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HNS 9 PT 3

ENVIRONMENTAL COMPARISONS IN COMMERCIAL PROPAGATION HOUSES

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RELEVANCE TO NURSERYMEN AND PRACTICAL APPLICATION

Application

The purpose of this project was to assess the variability of propagation environments for leafy summer cuttings in a cross-section of commercial HNS nurseries in the south and east of England.

Using a range of equipment for measuring the environment and some designed to assess the reaction of the cutting to its total environment, it was clear that conditions differed greatly in many respects crucial to survival and rooting, both between different nurseries, and within the same nursery.

When interpreted in the light of results from experiments at East Malling aimed at improving our knowledge and awareness in this area (Harrison-Murray *et al.*, 1993) it appears likely that a high proportion of the cuttings being propagated in commercial nurseries are experiencing sub-optimal conditions.

As the market increasingly demands highly specified and high quality plants produced to agreed seasonal schedules, nurserymen cannot afford to underperform in the initial foundation stage of propagation. Done correctly, propagation becomes an essential part of the production of high quality plants in a short time. Done incorrectly, it undermines efficient production, often leading to added cost rather than added value.

Summary

Eight nurseries were visited in which attempts had been made to produce good propagating conditions for summer cuttings, using either hand watering under polythene, or automatic mist or fog systems.

Visits took place in July and August 1989, in warm sunny weather. Since then the development of novel and improved equipment for assessing propagation environments has progressed rapidly at East Malling, and the final assessment of the many data collected on the eight commercial nurseries using earlier equipment has been delayed until we could be sure of their correct interpretation in the light of these improvements.

Considering the central importance of cutting propagation to the major container-based sector, there is a worrying lack of awareness among nurserymen of what constitutes a good environment for propagating leafy cuttings.

This view is supported by the very variable conditions observed on the nurseries visited, details of which are given later in this report, and focus attention on the continuing need to identify optimum environments as seen from the perspective of the cutting, and to indicate ways of providing and controlling these environments.

It is of further concern that, as well as finding large variations in important factors such as light intensity, relative humidity and leaf wetting between nurseries much as expected, there were similar large variations within the propagation areas on the same nursery. These were often the result of deficiencies in control equipment, low water pressure, partially blocked nozzles and inadequate enclosure of the environment.

It was also obvious that nurserymen still relied on considerable attention from skilled propagation staff to maintain even the present modest levels of environmental control, much of which was needed to counteract these mechanical deficiencies.

However, this often failed to achieve the desired effects. For example, the almost universal manual opening of vents frequently reduced relative humidity more than it reduced the high afternoon temperatures as intended. The most useful manual input was spraying-down to reduce both the internal variation and the effects of particularly stressful times of day.

The diversity of plants, attitudes and objectives within the UK HNS industry is so great that it is not realistic to seek one optimum environment. Instead, we need to understand how to make the different systems favoured by nurserymen, ranging from simple polythene to automated fog, perform in the best possible way. To achieve this we need to understand the relative importance of the different but interdependent components of the environments produced by these different systems, so that their intrinsic drawbacks can be managed and their opportunities exploited. Ideally, the system should respond rapidly and effectively to continually changing weather conditions, recognise the needs of different types of plants and require minimal attention. These are the objectives of ongoing work.

EXPERIMENTAL SECTION

Introduction

The hardy nursery stock industry propagates an estimated 200 million cuttings per year to supply the important container-growing sector. The majority are leafy cuttings propagated in summer, when they are subject to varying degrees of water stress which contributes to failure and/or delayed rooting. Failure rates vary with variety and local propagation conditions. An overall cutting loss of 25% equates with an immediate financial loss of £8 million, in terms of the value of the rooted liners (at 16p each in their modules) before containerisation. Less-than-optimal propagation performance has detrimental knock-on effects in addition to reduced output, including difficult weaning, slow establishment and growth, and poor batch uniformity with the need for regrading, all leading to added cost and a high financial penalty, rather than added value. Successful and efficient propagation sets the scene for fast and cost-effective production with minimal management problems and the ability to target markets with the required products.

This report describes conditions on eight commercial nurseries in terms of a range of environmental factors likely to be important in the rooting of cuttings. Because, subsequent to these nursery visits, we recognised the need for further development of our novel environmental measuring equipment so as to better predict rooting we are not able at this stage to categorise precisely the nurseries in terms of their suitability for rooting cuttings, although general comparisons are possible against the standards set-out in the environmental comparisons at East Malling (Harrison-Murray *et al.*, 1993).

Materials and methods

Protocol

Eight nurseries were visited during the relatively hot summer of 1989, mostly for one day each, but sometimes for longer. Many data were collected automatically and continuously, as well as by manually-read instruments. The data were analysed and summarised with the identity of nurseries remaining confidential.

A conscious decision was made to delay reporting the outcome of these investigations because our basic understanding of which, and to what extent, environmental factors determine the rooting success of cuttings was developing rapidly, both through HDC projects HO9 and HNS27, and in our associated MAFF work.

Central to this progress has been our progressive development of novel environmental measuring and control equipment. In particular, our ability to assess "potential transpiration" as an indication of the water loss from cuttings, has improved as we developed a succession of instruments which more accurately reflect the relative importance to cuttings of light intensity, humidity and leaf wetting. The early instrument, which can be described as a "volumetric evaporimeter", effectively distinguished different environments, but the correlation of these measurements with rooting was relatively poor because the instrument failed to take sufficient note of the importance of leaf wetting. Our new "electrical evaporimeter" is better in this respect, and so interpretation of the original data has benefited from the insights that have come from using it to monitor and control both fog and mist systems.

This is an ongoing process; for example, not only is the electrical evaporimeter undergoing further improvements to equate more accurately with the "cutting's eye view" of the environment, but other equipment has been developed to describe for the first time the water available from the compost which should balance the losses due to transpiration.

Observations

The type of nursery and production system used were described, and the propagation area inspected to identify sites suitable for taking measurements. These sites included not only the typically representative areas, but also any locally wet/dry, bright/dark or otherwise visually different areas. A record was made also of the weather, management practices, location of nursery and the types of cuttings being propagated at the time of the visit.

Measurements

Light transmission *

Light levels outside and at cutting height in the propagation environment were recorded using cross-calibrated quantum sensors measuring photosynthetically active radiation (PAR) in the 400 to 700 nm range. Using these values, the percentage of outside light reaching the cuttings was calculated.

* measurements made automatically and continuously

Air temperature and temperature lift *

Screened, cross-calibrated thermistors measured air temperatures both outside and in the propagation environments, the difference giving 'temperature lift'.

Compost temperature *

Measured using thermistors inserted into the compost at cutting base depth.

Humidity and vapour pressure deficit *

Humidity was measured using aspirated, wet and dry bulb psychrometers. The data from these instruments were used to calculate two distinctly different measures of humidity. The familiar term *relative humidity* (RH) is a measure of water vapour content of the air *relative* to how much water the air can hold at the same temperature. Less familiar is the term *vapour pressure deficit* (VPD), which measures in *absolute* terms how much the air is below saturation. As such, it is a more reliable measurement of the drying power of the air and is an important part of the driving force for transpiration which causes cuttings to lose water. Nurserymen are more likely to have access to relative humidity data, so when considering whether RH is high enough they should think in terms of how much below saturation (i.e. 100% RH, and 0 VPD) the readings are, remembering that for a given % RH, VPD is higher at higher temperatures (Figure 1).

Net water deposition

Water deposition (i.e. wetting) is of great importance, but is impossible to measure accurately because some of the water evaporates too quickly. Net water deposition (NWD) is the difference between water applied by the propagation system and that which evaporates, i.e. water surplus to evaporation.

Water was collected into transparent dishes of known area, which were weighed to the nearest milligram at set intervals. The use of transparent dishes minimised radiation-driven evaporation so that NWD came as close as possible to the actual water deposited. The data are presented as mm per day (in the same way as rainfall) for ease of interpretation. Typical areas were identified as well as locally wet and dry zones.

Potential transpiration

Novel sensors (of HRI design and manufacture - Harrison-Murray, 1991) were manually read at set intervals in an attempt to measure the potential for water-loss by cuttings and hence the general stressfulness of the environment. The sensor responds to irradiation, humidity (VPD), and wetting (NWD), as well as air movement. Values obtained from these sensors were compared to those for PAR and VPD for the same period to see how well the propagation system coped as these factors varied (Figure 2).

Generally, high VPD (lower % RH) increases potential transpiration, as does increasing PAR, whereas increased NWD (wetting) tends to suppress potential transpiration up to a limit.

It must be remembered that the effects on the *potential* for cuttings to lose water cannot be separated from the responses of the cutting (such as stomatal closure) which regulate how much of that potential is realised. The response of these sensors, in the

* measurements made automatically and continuously

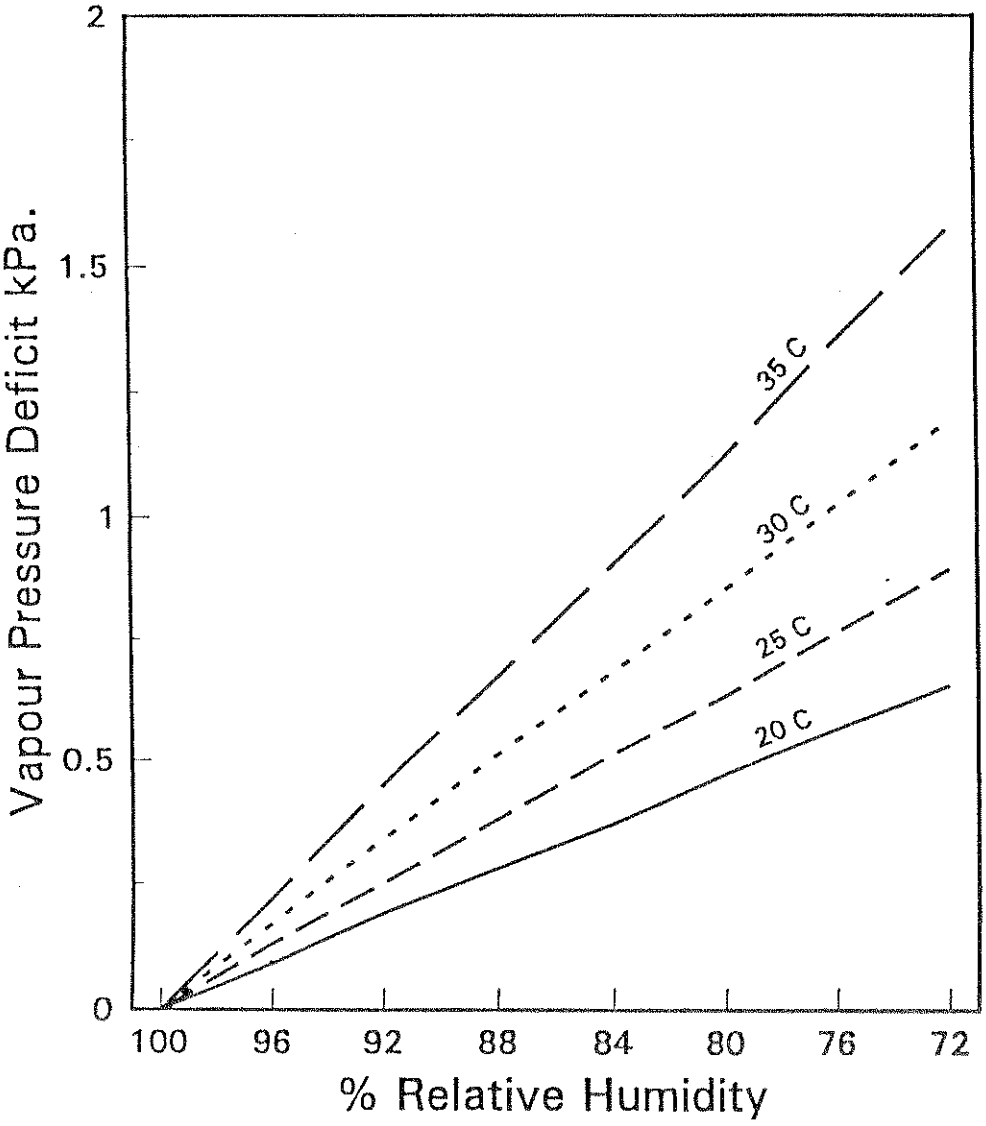

Figure 1. The effect of temperature on the relationship between vapour pressure deficit (VPD) and relative humidity.

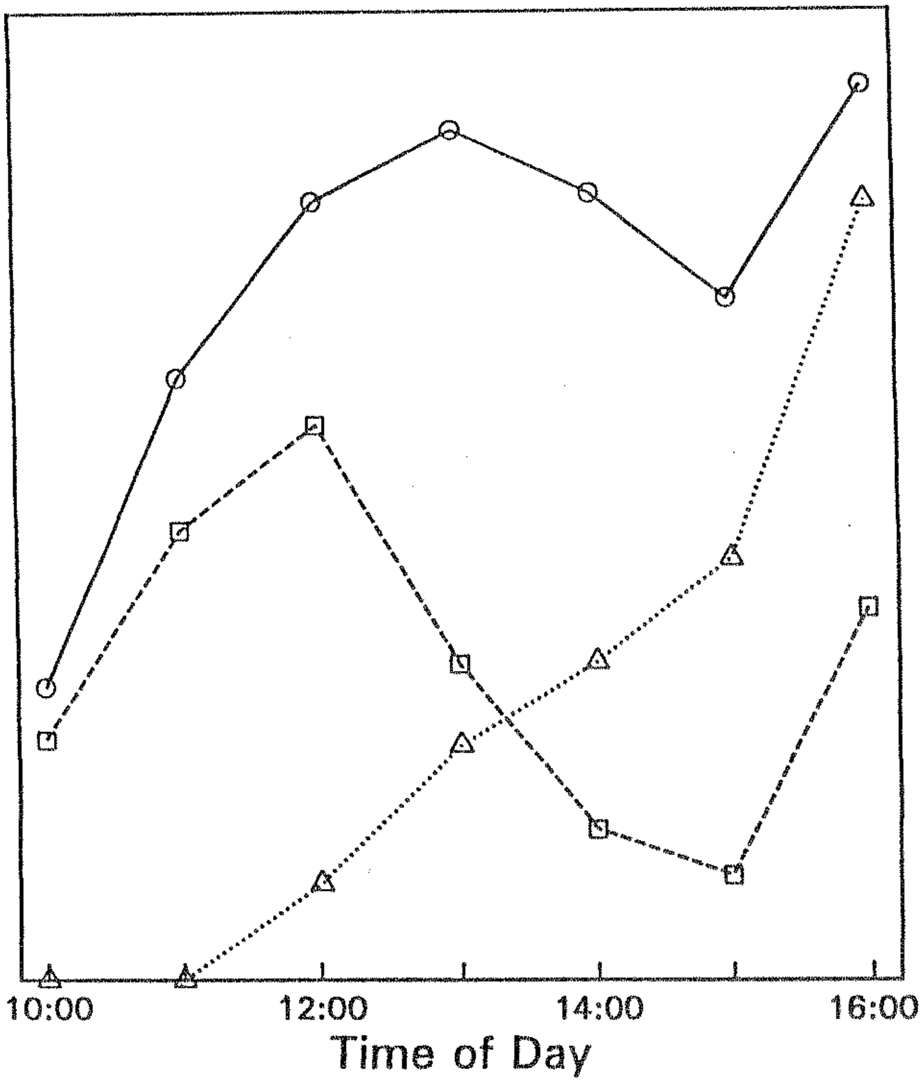

Figure 2. Typical timecourse of potential transpiration (solid line), vapour pressure deficit (dotted line), and light intensity (dashed line). Notice how potential transpiration is affected by both light and VPD.

context of our ongoing programme, possibly underestimates the importance of wetting of cuttings and the interpretation of the data collected is adjusted in the light of this.

Cautionary Note:

Many of the measurements made relate to each other and care should be taken to avoid considering factors in isolation. The interactions are many and complex and the type of propagation facility and its control system will play a part in the response of both the propagation environment (relative to outside) and the response of the cuttings within that environment.

Discussion and proposals for improvements are illustrative of what might be done in a particular situation; in the absence of other relevant information they are not intended as specific recommendations for particular nurseries.

Results

Nursery A

Description

A nursery in the south of England producing a number of more specialised and difficult subjects, including Magnolias and Japanese maples. The visit took place on a very hot, still day in early July. A conventional mist house, partially insulated with bubble polythene, was used, with manually operated ventilation. Frequency of misting was controlled by a radiation sensor.

Assessment of Propagation facilities

Light transmission

Overall between 29 and 36% of outside light, but about 20 to 25% near a heavily shaded end wall.

Air temperature

Already 32°C at 10.00 hrs, rising to 36°C by the time vents were opened, although this had very little effect on temperature. Variations in afternoon air temperatures reflected changing light levels (photosynthetically active radiation - PAR). Extrapolating from East Malling data, the maximum temperature lift from outside to inside the house was about 5°C.

Compost temperature

Temperatures in a tray of compost were between 26 and 31°C, which were well above the minimum set-point for the underbed heating.

Humidity

RH was rarely above 85%, despite the lack of ventilation. When vents were opened slightly (12 mm) in an attempt to reduce air temperatures, the humidity fell rapidly to 70%. Increased cloud cover in the afternoon reduced light intensities and air temperature, allowing RH to return towards 85% by the end of the day.

VPD doubled from 0.75 to 1.60 kPa when vents opened, falling slowly back to 0.75 kPa later in the day.

Net water deposition (NWD)

This was between 0 and 19.2 mm/day when measured in dry and wet areas respectively. It decreased in the afternoon when the lower light intensities reduced misting frequency.

Potential transpiration

This varied with location in the house and hence wetting, but generally over the day it also reflected variation in light intensity and relative humidity (and hence VPD).

Discussion

Restricting ventilation was relatively ineffective at controlling water loss from cuttings, simply causing a rise in air temperature. Typically, leaks in glasshouses are such that, even with vents closed, humidity cannot be kept above 85% on sunny days. Conditions were better in areas receiving more generous misting, and this is an example of where installation of a pump to counteract the poor mains pressure would help improve the uniformity of water distribution. In this particular nursery the drier areas were being exploited to meet the requirements of appropriate subjects, and for weaning, but dependency on staff awareness was thereby increased.

Consideration could be given to enclosing one mist bed under polythene to achieve a further reduction in stress for sensitive subjects. Ventilation could then be increased around the less sensitive subjects under open mist to ävoid excessive temperatures in the enclosed benches. The next improvement would be to install a moveable shade screen to reduce light during prolonged sunny weather, but this would probably be difficult and expensive in this old house.

On the basis of the data collected on a very hot day, this is an inherently variable and stressful environment giving little opportunity for control, in which good results depend on careful and frequent manual attention by the experienced staff.

Nursery B

Description

This nursery in the South East produces only 10% of its plants from cuttings. It used a modern glasshouse, within which was a smaller glass-walled fogged compartment utilising a novel, home-made system based on mains water pressure and 80 p.s.i.

compressed air. Fogging was under humidity control and distribution was via two horizontally operated nozzles mounted on one wall. Shading and ventilation were adjusted manually, and this extended to the adjacent weaning area in the remainder of the house.

The visit was made in mid-July on a hot, bright day with some cloud.

Assessment

Light transmission

Depending on location this varied between 28 and 40% until extra shade was applied, which reduced the range to between 13 and 20% in the afternoon. In the adjacent weaning area, light transmission was 57 to 72%. After weaning, newly potted-on material was transferred to a separate tunnel and temporarily covered with shade material. Light transmission there was 39 to 45% with shade and 72 to 87% without shade.

Air temperature

In the fogged compartment this rose from 26 to 33°C in the morning, until the vents were opened about 12 mm. This, and particularly the lower light intensities resulting from extra shading, caused air temperature to fall back to 29°C. Temperature lift was 4 to 8°C, falling to 3.5°C when vents opened. In the weaning area air temperatures of 22 to 26°C (0 to 2°C lift) were recorded. However, watering of plants and paths in this area effectively cooled it so that the afternoon temperatures of 22.3 to 25.0°C were up to 1.7°C *below* outside temperature.

Compost temperature

This was in the range 24 to 32°C, which was above the 20°C minimum set point.

Humidity

RH varied only by 4% all day, falling from 98.7 to 94.7% in the morning, with little change when the vents opened. The addition of extra shade returned RH to 97.5% in the afternoon. In the weaning area RH fell from 76% to 53%. Hosing-down increased humidity temporarily to 68%, but this fell to 54% within an hour.

VPD was relatively low, but increased five-fold from <0.05 to 0.26 KPa as temperatures increased during the morning, falling to 0.10 kPa with extra shade. In the weaning area VPD's of 0.60 to 1.50 kPa were measured (similar to those in the propagating house of Nursery A), falling to 0.90 kPa after watering.

Net water deposition

This ranged from 0 to 6.5 mm/day, but much of this variation was predictable, with a reducing gradient away from the nozzles. Local dry zones occurred very close to and between the nozzles. NWD also varied with the time of day, which related to the changing light intensity, temperature and VPD.

Potential transpiration

This increased during the morning, then fell in the afternoon as light intensity decreased, despite the vents being slightly open. Highest values were recorded furthest away from the nozzles, and in the locally dry areas. The weaning areas were more stressful and the growing tunnel even more so, as would be expected.

Discussion

To avoid the strong gradients created by these nozzles thought should be given to replacing them with purpose-built units and providing a larger compressor to cope with peak demands. This is an example of a very variable environment, some parts of which were relatively stress-free, but other parts highly stressful. The drawbacks of manual shading and ventilation were less significant against this background.

Nursery C

Description

A very large, computer-controlled glasshouse in the south of England, being part of a large production area. A high pressure distributed fog system was used, with additional overhead irrigation to increase wetting when high temperatures necessitated opening the vents. The fog was controlled via both light intensity and humidity sensors. Two diagonally opposed circulation fans and four times the recommended nozzle density were used to try to improve uniformity. The visit took place on a warm and sunny day in early August.

Assessment

Light transmission

Depending on the time of day this varied between 15 and 19% of outside light, although up to 21% was recorded near the edges of the glasshouse.

Air temperature

This rose steadily from 26 to 33°C despite the vents opening. Temperature lift was 8 to 12°C above outside levels.

Compost temperature

This was in the range 26 to 31°C and well above the minimum set point for the underfloor heating.

Humidity

In the morning RH was maintained above 99%, with no adverse effect when vents opened. From 13.30 hrs onwards there was an erratic fall to 94.5%, most likely due to higher air temperatures resulting from increased light intensity.

VPD was almost zero for the morning, rising to about 0.25 kPa in the afternoon.

Net water deposition

This was between 0.09 and 2.92 mm/day, most variation being due to blocked nozzles, with less predictable variations around individual nozzles. Most areas were drier in the afternoon when temperatures and evaporation were higher and humidity was lower, despite fog being under RH sensor control.

Potential transpiration

This varied in relation to position and time of day, and hence wetting. It increased in the afternoon, with the higher light intensities, and higher VPD. The highest values were mainly recorded in areas where wetting (NWD) was lowest.

Discussion

Although this was a very high specification unit, extreme temperatures (up to 45°C) had been recorded; wilting was evident in the afternoon of our visit. In view of the large size of this unit, environmental variations were remarkably small, due no doubt to the high density of nozzles. Such variations in wetting that were observed seemed attributable to blocked nozzles which occurred despite thorough filtering. Modifying the system to ensure that nozzles never dry-out between fog bursts might help by minimising scale deposit.

The system clearly failed to increase fog output in the afternoon sufficiently to compensate for the higher light intensities. This was probably partly the fault of the control system and partly inadequate output capacity of the fog. More frequent use of the irrigation nozzles to supplement the fog would help, but lack of any positive drainage from the concrete floor imposed a fundamental difficulty by limiting the amount of water that could be applied. A few centimetres depth of sand covered with capillary matting could provide adequate drainage in a section of the house used for stress-sensitive subjects. It is then likely that ventilation could be increased to reduce excessively high temperatures.

Nursery D

Description

A South East nursery producing plants mainly for the landscape garden market, using a manual propagation system. Well-sealed polythene tents provided a very humid environment, with additional hand watering as necessary. The tents are within a very well ventilated tunnel which had a double-skinned roof and a single layer of shade, and which is used also for weaning recently rooted cuttings. The weather during the visit, in mid-August, was warm and breezy.

Assessment

Light transmission

This increased from north to south and varied during the day between 13 and 16% of outside light. Shading was achieved by using two shade layers of white polythene as well as another acting as roof shade on the tunnel. In the weaning area, which had a single layer of shade netting, light transmission was 16 to 28%. The remainder of the tunnel received 35 to 39% of outside light.

Air temperature

In the propagation tents this was 29 to 35°C, although watering caused a rapid but temporary fall of 3.5°C. Temperature lift inside the tents was in the range of 5.3 to 11.0°C. The temperature in the remainder of the tunnel was 26.0 to 29.5°C, falling with the lower light intensities in the afternoon to 25.5°C. This represents a temperature lift of 2 to 5°C.

Compost temperature

This was in the range 25.0 to 30.5°C, with very little effect of watering.

Humidity

RH in the propagation tent fell from 99 to 93% until watering brought it back to 100%. It then fell back to 97% by the end of the day. In the rest of the tunnel, RH was in the range 45-63%. Higher light intensities and air temperatures were associated with the lower RH, and watering increased RH temporarily.

VPD was 0.06 to 0.38 kPa in the propagation tent and 1.45 to 2.10 kPa in the rest of the tunnel.

Net Water Deposition

Apart from occasional hand watering, no water was applied. However, drops from the condensation on the roof of the polythene tent, and the high humidity, kept the cuttings looking wet all day.

Potential transpiration

This increased 50% from north to south along the length of the propagation tent, due to increased light intensities at the southern end. There was also greater potential transpiration around midday due to the increase in light intensity. In the shaded weaning area, potential transpiration was approximately 70% higher than in the propagation tent. When recently transferred cuttings started to wilt in this area hand watering rapidly reduced potential transpiration to 35% *lower* than that of the propagation tent.

Discussion

The high temperatures in this closed polythene tent system, whilst not obviously detrimental to the cuttings, could be reduced by increasing the proportion of shading on the tunnel generally, and reducing it on the polythene propagation tents. By hand-watering with a fine spray this simple tent system was improved to become somewhat like enclosed mist. The requirement for frequent attention by skilled staff means that problem are seen quickly, but too frequent opening of the tents would itself be stressful, which puts a limit on the quality of the environment that can be achieved in this way.

Nursery E

Description

A large, traditional, timer-controlled open mist glasshouse in the south of England, visited in mid-August. Vents were operated manually, as was the reflective shading, which was mainly mounted internally. A number of species including *Berberis* and dwarf rhododendrons were propagated in large numbers. During the visit the weather was mild and breezy, with sunny spells between overcast showery periods.

Assessment

<u>Light transmission</u>

This varied between 10 and 17%, with the highest values in early afternoon, and at the ends of the house.

<u>Air temperature</u>

This was between 19.6 and 26.0°C, varying with the time of day and light intensity. A temperature lift of up to 6°C was recorded, although it was generally nearer 2°C and occasionally zero, due to very generous ventilation and heavy shade.

<u>Compost temperature</u>

This was above the set point for bottom heat and followed air temperatures inside the house.

<u>Humidity</u>

RH was between 76 and 86% until early afternoon. It then fell to levels as low as 57 to 65% before recovering a little to 70% by the end of the visit. With open vents and a mild breeze, this pattern probably reflects the fact that the timer control was not responding to higher light intensities and the falling RH in the afternoon.

VPD was between 0.32 and 1.41 kPa.

Net Water Deposition

This ranged between 0.19 and 9.4 mm/day in the driest and wettest locations respectively. Up to four-fold differences were measured along individual mist lines, and between different lines. Some areas showed distinct patterns of wetting, with cuttings losing leaves in the drier zones, where NWD was a quarter of that in the adjacent wetter areas where no leaf-drop occurred.

Potential transpiration

This showed a good relationship to light intensity, higher in the afternoon with increased VPD. Variations within the house were related also to NWD (wetting), with the drier sites having the highest potential transpiration.

Discussion

Free ventilation and heavy shade helped keep temperature lift low, but the low humidity emphasised the drier areas making some parts of the house very stressful, even on this overcast day.

Increasing light transmission would help rooting via increased photosynthesis. Some mist beds could be enclosed in polythene or supplied with fog to provide higher humidity for more stress-sensitive species. The use of a radiation or wetness sensor to control misting would allow the system to respond to changing weather.

Nursery F

Description

Utilising old, manually vented glasshouses in the eastern counties, this nursery only starts propagating after the peak of high summer temperatures. A modern, high pressure distributed fog system under humidity control was just starting to be used when we visited in late August. A general range of ornamental material was produced, much for local authority use. The weather was hot, sunny and breezy.

Assessment (over a 24 hour period)

Light transmission

This ranged between 16 and 21% depending on location and weather.

Air Temperature

A smooth diurnal pattern was recorded, falling from 31°C with the vents open on the first day, to an overnight minimum of 18°C, then rising steadily to 33.5°C on the second day (with the vents closed). This represents a temperature lift of around 4°C at each end of the day, with up to 9.5°C overnight and 8°C on the second day when vents were closed.

Compost Temperature

Bottom heat was not used, so temperatures of 22°C overnight to 27°C during daytime reflected air temperatures.

Humidity

Under humidity sensor control (set at 95-97%), RH was maintained between 93 to 96% on the first day, depending on location and despite the vents being open. Overnight RH was 95-97% (although the humidity control was turned down to 93%). On the second day, with the vents closed, RH ranged between 85 and 99%. The large fluctuations were most likely due to the varying light intensity and to the number of people coming and going during spells of propagation work.

VPD fell from around 0.25 kPa to <0.05 kPa overnight and then rose to 0.59 to 0.77 kPa on the second day, depending on location and light intensity.

Net water deposition

This ranged from 0.12 to 2.59 mm/day depending on location and time. Overnight, very little NWD occurred. The following morning, 10-fold variations were measured, and patches of wet and dry leaves were visible. Much of this variation was due to predictable gradients around the fog nozzles. Local dry spots also occurred under partially blocked nozzles. Later in the day the house became wetter and variation decreased to between three and four fold.

Potential transpiration

This increased with higher light intensities and VPD during the early part of the day. Lower VPD and increased wetting near midday reduced potential transpiration, although it continued to rise in the drier areas of the house.

Discussion

Thought might be given to enclosing the fogged areas in polythene to allow greater ventilation and cooling in the house generally, without loss of humidity around the cuttings. Reflective shade may also help reduce temperature lift and possibly allow propagation in the peak summer months.

The full potential of the fog system is limited by the condition of the old glasshouse and the need for manual venting, although this did not appear to have an adverse effect on VPD. A relatively low stress but variable environment was achieved.

Nursery G

Description

A nursery in the south of England, producing a general range of ornamental material. A well-sealed, polythene-enclosed, distributed dry fog system was used, inside a manually ventilated, well-shaded glasshouse. The enclosure was divided by a polythene curtain into two halves, each under independent humidity control and at different shade levels. A timer was used to switch off the fog overnight. Set points for humidity control were 99% RH under the heavier shaded half and 97% RH in the other half of the house. The visit took place in late August and the weather was hot, bright and breezy.

Assessment

Light transmission

The nominal "high humidity" section received between 6.2 and 7.2% light transmission and the relatively "low humidity" section 9.6 to 12.0% light. The lowest values in both halves were recorded in the afternoon.

Air temperature

With the well-ventilated space above the fogged enclosures, the heavy shade levels and the breezy weather, temperatures at cutting level rose from 22.5°C to only 30.6°C in the heavier shaded areas, and up to 32°C in the other area. Temperatures fell a little towards the end of the day.

Temperature lifts of up to 5.9°C and 6.4°C early in the day fell later to only 1.5°C and 2.2°C for the two areas, despite the hot, sunny weather.

Compost temperature

This was above the set point for the bench heating and was in the range 19 to 27°C.

Humidity

In the "low humidity", higher light intensity compartment, RH was 88.5 to 96.3% despite the controller being set at 97% RH and showing 99% RH whenever it was observed. The infrequent short bursts of fog in this area increased humidity temporarily. In the adjacent "high humidity", lower light intensity compartment, RH was 91.6 to 98.2%, with a 99% RH set point. Again, the controlling humidity sensor was over-reading at 102% RH whenever observed and no fog was visible in this area all day. In both areas RH fell during most of the day until in mid-afternoon it increased a little when the light intensity decreased and paths were watered.

VPD increased from 0.05 to 0.35 kPa and from 0.14 to 0.46 kPa in the higher and lower RH areas respectively. A fall to 0.24 and 0.17 kPa respectively corresponded with lower light intensities and associated lower air temperatures later in the day.

Net water deposition

No NWD was detected all day in either compartment despite some fogging. The leaves of cuttings however, appeared wet all day.

Potential transpiration

This increased during the morning, peaking around 1400 hrs along with a high VPD, air temperature and light intensity. It then fell a little during the remainder of the visit. Potential transpiration was 20 to 40% lower in the higher humidity area than in the lower RH area, due to the lower light intensity and VPD.

Discussion

It is likely that this propagation unit would benefit from recalibrating and checking the humidity sensors controlling the fog. More effective control would allow an increase in light intensity by reducing shade with likely benefit to rooting via increased photosynthesis.

The exceptionally heavy shade and well-sealed enclosure compensated to some extent for the inaccuracies of the control sensors and meant that very little water was applied to cuttings which were probably receiving far too little light. Free ventilation above the enclosures helped to keep temperature lift very low, despite outside air reaching 28°C.

Nursery H

Description

A large glasshouse complex in East Anglia producing plants for retail outlets and garden centres. A quarter of a large multi-bay glasshouse was further compartmentalised using heavy, weighted, PVC curtains. This provided a number of different propagation environments, including the following:

i) Compressed air-type fog (Macpenny type) adjusted to create relatively wet fog, under humidity control, set at 70% RH

ii) Compressed air-type fog (Sonicor type) adjusted to give dry fog, under humidity control set at 96% RH

iii) Open mist controlled by wetness sensor.

In all environments, ventilation and shading were automated. The weather at the end of August was breezy and warm with sunshine and overcast spells.

Assessment (NB. It was not possible to make all types of measurements in all environments)

Light transmission

The automated shade operated in the middle of the day when light intensities were increasing. The table on the next page summarises the light intensities in the three types of environment:

	-Shade	+Shade
Dry fog	42%	10%
Wetter fog	36%	6%
Mist	77%	17%

Air temperatures

In both fog systems temperatures rose from 22.4°C to 29.0°C with no obvious effect of the additional shading. Later in the day, as light intensity fell, air temperatures also fell to around 26°C. The air temperature in the rest of the glasshouse was 26 to 31°C; the temperature of the fogged compartments was therefore 2.5°C *below* this value, most likely due to lower light intensity and to evaporative cooling.

Compost temperature

This was above the 18°C minimum set point for bottom heat and was in the range 22 to 25°C for the dry fog area.

Humidity

In the dry fog (with a set point of 96% RH on its controller), RH was measured as 100% in the morning, falling to only 80% by the end of the day. In the wetter fog (set at 70% RH on a different type of controller) RH fell from 82% to 69%.

In the drier fog, VPD was 0 to 0.69 kPa, with fluctuations relating to changes in light intensity. In the wetter fog VPD was 0.48 to 1.13 kPa, with less obvious relationship to light intensity, and more effect of the breezy conditions exacerbated by the poorly sealed compartment and opening of doors.

Net water deposition

In both fog environments NWD was very variable. In the wetter fog, highest absolute values and greatest variation of 0 to 16.6 mm/day were recorded, with the drier fog having 0 to 5.6 mm/day. The misted area was intermediate between the two fog systems at 5.9 to 13.3 mm/day, with much less variation and no obvious dry areas. An open part of the glasshouse was also being used as extra mist space and NWD here was in the range 1.15 to 5.10 mm/day, the lower values, compared to the misted compartment, probably being due partly to the relatively higher evaporation rate.

In all misted areas and in the wetter fog, highest NWD occurred in the afternoon because the lower light intensities caused less evaporation. The area of drier fog, however, was less wet in the afternoon, because this system couldn't respond to increasing VPD.

Potential transpiration

In all environments potential transpiration followed fluctuations in light intensity, with the additional driving force of high VPD in the afternoon. The overall pattern for the day was an increase in potential transpiration in the morning, falling when extra shading was applied and rising to peak values at the end of the day when shade was removed. The greatest variation was seen in the wetter fog system, but variation between fog and mist systems was minimal and appeared to relate more to light intensity differences.

Discussion

The wetter fog system could work as a dry fog system (as intended) if its pressure regulators and nozzles were properly maintained, and this would also level out the extreme locally wet and dry areas. The roofs of all environments were made of porous shade material, so passive ventilation along with leaking of fog/humidity could occur. Thought should be given to enclosing the different areas with a sealed polythene roof, thus decreasing VPD and allowing free ventilation in the house to assist cooling.

Overall, this range of environments provided some interesting contrasts. The traditional mist system gave the least variable environment and was possibly no more stressful than the fog systems. Both fog systems were, in contrast, highly variable and in need of more regular and enthusiastic management to fulfil their potential.

Discussion

The propagation facilities of the eight nurseries in this survey ranged from large, mainly automated, units to small entirely manual ones, with polythene, mist and fog systems, differing methods of control, and various forms of glass and/or polythene structures. As such they were a representative selection of the UK HNS sector.

The considerable extent to which skilled staff were still required to apply ventilation, shading and water by hand was a measure of the pressing need to identify ideal environments for cutting propagation and to develop the necessary equipment and control systems.

The measurements of various environmental parameters taken during these visits adequately highlight the large differences between nurseries in propagation-relevant conditions. The relative importance of different combinations of environmental factors on the rooting of cuttings was described in relatively controlled comparative experiments at East Malling (Harrison-Murray *et al.*, 1993). Because our understanding of the environmental needs of cuttings is still being improved, partly through the development of more relevant environmental monitoring equipment, it is not sensible to ascribe a "propagation quality index" to these sample nurseries at this stage.

Once the needs of cuttings are better understood in environmental terms, including the contribution of the compost, environmental targets can be described. These are likely to be useful in at least two ways. Firstly, plants will be classified in groups on the basis of criteria which determine their environmental preferences, and the best ways of achieving a limited range of ideal environments can be described.

The need for this approach can be judged from the largely uncontrolled variation discovered in the course of these visits:

Light transmission ranged from 6 to 77% of outside light within one nursery (Nursery H) depending on the degree of shade, and associated with a variety of wetting/humidifying systems.

Between nurseries there were many-fold differences in light transmission (e.g. Nursery A - 29-36%, Nursery G - 6.2-7.2% in the heavy shade section).

The cuttings at Nursery A experienced drying conditions in its propagation area, as measured by vapour pressure deficit, similar to those experienced by cuttings in the weaning area of Nursery B.

Considerable local variation occurred, with solid walls increasing shade, but edges of benches sometimes receiving more light than the interior of the house.

Light drives photosynthesis, and in general the more light that a cutting receives within certain limits the more likely it is to develop a strong root system, but its ability to benefit from high light depends on how well the propagation system limits the increased tendency to lose water and avoids excessively high temperatures. Little is known about critical temperatures that might cause direct damage, but high temperatures increase respiration rate and so deplete carbohydrate. For a number of reasons it also becomes more difficult to restrict water loss as air temperature increases. The air above the cuttings was almost invariably hotter than that outside the house, up to 12°C higher in Nursery C. In almost all cases maximum daily temperatures above the propagation bench exceeded 30°C, and raised the temperature of the compost considerably above the minimum required.

It was commonly found that applying ventilation was relatively ineffective at reducing air temperature, frequently reducing relative humidity more significantly. None of the systems examined incorporated an effective way of reducing temperature without reducing humidity, as is possible with "wet fog" (Harrison-Murray *et al.*, 1993).

Relative humidity differed greatly between nurseries, being high in houses supplied with distributed fog (Nursery B - 95-99% RH, Nursery C - 95-99% RH, Nursery F - 93-96% RH, Nursery G - 89-98% RH) and under tightly sealed polythene (Nursery D, 93-99% RH). Nursery D, however, experienced high temperature lift inside the polythene enclosures, despite heavy shade. Nurseries with mist systems suffered lower humidities (Nursery A - 70-85% RH, Nursery E - 57-86% RH), but leaves were generally wetter.

Vapour pressure deficit is a more useful measure of humidity, being an important component of the leaf-to-air vapour pressure difference that drives the transpiration process. Vapour pressure deficits were generally lower in fog and sealed polythene systems, as in Nursery B (<0.05-0.26 kPa), Nursery C (0-0.25 kPa), Nursery D (0.06-0.38 kPa), Nursery F (0.05-0.25 kPa) and Nursery G (0.05-0.35 kPa in heavy shade), than under mist as in Nursery A (0.75-1.60 kPa) and E (0.32-1.41 kPa).

Water deposition is important because evaporation of water from the outside surfaces of leaves carries with it energy that would otherwise be available for evaporation from the leaf itself. Water deposition varied widely between the different systems and nurseries. Moderate maximum levels were recorded in the mist systems of Nurseries A (19.2 mm/day), E (9.4 mm/day) and H (13.3 mm/day), while fog systems gave no NWD (Nursery G) or low amounts in Nurseries B (6.5 mm/day), C (2.92 mm/day), F (2.59 mm/day) and H (dry fog, 5.6 mm/day). The wet fog system in Nursery H deposited up to 16.6 mm/day, equivalent to mist. It was very noticeable that blocked nozzles and other mechanical problems caused large internal variation in wetting, to the extent that batches of cuttings appeared wet while others nearby were dry and wilting.

The relative significance of humidity and leaf wetting in controlling water loss from cuttings is a topic that is currently receiving close attention, including the development of monitoring equipment that recognises the apparent relatively greater importance of leaf wetting than has hitherto been suspected. The large variations in environmental conditions across commercial nurseries underline the need to develop this equipment to monitor propagation environments in ways that will allow nurserymen to optimise conditions for particular subjects against recommendations arising from ongoing research.

Glossary

Aspirated wet and dry bulb psychrometer - A device for the accurate measurement of *relative humidity* and *vapour pressure deficit* based on the temperature difference between wet and dry bulb temperature sensors screened from radiation, and with a constant velocity air stream passing over them.

Carbohydrate - Organic compounds comprising carbon, hydrogen and oxygen which are important in metabolism and energy storage. In plants sugars and starches are responsible for energy storage and cellulose is the structural building block; these compounds are formed during *photosynthesis*.

"Dry fog" - Refers to fog in which a large proportion of the fine water droplets are small enough to remain suspended in the air for a relatively long time. It can therefore keep humidity high with relatively little wetting of compost, cuttings and other surfaces. However, some wetting is inevitable if 100% *relative humidity* is required. Dry fog can be produced by nozzles supplied by water and compressed air, or by very high water pressure systems.

Electrical evaporimeter - A device which gives an electrical signal proportional to the amount of water lost to the environment by a leaf-like surface.

High pressure distributed fog - Fog systems based on the use of high pressure water, (typically 700 psi) and distributed via a pipework manifold to nozzles.

Light sensor - See **Quantum sensor**

Net water deposition (NWD) - The difference between water applied by the propagation system and that which evaporates, i.e. water surplus to evaporation.

Photosynthesis - The process by which plants use light to convert carbon dioxide ($C0_2$) and water (H_20) into *carbohydrates*. It thus provides both the energy and the basic building blocks that plants need to survive and grow, including the production of roots and new shoots by cuttings.

Photosynthetically active radiation (PAR) - That part of the electromagnetic radiation spectrum responsible for plant *photosynthesis*. This is in the 400 nm to 700 nm waveband and accounts for a little over half of the incoming solar radiation.

Potential transpiration - The potential for water loss to the environment assuming no restrictions to the water supply. It can be estimated using an *evaporimeter* and is an indication of the stressfulness of the environment.

Quantum sensor - A type of light sensor whose response matches that of photochemical reactions (such as *photosynthesis*). The type used here also only responded to the 400 nm to 700 nm waveband and therefore measures *photosynthetically active radiation.*

Radiation sensor - A general term including the *Quantum sensor* used in these studies.

Relative humidity (RH) - A measure of the water vapour present in the air. It is expressed as a percentage of that which would be present if the air was saturated and at the same temperature.

Respiration - The process by which energy is released from *carbohydrates* in the plant. In the process oxygen is taken up and carbon dioxide ($C0_2$) is given off.

Stomata - Small pore-like openings, mainly on the underside of the leaf. They have the ability to open and close and provide a means of regulating $C0_2$, 0_2 and water vapour uptake and loss, as appropriate.

Temperature lift - The temperature of an enclosed environment e.g. glasshouse, poly-tent or tunnel, above that of the ambient air outside.

Thermistor - A sensitive temperature measuring device based on a semiconductor.

Transpiration - The loss of water by evaporation via the stomatal openings on the leaf surface.

Vapour pressure deficit (VPD) - A measure of how far the air is from being saturated with water vapour. It is measured in units of pressure because the vapour pressure of water in air is a convenient measurement of its concentration.

Volumetric evaporimeter - A device to measure the volume of water lost to the environment from a leaf-like surface with an unlimited supply of water and open stomata. The measurement provides an estimate of *potential transpiration.*

"Wet fog" - Fog with a relatively high proportion of water droplets which are large enough to fall out rapidly. Centrifugal systems tend to produce this type of fog, but compressed air driven nozzles can also do so if air pressure is low, water pressure is high, or the nozzle is of a very basic design.

Acknowledgements

We are grateful to nurserymen and their staff for access and discussion during these visits.

References

Harrison-Murray, R.S. (1991). A leaf-model evaporimeter for estimating potential transpiration in propagation environments. *Journal of Horticultural Science,* **66**, 131-139.

Harrison-Murray, R.S., Knight, L.J., and Thompson, R. (1993). Understanding the environmental needs of leafy cuttings during rooting. *Horticultural Development Council, HNS Sector, Final Report,* pp 53.

Research aspect of HDC contract on conventional cuttings (IHR EM component)

1. Title of Project: The environmental component of successful propagation by conventional cuttings.

2. Background: For leafy cuttings water stress can severely restrict expression of rooting potential. Fog is more efficient than mist in reducing water loss from cuttings but research is needed to optimise its use. Rooting of leafless winter cuttings is also very sensitive to their water status.

3. Objectives:
   1. Assess the importance of suboptimal environment on efficiency of cutting propagation in the industry.

   2. Identify the criteria for a good fog system and assess the practical potential of fog.

   3. Develop simple methods for nurserymen to test their own facilities.

4. Potential Benefit to the Industry: Industry representatives estimate that as many as 200 million cuttings are taken annually of which as many as 80 million may fail. Greater attention to the propagation environment would probably greatly reduce this wastage and would broaden the range of subjects that can be propagated in this way.

5. Closely Related Work Already Completed or in Progress: A complementary MAFF-commissioned programme on less applied aspects currently operates within IHR.

6. Description of Work: The programme within the IHR will be based at East Malling but will relate to other work on conventional cuttings at Efford EHS. It is expected to consist of:-

   1. Comparisons of various mist and fog propagation systems using cuttings of a small range of subjects combined with physical measurements of the environment to identify the relative importance of factors such as leaf wetting, air movement and air temperature. This will include an experimental ventilated dry fog house which can be modified over the course of the project to act as a test bed for the current view of both the ideal environment and the most effective method of approaching this ideal in practice. It will also extend to trials on commercial nurseries to meet objectives 1 and 3.

   2. Experiments to explore the interaction between propagation environment and stresses imposed before and after rooting (e.g. cold storage and rapid weaning) will be carried out using the comparison of two extreme environments (e.g. open mist vs. ventilated 'wet' fog).

7. Commencement Date and Duration: 1st July, 1987 for 3 years.

8. Project Leader: Dr R.S. Harrison-Murray

Other Staff:
Mrs Linda Grout - ASO

9. Location: IHR - East Malling

JMH:
26/6/87

Contract between the Kent Incorporated Society for Promoting Experiments in Horticulture and ADAS (hereinafter called the "Contractors") and the Horticultural Development Council (hereinafter called the "Council") for a research/development project.

PROPOSAL

1. Title of project HO/9/87.

Conventional cuttings - leafy and non-leafy; factors for success.

2. Background

This is a major on-going project. It could be timely to review the 'state of the art'. Practical aspects of particular interest include misting and fogging, direct sticking, cheaper and quicker methods of preparation and storage.

3. Objective of this project

To improve the quality and productivity of propagation, including comparison of 'direct sticking' and 'transplanted' methods; ultimately the specification of 'ideal' systems.

4. Potential benefit to the Industry

5. Closely related work already completed or in progress

This project will be an extension of existing proven, valuable work at several stations.

6. Description of the work

The project will link with existing work at East Malling, and will explore the effects of:

a) Stock bed and the condition and type of cutting.

b) Timing of operation and handling method including comparison of 'direct sticking' and 'transplanting'.

c) Composts and aeration.

d) Composts and fertiliser additions.

e) Cultural treatments (e.g. pruning and tipping) during the rooting and early liner stage.

The range of plants to be considered will be:

B. Eleagnus pungens maculata

A. Ilex aquifolium 'Golden King'

A. 'Handsworth'

A. 'Pyramidalis'

B. Mahonia 'Bealei'

A. Prunus laurocerasus cv. 'Otto Luyken' 'Zabelliana'

B. Prunus lusitanicus

A. Pyracantha spp.

B. Viburnum tinus

B. Cornus argentea marginata?

Note A & B (A) = based on existing work, to start in Year One, with additional work on the liner to finished plant stage in Year Two.

(B) = work on cuttings to be started in Year Two and taken on to the finished stage in Year Three.

7. Commencement date and duration

Start 1.4.87 at East Malling, 1.8.87 at Efford; duration three years.

8. Staff responsibilities

Project leader: B Howard in close liaison with Ms M Scott

Other staff: R Clements

9. Location

At IHR - East Malling and at Efford EHS.

TERMS AND CONDITIONS

12. The Council's standard terms and conditions of contract shall apply.

Signed for the Contractor(s)	Signature....P. Allington....
	Position...ADAS Programme Manager
	Date.......1. 6. 87..............
Signed for the Contractor(s)	Signature...R.L. Oxley..............
	Position....Secretary KISPEH.....
	Date........29th July 1987..........
Signed for the Council	Signature...[signature]...........
	Position....Chief Executive........
	Date...........7.5.87.............