Project title:	**Hardy nursery stock:** **Examination of techniques to raise humidity in mist houses**
Project number	**HNS 76**
Project leader	**Dr R.S. Harrison-Murray**
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ed has already been filled with sand. The final level of sand just covered the PVC pipe.

The results and conclusions in this report are based on an investigation conducted over one year. The conditions under which the experiment was carried out and the results obtained have been reported with detail and accuracy. However because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results especially if they are used as the basis for commercial product recommendations.

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PRACTICAL SECTION FOR GROWERS

This project is investigating ways in which nurserymen can achieve the sort of environmental conditions required for the cuttings of stress-sensitive species which require maximum environmental support to achieve high rooting percentage (e.g. soft cuttings of *Garrya elliptica* 'James Roof' or large cuttings of *Cotinus coggygria* 'Royal Purple' suitable for 'designer liner' production).

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.
- Increased ability to respond to a sharp rise in demand when a particular plant becomes fashionable.

Background and objectives

The purpose of this project is to provide reliable information on how to achieve optimal environmental conditions for stress sensitive cuttings. Such cuttings need a combination of generous leaf wetting and an atmosphere that is almost saturated with water vapour (i.e. 100% rh). A good fog system can achieve this but in practice most growers have found it hard to manage and it is consequently not in widespread use. Polythene-enclosed mist can achieve almost as good results but tends to suffer from excessively high temperatures. Furthermore, it is not favoured by many growers because polythene covers over each mist bed makes it difficult to monitor the condition of cuttings.

This project is investigating a number of alternative approaches, including the scaling up polythene-enclosed mist whilst learning how to avoid the excessive temperatures referred to above.

Summary of results and conclusions

The first stage of the project examined the factors determining the temperature and humidity achieved in a well-sealed polythene enclosure. The results showed that there was no reason why enclosed mist could not be scaled up to a large walk-in enclosure that would be acceptable to nurserymen. Such a facility has now been constructed and evaluated. In rooting trials it has been compared with a highly successful ventilated fog house and a conventional open mist system. Environmental conditions have been monitored and compared with many other experimental enclosures to gain insights into the factors controlling temperatures in well-sealed enclosures. Particular attention has focussed on the effect of the 'External to Floor Area Ratio' (EFAR), and the importance of thermal buffering by the sandbed or other material on which the propagation trays are stood.

The conclusions are summarised below:

- Polythene-enclosed mist can be scaled up sufficiently to make it attractive to commercial nurseries
- Humidity in the large-scale enclosed mist system was indistinguishable from that in a good fog system i.e. 100% rh
- If only part of the enclosure was misted then the high humidity was localised to the misted area. Also, if the interval between mist bursts is too long then humidity can drop between bursts.
- For the most sensitive subjects, fog was more supportive than enclosed mist. For example, in fog, *Garrya elliptica* 'James Roof' continued to elongate and achieved 100% rooting in four weeks; in enclosed mist, most cuttings did not elongate and only 67% had rooted after 8 weeks.
- What makes fog more supportive than enclosed mist was not identified. It may be due to the circulation of water droplets in the air underneath the leaves. Such water would help maintain humidity saturation close to the under-surface of the leaves as the air warms up.
- The addition of small quantities of fine droplet fog, such as can be produced ultrasonically, may allow that additional support to be reproduced in a mist + fog system. Since ultrasonic foggers have a low output it is envisaged that the mist will

provide the main support system during stressful conditions, which are usually confined to quite a short period in the middle of the day.

- Preliminary tests indicate that such a system will allow limited ventilation of the enclosure without the rh falling substantially below 100%.
- The tendency for temperature lift to increase as EFAR decreases was confirmed but, in proportional terms, the change in temperature lift was less than half the change in EFAR.
- Under-bed insulation tends to increase temperature lift in enclosures by reducing the loss of heat into the ground.
- The increase in temperature caused by under-bed insulation depends on the heat storage capacity of the material above the insulation. A layer of concrete or sand can store a much of the heat received in one day, thereby limiting the maximum temperature reached.
- Operating on benches and/or with a thin layer of capillary matting would provide minimal thermal buffering, leading to higher maximum temperatures.
- Heat loss by radiation is not likely to account for much of the heat loss from polythene enclosures. Both water and modern UV-stabilised polythenes such as Polytherm AF absorb strongly in the infrared waveband.

Action points for growers

It is now possible to make tentative recommendations for growers interested in exploring the use of a large-scale enclosed-mist to provide a more supportive environment for stress-sensitive or 'designer-liner' cuttings:

- Design a robust enclosure and ensure that it is well sealed. Even a small opening can dramatically reduce humidity.
- Ensure that entire floor area, including access paths, is kept wet by occasionally hosing down areas that are non-misted.
- Recognise that heavy condensation on the polythene provides no guarantee that humidity is high around the cuttings.
- External reflective shading is essential to minimise heat load. It is believed to be most effective if supported away from the polythene of the enclosure so that each receives the maximum airflow to keep it cool.

- Underbed insulation or propagation on benches rather than floor-level beds will tend to lead to higher daytime temperatures.
- Use at least 5 cm of sand beneath the propagation trays. This will ensure that the rooting medium is well drained even during frequent misting and will also act as a thermal buffer that will limit maximum temperatures even if there is underbed insulation.
- Remember that not all subjects will show any benefit of a more supportive environment. It is mainly subjects which are considered 'difficult' that are likely to show substantial benefit. Large 'designer liner' cuttings are likely to benefit, not only in terms of rooting but also subsequent growth and establishment.

Anticipated practical and financial benefits

This research should allow growers to exploit existing knowledge on the benefits of a highly supportive rooting environment for more difficult cuttings by making it possible for them to create, on a commercial scale, the sort of environments that have proved highly effective at a research level. In particular, it will benefit growers attempting to use larger than normal cuttings to shorten the time from cutting to saleable plant (i.e. the designer liner concept)

Cost benefit analysis

Estimate of number of cuttings that 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 improvement in propagation environment could reduce losses by 5% (equivalent to increasing average rooting percentage by just 1%) then the value of lost production saved

= 5% of £10M

= £500K

Total cost of the project is approximately £120K, therefore the cost of the project will be recouped in less than a year.

Over a ten year period, the ratio of benefit to total cost

= 500 x 10 / 120 = 41.7

SCIENCE SECTION

Introduction

Purpose

This project aims to meet the need for reliable information on how the design of propagation facilities influences the environment created and thus how well cuttings are protected from two stress factors: water stress and high temperature. Ventilated wet fog, such as the Agritech house at HRI-East Malling, achieves a suitable environment on a research scale, but for many reasons is not appropriate for most nurseries. Polythene enclosed mist often gives similar results but is prone to very high temperatures. This project is investigating alternative approaches and is designed to deliver:

- a set of **practical rules or guidelines** for improving an existing mist system or for designing a new propagation house from scratch.
- identification and explanation of the underlying principles (which apply equally to every type of facility from a fog system to a simple polythene tent).
- insights into the effect of the structure, shape, and size of a propagation unit on the problem of high temperature associated with restricting ventilation to raise humidity
- evaluation of the relative merits of three main alternatives:
  - polythene enclosed mist
  - ventilated mist with background fog to raise humidity of incoming air
  - ventilated mist with some form of passive humidification such as moist pads or curtains

Basic requirements of the environment for stress-sensitive cuttings

Leafy cuttings have a fundamental weak point: to be effective at photosynthesis their leaves inevitably tend to lose water yet, in the absence of roots their capacity for water uptake is severely restricted. However, the nurseryman can do much to mitigate this problem by creating an environment in which evaporative demand is minimised while still being favourable for photosynthesis. Earlier HDC-funded work showed that successful rooting of many difficult subjects (e.g. *Garrya elliptica* 'James Roof' and *Cotinus coggygria* 'Royal Purple') depends on the combination of generous wetting and high humidity, together with appropriate shading (Harrison-Murray *et al.*, 1993 and

1998). In practice, this is a difficult combination to achieve. In particular, reducing ventilation to raise humidity tends to lead to excessively high temperatures (e.g. air temperatures > 40 °C), forcing the propagator to ventilate on days when fine weather make damaging water stress most likely. What is needed now is reliable information on how the design of propagation facilities influences the environment achieved. In particular, the following questions need to be answered:

- What factors control the temperature which develops in polythene enclosures (such as are used in polythene-enclosed mist) - e.g. shape, size, how well sealed, air movement around?
- What factors control the humidity around cuttings in polythene enclosures, and are there important gradients in conditions?
- Are there any fundamental reasons why polythene-enclosed mist has traditionally been operated with small covers over individual mist lines rather than more conveniently large walk-in enclosures?
- Can the theoretical advantage of the combination of fog (for humidification of incoming air) and mist (for uniform leaf wetting) be realised in practice?

General background

Sizes of propagation facilities vary greatly among nurseries, and the types of structure vary from simple polythene tunnels to large climate-controlled glasshouses. Furthermore, in view of the large number of more robust species which can tolerate relatively stressful conditions (Harrison-Murray *et al.*, 1998), generally it will make sense to upgrade only part of the house, to be used for the sensitive subjects. By identifying the principles that are operating, the aim is to produce rules of design that can be applied to any system.

This work addresses a number of the HDC's stated objectives, particularly the exploitation and development of new opportunities. It will help unlock the proven benefits of highly supportive propagation environments and thus contribute to exploitation of the 'designer-liner' concept (HNS 69). That concept calls for the use of larger than normal cuttings that tend to require a more 'supportive' rooting environment.

Previous work in this project

The first stage of the project, described in the first annual report (Harrison-Murray, 2001), examined the effect of the size and shape of a polythene enclosure on the temperature rise which occurs within it. This is a major problem associated with raising humidity for cuttings and is thus of central importance. Enclosures of different shapes and size were designed to test the hypothesis that, for a given set of external conditions (mainly radiation and wind speed) the temperature lift would increase as the ratio of external surface area to floor area (EFAR) decreased. The results supported this hypothesis but the effect was much smaller than predicted on the basis of a simple theoretical model.

This result had important practical implications. The use of polythene enclosures to restrict ventilation and raise humidity has traditionally been done on a small scale. For example, when mist has been enclosed in a polythene tent it has usually been a single mist line that has been enclosed. Such small-scale enclosures restrict access and make it difficult to inspect the cuttings regularly so that they are unacceptable on a modern commercial nursery. However, in any attempt to scale up such enclosures, the width and breadth increase more than the height with the result that EFAR decreases. The earlier results showed that the increase the temperature lift associated with the decrease in EFAR can be much less than predicted on first principles. This encouraged the view that large walk-in polythene enclosed mist systems could be a realistic practical proposition. It was, therefore, decided to put this concept to the test in the second part of the project.

From the earlier results, it was not clear why the effect of EFAR was smaller than expected but two possibilities emerged. Firstly, that the experiment had been conducted on a deep drained sand bed without any thermal insulation to increase the efficiency of bottom heat. Heat flux measurements showed that a substantial proportion of the incoming energy flowed into the soil thereby limiting the rise in temperature. While most of the heat flowing into the soil during the day flowed back out again at night, this heat storage had a buffering effect which limited the maximum temperature achieved during the day. Since most, if not all, commercial propagation houses have some insulation beneath the beds, it was clearly important to take this into account in the practical trial of large-scale polythene-enclosed mist.

The second factor that was highlighted in the previous report was long-wave radiation exchange. Emission of long wave radiation from the ground to the atmosphere and beyond represents a means of energy loss that is not influenced by the external surface area, unlike energy loss by conduction and convection. However, the extent to which it actually contributes to the energy balance and thus to temperature within the enclosure does not depend simply on the absolute amount being radiated by the ground. Instead it depends on the balance between upward radiation from the ground and downward radiation from the surroundings. In an enclosure, the amount of downward radiation depends in part on a property of the cladding material known as the emissivity. Polythene is a poor emitter of long wave radiation and has a low emissivity but water has a high emissivity. It therefore seemed probable that condensation on the polythene of the enclosure would result in a similar amount of downward long wave radiation as upward and therefore almost no net loss of energy from the enclosure by this route. Nonetheless, it was decided to seek experimental confirmation of this, particularly since it might be possible to influence the amount and distribution of condensation by the use of double skinning or bubble wrap in construction of the enclosure.

Objectives of phase two

The objectives of this phase of the work were:

- To design and construct a walk-in polythene enclosed mist system on a large enough scale to be relevant to commercial nurseries.
- To compare rooting in this system with that in a ventilated fog system (the 'gold' standard) and a conventional mist system (industry standard control), using a representative selection of species.
- To determine how temperature lift in the new facility compares with that in the smaller model enclosures used earlier.
- To determine how effectively the polythene enclosure raises humidity around the cuttings compared with a fog system.
- To further investigate what determines the temperatures reached in polythene enclosed systems, particularly the importance of insulation in the floor and the absorption of long wave radiation by condensation on the polythene.

Materials and Methods

Design and construction of the large-scale polythene-enclosed mist system

Twin-span polythene house

The large-scale polythene enclosed mist system was constructed inside a new twin-span polythene house. The house was a HLX660, 12.8 x 19.5 m (Clovis Lande Associates Ltd, East Peckham, Kent) fitted with high level vents on both sides, sliding doors on the north end and vent panels on the south end. It was clad in Visqueen Polytherm AF.

The propagation bed

In the eastern half of the house, a 16 x 4.5 m propagation bed was constructed with 6 individually controllable mist and bottom heat systems (Figure 1). The bed consisted of 5 –7 cm layer of fine sand which was thermally insulated from the subsoil with 50 mm of expanded polystyrene sandwiched between two layers of polythene. At intervals of 2.4 m, drains ran across the bed into a gravel filled drain which also drained the adjacent path. Corrugated plastic land drain (ca. 50mm diameter), wrapped with capillary matting to keep out the fine sand, was used for the drains across the bed. They were laid in channels, created by leaving gaps between adjacent insulation panels, where the depth of the sand was about 10 cm. Thus the hydraulic suction created by the bed is about 10 cm of water, despite the sand being only 5 cm thick over most of the area. Figure 2 shows a section through one of the drains which illustrates some of these points.

The polythene - enclosed mist system covered the southern half of the propagation bed (Figure 1). In the first phase of the project, the need for a well sealed structure was established. Therefore, the aim was a robust and well-sealed structure with an expected lifespan of a few years. A number of alternatives were investigated and some different construction methods have been incorporated into the structure for long-term evaluation.

Supporting framework

The polythene enclosure is supported from a rectangular framework, 8 x 4.5m, made from galvanised steel 'channel'. Such U-shaped channel, or trunking, is widely used for supporting industrial electrical gear and cables. The channel is 41.3 x 41.3 mm in cross section and is obtainable in 6 m lengths for about £20 (e.g. MainStrut MC400, from Edmundson Electrical Ltd, Maidstone). The wide range of fittings available makes it a very versatile system for constructing robust framework in a greenhouse. The cost is generally comparable with that of galvanised tube but it is generally easier to use. For situations where corrosion will be a problem (e.g. in contact with damp sand) a UV stable GRP plastic version is available (from Mita (UK) Ltd, Bodelwyddan Business Park, Bodelwyddan, Denbighshire, LL185SX).

In our case, the steel framework is fixed to the horizontal members of the tunnel structure (variously referred to as 'roof cross bracing' or 'crop supports') but it could easily be free standing on legs or suspended from above on wires. In that case, it would be necessary to fit bracing pieces.

The polythene chamber

The polythene is 180 μm thick Polytherm AF, as used for cladding tunnels. It is suspended from UV-resistant black nylon monofilament, running alongside the steel frame and tensioned from it. In this way, the framework is outside the high humidity chamber to avoid corrosion. The four walls and roof are made from separate pieces with 10 to 20 cm excess to allow for effective joins between adjacent panels. Joins between roof and walls are made by folding the two pieces together and then clipping to the nylon monofil with miniature plastic pegs. Joins between the walls are clipped with 'Bulldog' or similar clips.

The roof was tensioned by inserting ties between the steel framework and the monofil to which the polythene has been clipped. The ties were either stiff electrical wire or plastic cable ties. Inserting them made a small hole in the polythene but this is not enough to cause significant leakage. By shortening the ties it was possible to make the roof polythene very taught. Sagging of the roof was further counteracted by tensioned wires (2.5mm galvanised) running across the framework.

A number of different means of tensioning the walls was tested. The most effective was to fit a lightweight aluminium grip-strip ('V-Grip', obtainable from Clovis Lande) about 30 cm above floor level with tensioning ties from this strip to heavy weights on the floor (e.g. concrete fence post or plastic drainpipe filled with gravel). The same system can be used to fix the upper edge to the steel framework but it is simpler to fix the upper edge to nylon monofil tensioned alongside the steel framework.

In the experimental system, access was via a opening in the eastern wall which was closed with clips as described above. In a commercial situation, a convenient access door would be essential, even if some leakage around it would be inevitable.

The mist system

There are six mist lines within the enclosure, configured as three individually controllable beds. The lines are supported from tensioned galvanised steel wire at about 10 cm below the roof of the chamber. The lines were 16mm PVC pipe fitted with 4 MAA-32 Amberlite nozzles, with antidrip valves, and with a stopcock at the end to facilitate removal of air.

Mist operation was controlled by Type LT1 controllers obtained from Access Irrigation Ltd, Crick, Northampton, NN6 7XS using a 'wet leaf' sensor (i.e. wetness sensor) or, by disconnecting the sensor, on timer alone.

Sand heating

Electrical soil heating is provided by Macpenny soil heating cables (1 kW, 81m) controlled by Eliwell EWTR 920 temperature controllers using platinum resistance sensors. The heating wires were installed 5cm below the sand surface using heavy duty PVC pipe as a former to ensure even spacing (see plate 17 in the Appendix).

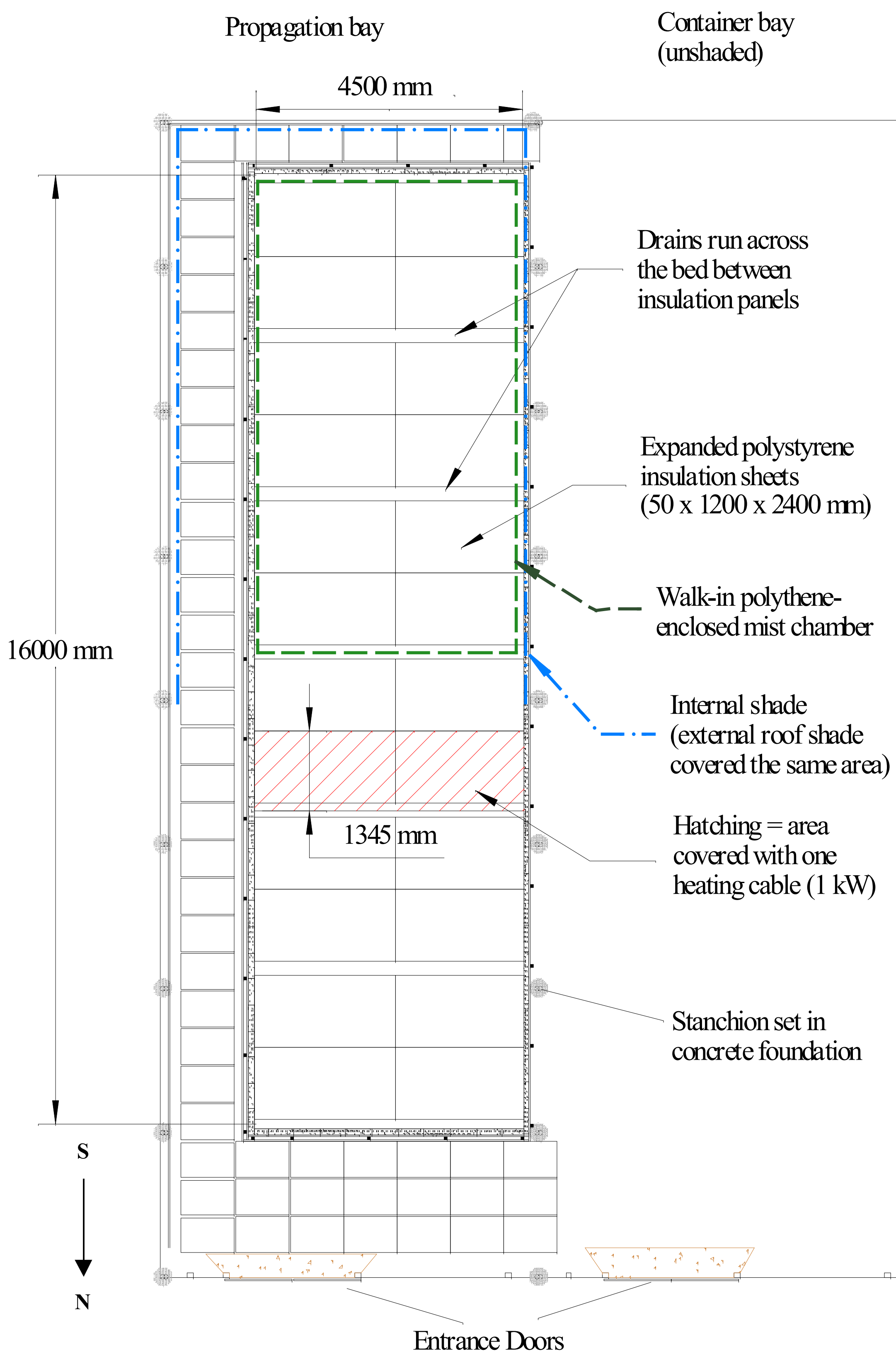

Figure 1. Plan of the twin-span polythene house, the propagation bed and the walk-in enclosed mist system

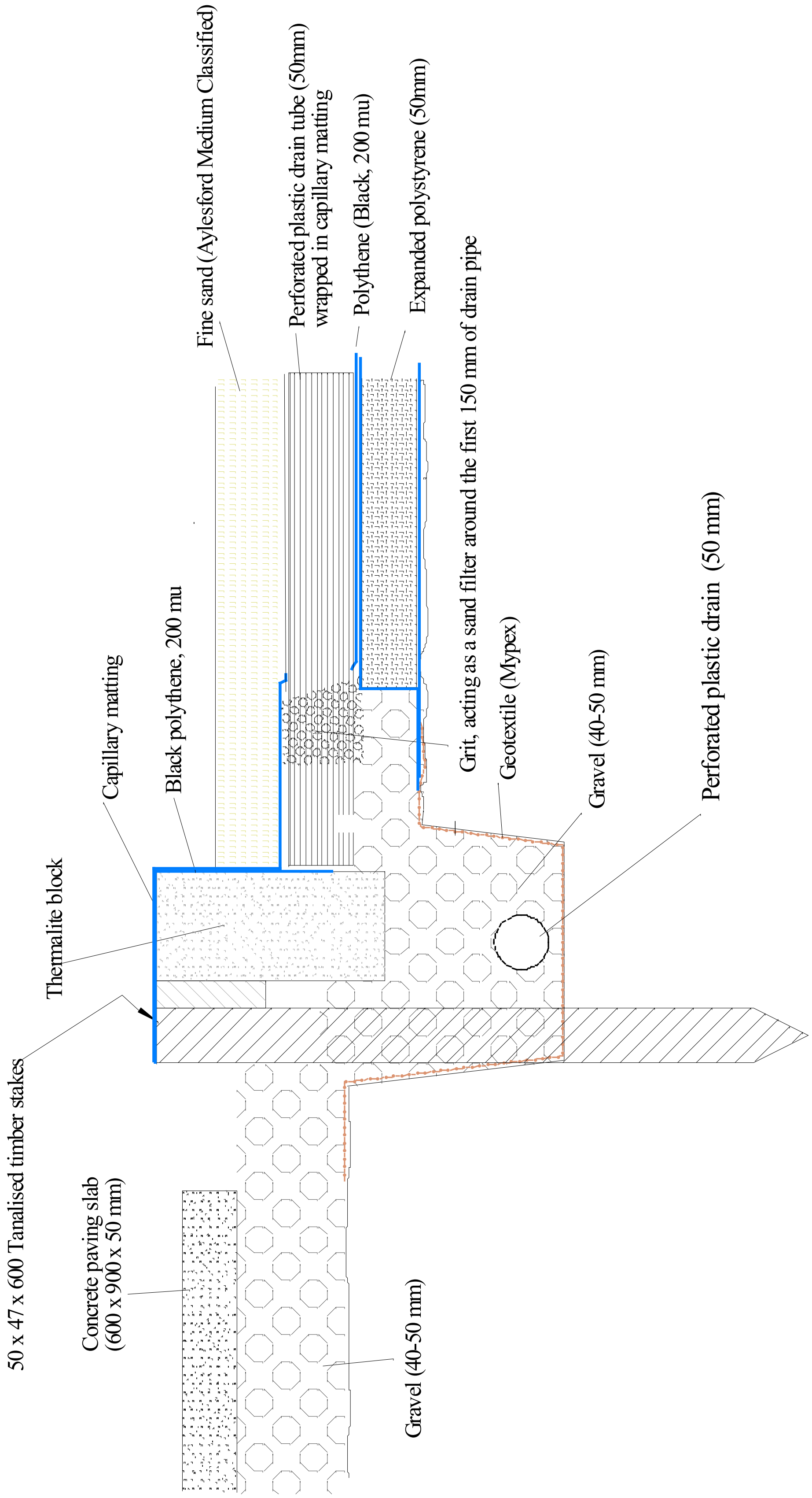

Figure 2. Section through the propagation bed at the junction of a branch drain with the main drain. Notice that insulation was continued beneath the drainage channels.

Rooting experiments

Plant material – main subjects

i. *Garrya elliptica* 'James Roof'

Collected on 17 July, 2001, from well established field grown plants which are pruned annually in winter with moderate severity.
Apical cuttings, 10 -12 cm long, dipped for 5 s to a depth of 8 mm in a solution of 1.25 g L^{-1} of IBA in a 50:50 (v/v) mixture of acetone and water.

ii. *Corylus maxima* 'Purpurea'

Collected on 17 July, 2001, from well established field grown plants which are hard-pruned annually in winter.
Apical cuttings bearing one fully expanded leaf were prepared and dipped for 5 s to a depth of 8 mm in a solution of 1.25 g L^{-1} of IBA in a 50:50 (v/v) mixture of acetone and water.

iii. *Cornus alba* 'Elegantissima'

Collected on 18 July, 2001, from young field grown plants which were not growing very strongly. Three quarters of harvested shoots bore terminal flowers which were pinched out, while the remainder were kept as intact apical cuttings.
Both types of shoots were prepared to two pairs of fully expanded leaves (giving a length of 15-20cm). They were dipped for 5 s to a depth of 8 mm in a solution of 1.25 g $L^{-1}$of IBA in a 50:50 (v/v) mixture of acetone and water.

iv. *Cotinus coggygria* 'Royal Purple' (Clone EM84)

Collected on 18 July, 2001, from well established field grown plants which are hard-pruned annually in winter.
Apical cuttings, about 15 cm long, were prepared and dipped for 5 s to a depth of 8 mm in a solution of 1.25 g L^{-1} of IBA in a 50:50 (v/v) mixture of acetone and water.

Plant material - additional subjects at reduced replication

v. *Acer platanoides* 'Drummondii'

Collected on 25 July, 2001, from well established stock plants, pruned annually in winter.
Apical cuttings, 15-20 cm long, with one fully expanded leaf were prepared and dipped for 5 s to a depth of 8 mm in a solution of 1.25 g L^{-1} of IBA in a 50:50 (v/v) mixture of acetone and water.

vi. *Acer platanoides* 'Crimson King'

Collected on 25 July, 2001, from well established stock plants, pruned annually in winter.
Apical cuttings, 15-20 cm long, with one fully expanded leaf were prepared and dipped for 5 s to a depth of 8 mm in a solution of 1.25 g L^{-1} of IBA in a 50:50 (v/v) mixture of acetone and water.

vii. Magnolia soulangiana

Collected on 25 July, 2001, from well established stock plants, pruned annually in winter.
Apical cuttings were prepared to two different lengths:

- 'Short', about 15 cm long, consisting of 2 internodes with one well expanded leaf
- 'Long', about 30 cm long, consisting of 4 internodes bearing 3 well expanded leaves.

Cuttings were dipped for 5 s to a depth of 8 mm in a solution of 1.25 g L^{-1} of IBA in a 50:50 (v/v) mixture of acetone and water.
The use of longer than normal cuttings of Magnolia can lead to more rapid production of high quality liners, an example of the 'designer liner' concept (Cameron and Harrison-Murray, 1998).

viii. Pre-branched cuttings of *Cotinus coggygria* 'Royal Purple'

Collected on 7 August, 2001 from well established stock plants in the field. The branches had developed following earlier collection of cuttings and had been allowed to grow to up to 40 cm, much longer than is suitable for 'designer liner' production. The main stem was thick and woody. As such, these cuttings were expected to be hard-to-root and sensitive to environment. The number of branches varied between 2 and 4 and this variation was distributed between the different rooting environments. Branches were trimmed to about 10 cm. Cuttings were dipped in a solution of 1.25 g L^{-1} of IBA in a 50:50 (v/v) mixture of acetone and water.

Rooting media

Peat:Bark mix (50:50 Shamrock medium grade peat : Cambark fine grade bark) in QP 96 propagation trays (PG Horticulture) leaving alternate cells empty.

Records of cutting responses

To record visible evidence of stress, cuttings were regularly inspected and photographs taken over the course of the rooting period.

Rooting of the main subjects was recorded on two occasions. Half were examined after 4 weeks and half after 8 weeks. The additional subjects were recorded after 8 weeks only. The quality of rooting was assessed by measuring the length and diameter of the root ball as it came out of the propagation tray.

On unrooted cuttings the extent of any callus development and/or basal necrosis was measured.

Propagation environments

The propagation environments were

'Fog'	a 'ventilated fog' house based on a spinning nozzle fogger
'Enclosed mist' (EM)	large-scale polythene-enclosed mist system inside a well--ventilated polythene house (Twin-span), as described above
'Open mist'(OM)	single mist bed surrounded by a polythene wall in a well--ventilated polythene tunnel (Tunnel M)

These are described in more detail below:

i. Fog

A spinning nozzle fogger operating in a 7 x 19.5 m polytunnel, well sealed along edges and end panels, created a combination of high humidity and leaf wetting that varied in a predictable way with distance from the fogger. The house was shaded with external reflective shade (Ludvig Svensson OLS 60) fixed over the outside of the tunnel, in contact with the polythene.

The fogger was built in the HRI workshops to a substantially modified version of the design of the Agritech machine, which is no longer available. It has a high output (up to 150 L h-1) but produces a wide range of droplet sizes. Much of the output is relatively large droplets which settle out rapidly (i.e. mist rather than fog) but this is mixed with sufficient fine fog droplets to keep the atmosphere visibly foggy for periods of up to an hour without the machine running. The machine incorporates a powerful fan to help distribute the fog.

An important feature of the facility is that the high output makes it possible to use forced ventilation to limit temperature build up, hence the term 'ventilated fog'. The fogger is positioned in line with air intake louvres through which fresh air is drawn when an extract fan operates. In this way, fog is injected into the incoming air stream and the air is humidified before it reaches the cuttings.

There are three aspects to the control system. Firstly, the fogger runs for one minute every hour to provide some humidification under all conditions. Secondly, it runs whenever evaporative demand measured by evapo-sensor (see glossary) exceeds a set point (normally 1° C wet leaf depression). Finally, it runs whenever the exhaust fan operated, i.e. if air temperature exceeds 32° C.

The result is a combination of leaf wetting and high humidity that, for many years, has proved successful in rooting many difficult-to-root subjects, particularly those prone to wilting and less obvious desiccation stress (e.g. *Cotinus coggygria* and *Garrya elliptica*).

ii. Enclosed Mist (EM)

8 x 4.5 m walk-in enclosure with overhead mist lines controlled by wetness sensor (i.e. 'electronic leaf'). The enclosure was constructed inside a 19.5 x 12.8 m twin-span

polythene house which was well ventilated. The relevant part of the house was shaded with external reflective shade over the roof combined with internal reflective shade walls (Ludvig Svensson OLS 60 on the roof and ULS16F internally). See earlier section on 'Design and construction of polythene enclosed mist system' for more details.

iii. Open mist (OM)

3 x 1.5 m mist bed in an well ventilated polythene tunnel (Clovis Lande HLX, 14 x 5.5 m, with adjustable low level side vents). Around the bed a 1 m high polythene curtain restricted draughts and thereby made conditions more uniform across the bed. A single mist line mounted at a height of 1.3 m was controlled by wetness sensor (Access Irrigation 'Mist and Wean' controller). The relevant part of the tunnel was shaded external reflective shade (Ludvig Svensson OLS 60) in contact with the roof.

Monitoring environmental conditions

The sensors were as follows:

- Six miniature psychrometers (type WVU/2 with PT100 thermometers, Delta-T Devices, Cambridge). These miniature units are fan-ventilated and double screened against radiation effects, but are unfortunately no longer manufactured. They measure air temperature and humidity (which can be expressed as relative humidity (rh), vapour pressure deficit (vpd, a measure of the drying power of the air), and water vapour partial pressure (vp, which serves as a measure of the concentration of water vapour). They were therefore of central importance.

  This project requires measurement of humidity close to saturation, for which the psychrometer principle (i.e. force ventilated wet and dry bulb) is the only appropriate method. It also requires a high level of accuracy to detect small differences in humidity and immunity from distortion due to radiative warming. To help achieve this, the radiation shielding was further improved for the second phase by fitting an inverted aluminium plate as an additional radiation shield over the top of the instruments, which is visible in some of the photographs (Appendix)

- 3 'Datahogs' logging air temperature and humidity and radiation (using pyranometer sensors) (Skye Instruments, Unit 32, Ddole Industrial Estate, Llandrindod Wells, Powys, LD1 6DF).
- 14 thermistors for soil temperatures installed as pairs at depths of 5 and 35 mm depth to provide an estimate of heat flux into the soil. To ensure precise placement, the probes were mounted in a spacer consisting of a nylon tube drilled across its diameter at the correct separation and with a wire marker for the sand surface
- Met station (PAR, temperature, humidity and wind speed)
- Miniature thermocouples constructed from 0.2 mm diameter wire (Type T, copper – constantan). These were used to measure the temperature of surfaces, particularly the polythene of the enclosures and the reflective shade material
- Infra-red thermometer (Minolta/Land Cyclops 33CF hand-held thermometer). This was used to make spot measurements of the temperature of leaves and other surfaces to complement the logged data from thermocouples etc.
- Net radiometer and solarimeter. These were used in combination to estimate the downward long wave radiation flux. From this information it was possible to estimate the effect of the polythene and any condensation on it on the long wave radiation balance inside enclosures used for raising humidity.

These were monitored with a Delta-T data logger (type DL2 with four-wire inputs for platinum resistance temperature sensors, Delta-T Devices, Cambridge). Configuration varied but usually involved logging the psychrometers at 30 min intervals, after the fan had run for at least 1min.

In addition to these logged data, a hot wire anemometer was used for spot measurements of air movement within the tunnel. To measure light transmission a pair of PAR (quantum) sensors was monitored using integrators (Delta-T Microvolt Integrators, type MV1).

The experimental enclosures

Two of the enclosures used in the first phase of the project were included in the second phase to provide a link between the two parts. Dimensions and cladding materials of these (Types E1 and E3) and the new enclosures (types E6 to E9) are listed below.

Table 1. Details of all experimental enclosures used in the 2nd phase of the project. (EFAR = External to Floor Area Ratio)

Enclosure 1 (E1)
(a small "walk-in" enclosure)

Dimensions (H x W x L)	2.1 x 1.5 x 2.5 m
EFAR	5.5
Cladding	50 µm (Pevistal non UV stabilised)

Enclosure 3 (E3)
(half-scale of E1)

Dimensions (H x W x L)	1.05 x 0.75 x 1.25 m
EFAR	5.5
Cladding	50 µm (Pevistal non UV stabilised)

Enclosure 6 (E6)
(the new large-scale walk-in enclosure used for enclosed mist trial)

Dimensions (H x W x L)	2.1 x 4.5 x 8 m
EFAR	2.45
Cladding	180 µm polythene (Visqueen Polytherm AF)

Enclosure 7 (E7)

Dimensions (H x W x L)	1.05 x 0.75 x 1.25 m
EFAR	5.5
Cladding	180 µm polythene (Visqueen Polytherm AF)

Enclosure 8 (E8)

Dimensions (H x W x L)	1.05 x 0.75 x 1.25 m
EFAR	5.5
Cladding	Bubble wrap polythene

Enclosure 9 (E9)

Dimensions (H x W x L)	1.05 x 0.75 x 1.25 m
EFAR	5.5
Cladding	180 µm polythene (Visqueen Polytherm AF) + bubble wrap polythene on the roof panel only

Results and Discussion

Rooting experiments

The main subjects

The main results are summarised graphically in Figures 3 – 11. While they illustrate that there were substantial differences in response between the subjects, there is a broadly consistent pattern. Key features are:

- Rooting percentage was lowest in open mist (OM)
- Basal necrosis (i.e. rotting) was consistently most severe in OM
- Except for *Garrya*, there was no significant difference between fog and enclosed-mist (EM)
- *Garrya* was the most sensitive to propagation environment. It was the only subject in which –
    - there was 0% rooting in OM
    - there was substantially less than 100% rooting in EM
    - rooting was severely delayed in EM (only 4% rooted in 28 days, compared to 100% in fog and 67% after 55 days in EM)
- Just as rooting of *Garrya* was delayed in EM but eventually reached a moderately high percentage (67%), similarly rooting of *Cotinus* was delayed in OM but eventually reached 63%.
- There were no significant effects on rootball volume except in *Corylus*, in which it was significantly greater in fog than in OM.
- All *Cornus alba* cuttings rooted irrespective of environment. This reflects the wide environmental tolerance that makes it easy-to-root.

It is worth noting that, on the basis of previous experience with these subjects, *Garrya* cuttings were placed about 3 m closer to the fogger than the other subjects were. This may account for 100% of *Garrya* rooting whereas a few *Cotinus* and *Corylus* failed to root.

Similarly, the rooting percentages achieved with *Cotinus* and *Corylus* in OM were higher than would often be observed because the mist had been set up to suit the stress-prone subjects: the controls were adjusted to ensure that leaves remained wet at all times and the polythene wall around the bed minimised exposure to dry air moving in from the surrounding between mist bursts.

Appearance of cuttings

Some wilting occurred briefly over the first few days in all environments, especially in *Garrya*. Despite heavy misting, the recovery was slower in EM than in fog. Cuttings of *Garrya* never recovered their non-wilted shape in OM, though they did not become progressively more wilted or desiccated.

After 28 days, a detailed inspection of cuttings was made. Listed below are the significant observations:

- *Garrya* – continued shoot extension, which was relatively pale green in colour, was clearly evident on all cuttings in fog but on only about 5% of cuttings in EM and none in OM. Brown spots developed on the younger leaves of about 50% of cuttings in fog and on nearly all cuttings in EM.
- *Cotinus* – continued shoot extension on about 20% of cuttings in fog only. The tendency of leaves to turn green was greatest in fog and least in OM.
- *Corylus* – continued shoot extension and greening of young leaves was greatest in fog and least in OM. Abscission of the shoot apex was least frequent in fog and most frequent in OM. One cutting in EM had shrivelled and died, apparently because most of its leaves were in the 'mist shadow' of adjacent cuttings. This indicates that adequate spacing to avoid excessive overlap of leaves is more necessary in mist than fog, and that raising humidity by polythene enclosure does not avoid the problem.
- *Cornus* – little shoot extension in any environment. Aerial roots (i.e. emerging from the stem above the level of rooting medium) occurred on many cuttings in fog and some in EM. There was some 'scorching' of leaf tips especially in OM.

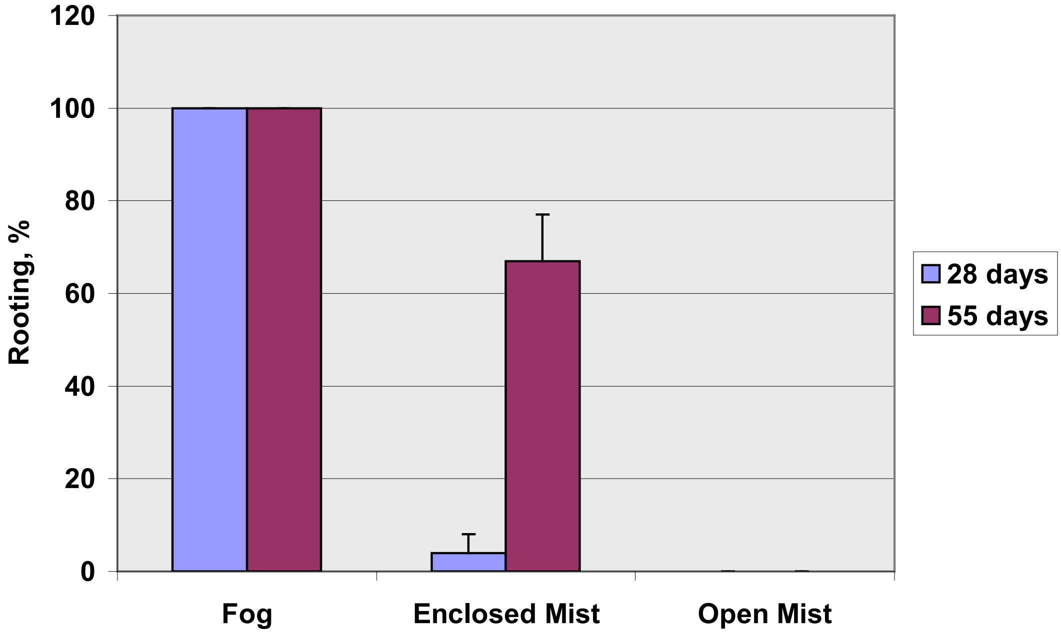

Figure 3. The effect of rooting environment on rooting of *Garrya elliptica* 'James Roof' cuttings inserted on 17 July. Bars represent means and standard errors, based on 24 cuttings on each occasion.

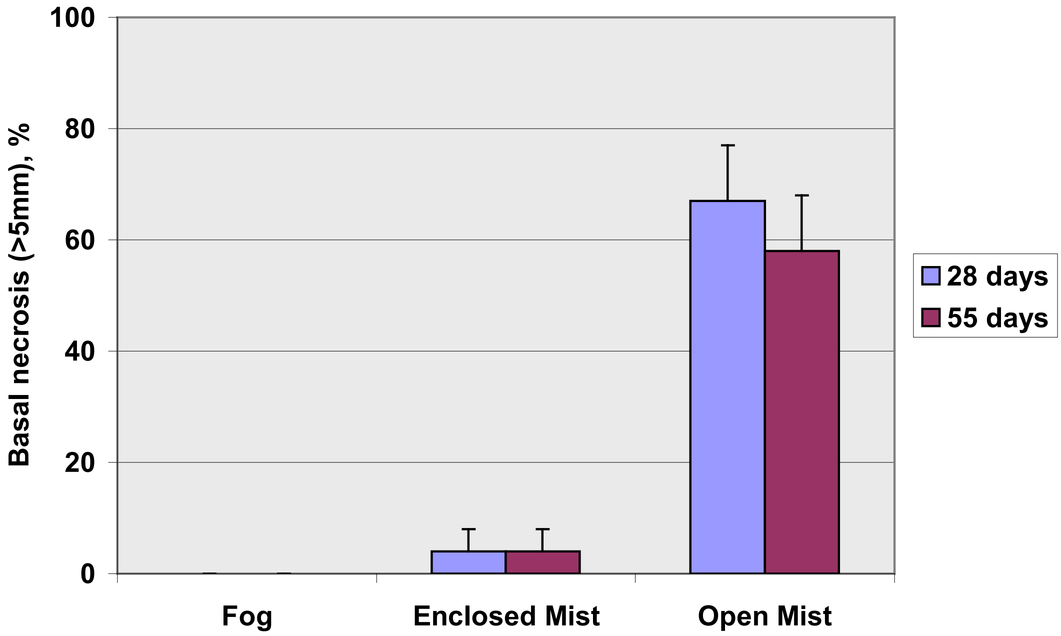

Figure 4. The effect of rooting environment on basal necrosis of *Garrya elliptica* 'James Roof' cuttings inserted on 17 July. Bars represent means and standard errors, based on 24 cuttings on each occasion.

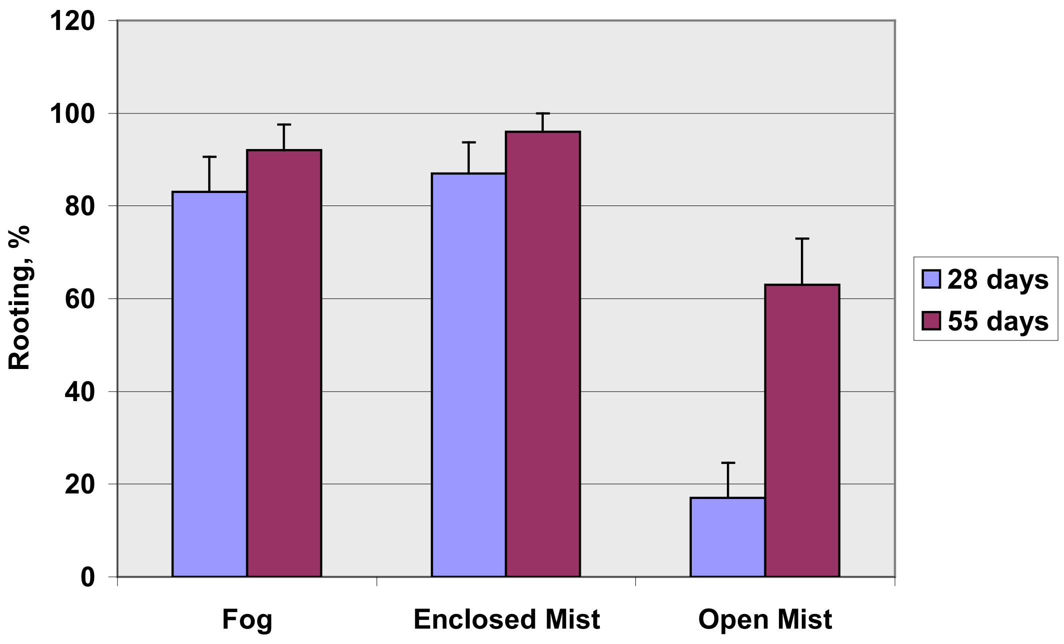

Figure 5. The effect of rooting environment on rooting of *Cotinus coggygria* 'Royal Purple' cuttings inserted on 18 July. Bars represent means and standard errors, based on 24 cuttings on each occasion.

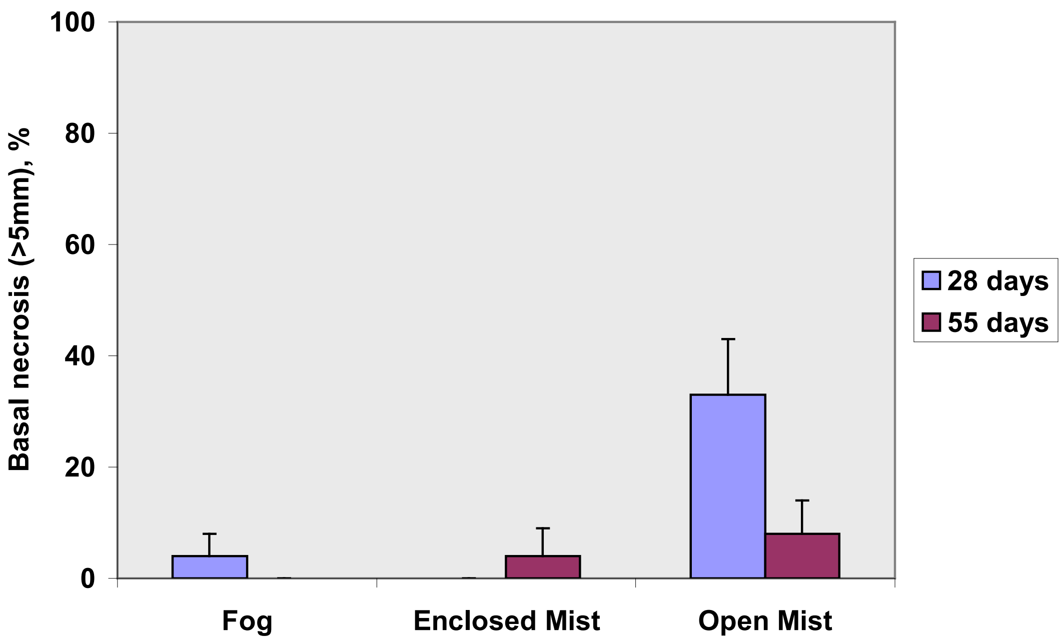

Figure 6. The effect of rooting environment on basal necrosis in *Cotinus coggygria* 'Royal Purple' cuttings inserted on 18 July. Bars represent means and standard errors, based on 24 cuttings on each occasion.

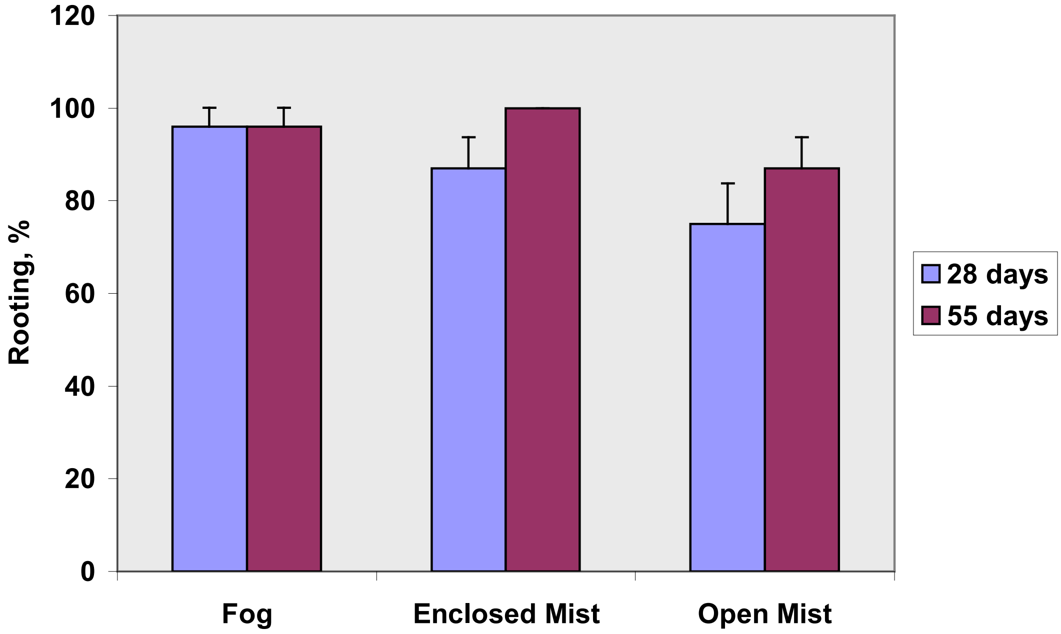

Figure 7. The effect of rooting environment on rooting of *Corylus maxima* 'Purpurea' cuttings inserted on 17 July. Bars represent means and standard errors, based on 24 cuttings on each occasion.

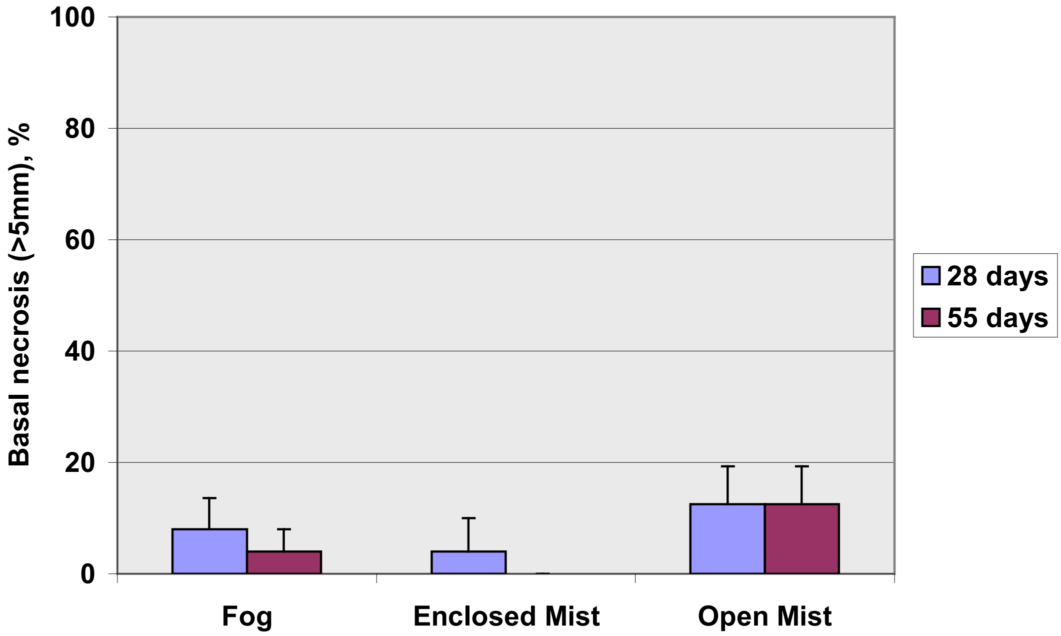

Figure 8. The effect of rooting environment on basal necrosis in *Corylus maxima* 'Purpurea' cuttings inserted on 17 July. Bars represent means and standard errors, based on 24 cuttings on each occasion.

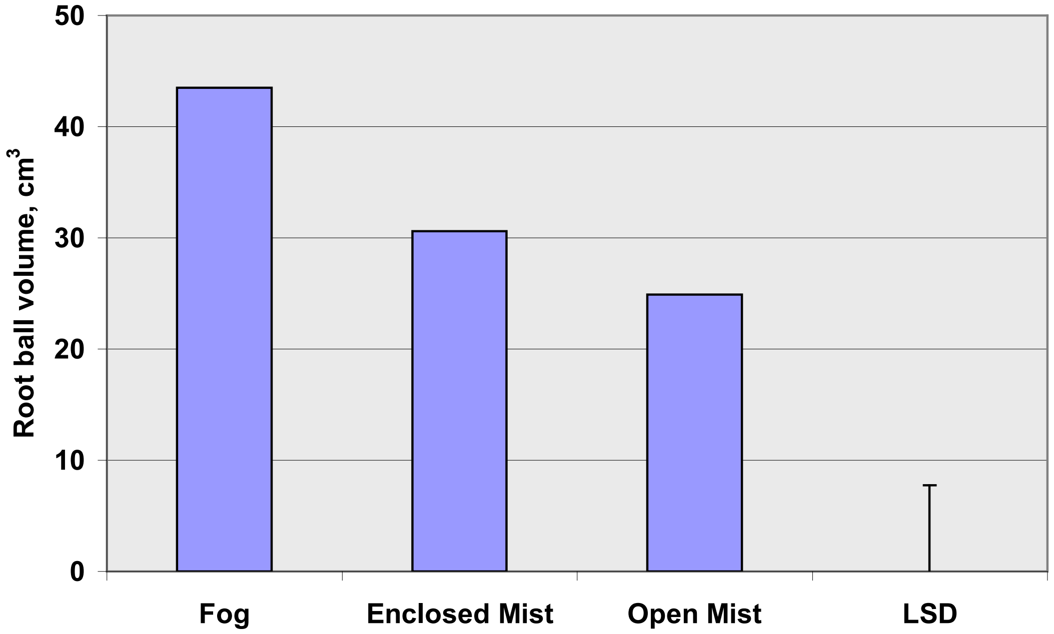

Figure 9. The effect of rooting environment on volume of the root ball of *Corylus maxima* 'Purpurea' cuttings inserted on 17 July (excluding non-rooted cuttings). Bars represent means and standard errors, based on 24 cuttings on each occasion.

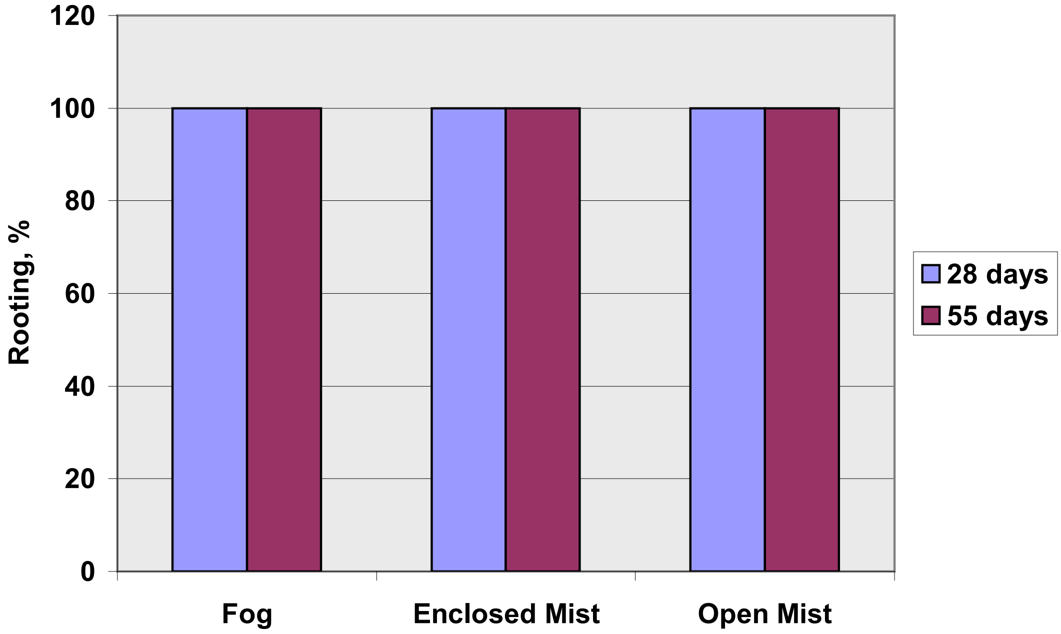

Figure 10. Rooting percentage of *Cornus alba* 'Elegantissima' cuttings inserted on 18 July in different environment. This graph is included to emphasise the contrast with the results for other subjects shown in the earlier graphs.

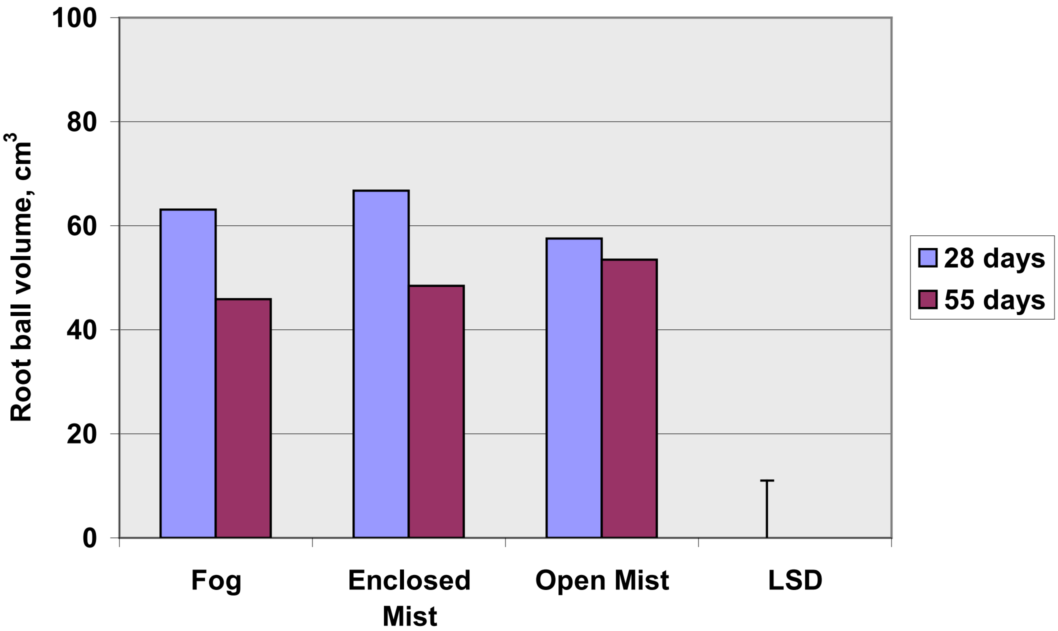

Figure 11. The effect of rooting environment on volume of the root ball of *Cornus alba* 'Elegantissima' cuttings inserted on 18 July. Bars represent means and the least significant difference (LSD, *P*=5%), based on 24 cuttings on each occasion.

Additional subjects

The results for these subjects are summarised in Table 1. Because the replication was limited, the overall pattern of results is more reliable than comparisons within any individual subject. The main features are:

- The pattern of results with these cuttings was similar to that seen with the more difficult of the subjects in the main trial, but with a rather larger benefit of fog compared to EM. The greater benefit of fog may reflect that all the additional subjects had relatively large individual leaves and/or a larger than normal leaf area per cutting (i.e. the pre-branched *Cotinus*).
- There was surprisingly little visual evidence of stress in the *Acers*, even in OM, despite their large soft leaves. Rooting was reduced in OM but we were surprised that any of the *Acers* rooted in that environment.
- The large *Magnolia* cuttings continued to grow in fog whereas they wilted badly in OM. While many rooted in OM, the quality of the resultant plant was very poor.
- New shoots arose from buds on the shortened branches of the pre-branched *Cotinus* but only in fog. As expected, the rooting potential of these large, woody, late-harvested cuttings was low so that even in fog only 67% rooted.

Table 1. Effects of rooting environment on rooting and basal necrosis of additional subjects, based on 10 cuttings per subject per environment. In view of this low level of replication the LSD (P=5%) values are large, but consistent features of the response of all subjects are more reliable than comparison within individual subjects.

	Fog	Enclosed mist	Open mist
Rooting, %			
A. platanoides 'Crimson King'	90	30	10
A. platanoides 'Drumondii'	100	70	30
Magnolia soulangiana	100	60	80
Pre-branched *C. cog.* 'Royal Purple'	67	39	0
LSD (mean)		32.8	
Roots per rooted cutting			
A. platanoides 'Crimson King'	6.1	5.0	8.0
A. platanoides 'Drumondii'	6.5	1.7	1.7
Magnolia soulangiana	7.8	5.4	5.4
Pre-branched *C. cog.* 'Royal Purple'	11.7	6.9	-
LSD		3.1	
> 5 cm basal necrosis, %			
A. platanoides 'Crimson King'	10	40	40
A. platanoides 'Drumondii'	20	10	0
Magnolia soulangiana	0	30	30
Pre-branched *C. cog.* 'Royal Purple'	55	50	100
LSD (mean)		33.2	

Comparison of conditions in the different propagation environments

This comparison is based on a detailed analysis of data collected over the period 20 July to 26 July, i.e. approximately the first week after cuttings in the main trial were inserted. This is the stage at which stress-prone subjects are most likely to be seen to wilt and is probably the stage at which the rooting process is most sensitive to water deficit. On this occasion it corresponded with generally fine weather and some wilting of *Garrya* cuttings was observed in both EM and fog, as well as severe wilting in OM.

Measurements logged every 30 minutes over this six-day period were combined to create an average diurnal cycle for each variable, some of which are illustrated below. The data were further summarised by calculating the overall mean, average daily maximum and minimum, and the average over the period from 12:00 to 16:00 hours. This corresponds to the part of the day when highest temperatures commonly occur and cuttings are most likely to develop severe water deficits. Hence it is referred to here as the 'peak stress period'.

Humidity

The vpd (vapour pressure deficit) is an absolute measure of how much additional water the air is capable of holding before it will be saturated and it is independent of temperature. As such, it is the most useful measure of humidity for describing the drying power of the air.

The vpd was virtually zero throughout the day in both fog and EM (Figure 12) and any difference between these two environments is smaller than the errors of measurement intrinsic in the instruments. Indeed the average value recorded in EM was negative (Table 4), which is meaningless, but even the diurnal maximum was only 0.057 kPa, which was only 7% of the average vpd in OM over the high stress period and just 3 % of the vpd in the surrounding air of the greenhouse. Figure 14 shows that, in the more familiar terms of relative humidity (rh), the humidity in fog and EM hardly departed from the 100% line. The average rh in fog and EM over the 12 - 16 h period deviated from 100% by less than half a percent (Table 3).

By comparison, the humidifying effect of OM was very small. Relative humidity during the peak stress period was increased from about 45 % to 74 % but this was equivalent to a vpd of 0.84, which implies a 'drying power' that was still about 40% of the ambient greenhouse air. At night, ambient vpd in the house was very low but, due to reduced misting frequency, it was little lower in the mist bed. Continued evaporative demand overnight must reduce the opportunity for cuttings to recover from water deficits which have built up during the day. It may, therefore, have contributed to the stress and reduced rooting that cuttings suffered in OM.

At this stage in the experiment, only one of the three mist beds in the EM chamber was operating. The data show that the humidity was markedly lower in the non-misted area than in the misted area. Over the 12-16 h period, the vpd in the non-misted bed, recorded about 1 m from the edge of the misted zone, was more than one third of the vpd in OM (Table 3). It was much lower than in the non-misted small enclosure (E7) but much of this difference is attributable to higher radiation levels in E7 (Figure 16 and Table 6) rather than to the humidifying effect of the mist. The vpd values differed by a factor of 2.5, while radiation differed by 1.7. Results for the non-misted enclosures reported previously (Harrison-Murray, 2001) showed that condensation on the relatively cool polythene tends to determine the absolute amount of water vapour in the air throughout the chamber. The present result indicates that this situation is not markedly altered by injection of mist, except in the area where the mist is actually deposited.

It is often revealing to look at changes in the concentration of water vapour in the air, measured as water vapour pressure (vp), partly because diffusion of water vapour occurs down concentration gradients and partly because it indicates whether there is a net gain or loss of water vapour in a particular part of the system. The diurnal cycle graph for vp (Figure 15) shows that on average vp was almost constant in the free air in the house. This implies that the decrease in rh and increase in vpd during daylight hours was almost entirely due to the increase in temperature of the air.

Misting in the OM bed increased vp slightly but some of the increase in rh and decrease in vpd in OM was due to the reduction of temperature by evaporative cooling (Table 2). In the enclosed systems, even without mist, there is a much larger increase in vp than in OM as the polythene traps both the humidity and the energy needed to drive evaporation (i.e. so called 'latent' heat). Providing extra water surface for evaporation increased vp in the misted compared to the non-misted parts of the EM system. As noted earlier, this brought EM to virtual saturation so that the further increase in vp evident in fog must be entirely attributable to the higher temperatures (see below).

Temperature

For most of the daily cycle, air temperatures were higher in fog than in EM despite the occasional operation of the forced ventilation system in the fog house (Figure 13). The average daily maximum was 32.8 in fog compared to 31.0 (Table 2) in EM and 25.8 in OM. The highest individual temperatures were recorded on 27 July, when outside temperatures reached 28 °C and the temperature in EM reached 34.6, just less than the 35.3 recorded in fog. By extrapolation from the graph of temperature against time for that particular day (not shown), it was estimated that, without the ventilation system the temperature would have reached about 37 in the fog house.

These results clearly show that the large-scale enclosed-mist system achieved the desired increase in humidity without excessive build up of temperature. The features that led to this outcome are analysed in the section on 'Modelling the energy balance of enclosed systems'.

Radiation

Radiation levels recorded in the three propagation environments (Figure 16 and Table 6) ranged from 17 to 20% of outside levels. The highest values were in EM so that the lower temperatures in EM than in fog cannot be attributed to a difference in shading. It is worth noting that the shade materials had a nominal shade factor of 60% yet overall about 80% of outside light was not reaching the cuttings. This implies that there was a further 50% loss attributable to absorption/reflection by the polythene, dirt on the outside of the polythene, water droplets on the inside of the polythene, and the metalwork of the house structure. Of these, reflection by water droplets is peculiar to high humidity systems and can be substantial.

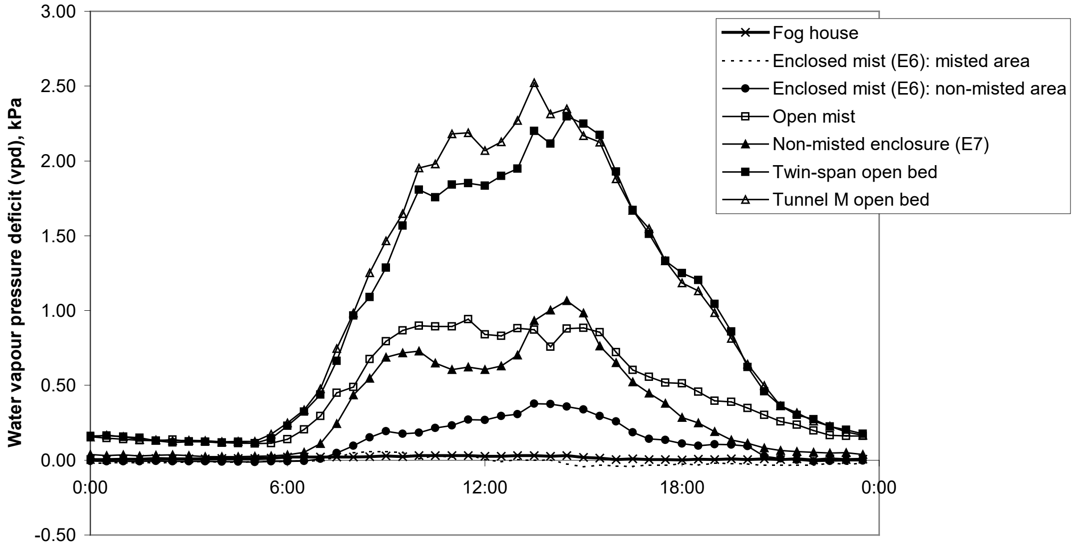

Figure 12. Comparison of the average diurnal cycle of water vapour pressure deficit (vpd) in the three propagation environments and in three other environments. Plotted values are means for the period 20-26 July, 2001.

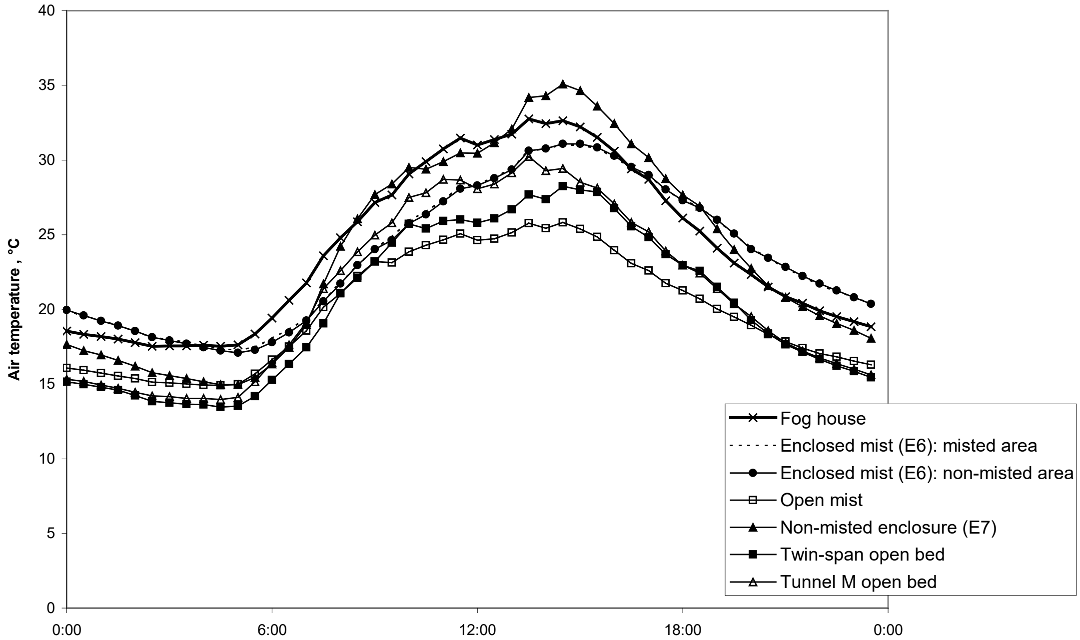

Figure 13. Comparison of the average diurnal cycle of air temperature in the three propagation environments and in three other environments. Plotted values are means for the period 20-26 July, 2001.

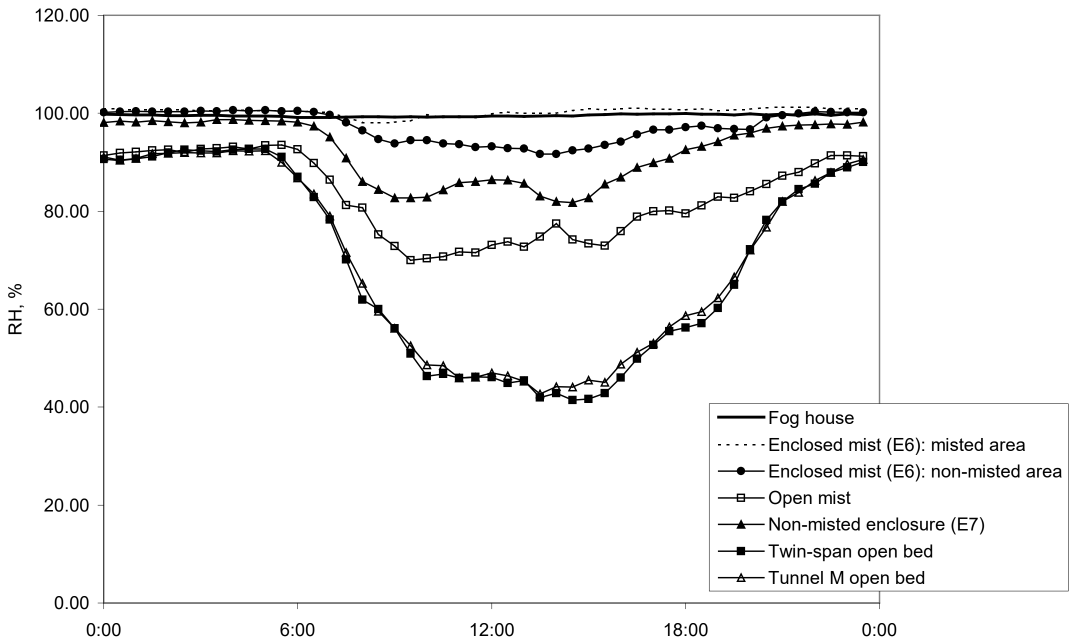

Figure 14. Comparison of the average diurnal cycle of relative humidity in the three propagation environments and in three other environments. Plotted values are means for the period 20-26 July, 2001.

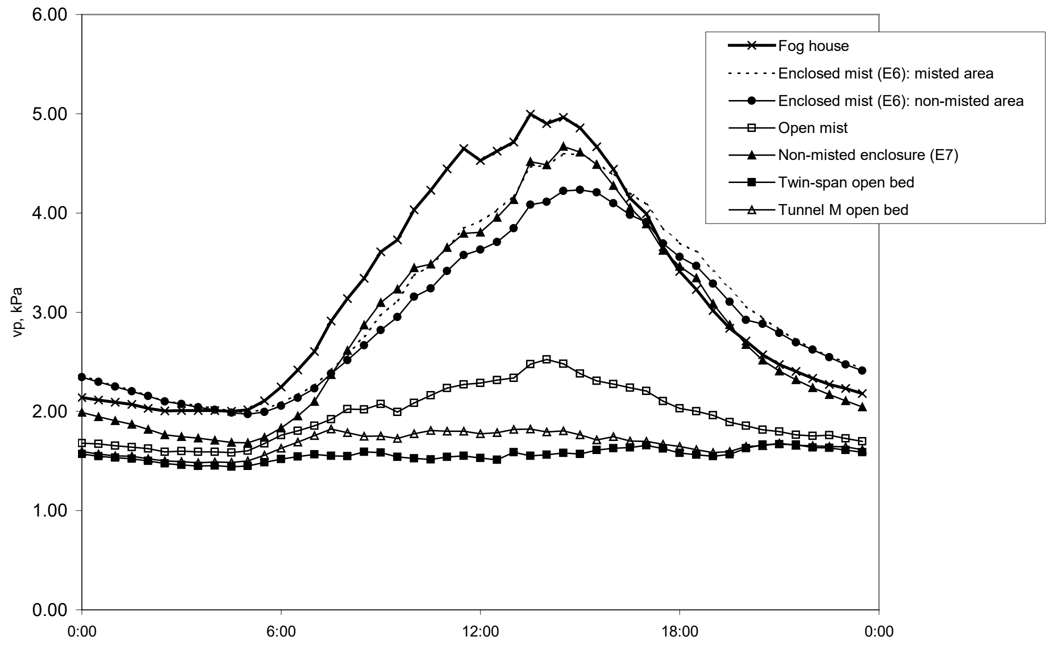

Figure 15. Comparison of the average diurnal cycle of water vapour pressure (vp) in the three propagation environments and in three other environments. Plotted values are means for the period 20-26 July, 2001.

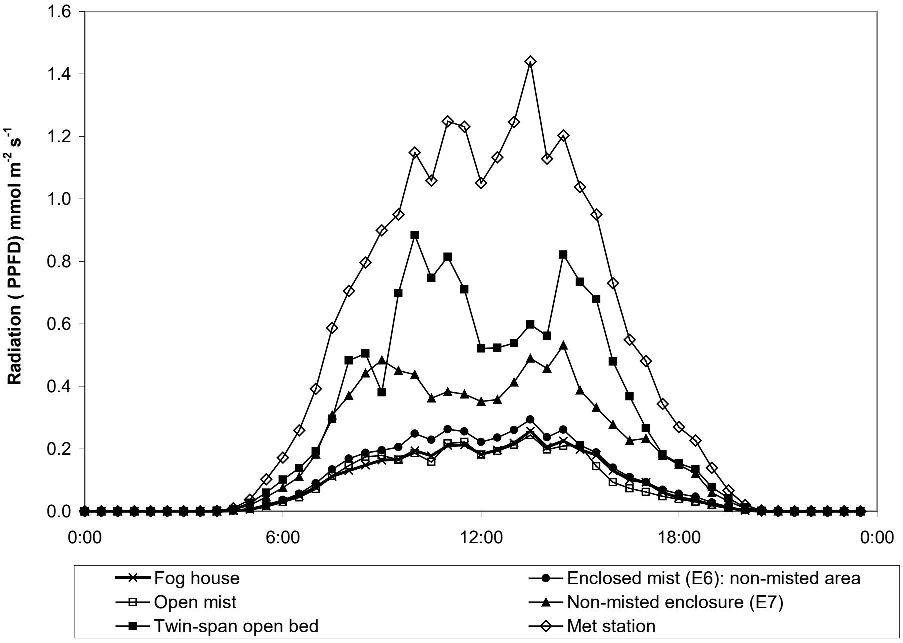

Figure 16. Comparison of the average diurnal cycle of solar radiation in the three propagation environments and in three other environments. Plotted values are means for the period 20-26 July, 2001.

Table 2. Mean air temperatures in the three propagation environments and in three other environments for the period 20-26 July, 2001.

	Air temperature, °C			
	Overall mean	12 - 16 h mean	Max	Min
EM (misted area)	23.97	30.11	31.06	17.25
Fog	24.50	31.80	32.76	17.52
Open mist	20.21	25.08	25.83	14.91
EM (non-misted area)	23.92	30.12	31.09	17.09
Non-misted enclosure (E7)	24.25	33.10	35.07	14.95
Twin-span open bed	20.62	27.17	28.25	13.44
Tunnel M open bed	21.54	28.69	30.22	13.98

Table 3. Mean relative humidities in the three propagation environments and in three other environments for the period 20-26 July, 2001.

	Relative humidity, %			
	Overall mean	12 - 16 h mean	Max	Min
EM (misted area)	100.3	100.4	101.2	98.0
Fog	99.5	99.5	99.9	99.1
Open mist	82.6	74.3	93.5	70.0
EM (non-misted area)	97.0	92.8	100.6	91.7
Non-misted enclosure (E7)	91.7	84.5	98.7	81.8
Twin-span open bed	67.4	43.7	92.7	41.4
Tunnel M open bed	68.2	45.4	92.3	42.7

Table 4. Mean vpd (vapour pressure deficit) in the three propagation environments and in three other environments for the period 20-26 July, 2001.

	vpd, kPa			
	Overall mean	12 - 16 h mean	Max	Min
EM (misted area)	-0.009	-0.016	0.057	-0.043
Fog	0.015	0.023	0.032	0.002
Open mist	0.475	0.836	0.942	0.112
EM (non-misted area)	0.119	0.319	0.378	-0.012
Non-misted enclosure (E7)	0.351	0.815	1.066	0.023
Twin-span open bed	1.000	2.072	2.297	0.113
Tunnel M open bed	1.062	2.203	2.523	0.124

Table 5. Mean water vapour content (expressed as water vapour pressure, vp) in the three propagation environments and in three other environments for the period 20-26 July, 2001.

	vp, kPa			
	Overall mean	12 - 16 h mean	Max	Min
EM (misted area)	3.12	4.35	4.60	1.99
Fog	3.24	4.74	5.00	2.00
Open mist	1.97	2.37	2.52	1.58
EM (non-misted area)	2.98	4.01	4.23	1.97
Non-misted enclosure (E7)	2.93	4.33	4.67	1.69
Twin-span open bed	1.56	1.57	1.67	1.44
Tunnel M open bed	1.67	1.78	1.82	1.48

Table 6. Mean levels of solar radiation (expressed as photosynthetically active photon flux density, PPFD) in the three propagation environments and in three other environments for the period 20-26 July, 2001.

	PPFD, µmol m^{-2} s^{-1}			
	Overall mean	12 - 16 h mean	Max	Min
Outside	0.48	1.10	1.44	0.00
Fog	0.09	0.20	0.26	0.00
Enclosed Mist (E6)	0.10	0.23	0.29	0.00
Open Mist	0.08	0.19	0.24	0.00
Non-misted enclosure (E7)	0.19	0.40	0.53	0.00
Twin-span open bed	0.28	0.61	0.88	0.00

Effect of misting frequency on humidity

Just as the results in the previous section showed that the humidifying effect of mist within the EM system was strongly localised, other data showed that the effect can be rather short lived even in the misted area itself. This was studied shortly before the cuttings were inserted so that the frequency of misting could be adjusted at will without influencing the rooting trials. Figure 17 shows within seconds of the start of a long mist burst rh increased to almost 100% from the background level of about 92% without mist. However, within 2 minutes rh started to drop and after 3 minutes was almost back to the starting point. Also evident in Figure 17 is the influence on rh in the non-misted area. A rise in rh was about half that seen in the misted area. It occurred with a delay of 10 to 20 s of that in the misted area but it started to decay almost immediately.

Figure 18 shows the effect of gradually reducing the length of the off period between mist bursts and then reducing the length of mist burst as well. It is clear that frequent, relatively short, mist bursts were more effective at maintaining a consistently high humidity in the misted area than a few long bursts. The amount of water applied was the same under the 4 s on / 2 min. off cycle as it was under the 20 s on / 10 min. off but it maintained rh at virtually 100% continuously. It also brought rh in the non-misted area close to 100% (varying between 97 and 99%). Only by setting the controller to 2 s on / 5 s off was rh in the non-misted area brought up to 100%. At this setting the amount of water being applied is 12 times as great as it was on the original setting.

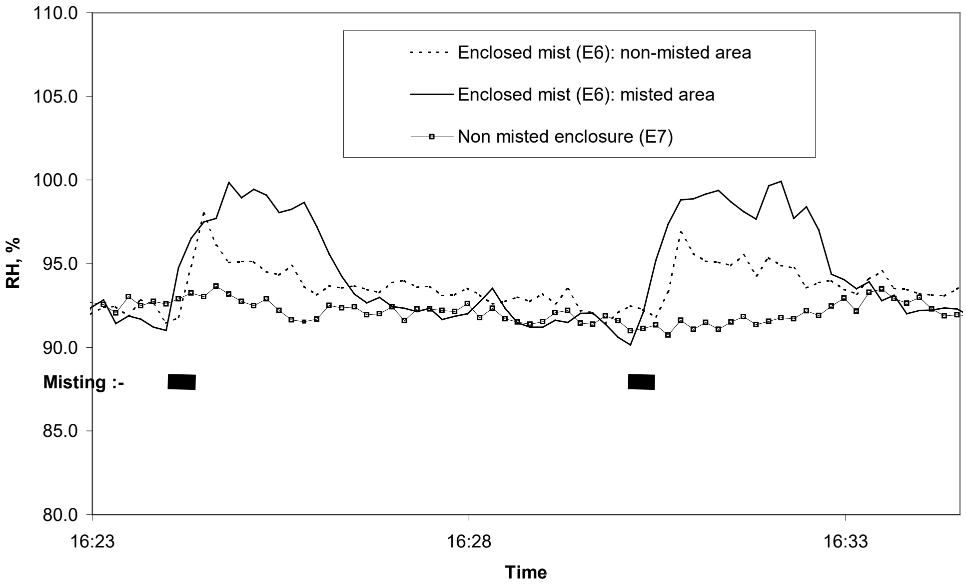

Figure 17. Fluctuations in relative humidity caused by individual mist bursts in the large-scale polythene-enclosed mist system. The data was collected on 11 July, 2001, before shade had been applied or cuttings inserted. At 10 s intervals, measurements were logged in the misted bed, an adjacent non-misted bed and, to provide a reference, in a small non-misted enclosure (E7).

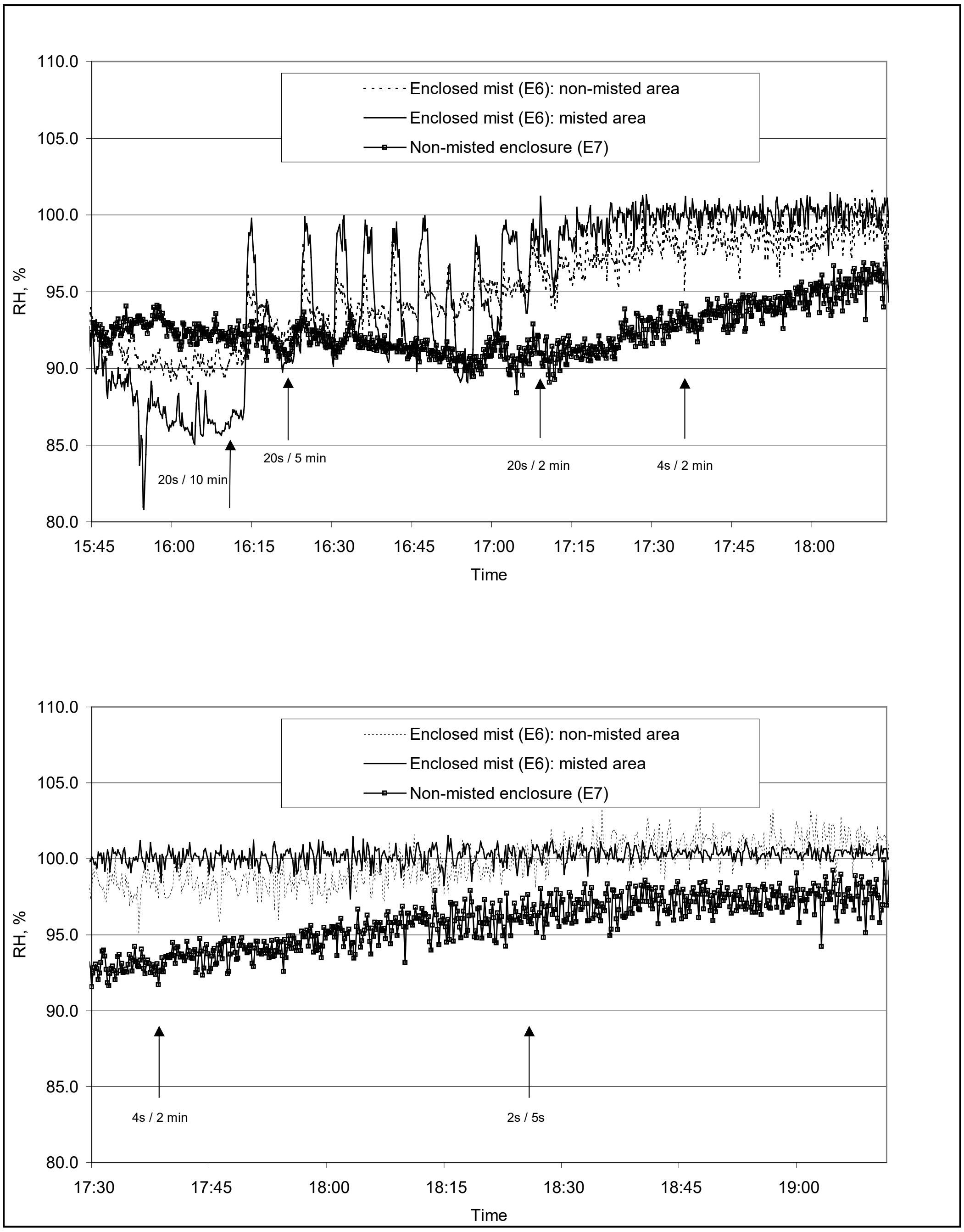

Figure 18. Effects of changing the length and frequency of mist bursts in the large-scale polythene-enclosed mist system (settings shown as duration on / off). The data was collected on 11 July, 2001, before shade had been applied or cuttings inserted. At 10 s intervals, measurements were logged in the misted bed, an adjacent non-misted bed and, to provide a reference, in a small non-misted enclosure (E7).

Water deposition rates

Rates of water deposition were measured on a number of occasions by weighing the amount of water that collected in petri dishes arranged around the edge of the block of cuttings over the course of at least one hour. During the hot weather at the start of the experiment there was no consistent difference in the amount of water applied in the different systems during daylight hours but more was applied in OM overnight. Later, this difference was also seen during the day. For example, on a warm overcast afternoon in October, the average rate of application was 226 $\mu m\ h^{-1}$ (i.e. about 0.2 $mm\ h^{-1}$) in OM compared to 14 $\mu m\ h^{-1}$ in EM and 7 $\mu m\ h^{-1}$ in fog. By contrast, on a sunny morning, deposition increased to 54 $\mu m\ h^{-1}$ in EM and to 50 $\mu m\ h^{-1}$ in fog but was actually slightly reduced in OM at 135 $\mu m\ h^{-1}$. These results reflect the fact that in high humidity systems, evaporative demand is driven exclusively by radiation level whereas in OM the ambient humidity and the amount of air movement also have an influence.

Combining mist and fog

The results of the rooting trial show that fog provided a slightly more favourable environment than EM, particularly for the *Garrya* cuttings, despite there being no detectable difference in humidity and cuttings appearing well wetted at all times in both systems. What is it about fog that made it more supportive then? The explanation may lie in the fact that the psychrometers measure the humidity in the air as a whole, sucking air in at 10 cm above the bed to make their measurement. Water loss from leaves depends on the conditions outside their stomata, which in most HNS species are concentrated on the under-surface of the leaves. As the leaves absorb radiation they tend to warm up and this warmth is then transferred to the air passing close to them. As a result, even if the bulk air is saturated, the relative humidity drops and the vpd increases next to the leaves. However, if there are droplets of liquid water suspended in the air, as there are in fog, then those droplets will tend to evaporate and thus maintain an rh close to 100%.

An alternative explanation is that, close to the fogger, some liquid water was deposited on the underside of the *Garrya* cuttings where is could have blocked some stomata or been absorbed through the epidermis. However, substantial wetting of the under-surface of leaves is rarely observed even close to the fogger so that this explanation is considered less likely.

In the light of these ideas, the original concept of adding a fog to a mist system to purely humidify the air would not be likely to improve on the results obtained with enclosed mist. Instead, the fog would need to be injected within the canopy. This line of thought led to the decision to experiment with ultrasonic fog rather than pressurised water fog as originally envisaged. Ultrasonic fog consists of a high proportion of very small droplets which can remain suspended in the air almost indefinitely. However, *en masse*, it has a tendency to flow downwards and can accumulate in low areas as a 'sea of fog'. Preliminary experiments with a small Vindon ultrasonic fogger normally used for humidifying a controlled environment cabinet were promising. However, they showed that the velocity of the air stream used to deliver the fog from the ultrasonic generator needs to be very low if the fog is to have a chance to settle within a bed surrounded by a low retaining wall.

Further experiments have been conducted with a Centronics HU-25 fogger which has the facility to vary the speed of the air delivery fan. It is a small unit capable of atomising up to 1.2 litres of water per hour. Experiments over the course of the winter suggest that this will be sufficient for a bed of about 4 m^2. Even with dry sand, bottom heat on and moderate ventilation, the fogger was able to raise the rh in the beds to 100% very rapidly while the surrounding air was at about 80% rh. Further testing will be conducted in spring, when radiation levels in the unshaded house are more representative of conditions under shade in midsummer.

Modelling the energy balance of enclosed systems

The original model

At the start of this project, a hypothesis was put forward based on a conceptual model of the physical principles which determine temperature in polythene enclosures. The model envisaged that the maximum temperature reached would be the temperature required to achieve a balance between the energy gained and energy lost. Since the energy income is largely in the form of solar radiation then the energy income of a particular enclosure depends on the area of ground absorbing that radiation , i.e. the floor area of the enclosure. By contrast, it was envisaged that heat loss would be mainly by conduction and convection through the polythene walls and floor and would depend on the area of these external surfaces. This led to the prediction that the temperature lift would be inversely proportional to the ratio of external surface area and the floor area or EFAR (External to Floor Area Ratio).

Data presented in the previous report (Harrison-Murray, 2001) showed that temperatures did indeed tend to be higher in enclosures with a low EFAR but the increase was much smaller than predicted. On the basis of that finding it was predicted that it should be possible to scale up the small 'walk-in' enclosure without temperatures becoming excessive. However, recognising that nurserymen have run into problems of high temperature when they have attempted to raise humidity by restricting ventilation, it was clear that it would be important to identify the factors that had limited temperature rise in these experiments. It seemed likely that the same factors would explain why the effect of EFAR on temperature was less than expected. Two suggestions were put forward to explain this discrepancy. Firstly, that heat flux into the soil was a significant route for energy loss, particularly in the absence of under-bed insulation. Secondly, that the net loss of heat as long wave radiation (see glossary for explanation of this term) accounts for a much greater proportion of total energy loss than is the case for well ventilated environments.

These possibilities were explored this year. The work included temperature measurements in the new large-scale enclosure, with a floor area ten times larger than the 'walk-in' enclosure tested previously and a correspondingly low EFAR value (2.45 compared with 5.5). This presented an opportunity to test the original hypothesis further and to test the effect of under-bed insulation and thus the importance of heat loss into the ground. Before shade had been installed, the new enclosure (E6) was compared with two of the enclosures used previously (E1 and E3). Since E6 was erected on the insulated bed in the new house whereas E1 and E3 were on an non-insulated bed in the original house, an additional E3 type enclosure (E3a) was placed in the new house to measure the effect of the insulation. The polythene used to construct E6 (Polytherm AF) was much thicker than that used in the smaller enclosures and contained additives to provide UV stabilisation and to make the surface more wettable to encourage droplets of condensation to coalesce. The possibility that this would have a significant effect on energy transfer process and thus on temperature was tested by making up another enclosure of identical dimensions to E3 but clad in Polytherm AF (E7).

Effect of the type of polythene

The pattern of condensation on the walls of the enclosure was influenced by the nature of the polythene. With Polytherm AF cladding, both on E7 and E6, few droplets of condensation were evident on the bottom 20 - 40 cm of the walls, whereas droplets of condensation extended to ground level on the thinner polythene. It was not clear whether this was due to the surface treatment of the Polytherm, allowing heavy condensation to coalesce or to warming of the Polytherm near the ground. Whatever the explanation, no difference in air temperature was detected between E7 and E3a, enclosures which differed only with respect to the type of polythene (data not shown). It was therefore concluded that the type of polythene has no effect of any practical significance on heat exchange processes.

A separate experiment examined the effect of using bubble-wrap polythene as a more thermally insulating cladding material than conventional polythene sheet. One purpose was to try to prevent condensation on the roof panel so as to increase radiative heat loss. Water is a strong absorber of long wave radiation and therefore tends to trap heat by the ‘greenhouse’ effect (similar to the effect of glass in glasshouse or CO_2 in relation to global warming). In the event, bubble wrap on the roof reduced condensation on the roof panel and increased condensation on the walls. Since it did not prevent condensation on the roof completely, no substantial effect on long-wave transmission could be expected.

The data summarised in Table 7 show that the use of bubble-wrap raised air temperatures compared to normal polythene sheet but the effect was remarkably small. This suggests that the air near the polythene inside the enclosure is already so slow moving that the resistance to heat flow across this layer (the technical term for which is the ‘boundary layer resistance’) is already large. Under these circumstances, the effect of the additional trapped layer of air in the bubble-wrap would have been minimised. Table 7 slightly underestimates the effect of bubble-wrap because light transmission into the enclosure was slightly reduced by the bubble-wrap.

Table 7. The effect of insulation with ‘bubble wrap’ polythene on air temperatures in a small polythene enclosure (H x W x L = 1.05 x 0.75 x 1.25 m) standing on the insulated sand bed. The bubble wrap either replaced the normal polythene sheet (E8) or it was an additional layer on the roof panel only (E9). Values are means for the period 30 Sept. to 15 Oct. 2001.

	Air temperature, °C			
Enclosure	Overall mean	12 - 16 h mean	Max	Min
E7 (polythene sheet)	17.44	24.52	25.97	12.61
E8 (bubble wrap)	17.78	25.19	26.08	12.81
E9 (bubble wrap on roof only)	17.67	25.79	26.91	12.54
None (i.e. open bed)	15.76	20.89	21.45	12.25

Under-bed insulation

The results summarised in Table 8 show that temperature lift on the insulated bed in the Twin-span house was 64% greater than in the same shaped enclosure on the non-insulated bed in Tunnel M (E7 compared with E3). Temperatures in E7 rose more rapidly in the morning and fell more rapidly in the evening than in E3 but the shape of the diurnal cycle was not affected (Figure 19). Ambient air temperatures in the two houses were very similar (Figure 19), reflecting similar light transmission and ventilation.

Table 8. Mean temperature lift in various polythene enclosures relative to the immediate surroundings. E1 and E3 were in Tunnel M, on a non-insulated sand bed; E6 and E7 were in the Twin-span house, on an insulated sand bed. The E6 enclosure was later set up as the large-scale enclosed-mist chamber. Values are means for the period 24 June to 3 July 2001, before any shade or mist had been installed.

	Air temperature lift, °C			
Enclosure	Overall mean	12 - 16 h mean	Max	Min
E1	2.67	4.41	5.06	1.33
E3	2.35	4.02	4.81	1.15
E6	6.59	9.06	10.10	2.96
E7	3.85	6.26	7.10	1.00

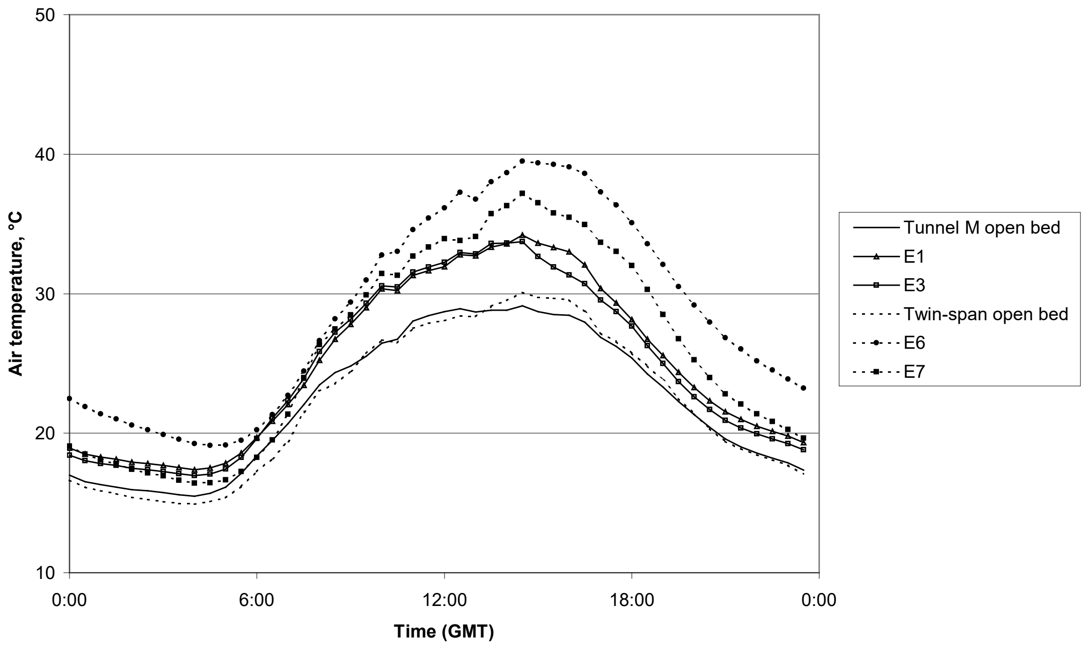

Figure 19. Average diurnal cycle of air temperature in four polythene enclosures without shade or mist, based on data collected from 24 June to 3 July, 2001. E1 and E3 were on the uninsulated bed in Tunnel M; E6 and E7 were on the insulated bed in the Twin-span. E7 was the same shape and size as E3, while E6 was much larger (later used in the large-scale enclosed-mist trial).

Thermal buffering effect of the substrate

Measurements of the temperature gradient in the sandbed were used to estimate heat flux into the sand. The results shown in Figure 20 show that the insulation had little effect on heat flow into the sand in the early part of the day but, as incoming radiation peaked around midday, heat flow into the insulated bed declined while heat flow into the non-insulated bed continued to increase and remained higher than in the insulated bed for the rest of daylight period. Furthermore, there was much greater flow in the reverse direction (i.e. which appears as more negative values on the graph) from the insulated bed overnight. This indicates that, on the insulated bed, there was mainly temporary heat storage in the sand itself rather than flow of heat into the earth beneath the bed. This is evident from the fact that the mean heat flux for the full 24 h day came close to zero in the insulated but not in the uninsulated bed (Table 9).

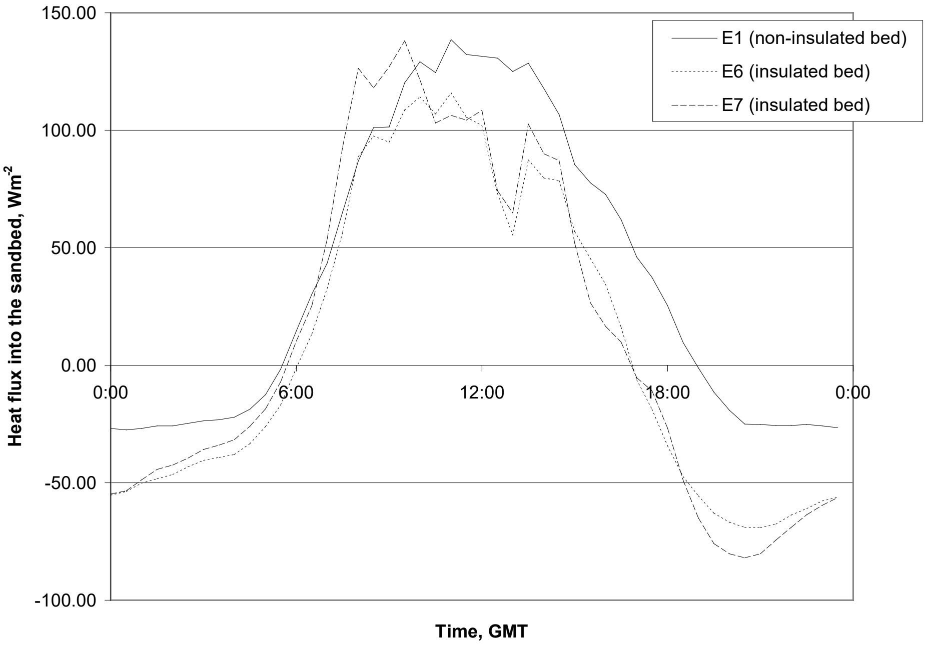

Figure 20. Average diurnal cycle of heat flux into the sandbed, based on temperature gradient data collected from 24 June to 3 July, 2001. E3 was on the non-insulated bed in Tunnel M; E6 and E7 were on the insulated bed in the Twin-span.

Table 9. The effect of under-bed insulation on mean heat flux into the sandbed estimated from temperature gradients in the sand underneath three different enclosures. Data are from the period 24 June – 3 July, 2001, before shade was installed or mist operating.

	Heat flux into the sandbed, Wm^{-2}			
Enclosure	Overall mean	12 - 16 h mean	Max	Min
E3 (on non-insulated bed)	36	108	139	-27
E6 (on insulated bed)	6	68	116	-69
E7 (on insulated bed)	10	69	138	-82

These results suggest that under-bed insulation need not create a major problem as long as the thermal capacity of the material above it is sufficient to store a substantial proportion of the energy received during the hottest part of the day. Higher temperatures would have been observed in E6 if the sand layer had been thinner or replaced by capillary matting. Similarly, if propagation is done on benches rather than ground-level beds, the opportunity for thermal buffering from the floor material will be much reduced. Indeed, presumably, even a dense canopy of cuttings obstructs the thermal buffering effect to some extent.

Effect of EFAR

During the peak-stress period of 12:00 to 16:00 h, the temperature lift in the large E6 enclosure averaged 1.45 times that in the adjacent E7 whereas the EFAR value E7 was 2.24 times that of E6. The results confirm that EFAR affects temperature lift in the predicted direction but the size of the effect is smaller than predicted on the simple model, though larger than observed previously. This can partly be attributed to the effect of heat storage, as discussed above. By making the comparison based on 24h means, temporary heat storage is eliminated and only net heat flux into the ground will have any effect and this was small in the insulated bed. The overall mean in E6 was 1.7 times that in E7, which represents 57 % of the predicted difference. This is substantially better agreement than seen previously but is nonetheless too large to be attributed to measurement errors. The remaining discrepancy suggests that there is at least one other respect in which the original model is an oversimplification.

Long-wave radiation balance

Upward long-wave (or thermal) radiation from the bed, cuttings etc can be reliably predicted from their surface temperature but it is more difficult to estimate the downward flux from transparent materials such as the polythene and the atmosphere itself. Whilst water is transparent to light it absorbs and radiates strongly in the long-wave band so that a thick layer of condensation on the roof of an enclosure seemed likely to dominate the amount of downward long-wave radiation. On that assumption, it was shown that net loss of energy as radiation was unlikely to contribute greatly to total loss of energy from a polythene enclosure (Harrison-Murray, 2001). However, since the condensation is in the form of hanging drops with areas between drops where the layer is very thin, it was decided to test the assumption by making measurements of the downward long-wave radiation in the presence and absence of condensation.

The measurements are difficult, involving a comparison between the readings from a solarimeter, which measures short-wave radiation, and a net radiometer which is sensitive to all wavelengths. The net radiometer has a polythene dome and requires a supply of dry compressed air to keep the dome inflated. Persistent difficulties were encountered with moisture trapped somewhere within the instrument which led to condensation forming inside the dome which invalidated the data. Eventually, this moisture was flushed from the system and some reliable measurements were obtained. Figure 21 is an example and shows the values from the two instruments and the calculated difference between them which is attributable to the long-wave component. An additional line shows the equivalent 'sky' temperature, based on the assumption that the radiation is coming from a 'black body' (i.e. a good emitter of thermal radiation such as a matt black surface or water). Erratic estimates of sky temperature occurred whenever there were sudden changes in radiation level as a cloud obscured the sun, presumably due to differences in the rate of response of the two instruments.

Despite these difficulties, it is obvious that opening a ventilation 'door' in the enclosure, causing rapid cooling of the layer of condensation on the roof, reduced the apparent sky temperature from about 40 to about 30 C. These values are close to the temperature change observed by direct readings with a thermocouple. This result appears to confirm the expectation that the downward flux of radiation is dominated by radiation from the layer of condensation on the polythene.

More surprising is that sky temperature remained between 10 and 20 C after the enclosure was removed completely. Outside, under similarly sunny conditions, values between 0 and -10 were observed as expected. The much higher values observed inside the Twin-span house suggest that, in addition to some radiation from the hot metal structure, the Polytherm AF cladding must be emitting a substantial proportion of the downward thermal radiation. Since pure polythene is a poor absorber and emitter of thermal radiation, this presumably reflects the effect of the additives that contribute to the enhanced energy conservation and frost protection of Polytherm AF compared to normal polythene.

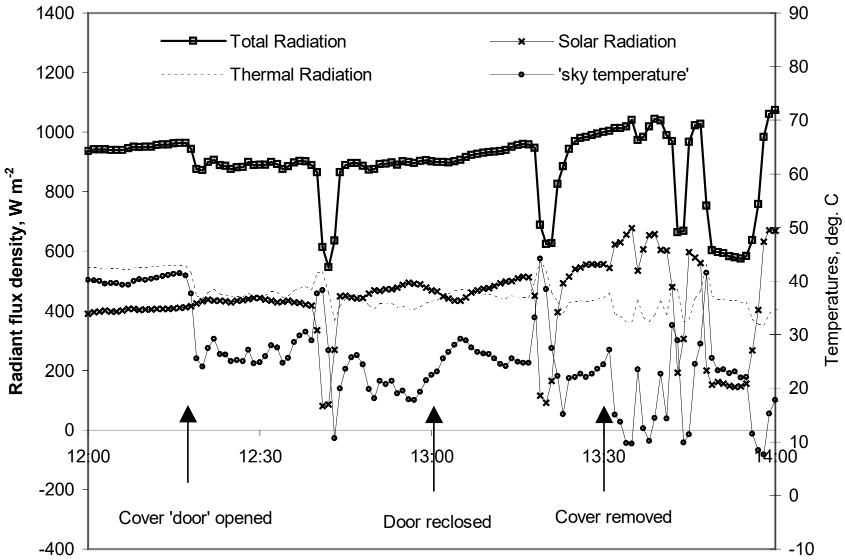

Figure 21 . Example of estimation of the effective 'sky temperature' inside a polythene enclosure laden with condensation. Downward long-wave (thermal) radiation was calculated as the difference between downward solar radiation and total downward radiation. This value was then converted to sky temperature using Stephan Boltzmann's equation, assuming an emissivity of one.

On account of the difficulties encountered with the net radiometer, a hand-held infra-red thermometer was used to make spot measurements of the radiation temperature of various surfaces. The results in Table 10 show that the apparent sky temperature inside the Twin-span was about 30 °C above the apparent sky temperature under clear sky conditions. This confirms the evidence from the radiometers and indicates that the rate of radiative heat loss from a polythene enclosure must be near the lower limit of the range previously estimated (Harrison-Murray, 2001).

Table 10. Spot measurements of apparent temperature (°C) of various surfaces made with a hand-held infra-red thermometer on 14-15 August, 2001. Values are the means of up to 5 readings for each surface. The air temperature measured with a conventional thermometer in the met. station is included for comparison. The sky was fairly clear at the time but comparisons between different locations would have been influenced by slight changes in atmospheric conditions between the measurements.

	Time, GMT	
	14:00 – 14:30	18:15 – 18:30
Sky	+1	-14
Twin-span roof: non – shaded part	29	15
Twin-span roof: shaded part	37	21
EM (E6) roof	40	27
EM (E6) sand bed	37	31
Fog house roof	38	27
Fog house sand bed	35	28
Glasshouse	-	20
Air temperature (from the met. station)	29	24

Effect of the location of shade

As noted earlier, once shade was in place and the enclosed mist system was established in E6, temperatures were lower than in the fog house which has no insulation beneath the beds. If the thermostat for the forced ventilation had been set lower then the fog house could certainly have been made cooler than the EM system but why did it tend to be warmer in the first place? Listed below are the possibilities which have been considered:

- Whilst both houses are shaded with Ludvig Svensson reflective shade, that on the fog house is now about 5 years old and therefore reflects less radiation and absorbs more.
- The shade on the fog house is in contact with the high humidity enclosure whereas the shade over the EM is remote from the enclosure and therefore likely to be cooler.
- The presence of fog suspended in the atmosphere impedes radiative heat loss.

Of these, the second is considered the most likely. By restricting air exchange over the polythene it would tend to make the polythene warmer, thereby inhibiting heat loss by both radiation and conduction/convection. Since the shade material itself is made warmer by contact with the warm polythene it would contribute additional downward thermal radiation compared to shade that is kept cool by good ventilation.

Since shade is a vital component in preventing excessive temperature rise, it is important to establish how to get the best from it. An experiment to investigate this has therefore been set up. Three E7 enclosures have been set up, one with shade in close contact with the polythene, one shaded remotely and one without shade. In addition to the usual measurements of air temperature, the temperature of the polythene and the shade is being monitored with thermocouples. At the time of writing no substantial differences have been observed but this may well be due to the low radiation levels and low solar angle that have applied since it was set up in November . The experiment will be continued until radiation levels are high enough for a fair test. It is expected that it will be followed by a comparison of new reflective shade with the old material from the fog house.

Conclusions

The main conclusions from the second phase of the project are as follows:

- It is practical to scale up polythene-enclosed mist sufficiently to make it more attractive to commercial nurseries than the traditional approach of creating a polythene tent over individual mist lines.
- Humidity in the large-scale enclosed mist system was not detectably below saturation and, as such, was indistinguishable from that in a good fog system.
- The high humidity was localised to the misted area and, if the interval between mist bursts is too long, then humidity will drop even in a polythene enclosure.
- Fog was more supportive than enclosed mist for the most sensitive cuttings, which in these trials was *Garrya elliptica*.
- In a wet fog environment, *Garrya* continued to elongate and achieved 100% rooting in four weeks; in enclosed mist, most cuttings did not elongate and only 67% had rooted after 8 weeks.
- The additional support provided by fog may be due to the circulation of water droplets in the air underneath the leaves. Such water would help maintain humidity

saturation close to the under-surface of the leaves as energy absorbed by leaves is transferred to the air around them.

- The addition of small quantities of fine droplet fog, such as can be produced ultrasonically, may allow that additional benefit to be achieved in a mist + fog system
- Preliminary tests indicate that such a system would be compatible with limited ventilation.
- The tendency for temperatures to increase as EFAR decreases was confirmed but the rate of increase is at most about half the decrease in EFAR.
- Underbed insulation tends to increase temperatures in enclosures by reducing the loss of heat into the ground.
- The increase in temperature caused by under-bed insulation depends on the heat storage capacity of the material above the insulation. A substantial layer of concrete or sand can store a substantial part of the heat received during the day and release it again at night.
- This thermal buffering is an important part of avoiding excessively high temperatures. Operating on benches and/or with a thin layer of capillary matting under the trays would provide minimal thermal buffering.
- The polythene and water condensed on it are the dominant source of downward long-wave radiation in a high humidity enclosure. Since their temperature is close to that of the ground and the cuttings in the enclosure, the net upward radiation must be small and probably accounts for a small proportion of the total energy loss.

Future work

The project has demonstrated the considerable improvement over conventional mist that is possible without resort to the use of fog. The next question is what further improvement is possible if a modest input of fog is used to complement mist?

The project has also revealed the complexity of the physical processes that determine the conditions actually achieved when attempting to raise humidity with a polythene enclosure. The insights achieved are useful but not comprehensive and further experiment to reinforce and extend the conclusions is required. The possibilities are many and some are listed below as a basis for discussion with the industry representatives:

- Test polythene-enclosed mist on a commercial nursery to identify practical difficulties and to test the effect on performance of cuttings. This depends on identifying a nursery willing to collaborate, with facilities in which a suitable enclosure could be erected within an existing mist house. Air temperature would need to be recorded regularly, possibly complemented by installation of a logger for a few days to obtain a more complete picture.
- Test the benefit of combining ultrasonic fog with enclosed mist, with and without limited ventilation.
- If results are encouraging, then develop a control system that suppresses misting until evaporative demand is too great to be met by fog alone.
- Further explore the reason for the lower temperatures observed in the enclosed mist compared to fog. Start with measurements on the systems without shade or fog/mist, then add first shade and finally add fog/mist.
- Use the miniature enclosures to confirm some of the conclusions from this year's work and to test additional features relating to the design of high humidity systems. Specifically:
    - under-bed insulation
    - thermal mass of the substrate e.g. capillary matting vs. thin layer of sand vs. 5 cm of sand
    - reflective vs. absorbent vs. paint-on shade materials
    - effect of a dense leaf canopy
    - effect of dry areas within the enclosure
- Development of a more formal model which could be used by growers and their advisors to predict the temperature rise in a proposed system or to analyse how an existing system might be improved. This would require collaboration with relevant experts (e.g. Paul Hamer, Silsoe Research Institute)

TECHNOLOGY TRANSFER

Presentation to the IPPS conference [Cameron R.W.F and Harrison-Murray R.S. (2001). Cutting Production - Alternative Strategies and Potential Techniques for the Future. Presentation to The International Plant Propagators' Society Great Britain and Ireland Region August 2001 and Abstract in the IPPS International Combined Proceedings Vol. 51. (2002)]

GLOSSARY : 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. It is used in a polytunnel with an extract fan, that is refered to as the 'Agritech' ventilated fog house.

apical cutting - one which includes the shoot tip

boundary layer – the layer of air in contact with a surface within which flow of air is slowed down by friction between the airstream and the surface. The existence of the boundary layer phenomenon is evidenced by an increase in rate of air movement with distance away from a surface but there is no sharp distinction that defines the edge of the boundary layer.

EFAR – External to Floor Area Ratio

EM - Enclosed Mist, i.e. mist operated within a polythene enclosure to raise humidity

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 that 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 and to monitor how effectively any kind of propagation environment is restricting water loss from cuttings. It also has potential in irrigation control which is being developed in a current Horticulture LINK project (HL0132LHN 'Improving the control and efficiency of water use in container-grown hardy ornamental nursery stock'). A commercial version is being developed by Skye Instruments (Unit 32, Ddole Industrial Estate, Llandrindod Wells, Powys, LD1 6DF).

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

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.)

long wave radiation – (also known as terrestrial and thermal radiation) the radiation emitted by surfaces in our terrestrial environment. Being much cooler than the surface of the sun the wavelengths are much longer, mainly between 3 and 100 μm, with a peak at about 10 μm. The intensity of long wave emissions increases with temperature but also varies between materials and surfaces. Materials that have high emittance always have correspondingly high absorbance.

OM - Open Mist, i.e. a mist bed operating in a freely ventilated location either within a relatively dry glasshouse environment or outside.

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).

rh – relative humidity is the water vapour pressure in the atmosphere expressed as a proportion of the vapour pressure of a saturated atmosphere at the same temperature. It is usually expressed as a percentage.

solar radiation – the short wave radiation that we receive from the sun, mainly between wavelengths of 0.3 to 3 μm. About 50% of it is in the visible waveband (0.4 to 0.7 μm). It reaches a maximum irradiance of about 800 W m^{-2}, with short-term peaks to about 1000 associated with reflection from clouds.

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.

temperature lift – the difference in temperature between air in an enclosure and the air immediately outside it (i.e. temperature inside – temperature outside the walls of the enclosure). It can also be applied to a greenhouse and in many other contexts.

vp – vapour pressure, i.e. the partial pressure of water vapour in the atmosphere or other gas mixture

vpd – vapour pressure deficit, i.e. the difference between the water vapour pressure and the saturated vapour at the same temperature

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APPENDIX

Plate 1. Outside of the large-scale enclosed mist chamber, with data logging equipment in the foreground. Notice that the roof and gable are shaded externally while vertical shade walls are inside the polyhouse (end wall not yet covered at the time of this photo).

Plate 2. Inside the large-scale enclosed mist system. Transparent plastic dishes on stands amongst the cutting are for monitoring water deposition.

Plate 3. One wall of the large enclosure, showing the use of V-Grip to suspend the polythene from the supporting framework and to apply tension.

Plate 4. The twin-span polyhouse showing the external roof shade. Nylon monofil sewn into the edges of each piece of shade cloth and anchored to eyes in the gutters held the shade securely in place.

Plate 5. The open mist bed with surrounding polythene curtain to reduce currents of dry air from the surrounding non-misted areas. Note the plastic dishes for measuring wetting and the reflective 'hat' on the psychrometer to minimise the effect of radiation on measurements of temperature and humidity.

Plate 6. The ventilated fog house with fog lingering in the air about 10 minutes after the last operation of the fogger. The fogger is at the back left of the picture, with the air intake for forced ventilation immediately behind it.

Plate 7. *Garrya elliptica* 'James Roof' cuttings after 28 days in OM (left), EM (centre) or fog (right)

Plate 8. Cuttings of *Garrya elliptica* 'James Roof' after 28 days in fog (top), EM (centre) or OM (bottom).

Plate 9. *Cotinus coggygria* 'Royal Purple' cuttings after 28 days in OM (left), EM (centre) or fog (right)

Plate 10. *Corylus maxima* 'Purpurea' cuttings after 28 days in OM (left), EM (centre) or fog (right)

Plate 11. *Cornus alba* 'Elegantissima' cuttings after 28 days in OM (left), EM (centre) or fog (right)

Plate 12. *Magnolia soulangiana* and other additional subjects after 3 weeks in fog (top left), EM (top right), and OM (bottom left). The photograph at bottom right compares rooted cuttings at about 5 weeks (left to right: fog, EM, OM)

Plate 13. A slow moving stream of air carrying very fine droplet fog (generated ultrasonically) falls gently downward. If air currents are reduced sufficiently the fog can be contained as a blanket around cuttings.

Plate 14. View from above a 30cm polythene wall which is retaining a layer of fine droplet ultrasonic fog in a small fog 'pen'. The inverted pot and saucer make a effective distributor of the fog, which is fed in through a pipe buried in the sand. The aluminium dish is a reflective 'hat' over a psychrometer used to monitor the effect of the fog on humidity.

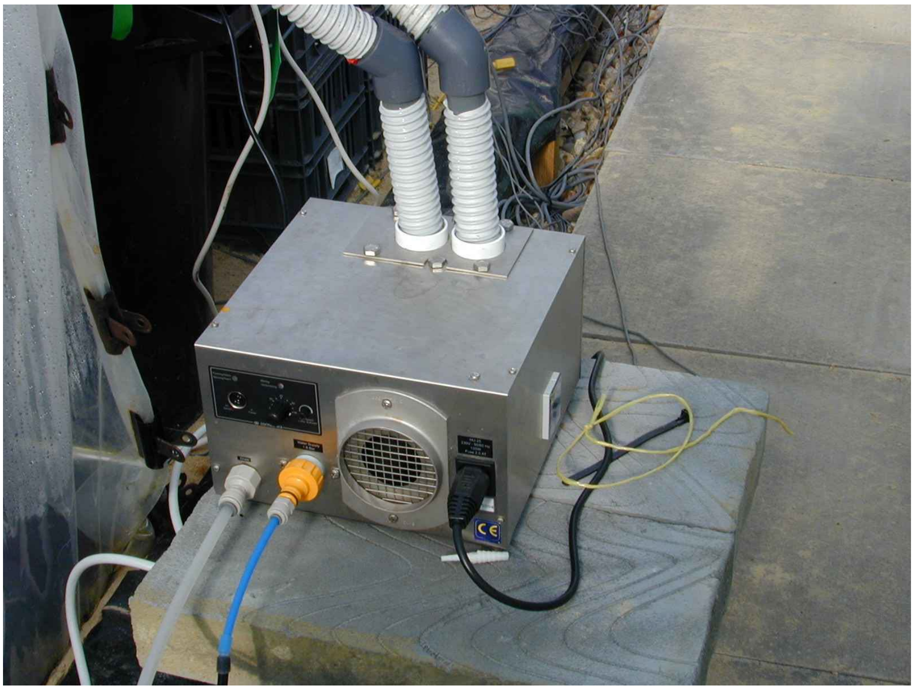

Plate 15. A small ultrasonic fog generator (Type HU-25 from Contronics (UK)). Demineralised water enters through the blue pipe, and the tank is flushed to waste at intervals through the clear pipe. Air drawn in through the grill carries fog out through the pipes at the back of the unit. The fan speed is adjustable and a humidity sensor can be used to regulate fogging.

Plate 16. The solarimeter (at the front, with a double glass dome) and net radiometer (at the back with a single inflated polythene dome) inside a E3 type enclosure for thermal radiation measurements.

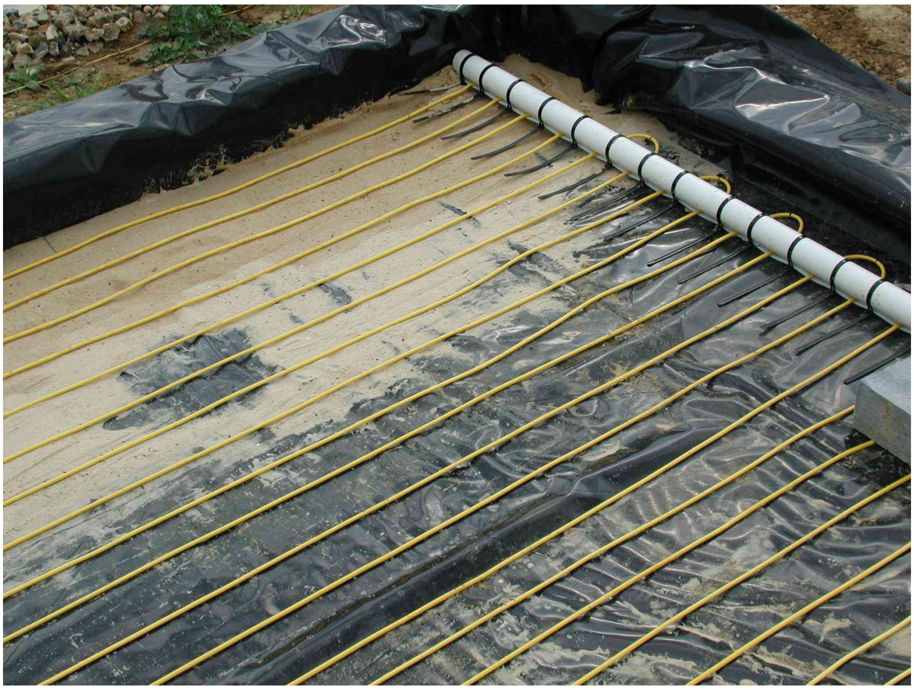

Plate 17. Construction of the propagation bed for the large-scale enclosed mist. The photograph shows the polythene liner, which covers a layer of expanded polystyrene sheets, and, on top of the polythene, the heating wires, which are held at the correct spacing by a former made from PVC pipe. A**Annual report** **Feb, 2002**
(year 2)

Previous reports **March 2001**

Key workers: **Mrs W. Oakley**

Location of project:

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