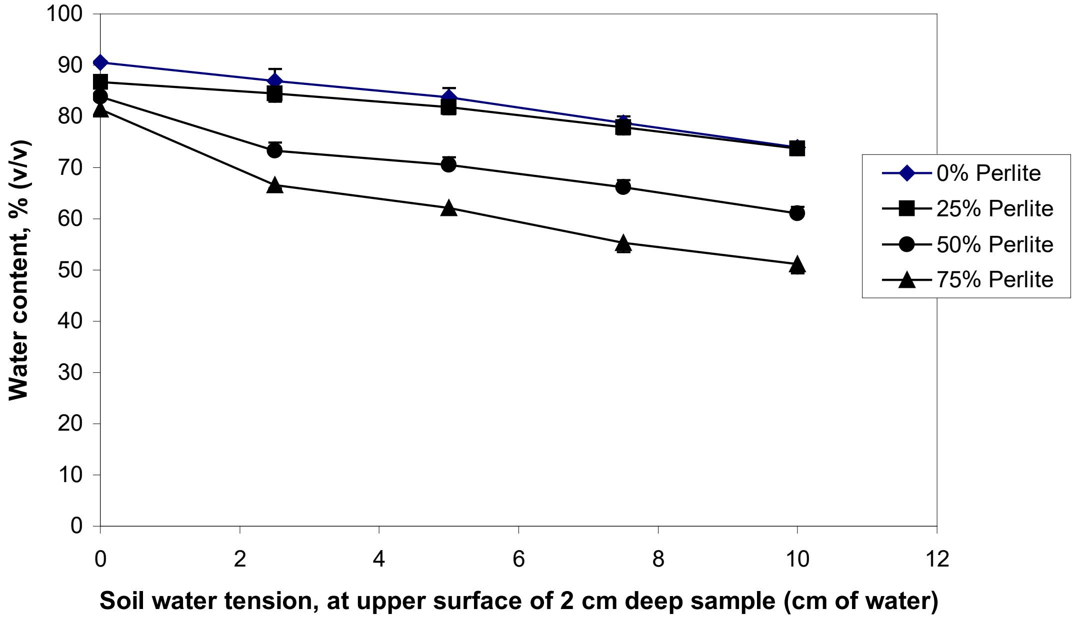
APPENDIX 1.

Soil water release curves for all media tested.



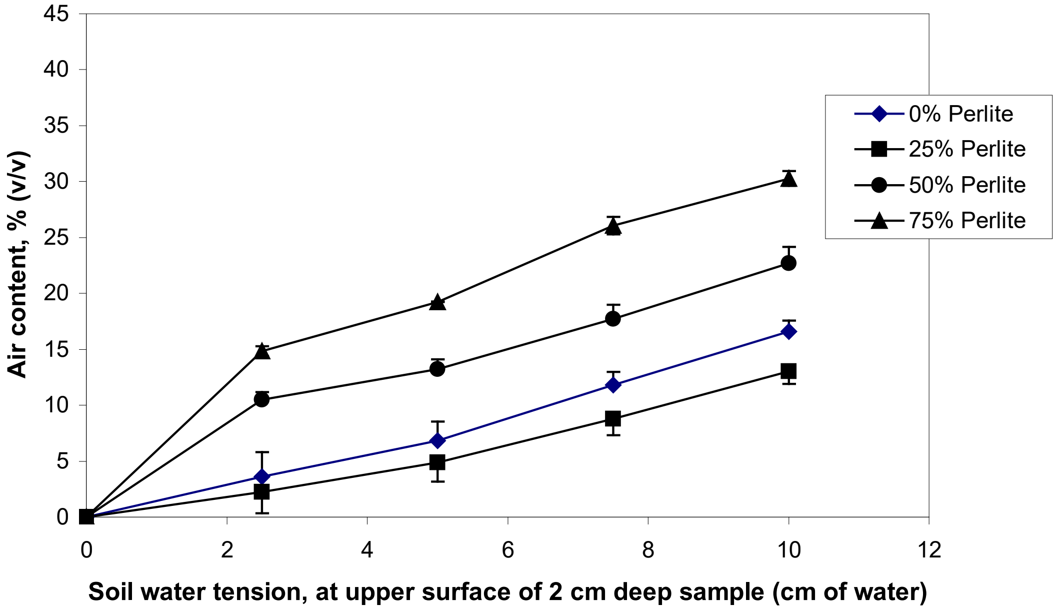
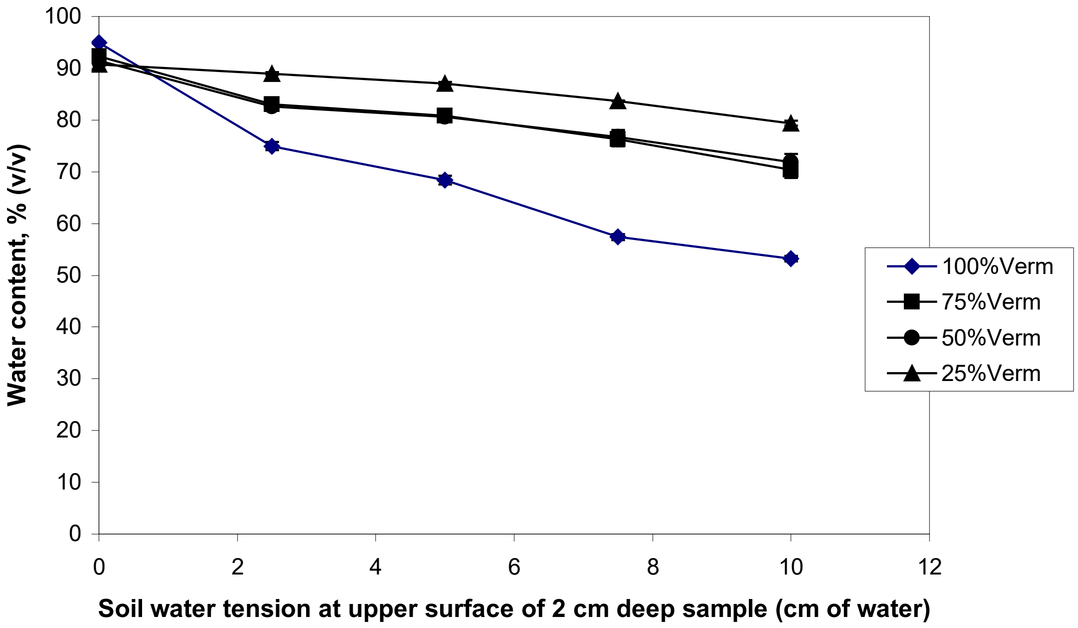


Figure 10. Water release curve (upper) and the air contents derived from them (lower), using an estimate of total porosity derived from the particle density and bulk density. The data are for mixtures of **fine peat** (Shamrock fine grade sphagnum peat) and **coarse perlite** (Silvaperl standard grade).



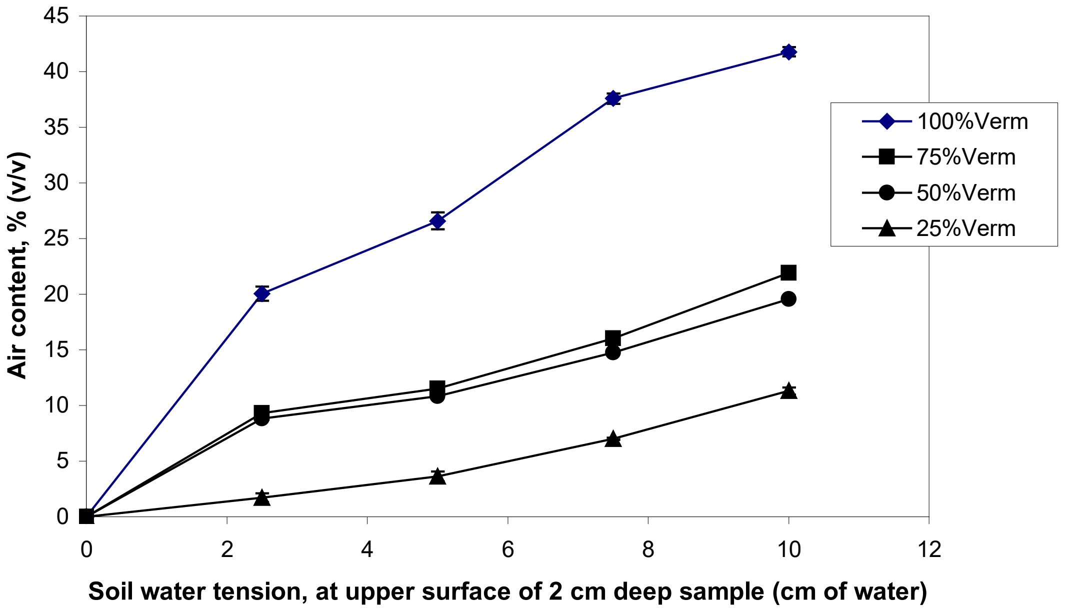
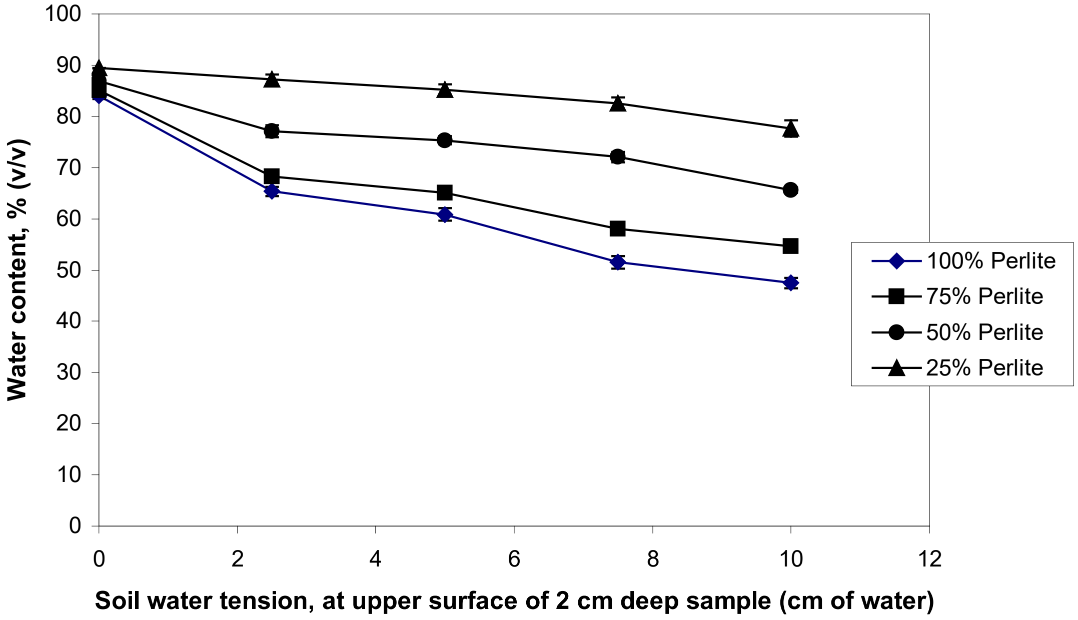


Figure 11. Water release curve (upper) and the air contents derived from them (lower), using an estimate of total porosity derived from the particle density and bulk density. The data are for mixtures of **fine peat** (Shamrock fine grade sphagnum peat) and **medium grade vermiculite** (Pro Gro).



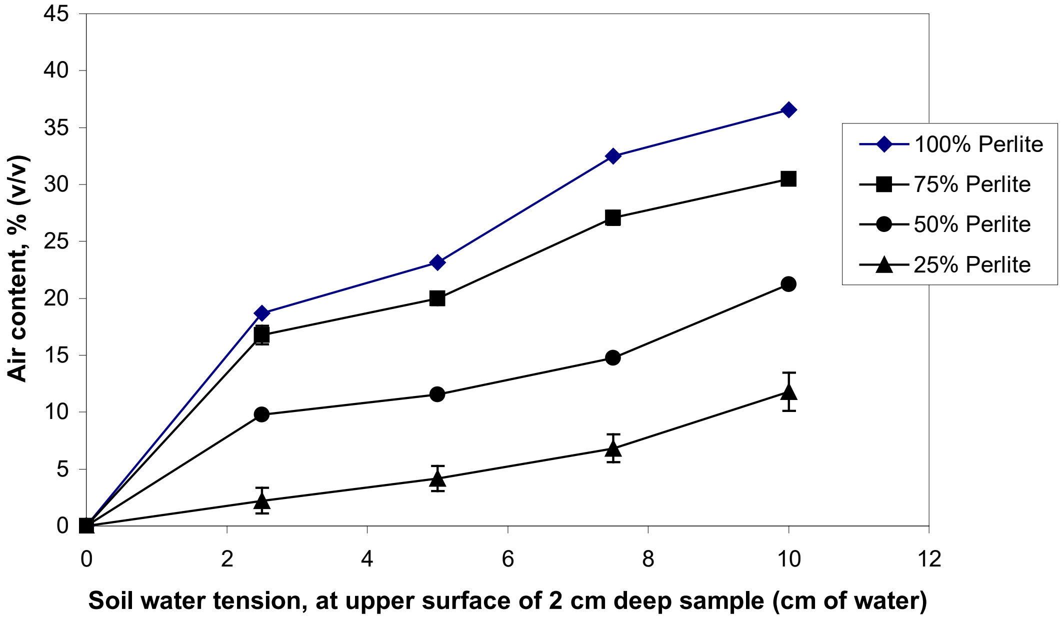
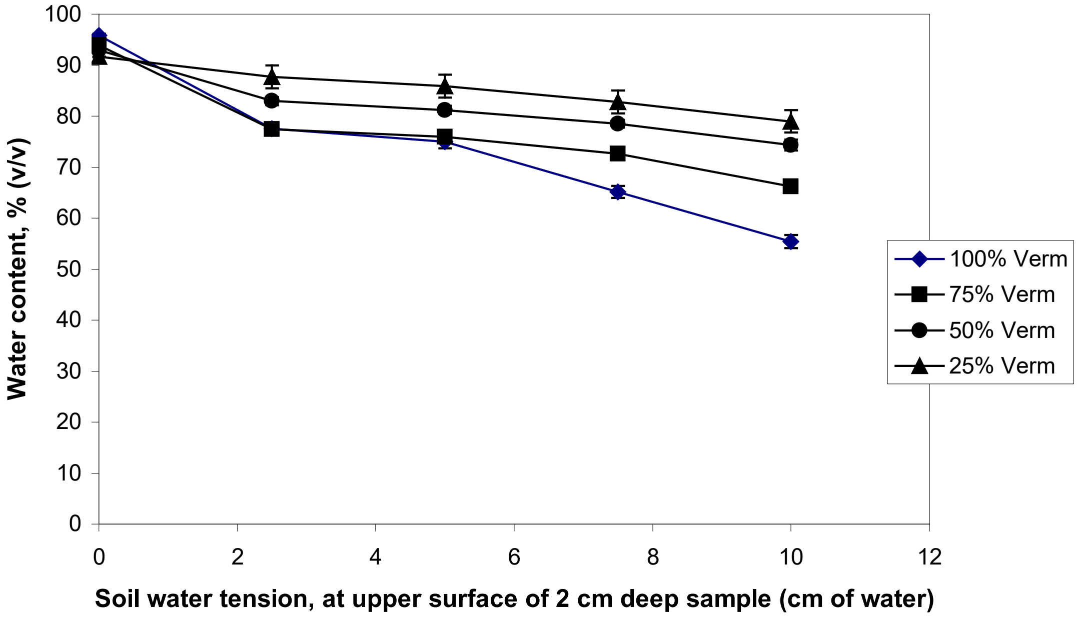


Figure 12. Water release curve (upper) and the air contents derived from them (lower), using an estimate of total porosity derived from the particle density and bulk density. The data are for mixtures of **fine peat** (Shamrock fine grade sphagnum peat) and **fine perlite** (Silvaperl fine grade).



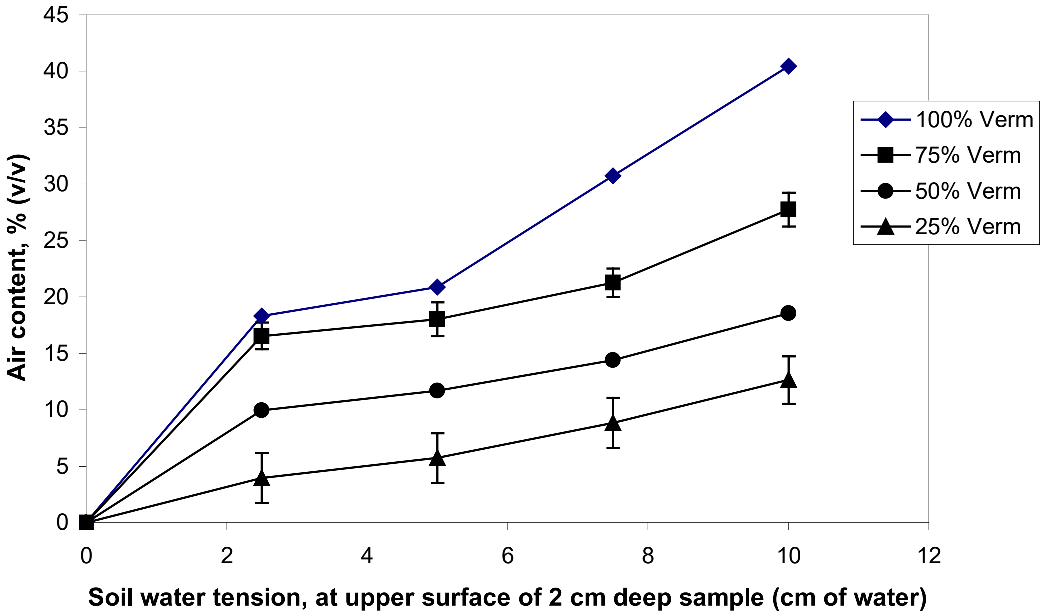
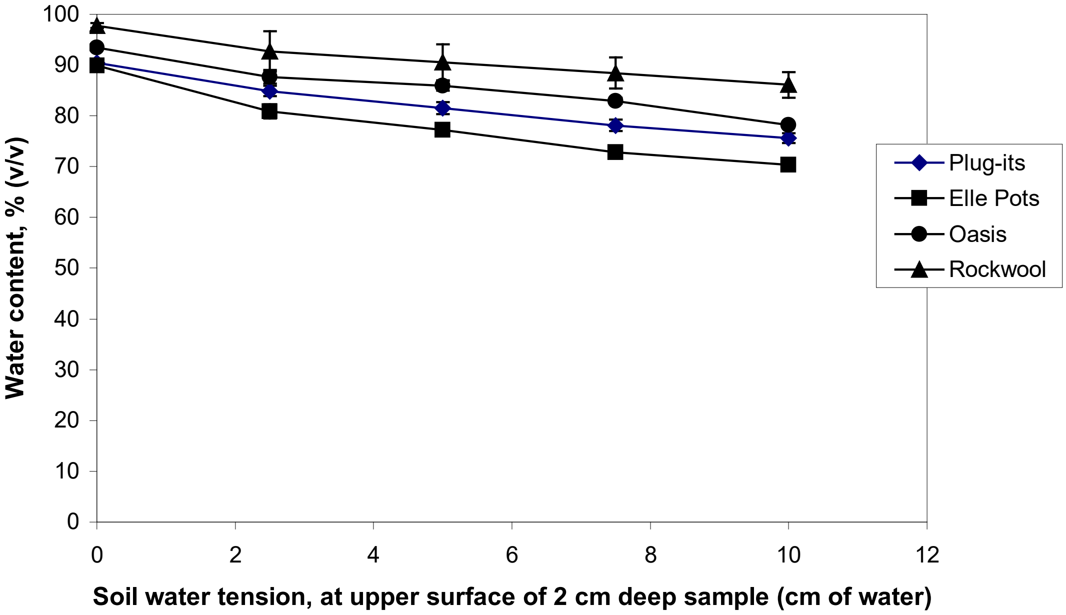


Figure 13. Water release curve (upper) and the air contents derived from them (lower), using an estimate of total porosity derived from the particle density and bulk density. The data are for mixtures of **fine peat** (Shamrock fine grade sphagnum peat) and **fine vermiculite** (Pro Gro).



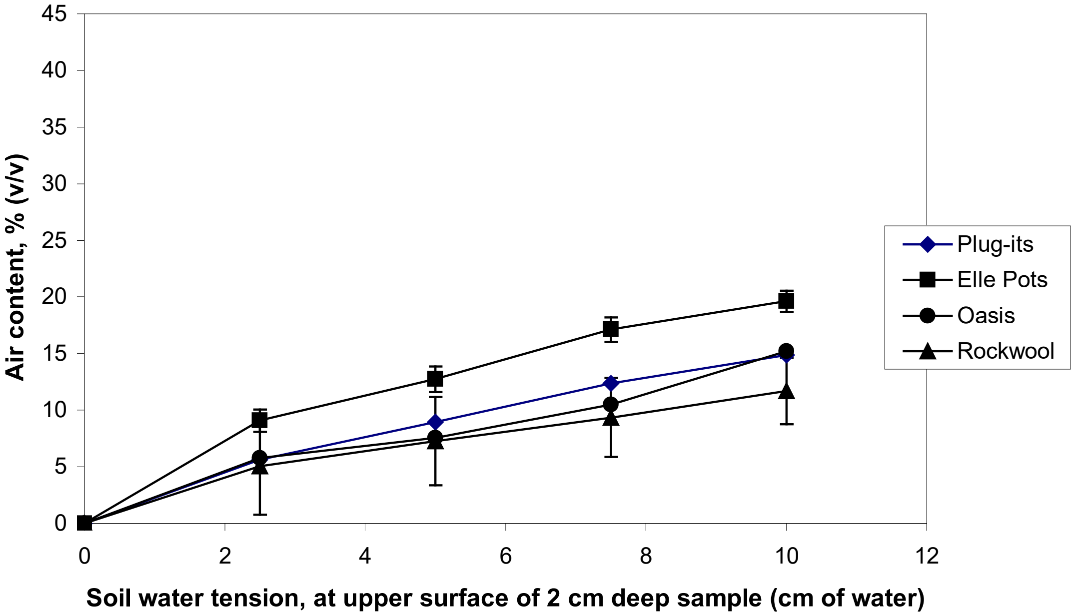
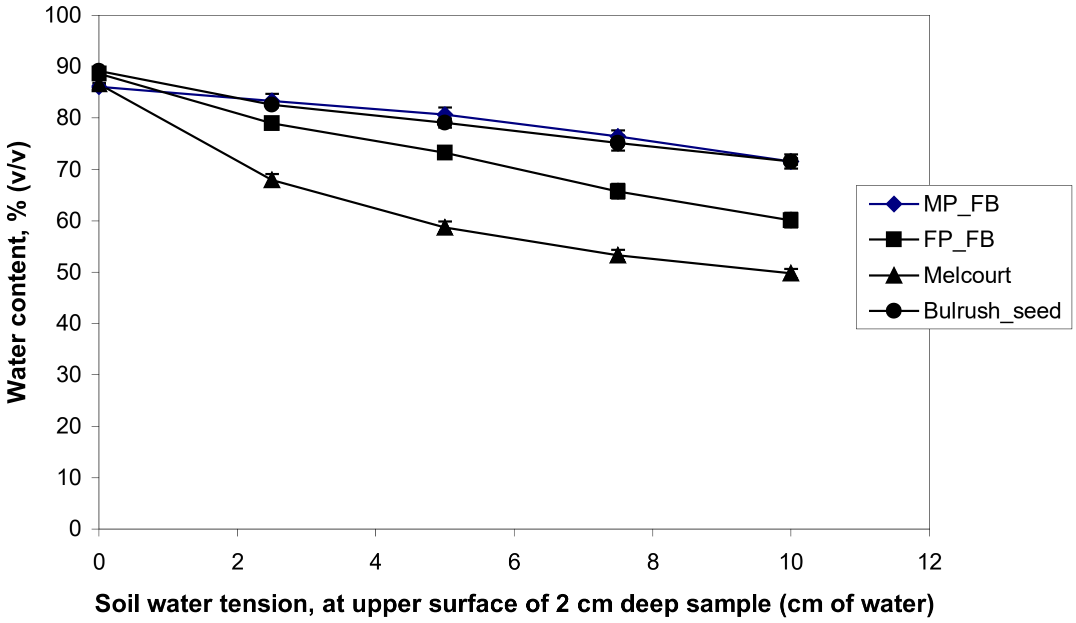


Figure 14. Water release curve (upper) and the air contents derived from them (lower), using an estimate of total porosity derived from the particle density and bulk density. The data are for various commercially available ‘plugs’. The **Plug-Its** and **Elle Pots** were broken down and the mix was repacked to a similar density as a 2 cm layer in a sample holder. For the **Oasis** and **Rockwool**, a 2 cm section was cut from the block and a ring of PVC insulating tape was applied around the vertical sides to aid repeated handling.



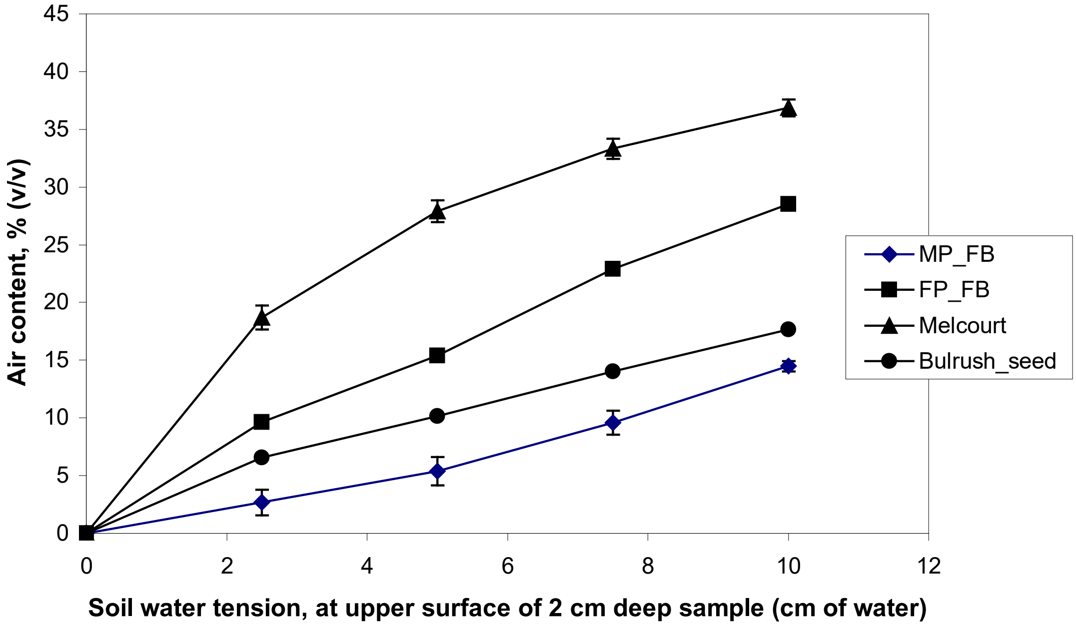


Figure 15. Water release curve (upper) and the air contents derived from them (lower), using an estimate of total porosity derived from the particle density and bulk density. The data are for **three different mixtures of peat and bark** (Shamrock sphagnum peat, fine grade [FP] or medium grade [MP]) and matured pine bark (Cambark fine grade, FB) or Melcourt Propagation Bark (Melcourt). In addition, this group included Bulrush seed propagation compost, ('**Bulrush_seed**', based on **peat with a small proportion of vermiculite**).