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Project leader:	Chris Burgess, CB Consultant Agronomist
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Key workers:	Chris Burgess, Project manager. Main author of report. Richard Harrison-Murray, Research Consultant. Jill England, Horticultural Consultant, ADAS. Olga Grant, HNS Researcher, EMR. Supply of logging equipment.
Project locations:	New Place Nurseries Ltd c/o John Hedger London Road Pulborough West Sussex, RH20 1AT Tel 01798 873774 Lowaters Nursery c/o Charles Carr Hook Lane Warsash Southampton. SO31 9HH Tel 01489 559334 Binsted Nursery c/o Martin Emmett Binsted Lane Binsted, Arundel West Sussex, BN18 0LL Tel 01243 551277
Project co-ordinator:	Neal Wright Micropropagation Services Brookside Nurseries Kirk Ley Road East Leake Loughborough, LE12 6PE Tel 01509 856295
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CONTENTS

Grower Summary

Headline 1

Background and expected deliverables 1

Summary of the project and main conclusions 1

Financial benefits 5

Action points for growers 6

Science Section

Introduction 7

Objectives 8

Materials and Methods 9

Results and Discussion 19

Control of rooting environment under mist 19

Rooting results 38

Grower comments from using the Evaposensor 44

Financial benefits of the project 45

Conclusions 46

Further work 48

Acknowledgments 50

Appendix A – Further technical Information for growers considering using Evaposensor control

ETS Controller – connection options and modes of use 51

Practical set-up and maintenance 54

Grower Summary

Headline

An Evaposensor and Evapomist controller improved control of the mist environment in 5 out of 6 propagation nurseries.

Background and expected deliverables

Water stress on cuttings can still occur under mist or fog because existing controllers (such as simple timers, electronic leaf, or those using solar radiation integral) can fail to match misting frequency to the needs of the cutting, especially as light level, humidity, temperature and air movement vary during the day. The Evaposensor, with its wet and dry artificial 'leaves', responds to all these factors making it possible to detect and control the evaporative demand on cuttings in a reliable and reproducible way. The Evaposensor was invented at East Malling Research by Richard Harrison-Murray, originally as a research tool for controlling mist and fog environments. It was never commercialised, partly because the commercial organisation who made the Nobel humidity controller needed to interface with the Evaposensor, pulled out of the market in the 1990's. The objective of this project was to evaluate the technical performance of the Evaposensor on nurseries against their current mist control systems, and to develop an alternative electronic interface to the Nobel, so that the Evaposensor could be commercially available to the industry. The comparative performance of the Evaposensor was also tested in terms of rooting of leafy cuttings across a range of HNS subjects.

Summary of the project and main conclusions

Principles of Evaposensor control

The Evaposensor consists of two temperature sensing 'leaves'. One leaf remains wet via a wick and distilled water reservoir, and the other 'dry' leaf gets wetted periodically by bursts of mist or fog. Unlike conventional 'wet / dry hygrometers' in an aspirated screen for measuring relative humidity, the Evaposensor is placed just above cutting height. Here it is influenced by the mist, solar radiation, air temperature, humidity and air movement – i.e. *all* the factors affecting the rate of transpiration water loss from the cutting.

- The wet leaf remains cooler than 'dry' leaf by evaporative cooling.
- The temperature difference is called the ***Wet Leaf Depression (WLD) - °C.***

- WLD is proportional to ***potential transpiration***. Hence to potential ***water stress*** on the cutting.
- During misting, the 'dry' leaf becomes wet and WLD falls to near 0 °C, reflecting the effect of mist on transpiration.
- As the 'dry' leaf dries out, the WLD rises until the ***set point*** on the controller is reached, and another burst of mist is triggered.
- ***WLD set point*** represents a ***level of cutting support*** that can be reproduced across different facilities, nurseries and seasons.
- Whatever the background environment, the system applies the amount of mist (or fog) needed to limit transpiration to the level set on the controller.

The Evaposensor is a good basis for controlling mist (or fog) in propagation, as it senses WLD in an analogous way to the 'transpiration stress' experienced by cuttings or a plant. Misting frequency is automatically adjusted along with the weather to accurately reflect changes in evaporative demand.

Facilities

The project was undertaken from summer 2007 to summer 2009 in propagation units under glass at New Place Nurseries, Pulborough, W. Sussex in Year 1, Binsted Nursery, Arundel W. Sussex, and Lowaters Nursery, Warsash, Southampton in Year 2. Both New Place and Lowaters used open mist from Naan mist units on short risers over a drained sand bed base. The sand was uncovered at New Place, giving good capillary contact and drainage with the rooting trays, whereas a woven ground cover layer over the sand at Lowaters may have interfered with optimum capillary contact and drainage on this site. Binsted had open mist from overhead lines with inverted Macpenny type nozzles. Cutting trays here were stood on capillary matting over polythene on a concrete floor base. While uniformity of wetting of trays may have been good with this system, over wetting of the rooting medium could occur under frequent heavy misting because of the lack of capillary 'suction' of surplus water from trays. Summer shading was used as necessary with whitewashed glass and / or shade screens. Shade was typically heaviest at New Place, followed by Lowaters then Binsted.

Follow-on project HNS 159a during 2009

Evaposensor control was also tested at Boningale Nursery (Wolverhampton), Living Landscapes (Chester) and Micropropagation Services (Loughborough) during 2009 for additional demonstration and promotion via Grower Walks. The Evaposensor system proved easier to manage compared to the traditional wet leaf mist control with which it was compared at two of the sites. The wet leaf system tended to apply too much mist (even at night) and sensitivity control was very unreliable. At Micropropagation Services, the Evaposensor also required less adjustment and provided an easier to manage environment for weaning micropropagated material and mini-cuttings compared to their light-sum standard control.

The development of the commercial production version of the ETS Evapomist controller incorporated several features which enhance its versatility. It can be used either as a stand-alone controller operating a single solenoid valve or linked to an existing timer or sequencer, such as a Heron or other device, to control multiple beds. **See full report for further details.**

Photo GS1. Mist propagation facility Lowaters Nursery

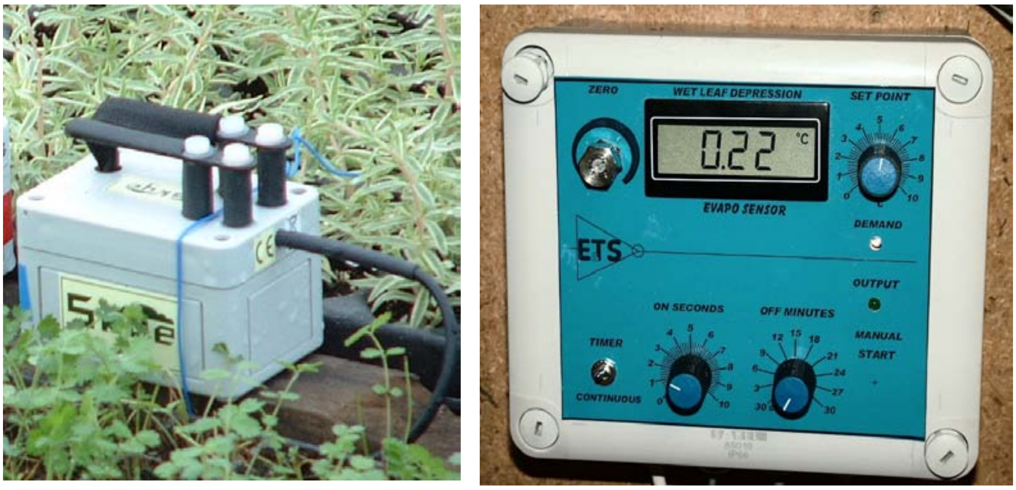


Photo GS2. Evaposensor (Skye) and Evapomist controller (ETS)

Grower comments from using Evaposensor mist control in HNS 159 & 159a

‘We have been very pleased by the simplicity of management of the device. The user interface is friendly and easy to understand… The Evaposensor beds continue to perform at their optimum without regular manual intervention, therefore at weekends and spring and autumn periods when weather can rapidly change we are not using valuable skilled staff time in making regular tweaks to the system which are sometimes missed…’

Charles Carr, Nursery manager, Lowaters Nursery

‘The advantage of the Evaposensor system is that it automatically takes care of day-to-day weather changes which in the main do not happen [with the timer based system]… The fact that we have already installed two Evaposensors underlines our commitment towards further expansion of the system. I am particularly keen to look at it in polytunnels.’

John Hedger, Managing Director, New Place Nurseries

‘It has been an easy system to adapt to and change from the conventional leaf system. Very quickly I found I could leave the sensor to totally control the misting, the beds did not become too wet or too dry making a very good rooting environment… I am very keen to have the entire mist house at Boningale changed to the Evaposystem…’

Nerys Arch, Propagation manager, Boningale Nursery

‘I have found that the Evaposensor to be a very useful controller. It is more controllable and keeps the mist beds drier at night than our wet leaf system… I have found for subjects susceptible to over wetting the rooting is approximately 5 – 10% better than on the wet leaf beds. We should seriously consider controlling the whole system with an Evaposensor’.

David Crabtree, Manager, Barrow Nursery, Living Landscapes

Conclusions

Hardware

Through collaboration with Electronic and Technical Services Ltd (ETS) an Evaposensor mist controller is now available to growers at a price of about £350 (including sensor). It features

- Very stable electronics.
- Large digital display of WLD and LEDs to indicate current status.
- Built in timers for control of burst length and minimum interval between bursts.
- Stand-alone mist controller or an interface to existing equipment.
- Analogue output expands the options for integration with other equipment and has already led to success in automatic scheduling of irrigation (HNS 97a).

User experience

- Staff readily grasp the basic concepts of Evaposensor control and the ETS unit.
- Some nurseries are happy to leave the WLD set point alone, allowing the Evaposensor to do all the work of compensating for day to day variations in weather and season. Others like to exploit the convenience of the calibrated set point control to fine tune conditions to suit particular species, season, stage of rooting, etc.
- In some cases, the “Interval” control can be useful to set an upper limit on misting.

Rooting performance

Results varied between species and varieties, reflecting their differing needs, so conclusions are drawn from the average of well over 100 batches of cuttings:

- The Evaposensor resulted in the rooting of an additional 12% of cuttings on one nursery, 4% of cuttings on a second nursery and had no effect either way on a third nursery. Similarly, in HNS 159a, average rooting results were as good as or better than those achieved with the nursery’s existing control system.
- About 8 out of 10 species / varieties rooted as well or better under Evaposensor control than under the nursery’s existing control system.

How does Evaposensor control increase rooting?

- Evaposensor control tends to vary the amount of mist applied more than other systems, such as timers, light-sum or the traditional “electronic leaf” (or “wet leaf”) systems.
- The increase in rooting could be attributed to the way that it concentrates misting into periods when the potential for cuttings to be stressed is greatest.
- The ability to adjust evaporative demand to suit particular types of cutting is likely to further increase average rooting percentage on nurseries that adopt this approach.

Financial benefits

The financial benefit of installing the Evaposensor control equipment will partly depend on the scale of overall improvement in % of useable cuttings produced and savings in labour and other inputs by minimising wastage. Other benefits are less straightforward to calculate financially, but still have a monetary value, such as ease of management, ability to rely less on skilled staff (especially for weekend or holiday cover), and the opportunities for self-propagating new or difficult cultivars that would otherwise have to be bought in.

Equipment costs as at autumn 2009 are approximately £200 for an ETS Controller and £150 for a Pt100 type Skye Evaposensor including 15 m cable.

Example data, provided by Lowaters Nursery, indicates that their costs of installing Evaposensor control equipment for their 200,000 cuttings/yr unit, stood at a few hundred pounds would be easily and rapidly recouped by the benefits. Assuming an average 12% increase in rooting, and for their size unit, some 81 hours of propagation labour / annum could be saved from wasted inputs, worth about £800 / year. Alternatively, an increase of 12% on a 200,000 annual liner production at £0.75 / unit would be an £18,000 increase in output.

Lowaters have observed that many of the subjects which performed best under the Evaposensor have been unusual cultivars, or those with limited stock material, where previously they may have missed their production target due to significant losses. Improving saleable outputs of these would be of significant benefit.

Action points for growers

The Evaposensor and controller set up is considered a user-friendly system and has given better automatic mist control in propagation environments than several traditional alternatives. The equipment is now commercially available.

Addresses of equipment suppliers:

Evaposensor *(specify type: SKTS 500/PT100/4):*
Skye Instruments Ltd
21 Ddole Enterprise Park
Llandrindod Wells
Powys LD1 6DF
Tel 01597 824811
www.skyeinstruments.com
email: technical@skyeinstruments.com

ETS Evapomist controller
Electronic and Technical Services Ltd
40 Acreville Road
Bebington
Wirral
CH63 2HY
Tel 0151 645 8491
www.ets-controls.co.uk
email: john@ets-controls.co.uk

Science Section

INTRODUCTION

Preventing water stress on cuttings from transpiration losses is one of the most important things the propagator can do to help cuttings root. Stress can still occur under mist (or fog) because existing controllers (timers, electronic leaves, or even radiation integrators such as the Solarmist controller), may fail to match misting frequency well enough to the needs of the cutting to cope with fluctuations in light level, humidity, temperature and air movement. The Evaposensor, with its wet and dry artificial 'leaves', responds to all these factors making it possible to detect and control the evaporative demand on cuttings in a reliable and reproducible way. It allows optimum conditions for a particular subject to be quantified and reproduced in a way that is not possible with any other type of mist control. In previous research spanning over a decade at East Malling, Evaposensor control contributed to successful propagation of difficult to root species such as *Cotinus coggygria, Garrya elliptica, Acer cappadocicum and A. palmatum cvs.,* some *Rhododendron* and *Pieris cvs.*, and *Corylus maxima*. The Evaposensor was invented at EMR by Richard Harrison-Murray in the late 1980's, originally as a research tool for controlling mist and fog propagation environments. The objective of this project was to evaluate its performance by nurseries and enable it to be taken up commercially by the industry. The Evaposensor has also been evaluated on nurseries in LINK and other projects for irrigation scheduling.

The Evaposensor needs an interface electronic controller to enable the output from the wet and dry 'leaves' (platinum resistance temperature probes) to trigger mist or fog bursts – either in conjunction with existing timers (such as a Heron controller), or as a stand-alone controller. A Nobel humidity controller was originally used at EMR, but the manufacturers pulled out of this market in the late 1990's, so an alternative interface was developed as part of the project by John Walker of Electronic & Technical Services (ETS) Ltd and was evaluated alongside the obsolete Nobel device. The Evaposensor (Pt100 temperature element version – Part no. SKTS 500/PT100/4) is currently available from Skye Instruments Ltd.

The first year of the project was located at one nursery site, and the Annual Report 2008 describes the improved environmental control of the mist environment achieved by the evaposensor working via a Nobel controller, and also via a pre-production prototype of a controller from ETS Ltd. This Final Report covers its trialling on an additional two nurseries with different ambient environments, and extends the range of cuttings subjects assessed. The ETS Evaposensor controller was also developed further during this period and is now available as a commercial production product. Some follow-on work during 2009 (HNS 159a) has trialled and promoted (through Grower walks held in October 2009) Evaposensor mist control on three further nurseries in the Midlands.

OBJECTIVES

i) Overall aims

To evaluate the Evaposensor as an environment controller for mist propagation in nursery situations against current grower systems, and, in conjunction with manufacturers, to develop and test a suitable interface to enable commercial uptake of the equipment.

ii) Specific objectives

1. Make Evaposensor-control of mist available to the industry by facilitating the development of a suitable interface by Electronic and Technical Services (ETS) Ltd (essentially an up-to-date replacement for the obsolete Nobel controller). Test the new interface and any alternatives developed by other manufacturers.

2. Evaluate technical performance of the Evaposensor in several commercial nursery environments against growers' current mist propagation control methods.

3. Assess comparative performance for a range of HNS subjects propagated by leafy cuttings, in terms of % rooting success, speed of rooting, and quality for potting on.

4. Collect data on key propagation environment parameters to help explain treatment differences.

5. Evaluate installation as a retrofit with nursery's existing mist systems, ease of use, and settings adjustment to aid the production of a User Manual.

6. Provide opportunities for other interested growers to become more familiar with the Evaposensor through visiting these nursery demonstrations, as well as written output from the project.

MATERIALS AND METHODS

Nursery sites

The first year of the project took place at one site, New Place Nurseries Ltd, Pulborough, W. Sussex. In the second year, Binsted Nursery, Arundel, W. Sussex and Lowaters Nursery, Warsash, Southampton also hosted trials in addition to New Place Nurseries.

Propagation facilities

New Place Nursery (Photo 1)

Glasshouse with open mist on sandbeds. Naan mist units (red nozzle – 61 litres/hr) on 50 cm risers spaced at 1.2 x 1.2 m. Two lines of beds either side of central path down glasshouse.

Shade screen operated automatically according to solar radiation level. In addition, further white shading paint was used on the glass during summer 2007. This was removed before summer 2008 and the shade screen material renewed, which alone provided sufficient shade requirement for the remainder of the trial.

Grower's conventional mist control via Heron MCI timer. Each 'station' operated a solenoid controlling four lines of five mist nozzles – an area of approx 4.8 m x 4.8 m (23 m^2).

Binsted Nursery (Photo 2)

Glasshouse with open mist on a concrete standing base covered with polythene, capillary matting and woven ground cover layer on top. Overhead mist lines in roof with inverted Macpenny type mist nozzles. One line over each of two beds (approx 2.75 m width) per bay either side of central access path.

White glass shading paint was applied to the walls and roof between May and October, but no additional shade screens were used.

Grower's conventional mist control was via a Priva environmental computer which provided background timer based bursts but with additional bursts according to external light sum and internal humidity set points.

Lowaters Nursery (Photo 3)

Glasshouse with open mist on drained sandbeds (approx 2.6 m width) covered with woven ground cover. Two lines per bed of Naan mist units with red nozzles on 50 cm risers.

Shade screen operated automatically according to ambient light level.

Grower's conventional mist control via a Heron MCI timer, but with additional mist bursts according to a light sum from an external sensor.

Photo 1. Mist propagation facility New Place Nurseries

Photo 2. Mist propagation facility Binsted Nursery

Photo 3. Mist propagation facility Lowaters Nursery

Mist Control Treatments

Treatment comparisons were primarily aimed at simply comparing the standard mist control method used on each nursery with Evaposensor control. However it was also necessary to verify the functioning of the newly developed controller for the Evaposensor from ETS Ltd against the obsolete Nobel controller. Nobel and ETS controllers were run alongside each other at New Place Nursery in both Year 1 and 2 of the project. At the end of Year 1 we had sufficient confidence in the ETS Evaposensor control to only need this treatment to compare to the grower's standard at Binsted Nursery and Lowaters Nursery.

<u>ETS Controller development</u>

The features of the ETS Controller are described in more detail in the Results and Discussion section. The Mk1 prototype developed first during Year 1, and used at New Place Nursery, was a basic interface which allowed a mist trigger Wet Leaf Depression (WLD) to be set and it displayed the current WLD value as sensed by the Evaposensor. It required connection to a controller, such as a Heron panel, to provide the 24V power to the solenoid valve as well as set the mist burst duration and minimum mist burst interval.

A Mk2 prototype was installed at Binsted and Lowaters Nursery for Year 2 of the project. This allowed more flexibility in its use as it also incorporated its own 24V AC power supply and mist burst length / interval timer control. It could be therefore be used independently of other controllers to control one solenoid valve / propagation zone. Alternatively it could be connected in the same way as the Mk1, via a Heron controller for example, making use of the Heron's 'background' timer settings for mist 'opportunity' interval and burst length.

A Mk3 'production' version was developed later during Year 3 of the project, and this replaced the Mk1 prototype at New Place from the end November of 2008. This made use of more robust components and design, with some improved features, but essentially its functionality was similar to the Mk2.

New Place Nursery Treatments

1 **Heron timer** - Grower's standard control system. Typically 2 sec. mist burst duration at a manually adjusted frequency according to the season and weather conditions. Several programs are used to vary the frequency of misting over the course of the day and to allow some beds to run drier if required. In summer up to a maximum frequency of about 1 burst per 10 mins down to about 1 burst per 30 mins or less in winter. Normally mist only during daylight hours or just one or two bursts during the night.

2 **Evaposensor via Nobel controller.** 2 sec. mist burst duration with frequency according to Wet Leaf Depression (WLD) set point and rate of evaporation. Linked to Heron to give a 2 sec. mist burst 'opportunity' every minute but mist only occurred when WLD set point was exceeded. ETS set points ranged from about 1.3 – 1.7 °C during the project.

3 **Evaposensor via ETS controller.** As Treatment 2 but using an ETS Mk1 prototype controller.

Each treatment was applied to a single 23 m^2 plot (4 mist lines) down the south side of the glasshouse.

The Nobel controller was installed in early May 2007, and the experiment ran with a comparison of just Treatments 1 and 2 from 9 May until 25 September 2007 by which time the Mk1 ETS unit had been developed and was installed to run as Treatment 3 alongside. This was eventually replaced by a Mk3 production unit on 28 November 2008.

Binsted Nursery Treatments

1 **Priva environmental computer** – Grower's standard system. A fairly complex arrangement of settings had been developed by Binsted nursery with experience over time to control the mist in the propagation house. Set points differed during the day, from 2 h post-sunrise to 3 h pre-sunset, and at night. In the middle part of the day, for example, minimum mist intervals were 15 min to a maximum interval of 90 min but with additional bursts triggered by an external light sum of 100 – 120 J cm^{-2} or humidity deficit above 12 g H_2O kg^{-1} air. Typically

additional mist bursts were triggered by light sum. Mist burst lengths were 2 s in winter and 3 s in summer. In practice, this regime resulted in a significantly drier mist regime than typically used at New Place Nursery.

2 **Evaposensor via ETS Mk2 controller.** The ETS Mk2 was installed as a 'stand alone' controller, making use of its own timers to set mist burst length and minimum burst interval and solenoid power supply. Initially a WLD set point of 3 °C was used, but this was increased to 4 – 5 °C for most of the trial period. Burst length was maintained at 3 s. The minimum burst interval was initially set to 1 minute, giving an "opportunity" for misting every minute, as on the other sites. Later, the nursery staff raised this setting to between 7 min and 15 min during much of the trial, to limit the amount of mist applied.

Each treatment was applied to a single bed running the full length of the glasshouse.

The ETS controller was installed and treatments started on 19 June 2008, and continued until 9 December 2008.

<u>Lowaters Nursery Treatments</u>

1 **Heron timer with light sum modulation** – Grower's standard system. Timer based mist applications (frequency varied through the day), but with additional mist bursts according to light sum. Light sum settings for mist triggering was varied by the propagator during the year from as low as 15 J/cm^2 when additional wetting was required in summer, up to 40 - 70 J/cm^2 in the autumn and winter. Typically mist burst lengths were set to 3 s, but ranged from 2 to 4 sec during the year.

2 **Evaposensor via ETS Mk2 controller.** A 3 °C WLD was set initially at installation in mid June 2008, but this was increased to 4.0 and then from July – late Nov 2008 the set point varied between 4.5 and 5.0 °C WLD. Over winter from Dec 2008 – early Mar 2009, the set point was reduced to 2.0 – 3.0 °C before gradually being increased again the following spring from mid Mar to the end of the trial, when set points ranged from 3.5 to 5.0 °C. As at Binsted Nursery, the ETS controller was operated independently from the Heron, and used its own mist burst length and interval timers. In contrast to Binsted, however, the interval between mist burst 'opportunities' was set at about 2 minutes throughout the trial, thus allowing the Evaposensor full control of actual mist burst frequency.

Mist bursts were set to achieve about 3 s actual burst length, but, as with the Heron treatment, ranged from about 2 – 4 sec during the trial. There were occasional problems achieving the specified water pressure of 3.0 Bar which may have contributed to a slow solenoid response and required a shorter actual setting on the controller.

Treatments were each applied to a complete single bed.

The ETS controller was installed on 18 June 2008 and treatments continued through to the end of the trial in April / May 2009.

Photo 4. One Evaposensor linked to Nobel or ETS interface to control mist burst frequency and the other Evaposensor connected to logger to monitor environment achieved. PAR quantum sensor to record light levels also shown.

Cuttings

See Results and Discussion for details of species used.

At New Place Nursery, over Year 1 and 2 of the trial, between 9 May 2007 and 12 Sept 2008, a total of 55 batches of different species were propagated and monitored for at least two of the above treatments, enabling comparisons to be made (see Results for details). Although environment monitoring continued until the end of the trial, due to commercial pressures on the nursery, comparative treatment batches of cuttings were not monitored and recorded by staff after September 2008. 84 and 104 cell trays were typically used, but some larger cutting subjects were rooted in 66 and 77 cell trays.

Lowaters Nursery monitored 53 batches of cuttings in Year 2 between 6 June 2008 and 8 April 2009. Most subjects were rooted in 104 cell trays but with some in 20, 40 and 51 cell trays.

Binsted Nursery were propagating mainly *Dianthus* and herb species during Year 2 of the trial, in contrast to the woody shrub with some herbaceous perennials range propagated at New Place and Lowaters Nursery. 14 batches, stuck into P60 or P84 cell trays were monitored between 24 June and 20 November 2008.

Where possible, four replicate trays of each species were monitored under each mist control treatment, although for some subjects propagated in small numbers, only two or three replicates, or even a single tray were available. As there was no replication of mist control plots, some attempt was made at placing assessed trays in comparable zones on the different mist controlled beds (ie trying to avoid confounding of positional effects such as distance from the glass wall or heating pipes with mist control treatment).

Records were made of the date stuck, number of cuttings per tray, and date removed from mist (ie when sufficient rooting had occurred for potting on). A simple count per tray of 'viable plugs for potting' was made when the cuttings were removed from the mist, and this was used to calculate the percentage rooted. The decision on when to remove cuttings from the mist and assess them was made by the grower based on inspection and commercial experience. In most cases cuttings from all treatments were removed at the same time.

Environment monitoring

DL2 loggers (Delta-T Devices Ltd) and Skye Datahog (Skye Instruments Ltd) were used to monitor relevant environmental variables.

It was important to get some measure of the amount of misting each treatment received. The amount of time when misting occurred was recorded by counting AC pulses (50 Hz) delivered to the solenoids on each of the bed treatments during mist bursts, via counter channels on the DL2. From this, the mist duration in seconds per hour could be calculated.

At New Place Nursery, the evapotranspirative environment achieved around the cuttings was measured with a monitoring Evaposensor in each treatment. The 'Wet leaf' and 'Dry leaf' temperatures were logged by the DL2, so the WLD could be calculated. For technical reasons, an Evaposensor connected to a mist control interface (whether Nobel or ETS), could not be logged directly at the same time but, from mid January 2008, a signal from the controller interface proportional to the WLD was logged at New Place, and subsequently this technique was used at the other two nurseries. There were insufficient additional monitoring Evaposensors available to monitor both 'grower standard' and Evaposensor control' treatments for Lowaters and Binsted Nurseries in Year 2. As a primary aim of the project was to assess performance of the new ETS controller, it was decided this should be placed on the

Evaposensor control plots to provide a check on this control system, and to provide data to help explain any problems should they occur.

It was important to position Evaposensors so that their 'leaves' were not shaded from either solar radiation or mist by the cutting foliage, which meant supporting them on wooden blocks or upturned pots between cutting trays (Photo 4).

Light levels were recorded on the DL2 using a photosynthetically active radiation (PAR) quantum sensors at cuttings level and (New Place and Lowaters Nursery only) another placed on a shed roof outside the glasshouse. This was primarily to allow relative levels to be compared. At New Place and Lowaters nurseries, a shade screen in the glasshouse was closed under bright conditions. The relative 'PAR-in' and 'PAR-out' values enabled an estimate of when the shading was in place, as this was controlled automatically for the whole glasshouse independently of our experiment.

Glasshouse ambient relative humidity and temperature under the shade screens were recorded on all nurseries with sensors (Skye Instruments Ltd) either wired to the DL2 logger, or, at New Place Nursery, using a dedicated Skye Datahog. The New Place Datahog was also fitted with a pyranometer (measuring total solar radiation in W/m^2) and was hung on a glasshouse stanchion above the mist beds but underneath the shade screen. For Lowaters and Binsted Nurseries, it was possible to get an approximation of total solar radiation from a calibration of the PAR sensors against the Skye pyranometer done on a sunny morning under glass.

Both the Skye Datahog and Delta-T DL2 loggers were set to log values every 30 minutes. For the DL2 records of temperatures and PAR measurements, the logged values were means of 1 min samples, and the solenoid activity counts were means of 10 min samples (hence misting rate in s/h was 10 min sample x 6 / 50 Hz).

Analysis of environment data

Data was downloaded periodically from the loggers, and analysed using an Excel spreadsheet. Data was split into 1 month periods as convenient blocks of time for summarising means such as daily or diurnal averages, and also to observe changes with season of the year.

It was important to correct any 'zero error' differences in the readings from the Wet and Dry leaves from the Evaposensor. The absolute temperatures of these probes were not required, but only the temperature difference between them. Typically the wet probe would be slightly cooler due to evaporative cooling than the dry probe. Very small differences in electrical resistance in the cabling circuit using Pt100 probes in particular, will register as large temperature differences. The measured values in the raw data therefore needed correcting using a ‘zero offset value’ as recorded when both temperature probes were placed in a beaker of water, stirred and allowed to equilibrate for 5 minutes or so.

The half-hourly data from both the DL2 and Datahog loggers were combined and synchronised on a spreadsheet. Means were obtained using Pivot tables so that the following graphs could be obtained:

a) Hourly means i.e. half-hour logged values averaged to give hourly averages over the whole logged month, or simply plots of half-hour means. A detailed picture of the data could be viewed for selected periods of interest of a few days at a time.

b) Daily means i.e. means of all values per day to give a single daily mean for each day over the logged period.

c) Diurnal values i.e. values averaged over the month’s data for each of 24 hourly values during the day.

The following variables could be graphed as required:

i) Ambient air temperature in glasshouse - °C
ii) Ambient relative humidity in glasshouse - % RH
iii) Ambient radiation in glasshouse - W / m^2
iv) Amount of shade - %
v) Wet Leaf Depression (WLD) for each treatment - °C
vi) Amount of misting for each treatment - s / h

Measurement of mist deposition uniformity

The mist distribution appeared uniform visually but, at New Place Nursery, doubts about its uniformity were raised when distinct patches of Botrytis infection appeared during late summer 2007. It seemed possible that localised wet spots might have contributed to the problem. Uniformity was measured on 25th September 2007 by supporting 30 Petri dishes of 88 mm diameter on upturned plastic cups in a 5 x 6 square array spaced at 0.3 m over one bed, running the mist for a total of 60 seconds, and weighing each dish before and after misting (Photo 5).

A similar mist uniformity test was undertaken at Lowaters Nursery on 26 February 2009.

Photo 5. Testing mist distribution uniformity at New Place Nurseries, September 2007

RESULTS & DISCUSSION

Control of rooting environment under mist

A lot of environmental data were collected during the project and only a small selection is presented here. The key aspects of the performance of the Evaposensor and Mk 2 ETS controller are well illustrated with reference to some of the data from Lowaters Nursery in Year 2. Year 1 results from New Place Nursery were dealt with in some detail in the Annual report, and further references to Year 2 data from New Place and Binsted Nurseries are included to illustrate important differences or other points as required.

Lowaters Nursery

Sensitivity of Evaposensor control to the environment

An important feature of Evaposensor control was its much greater sensitivity to adjustment of the frequency of mist applied with changes in the environment, especially solar radiation, than the Heron control system. Even though the Heron control incorporated extra mist bursts according to light sum in addition to the regular timed applications, the Evaposensor treatment applied relatively much more mist under brighter conditions when cuttings would have been under the most transpiration stress.

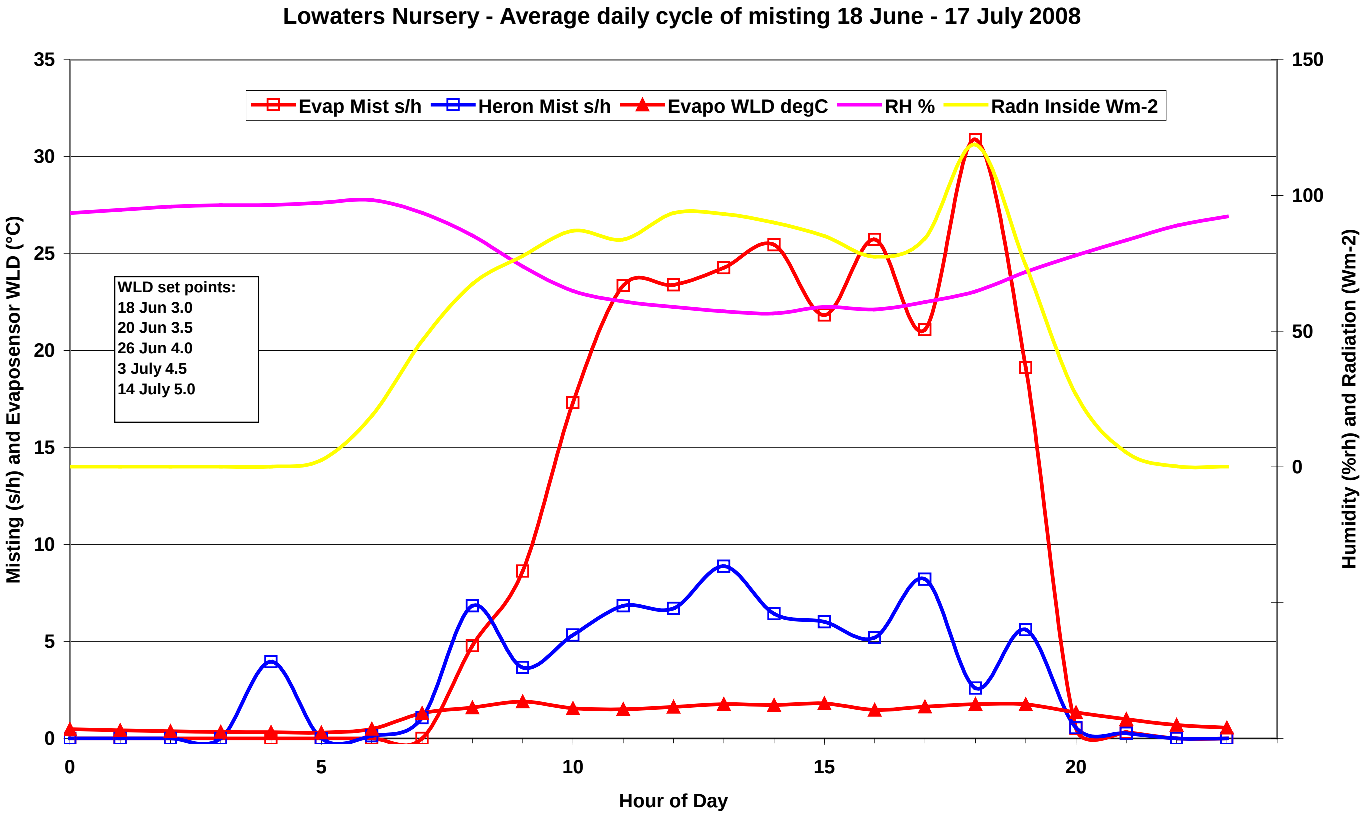


Fig 1. Lowaters Nursery. Mean diurnal pattern of mist and ambient environment for Evaposensor vs Heron treatments mid June – mid July 2008, and WLD achieved on Evaposensor bed.

Figs 1-3 show the much greater amount of misting applied under Evaposensor control than Heron control during the mid June – mid July period. Fig 2 shows the largest amounts of mist applied on the Evaposensor treatment in late June / early July, and Fig 3 shows detail for the 3 – 9 July period. Note that Fig 3 are half-hourly plots of mean values, but misting is expressed as seconds per hour. Therefore the regular 8 s/h peaks (blue line) applied by the Heron timer treatment actually represent single bursts of 4 seconds. Likewise, the peak value of 113 s/h occurring under Evaposensor control at 18:00 on 3 July actually represents 57 secs in this half-hour or about 15 bursts of 4 seconds on average every 2 mins at that time.

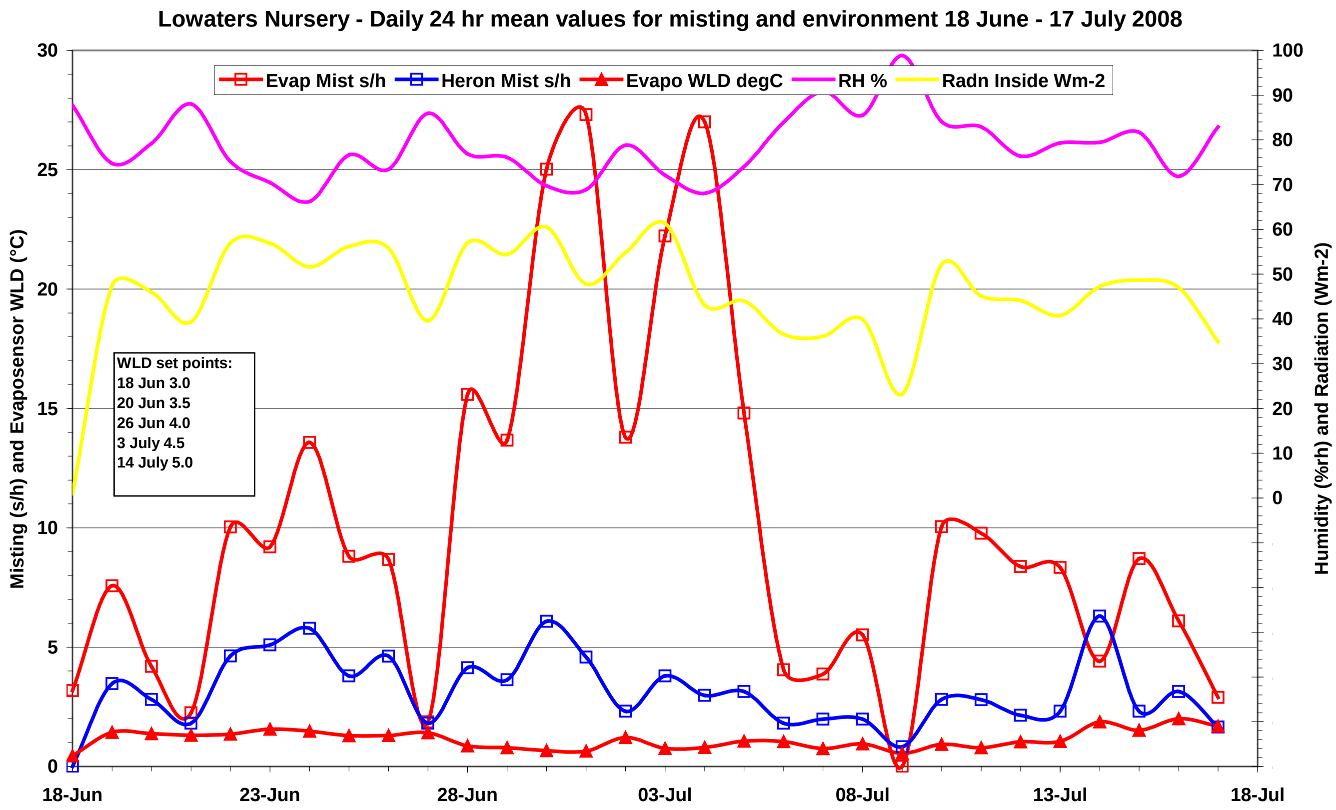


Fig 2. Lowaters. Daily mean values for ambient and mist environments 18 June – 17 July 2008.

An estimate of shade is shown during daylight hours in Fig 3 (black line) as the proportion of radiation at cutting level compared to outside, and illustrates the automatic shade screen operating during parts of each day for this period except for 9 July which was relatively dull. The shade screen was set to open late in the afternoon / early evening, but if conditions were still sunny at this time, a significant peak of radiation could reach the cuttings (and Evaposensor and light sensor as on 3 July). This then resulted in additional bursts of mist late in the day. This pattern of late pm misting occurred on a lot of sunny days during this mid summer period and explains the peak at 18:00 for the Evaposensor treatment shown in the diurnal mean chart (Fig 1).

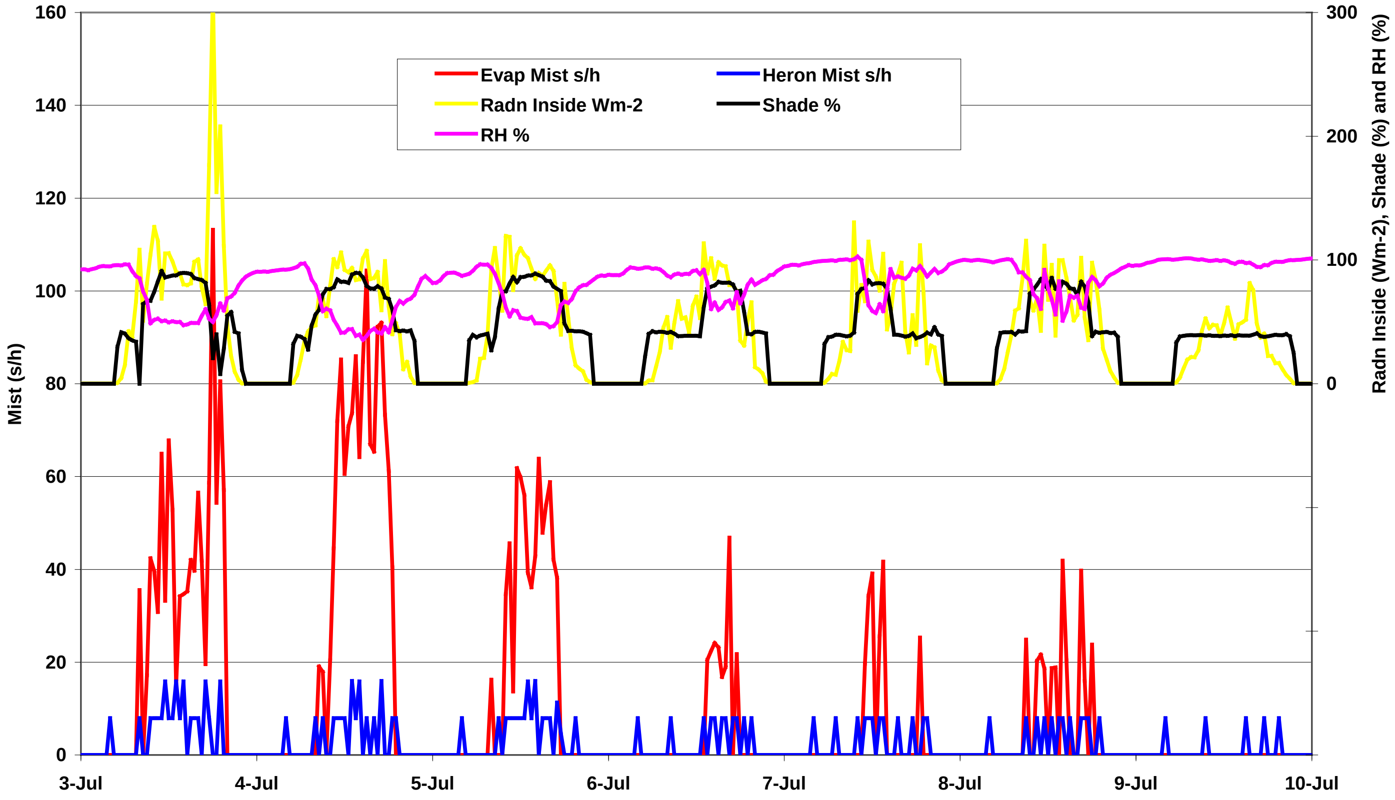


Fig 3. Lowaters. Half-hourly mean values for misting, inside radiation and relative humidity 3 – 9 July 2008. Black line shows automatic shade screen operation during bright periods on each day except on 9 July (dull and shade screen not applied).

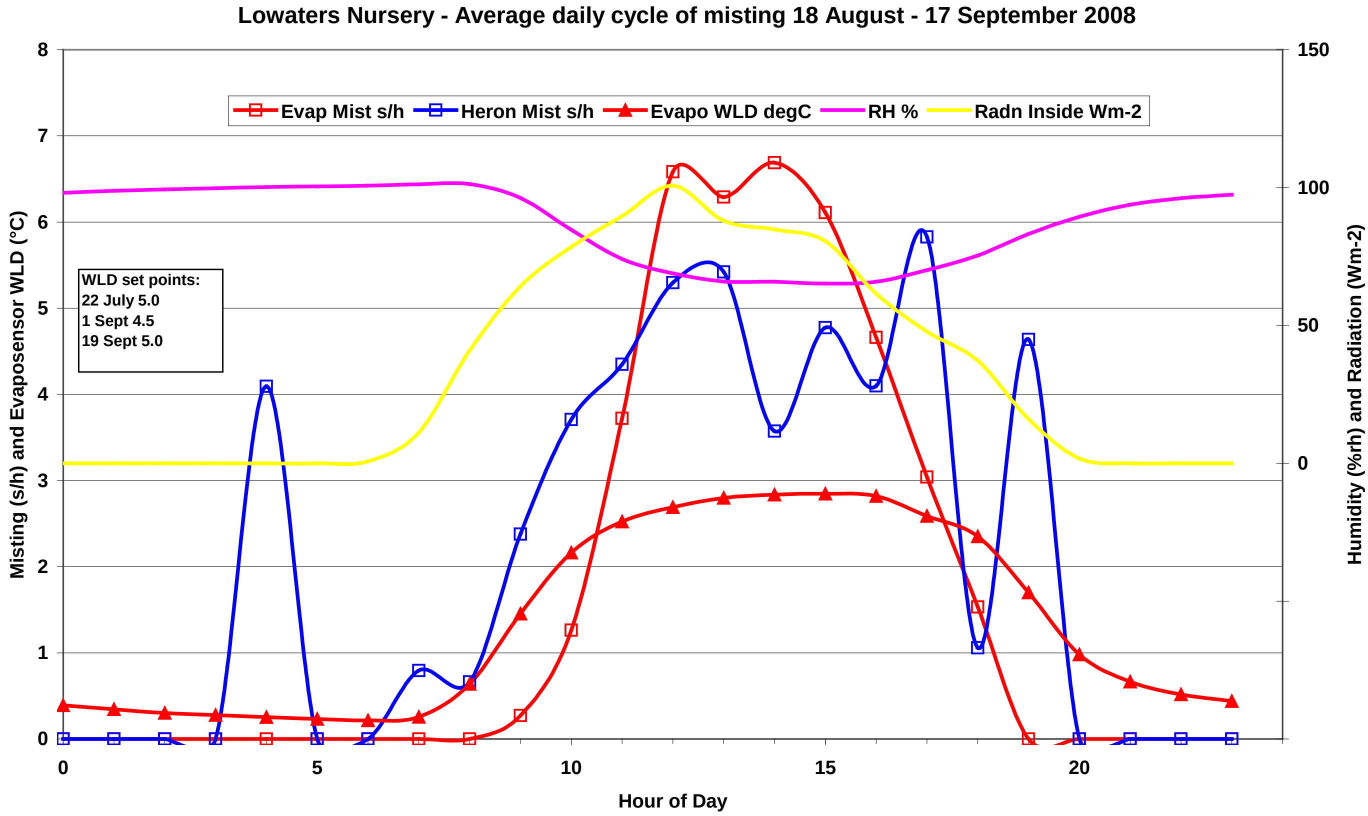


Fig 4. Lowaters. Mean diurnal pattern of mist and environment mid August – mid September.

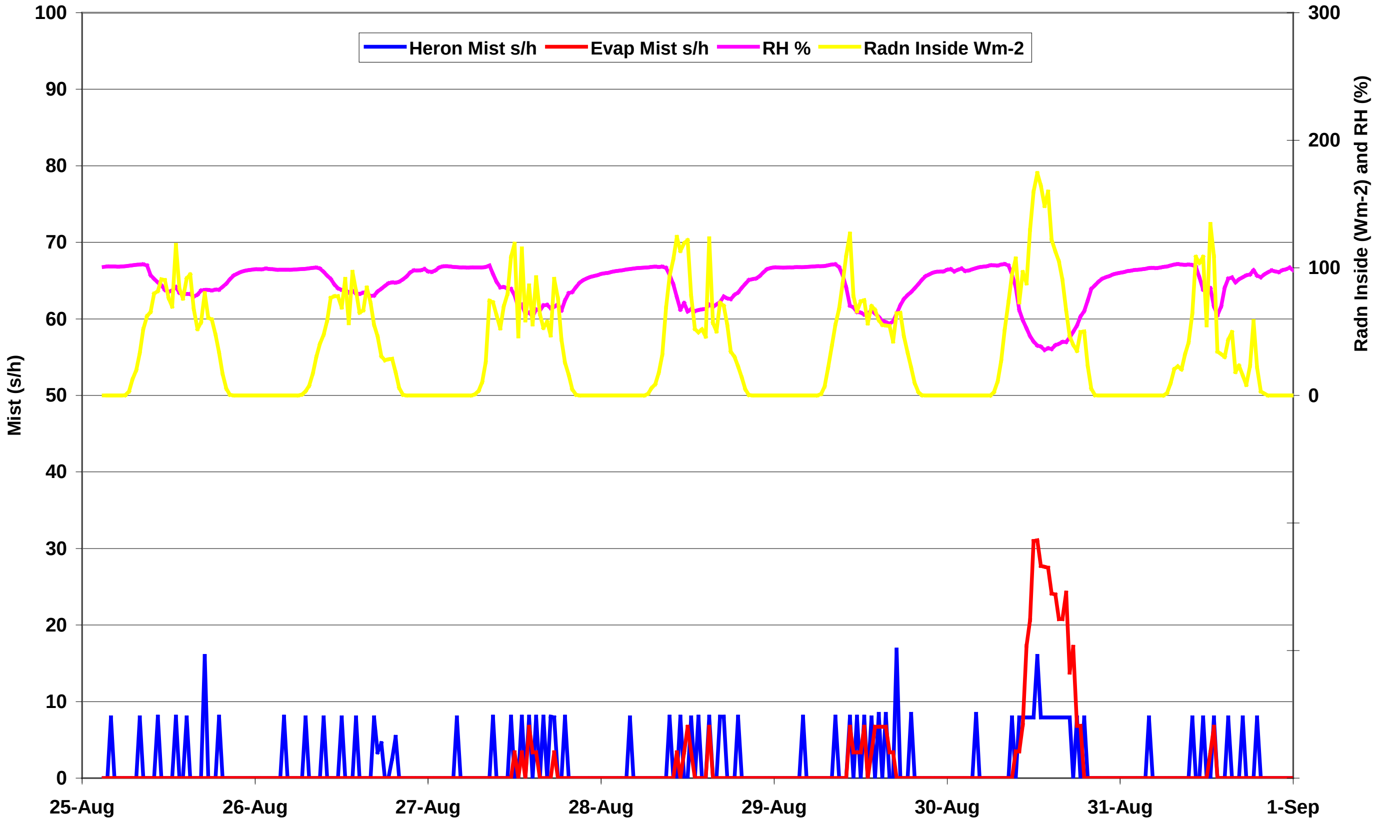


Fig 5. Lowaters. Half-hourly means. Detail of misting and environment 25 – 31 August 2008.

The weather in August was frequently overcast, cool and wet compared to the hot weather in June and July. Figs 4 & 5 illustrate the much lower amounts of mist in the Evaposensor treatment; although some mist was still applied most days under Evaposensor control, the total applied was often less than the Heron treatment for the mid August – mid September period, and it was concentrated when most needed around the middle of the day when brightest and ambient humidity lowest. Note the difference in Y-axis scales for misting s/h and WLD °C when comparing Figs 1 and 4.

Adjustment of Evaposensor WLD set points by the grower

No fixed set points were prescribed for the treatments and the grower was encouraged to adjust these during the trial as they felt appropriate in response to how the crop looked and whether, in their experience, trays appeared obviously too wet or dry. As there were no well defined optimal set points and we only had experience from New Place Nursery in Year 1, it was important to allow the grower to experiment with the equipment and not be constrained by a fixed setting that might well be inappropriate.

Lowaters Nursery felt that the initial setting of about 1.5 °C WLD, as used at New Place, was applying mist too frequently, causing trays to become too wet, and they rapidly increased settings to 4 – 5 °C. Fig 6 illustrates one of the WLD set point changes in July 2008. Note that the set point is the peak WLD before a mist burst is triggered, so the actual WLD recorded over time, plotted as half-hour mean values (black line), will be lower with peaks rarely reaching the set point.

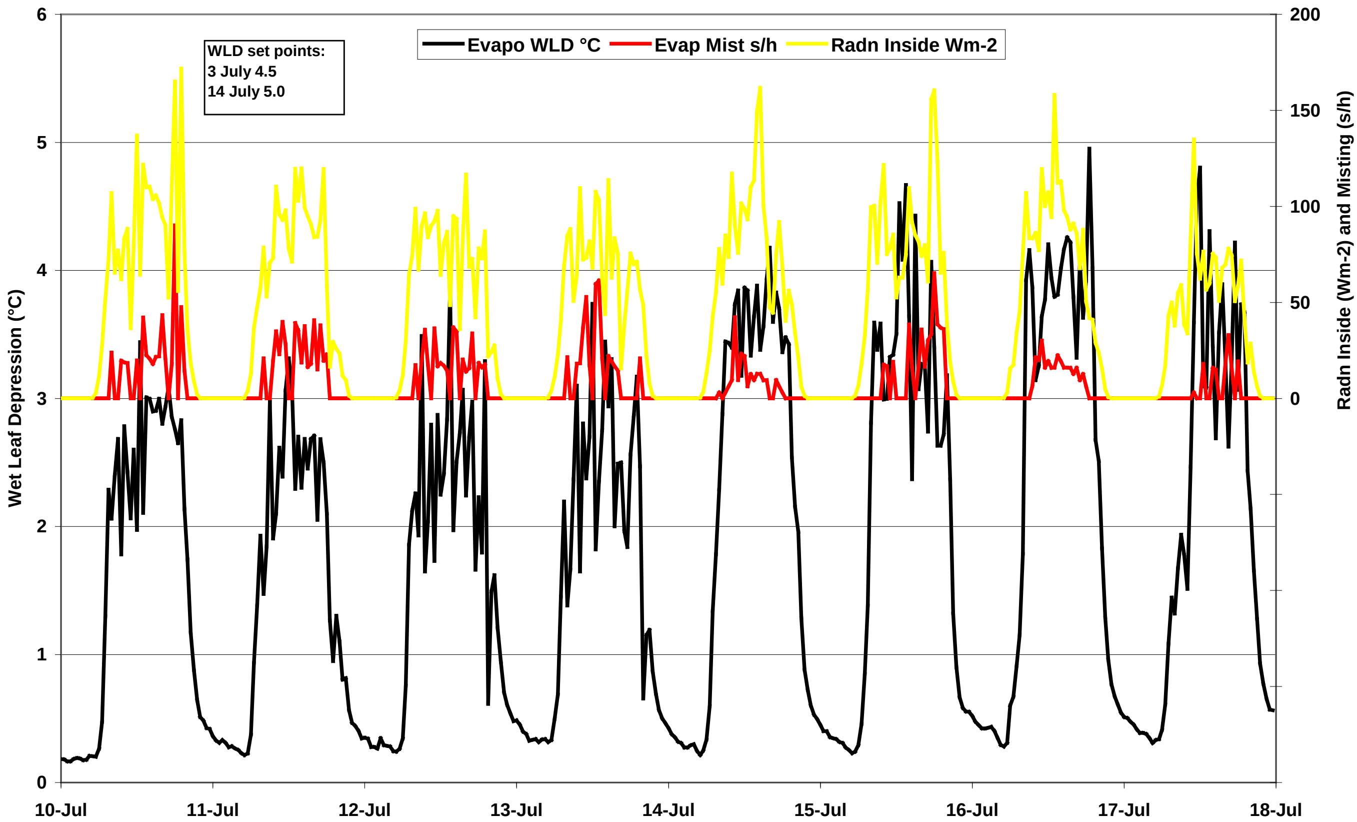


Fig 6. Lowaters. Half-hourly means. Effect of increasing WLD set point from 4.5 to 5.0 °C on 14 July 2008.

The WLD set points on the ETS evaposensor controller were retained between 4.5 °C and 5.0 °C from early July until late November 2008. By October / November, Evaposensor control was applying less mist in total than the Heron system, and on a third to half of days, no mist at all was applied. Misting did still occur as required, typically between 11:00 and 15:00 on bright days, whereas the Heron programme was still applying regular mist bursts throughout the day including early (5:00) and late (18:00 and 20:00) irrespective of the weather. With lower light levels at this time of year, the Heron controlled misting was down to timed bursts only with no addition misting triggered by the radiation integrator set points. Heron mist burst length settings were reduced from 4 to 2 seconds on 29 October (although duration of solenoid opening was logged as 6 and 3 s respectively).

The WLD set point was reduced from 4.5 to 3.0 °C on 26 November, then 2.0 °C on 2 December where it remained until 8 March 2009 when it was increased to 3.0 °C followed by several adjustments up to 5.0 °C by 17 March. From then on it was adjusted occasionally varying between 4.0 and 5.5 °C up to the end of June 2009.

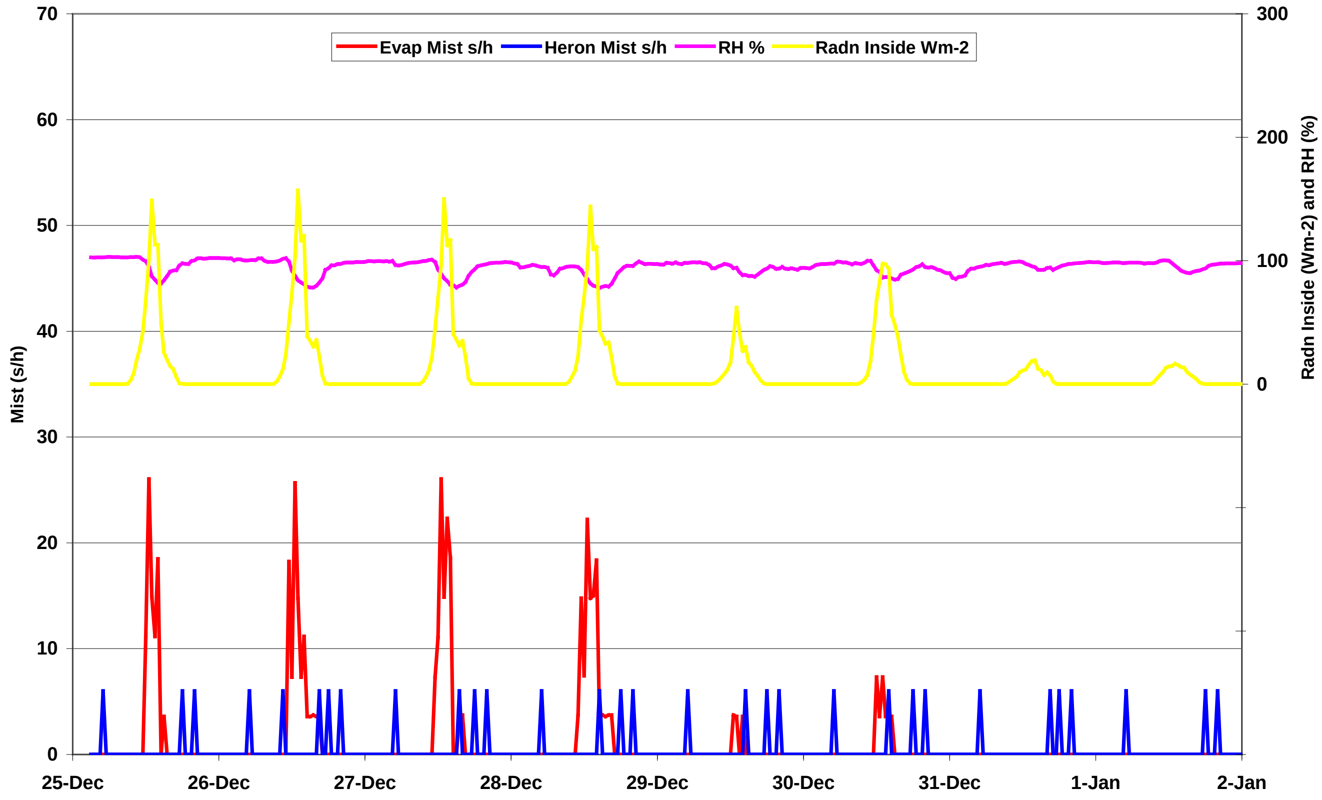


Fig 7. Lowaters. Half-hourly means. Misting restricted to bright periods only in winter from Evaposensor control compared to regular timed bursts of mist during the day from under Heron timer control.

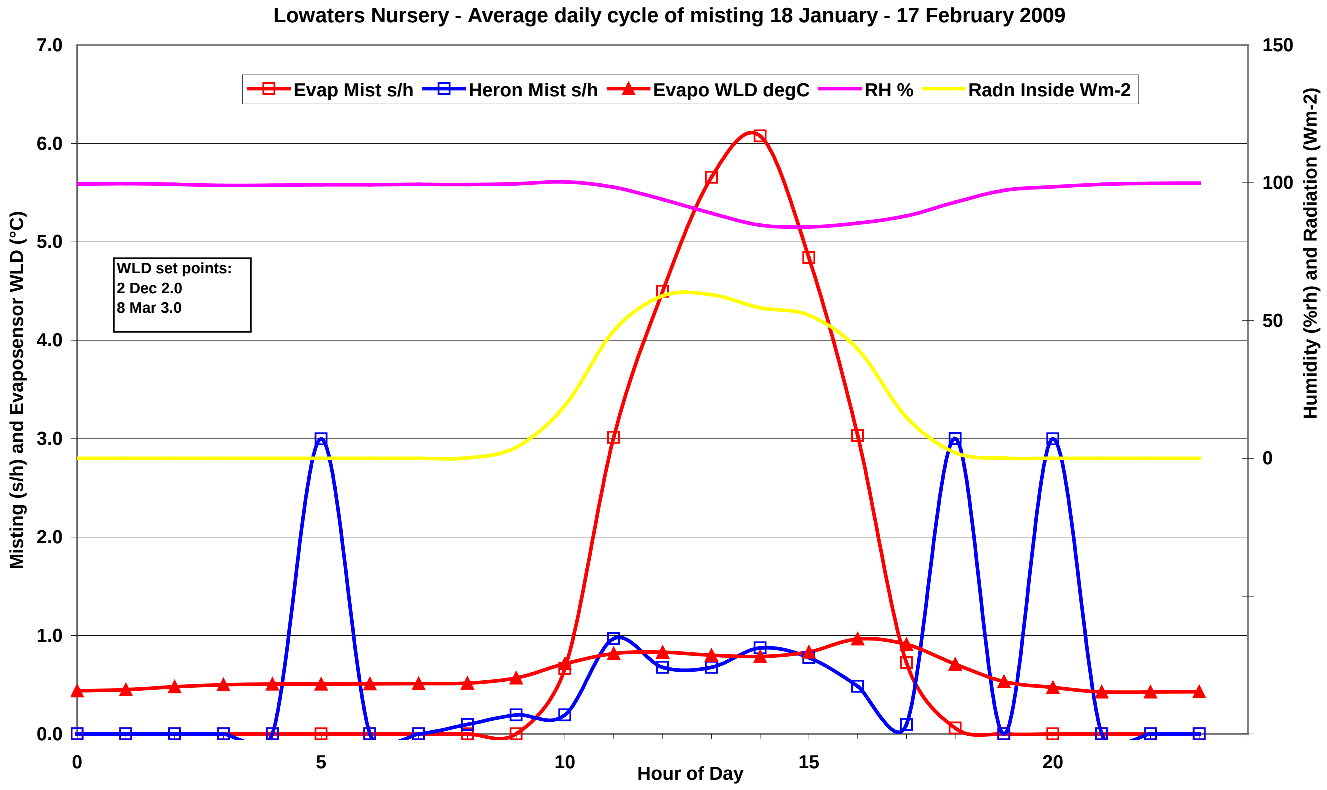


Fig 8. Lowaters. Mean diurnal pattern of mist and ambient environment for Evaposensor vs Heron treatments mid January – mid February 2009, and WLD achieved on Evaposensor bed.

By mid January – mid February 2009, radiation levels were increasing but variable from day to day. Although overall misting was a lot lower than in high summer, the Evaposensor bed was receiving about twice as much mist as the Heron controlled bed, and it was again concentrated in the middle of the day (Fig 8). The Evaposensor control continued to adjust mist output well to match the variable daily weather: on bright / low humidity days misting frequency was quite high (up to 3.3 s/h, which equates to about 3 bursts per hour during daylight hours) whereas on the most dull and humid days there was no misting at all (Fig 9).

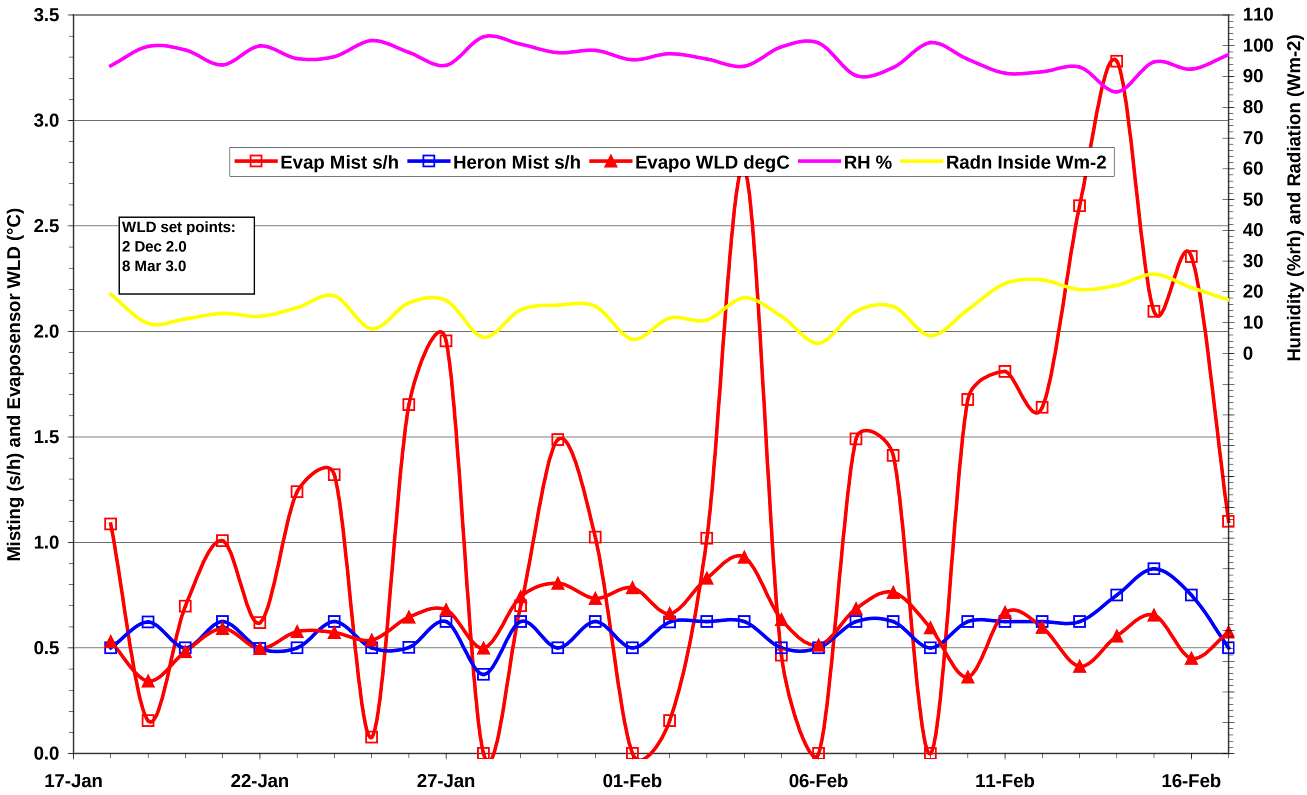


Fig 9. Lowaters. Daily mean values for ambient and mist environments 18 January – 17 February 2009.

By mid February – mid March, Evaposensor control was applying large amounts of mist compared to the Heron control on bright days (Fig. 10) and overall about five times as much mist. Light sum settings for the Heron bed at this stage (50 J/cm^2) were too high to trigger additional mist bursts. From 27 February, an additional monitoring Evaposensor became available, and this was linked to a Delta-T Devices GP1 logger and placed on the Heron bed in order to obtain some comparative data of WLD levels under the two mist control treatments. Fig 11 (hourly mean plots) shows about a two-fold difference in WLD levels between the treatments and the relatively large amounts of mist required to maintain the Evaposensor bed below the 2.0 °C set point. The propagator decided that the cell trays were getting too wet at this point and so raised the WLD set point to 3.0 °C to compensate, with further adjustments to set point being made during the spring and summer to 4.0 – 5.5 °C as previously described.

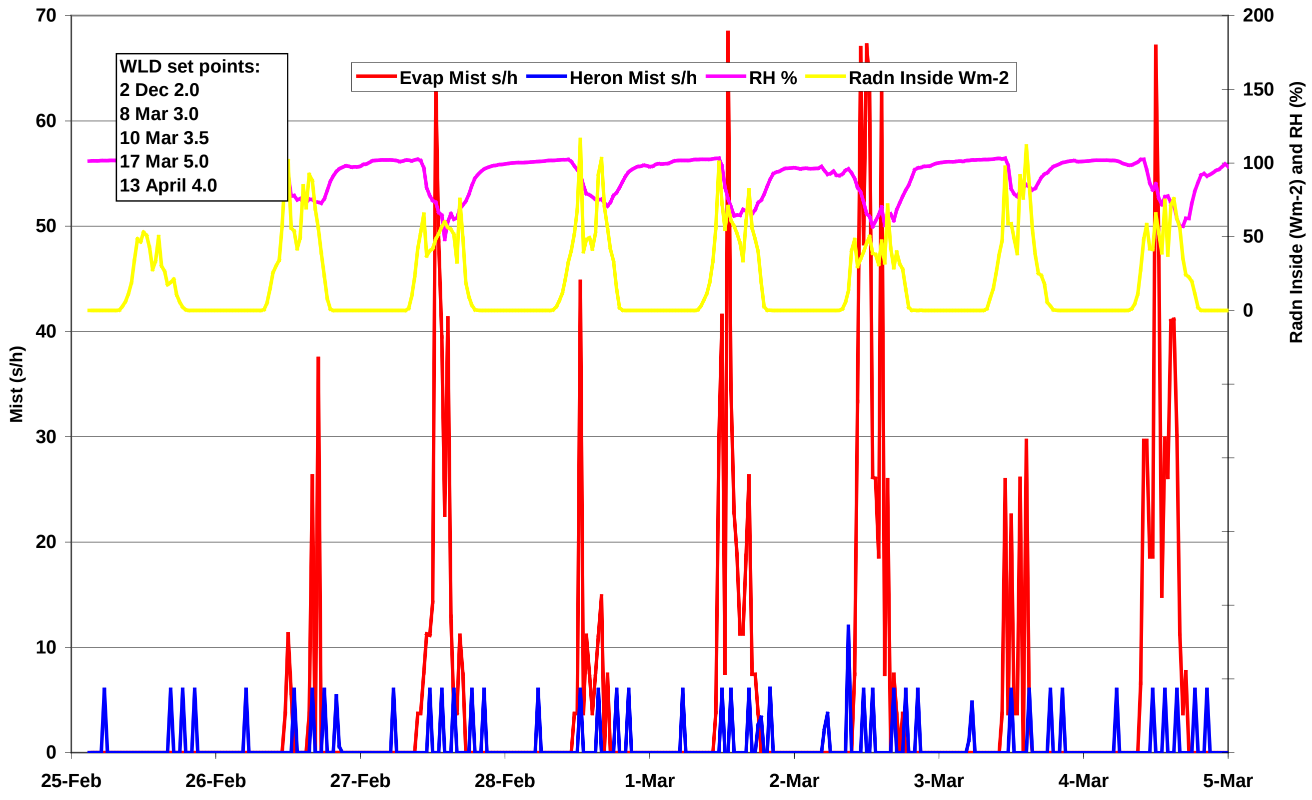


Fig 10. Lowaters. Half-hourly means. Evaposensor control applying relatively large amounts of mist in late February / early March 2009 in response to bright conditions at a 2.0 °C WLD set point.

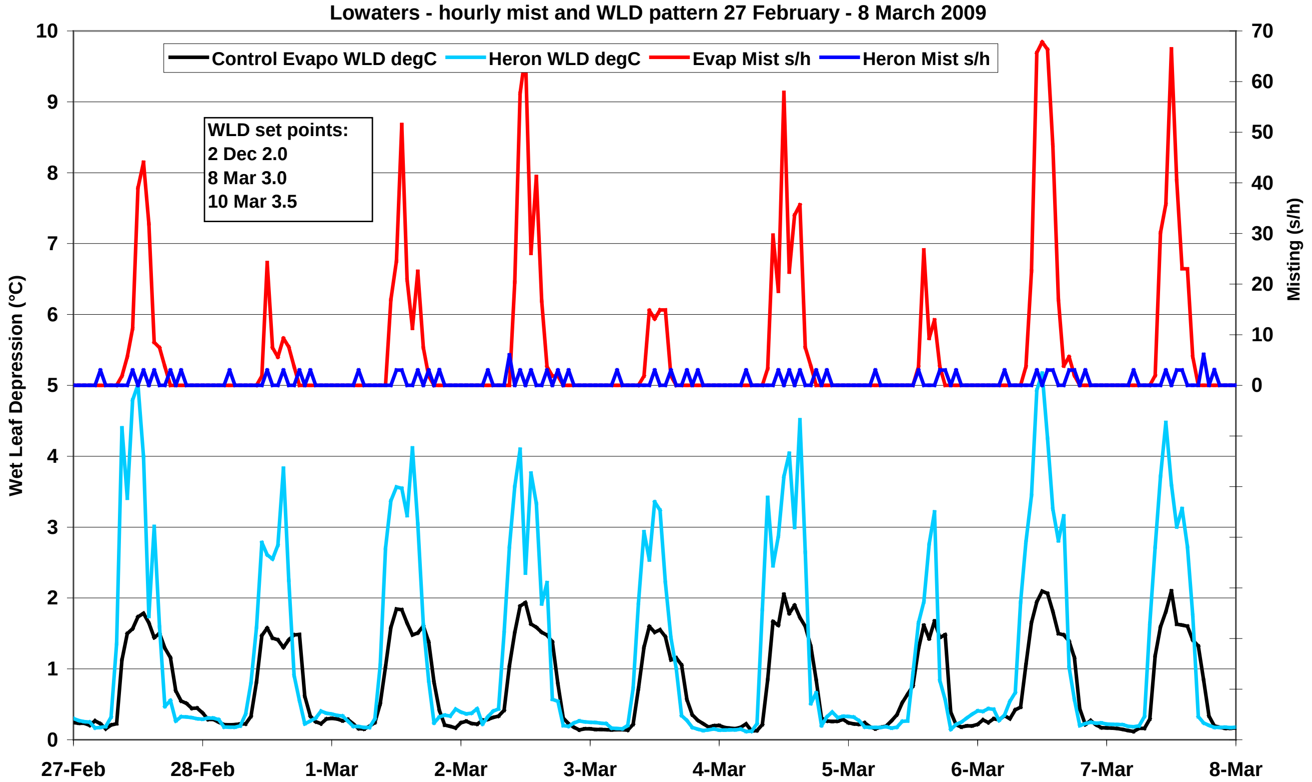


Fig 11. Lowaters. Hourly means for misting and WLD levels for both treatments late February / early March 2009.

The propagator reduced the Heron light sum setting in early April from 30 J/cm^2 to 10 then 15 J/cm^2 to increase misting on that treatment, but this was still not sufficient to prevent WLD levels rising up to 9.0 °C on some days. Although misting under Evaposensor control was now less than it had been six weeks previously, in response to raising the WLD set point, it was still maintaining a lower and more stable WLD than the Heron control treatment (Figs 12 – 13).

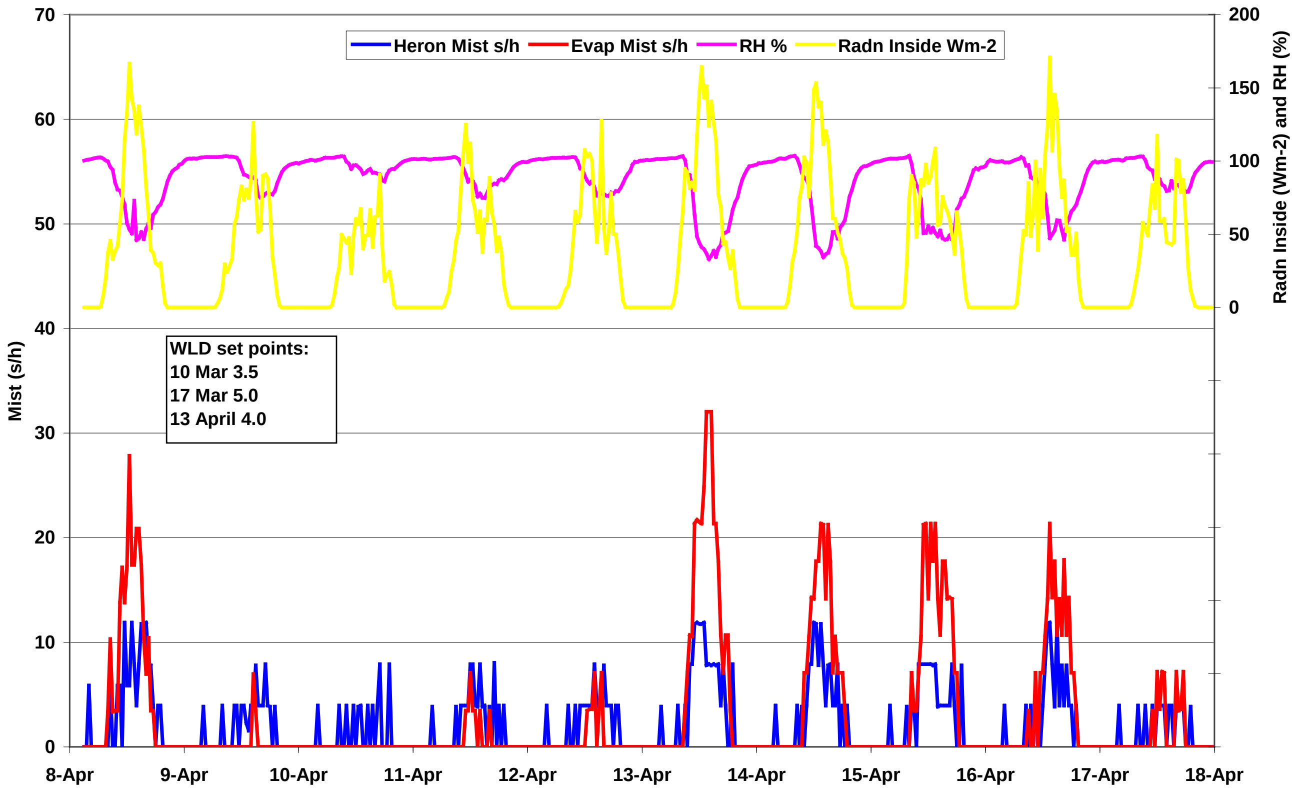


Fig 12. Lowaters. Half-hourly means. Smaller amounts of mist being applied from Evaposensor control during mid April 2009 with the higher WLD set point compared to the 2.0 °C set point in Fig 10.

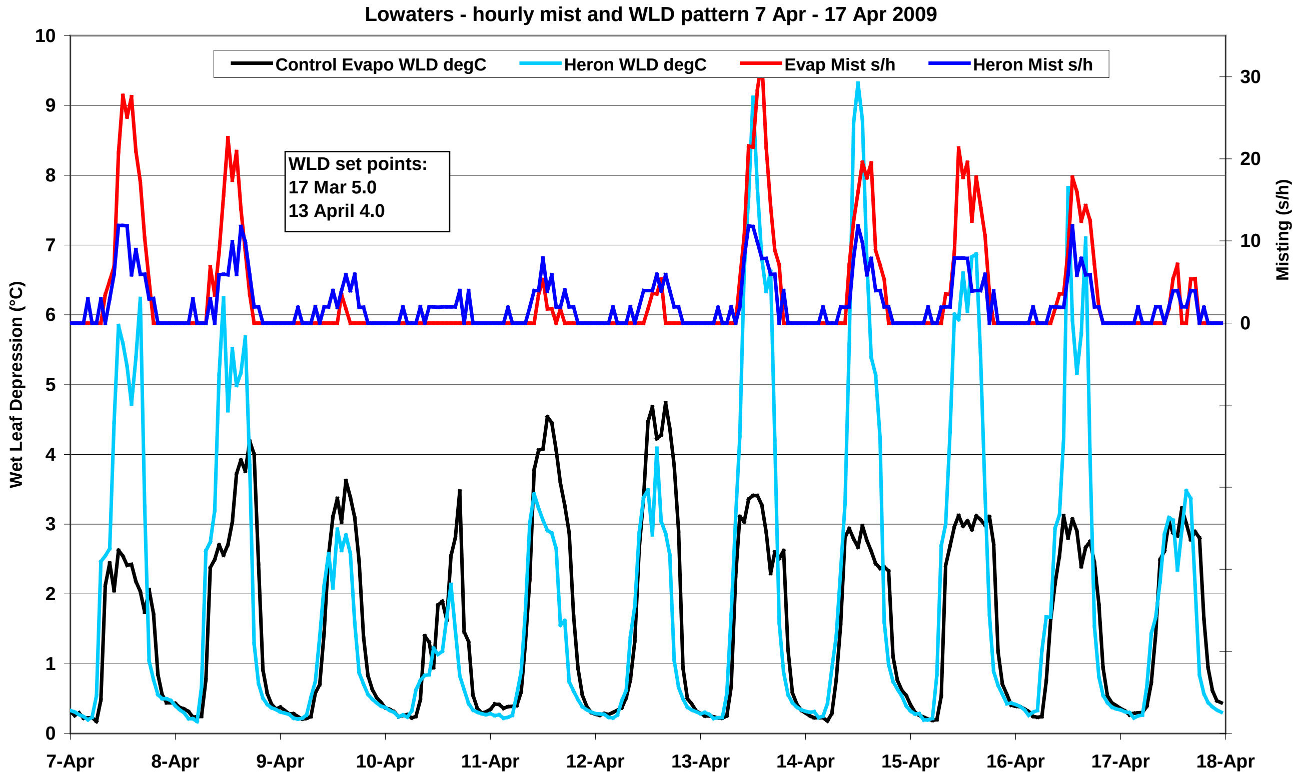


Fig 13. Lowaters. Hourly means. Relatively high WLD (transpiration stress) levels occurring under Heron control even though some additional mist being triggered by light sum setting. Note change of set point on Evaposensor bed from 5.0 to 4.0 °C on 13 April.

Balancing optimum misting and moisture content of the rooting medium

It can be difficult to optimise both the wetting of cutting foliage and moisture in the rooting medium via the mist system. A high frequency of mist necessary to minimise cutting stress under hot / bright conditions may result in cells becoming too wet unless the medium is very coarse-textured (hence free-draining) or the standing base provides positive capillary drainage to suck out the excess water. Conversely, under cool / dull and winter conditions, when little or no misting is required, rooting media may get too dry, often exacerbated by supplementary bed heating, unless some additional water is applied by hand-held lance or by manually triggering extra mist bursts.

At Lowaters, the grower quickly decided that the initial 1.5 °C WLD setting used was too wet. It is possible that they were not used to the relative sensitivity of Evaposensor mist control to changes in the weather compared to their standard system, and therefore judged it to be misting too frequently in sunny conditions, even though the Evaposensor control was arguably responding more closely to cuttings' needs through limiting transpiration stress. However, slightly impeded drainage may also have been a factor. Although sand beds were used, they were covered with Mypex which may have affected capillary contact between the rooting media and the sand. The Mypex had been in place for some years and an accumulation of lime and other deposits may have reduced its porosity.

Using short mist bursts should reduce run off from the foliage and thus the amount of water received by the rooting medium relative to the amount of foliage wetting. The minimum practical burst length, however, is limited to between 1 – 3 seconds, depending on mist system factors such as water pressure and speed of solenoid response, in order to maintain acceptable distribution uniformity.

Summary of relative rates of mist applied by Evaposensor and Heron control at Lowaters Nursery 2008 – 2009

Based on monthly averages, amount of mist applied under Evaposensor control varied by a factor of over 20 times between 'winter' and 'summer', whereas Heron controlled output varied by a factor of less than 6 (Table 1). This echoes the even larger day to day variations in misting that occur under Evaposensor control that were illustrated in the graphs and discussed in the detailed analyses above. In contrast, the light-sum system used by the Heron resulted in rather modest variation in misting in response to weather or season. Since Evaposensor control relates directly to the rate of evaporation from a leaf-like sensor, it is reasonable to expect that it more accurately reflects the potential for cuttings to suffer desiccation stress. Furthermore, the propagator at Lowaters soon recognised that it was much easier to fine tune the misting regime with the single WLD set point knob on the Evaposensor controller than to adjust light-sum, burst length and background timer settings that combine to determine the amount of mist applied by the Heron system.

Table 1. Relative rates of mist for a selection of monthly time periods at Lowaters Nursery

	Mean mist seconds / day		**Ratio**
Monthly time period	**Evapo control**	**Heron control**	**Evapo : Heron**
18 June – 17 July 2008	238	75	315%
18 Aug – 17 Sept 2008	40	50	79%
18 Nov – 17 Dec 2008	11	13	86%
18 Jan – 17 Feb 2009	30	14	204%
18 Feb – 17 Mar 2009	90	17	516%
18 Mar – 17 Apr 2009	73	62	117%
18 Apr – 17 May 2009	102	64	159%

New Place Nursery

Comparative performance of Nobel vs ETS controller

The ETS Mk1 prototype controller was installed at New Place Nursery in September 2007 as a comparative treatment with the Nobel controller that had been installed in early May 2007 at the start of the project. As described in the Year 1 Annual Report, early results up to April 2008 from the two Evaposensor controllers running in parallel were good and gave early confidence in the ETS design as a suitable replacement for the Nobel. It was decided to retain the ETS Mk1 at New Place to obtain further parallel data with the Nobel. Meanwhile, Mk2 units were installed at Lowaters and Binsted Nursery, and the first Mk3 'production version' replaced the Mk1 at New Place Nursery in late November 2008.

Figs 14 – 16, covering the mid May to mid June 2008 period, show that both Evaposensor mist controllers (set at about 1.5 °C WLD) continued to give similar patterns of misting. The adjustment of mist in response to environmental conditions is clearly shown in Figs 15 and 16 compared to the static timer treatment settings. On the bright sunny days of 4 – 7 June, inside radiation levels show an early morning peak until the shade screen closed, however ambient humidity was still high enough at that time to limit the amount of mist applied until later in the day when RH dropped. The absence of mist from any treatment on 26 May was caused by the Heron controller 'tripping out' due to a minor fault.

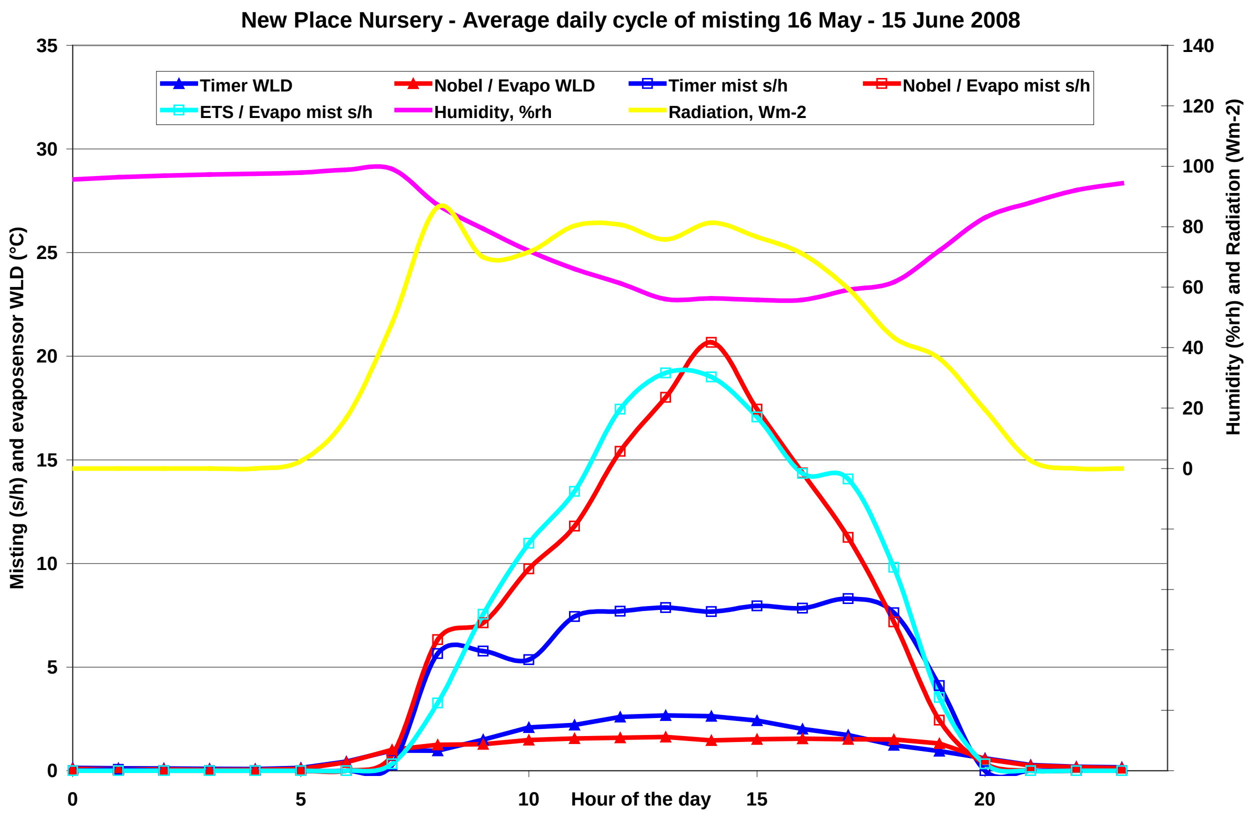


Fig 14. New Place Nursery. Mean diurnal pattern of mist and ambient environment for Nobel and ETS Evaposensor vs. Heron Timer treatments mid May – mid June 2008.

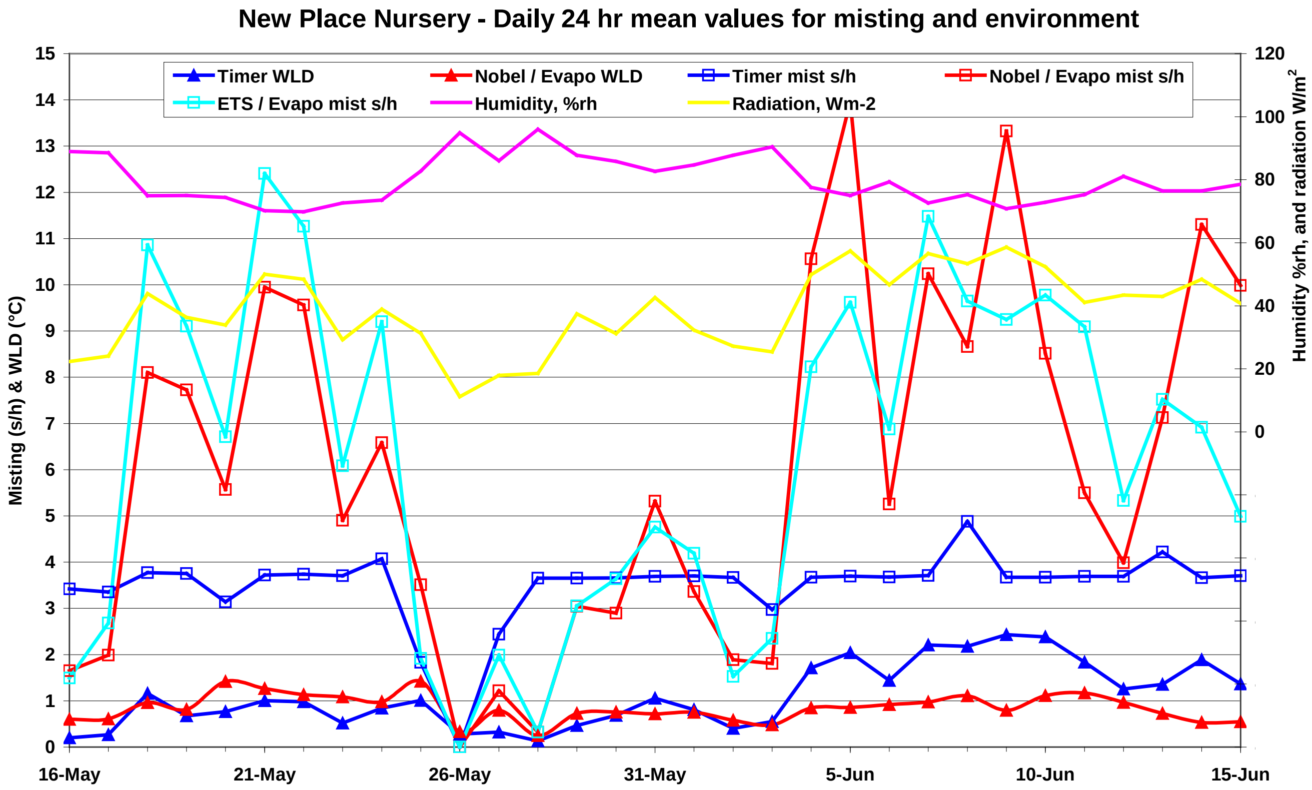


Fig 15. New Place. Daily mean values for ambient and mist environments 16 May – 15 June 2008.

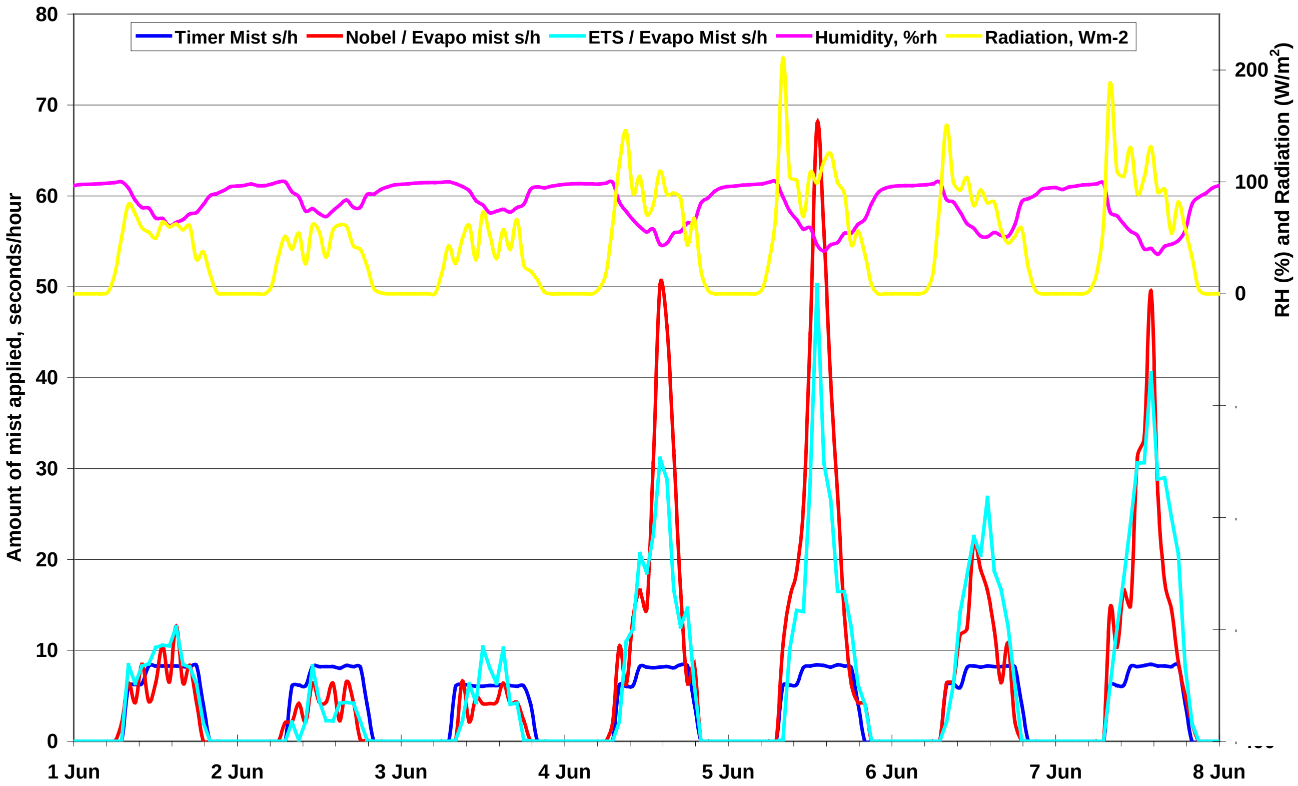


Fig 16. New Place. Hourly mean values for misting, inside radiation and relative humidity 1 - 8 June 2008.

No monitored WLD data was available from the ETS treatment during this period, because of a fault with the monitoring Evaposensor on this bed. This was an old unit that had been used for many years at East Malling Research and water ingress had caused a problem with internal electrical connections.

Binsted Nursery

Binsted Nursery was characterised by having higher light levels at cutting level than at Lowaters or New Place Nurseries, because no shade screen was used and just white shading paint on the glass walls and roof between May and October. Also, the capillary matting and polythene over concrete standing base at Binsted, restricted the amount of misting that could be used without over wetting the rooting media. Once the matting was fully wet, there would be no capillary tension pulling surplus water from cells, unlike on a sand bed, and thus the grower had little option but to reduce misting to avoid saturating the rooting medium, even if optimum misting to suit cutting foliage was compromised.

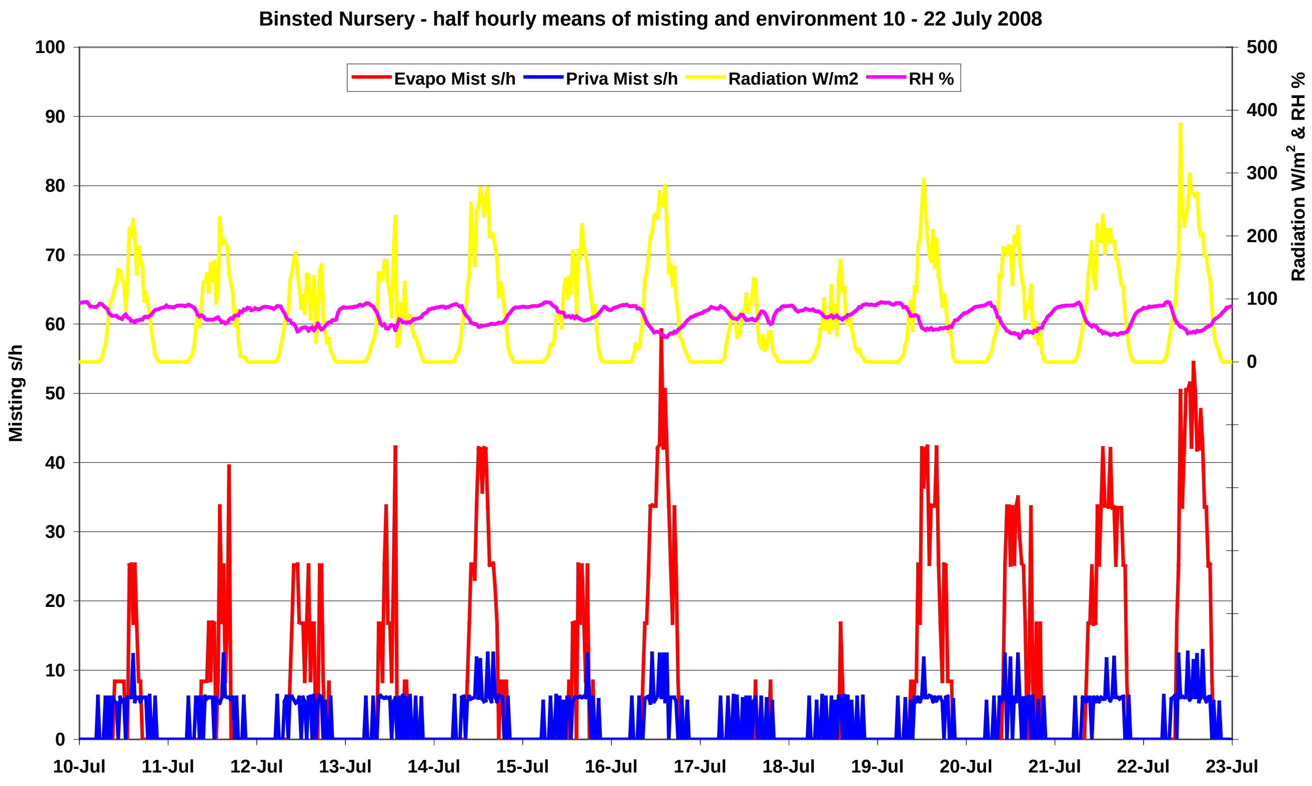


Fig 17. Binsted Nursery. Half-hourly means. Misting and environment pattern while Evaposensor control minimum burst interval setting at 1 minute.

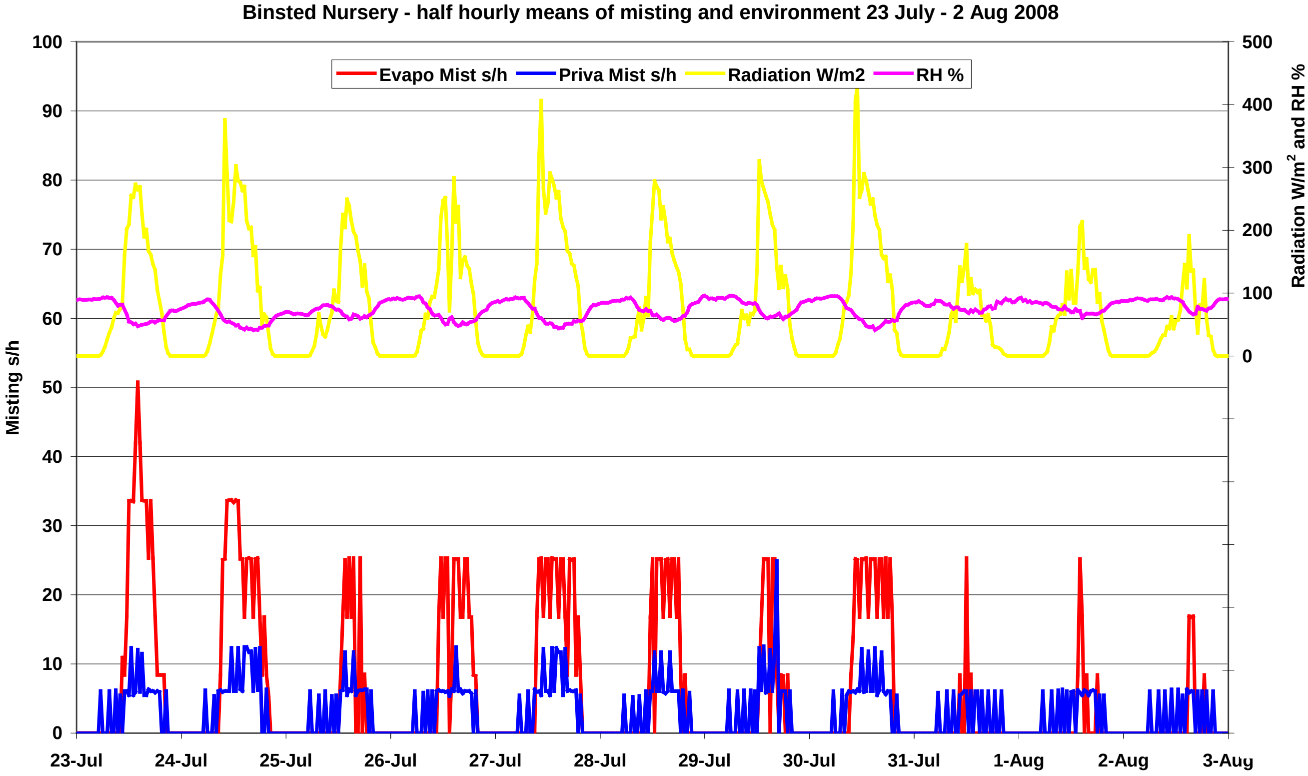


Fig 18. Binsted. Half-hourly means. Misting and environment pattern following increase in Evaposensor control minimum burst interval setting to 15 mins on 24 July.

For Evaposensor control, the WLD set point was set at 4 °C on 19 June then 5 °C on 23 July. Minimum burst interval was initially on the usual low setting of 1 minute, thus effectively giving full control of mist burst frequency to the Evaposensor (Fig 17). The rooting medium was getting too wet at this setting on bright days, however, so the minimum mist burst interval was increased to 10 mins on 23 July and then 15 mins on 24 July. Figure 18 illustrates the capping or limiting of mist that was thus applied by the Evaposensor treatment on bright days. The Evaposensor continued to apply more mist in total than the Priva control on such days, but less mist than Priva control on dull days. From mid September onwards the minimum mist interval was reduced from 15 to 7 minutes.

Where drainage of rooting media cannot be improved in the short term, the facility on the ETS controller to use the minimum burst interval to set an upper limit on misting, and thus to partially override the Evaposensor can be a useful pragmatic solution to a problem of over wet rooting medium. This is better than increasing the WLD set point too much and risk applying no mist except in conditions of the highest transpiration rate. By keeping the WLD set point low to moderate (e.g. 1.0 to 5.0 °C) during the sticking to rooting phase, and extending the minimum mist interval if necessary, then some regular misting will still occur when required, even if not enough to keep the WLD from peaking above the set point for short periods. However, for the more desiccation sensitive subjects, these WLD peaks could cause serious loss of rooting and what is really required is to improve capillary drainage or, possibly, increase shade.

From late August 2008 onwards, as radiation levels fell during late summer and autumn, there were an increasing number of days when the Evaposensor misted less than the Priva control. The Priva, however, continued to apply the same intensity of regular timed mist bursts through to the completion of the project at Binsted in early December (data not shown).

Plotting graphs of misting intensity against radiation or humidity deficit (either the parameter Δx, used in the Priva program or vpd) is a useful way to explore the behaviour of the control system to the factors that influence stress on cuttings. The regression gradients in Fig 19 illustrate the contrasting behaviour of the Evaposensor system and the Priva's program. Even with the maximum misting frequency under Evaposensor control capped by a 15 minute minimum interval, it was still more responsive to radiation than the Priva control system. Notice also that the Evaposensor control ceased to apply any mist under low light conditions, whereas the Priva continued to apply regular timed bursts of mist even under very dull conditions.

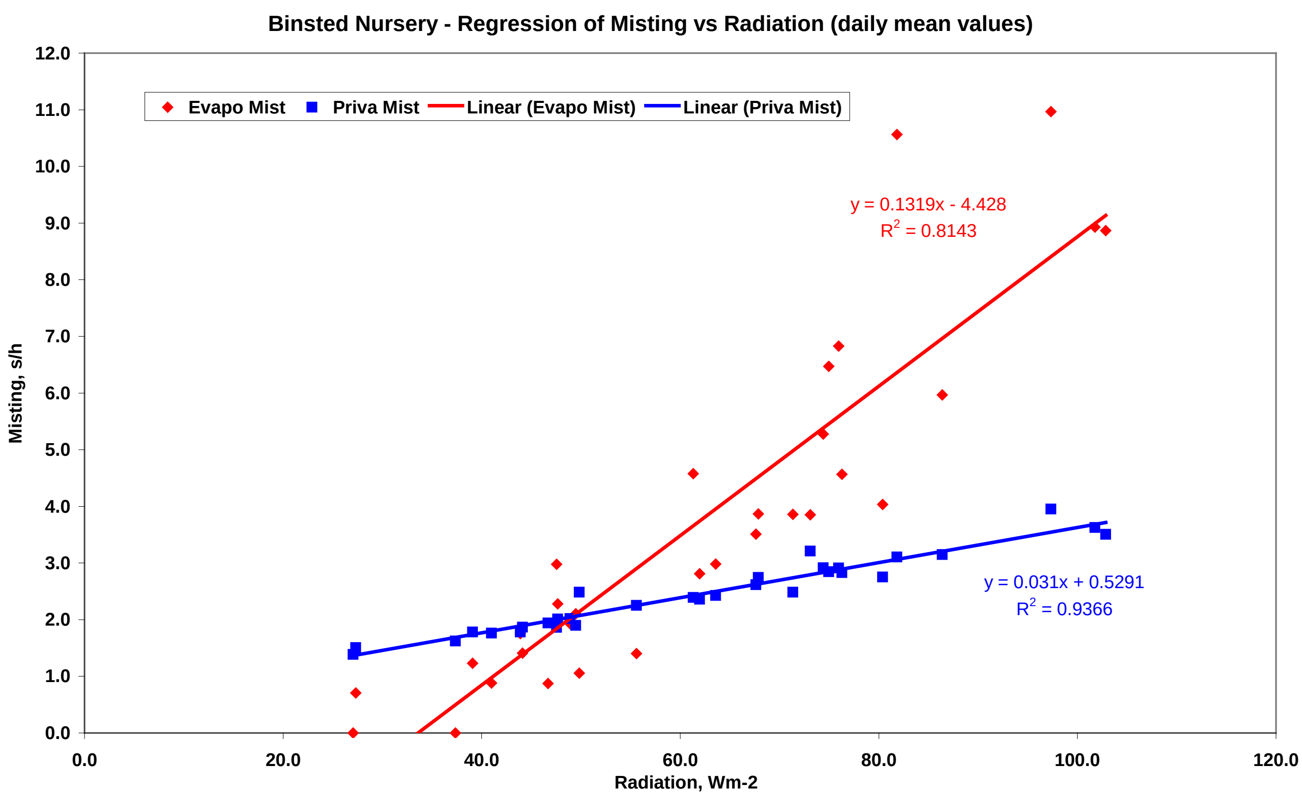
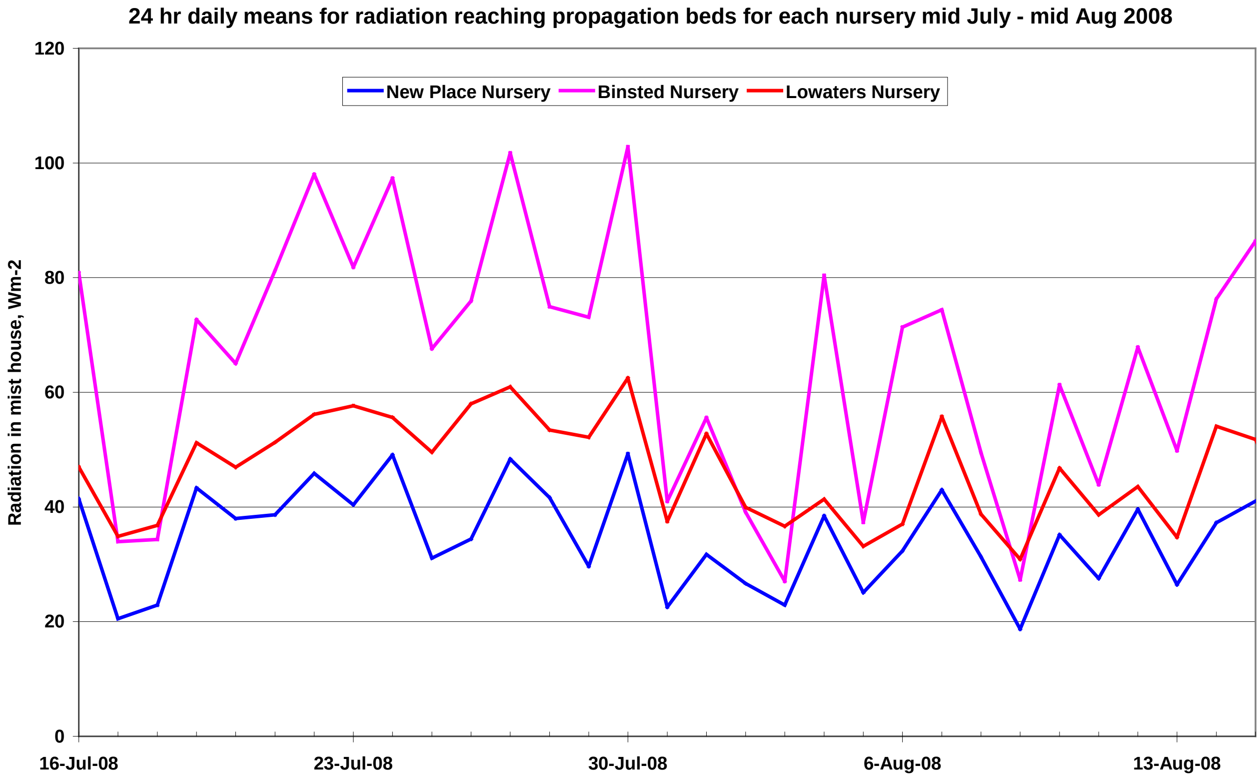


Fig 19. Binsted. Regression of misting against radiation for Evaposensor and Priva control (plotted values are daily means for the period 23 July – 22 August 2008).

Comparison of nursery environments and misting regimes

Fig 20 illustrates mean daily radiation levels reaching the cuttings during mid July – mid August 2008 across the three nurseries. Weather conditions would have been broadly similar for these nurseries located within about 35 miles apart. The relatively light shade at Binsted nursery is reflected in generally higher radiation levels compared with Lowaters, and the even lower radiation levels at New Place where shade was heaviest.

These and other differences between the nurseries are summarised in Table 2. At New Place, the WLD set point for both the Nobel and ETS controlled Evaposensor treatment was approximately 1.5 °C compared to 4 – 5 °C at Lowaters and Binsted, so that the system at New Place was set to a more supportive, i.e. less stressful, environment for the cuttings . However, due to the differences in light levels, the amounts of mist applied to achieve these mean WLD levels were broadly similar across the nurseries. The amounts of mist applied to the standard treatments at this time of year were half to two-thirds as much. Although the WLD was not monitored for the Standard treatments at Binsted and Lowaters for this period, with the reduced misting, 'daytime' mean WLD's would have been significantly greater than 3.7 – 3.9 °C for the



Evaposensor treatments with consequently greater water stress placed on those cuttings.

Fig 20. Comparison between nurseries of mean daily net radiation reaching cuttings and Evaposensor (including influence of any shade screens etc.).

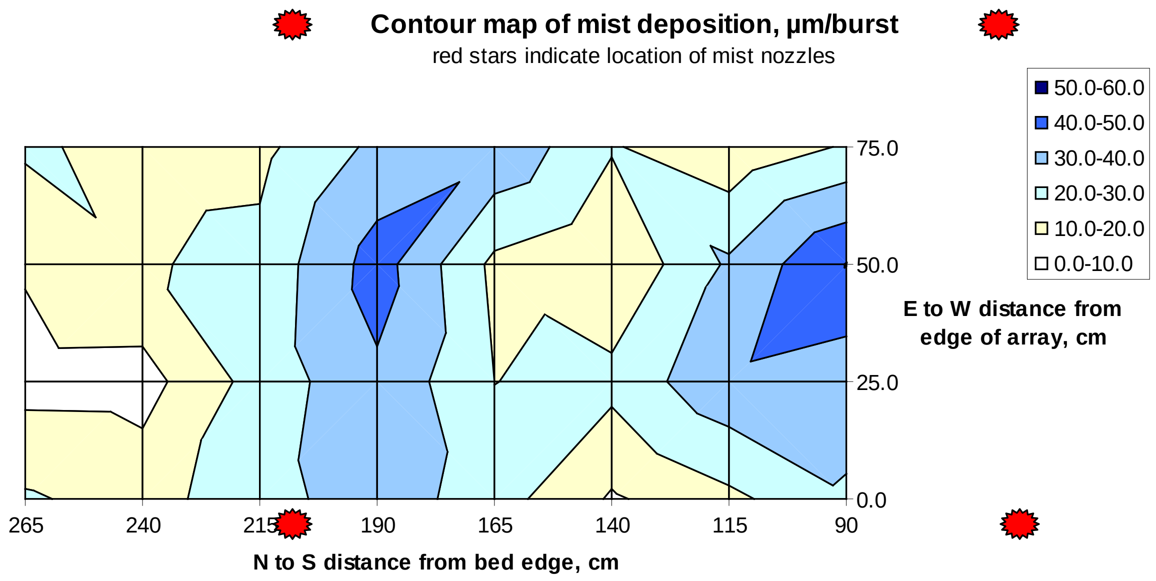
Table 2. Mean misting and environment values for mid July to mid August 2008 across the three nurseries.

Nursery	Misting s/h Standard	Misting s/h Evapo.	Monitored WLD °C Standard	Monitored WLD °C Evapo.	Inside Rad. Wm^{-2}	RH %	Air temp °C
	Overall means 0.00 – 24.00h						
New Place	3.6	4.5	1.1	0.6	34	82	19.5
Binsted	2.5	3.8	n/a	2.3	62	79	19.7
Lowaters	3.1	5.0	n/a	2.1	47	79	21.3
	Daytime means 10.00 – 16.00 BST						
New Place	7.7	10.9	2.3	0.9	74	66	23.3
Binsted	5.4	11.2	n/a	3.9	165	68	22.7
Lowaters	6.5	11.4	n/a	3.7	101	58	26.0

Uniformity of mist deposition

The test at Lowaters Nursery in February 2009 (Fig 21 and Table 3) showed that distribution was at least as non-uniform as that measured in September 2007 at New Place Nursery (see Year 1 annual report). There was a 6 to 8 fold range in the minimum to maximum depositions recorded. This clearly has implications for positioning of the Evaposensor on the bed, as for a given set point, the crop would receive more mist if the Evaposensor was placed on a dry area compared to a wet area. The non-uniformity of the mist would also have accounted for some small differences between monitoring and control Evaposensors on the same bed, which were noticed in the logged data. Such non-uniformity is common in mist systems and is hard to avoid. However, it only likely to lead to noticeable patchiness in rooting results when the mist control system is not applying enough mist so that the drier spots are distinctly too dry.

The time it takes for the dry leaf of the Evaposensor to dry between mist bursts is unlikely to vary as much for different positions on the bed as the absolute levels of deposition measured, especially if some run-off occurs under the wettest areas. Also, although non-uniformity of mist deposition makes it less easy to define WLD set points absolutely, in practice the grower would simply adjust the set point up or down slightly to compensate if the bed as a whole appeared to be running slightly too wet or too dry.



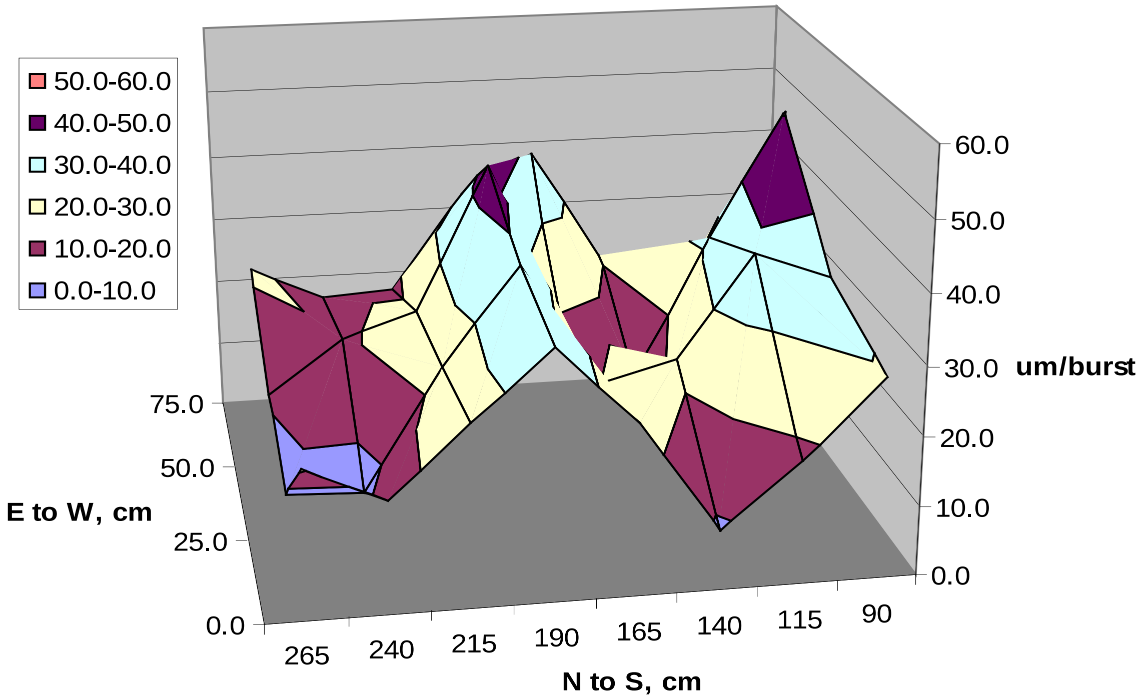


Fig 21. A contour map and 3D graph of mist distribution at Lowaters Nursery, tested on 26 February 2009.

Table 3. Mist uniformity data from tests at New Place Nursery (September 2007) and Lowaters Nursery (February 2009).

	New Place Nursery	Lowaters Nursery
Mean output µm per 2 sec burst and (mm/h) equivalent	28 (50)	24 (46)
Min output	10 (19)	6 (12)
Max output	58 (105)	50 (97)
Coefficient of Uniformity (CU), %	72	63
Scheduling Coefficient (SC_{min})	2.7	3.9

Rooting results

Table 4, below, combines the Year 1 and Year 2 rooting results from New Place Nursery, and Table 5 shows those from Lowaters Nursery in Year 2. The standard error of the mean (SE) is given after the mean % rooting except where there was only one replicate tray of cuttings available[1].

Table 4. New Place Nursery. Rooting results Year 1 & Year 2.
Means of typically four replicates of 77 – 104 cuttings per tray. Rooting % with SE of mean except where only 1 tray of cuttings available. Species in **bold** showed most improvement in rooting under Evaposensor mist control compared to Timer control.

	Mean % rooting						
Species	**ETS / Evapo**	**Nobel / Evapo**	**Timer**	**Difference in % rooting with Evapo**	**Date stuck**	**Mean Date removed**	**Mean Weeks in propag'n**
***Alnus glutinosa* Imperialis**		50 ±2.9	42 (n=1)	**8**	13/06/07	24/07/07	5.9
***Berberis darwinii* Compacta**		80 ±5.0	61 ±12.0	**20**	16/10/07	15/01/08	13.0
Blueberry Chandler		39 ±7.1	23 ±7.2	**16**	14/05/07	17/09/07	18.0
Buddleja davidii Blue Horizon		100 ±0.0	100 ±0.0	0	09/05/07	24/05/07	2.1
Caryopteris Worcester Gold		97 ±0.5	98 ±1.1	-1	09/05/07	26/05/07	2.5
Ceanothus Puget Blue	68 ±9.5	51 ±5.3	73 ±5.9	-14	26/06/08	18/09/08	12.0
Ceanothus thyrsiflorus repens	94 ±1.0	91 ±4.0	96 ±3.2	-4	26/09/07	10/12/07	10.7
Ceanothus Zanzibar		63 ±5.7	77 ±4.5	-14	26/09/07	16/01/08	16.0
***Ceratostigma willmottianum* Forest Blue**	89 ±1.7		74 ±11.0	**15**	16/06/08	13/08/08	8.3
Cistus Sunset	96 ±1.0	94 ±3.2	95 ±2.7	0	06/02/08	25/03/08	6.9
Convolvulus cneorum		81 ±4.4	99 ±0.6	-18	n/a	16/07/07	n/a
Convolvulus cneorum (2)	50 ±4.9	90 ±6.3	98 ±1.5	-28	12/02/08	02/05/08	11.4
Cornus alba Elegantissima		42 ±5.6	48 ±7.6	-6	26/06/07	17/07/07	3.0
Crinodendron hookerianum	90 ±2.5	100 ±0.4	94 ±6.1	1	22/07/08	12/09/08	7.4
Daphne Eternal Fragrance		79 ±2.3	79 ±4.6	0	14/05/07	04/07/07	7.3
Elaeagnus Quicksilver		43 ±7.3	55 ±7.3	-12	26/06/07	24/07/07	4.0
Elaeagnus Quicksilver (2)	98 ±1.2	98 ±0.5	98 ±1.6	0	03/06/08	09/07/08	5.1
Euonymus fortunei Harlequin	99 ±0.7	99 ±0.5	97 ±1.5	2	23/05/08	18/07/08	8.0
Exochorda serratifolia Snow White		65 ±4.0	62 ±3.8	3	07/07/08	12/09/08	9.6
***Exochorda x macrantha* The Bride**	53 ±1.0		44 ±22.0	**9**	16/06/08	13/08/08	8.3
Fallopia baldschuanica	83 ±10.5	96 ±3.5	94 ±3.0	-5	17/04/08	12/05/08	3.6
***Fatshedera lizei* Annemieke**	96 ±1.4	88 ±2.0	79 ±6.1	**13**	02/06/08	18/07/08	6.6
***Gardenia jasminoides* Kleim's Hardy**	88 (n=1)		71 (n=1)	**17**	19/06/08	13/08/08	7.9
Halimiocistus sahucii	35 ±1.4	63 ±6.1	79 ±7.2	-30	05/02/08	25/03/08	7.0
Hydrangea petiolaris		88 ±1.9	63 ±24.0	**25**	07/06/07	17/09/07	14.6
Lavandula stoechas Alba	91 ±2.3	91 ±5.1	87 ±5.6	4	27/03/08	02/05/08	5.1
Lavatera Blushing Bride		88 ±1.3	87 ±4.0	2	09/05/07	01/06/07	3.3
Lavendula Hidcote		99 ±0.6	99 ±0.6	0	11/05/07	04/06/07	3.4
Lonicera japonica Mint Crisp	66 ±8.2		61 ±7.4	4	17/06/08	18/07/08	4.4
Osmanthus delavayi	76 ±8.1		75 ±5.5	0	30/07/08	12/09/08	6.3
Parthenocissus henryana	35 ±8.4	29 ±4.0	29 ±2.9	2	28/05/08	25/06/08	4.0

[1] The SE is a measure of the variability of rooting between trays within a treatment – the lower the SE, the more uniform the rooting within that treatment. Thus there is more confidence that a pair of treatment means are truly different if they are separated by SE's that do not 'overlap'.

Table 4 (continued). New Place Nursery. Rooting results Year 1 & Year 2.

	Mean % rooting						
Species	**ETS / Evapo**	**Nobel / Evapo**	**Timer**	**Mean diff. in % rooting with Evapo**	**Date stuck**	**Mean Date removed**	**Mean Weeks in propag'n**
Photinia x fraseri Little Red Robin	96 ±0.7	87 ±9.3	91 ±2.2	1	14/07/08	12/09/08	8.6
***Physocarpus* Diablo**		95 ±0.9	87 ±7.1	**7**	09/05/07	11/06/07	4.7
Pieris Carnival		96 ±1.4	96 ±0.9	0	05/06/07	17/09/07	14.9
***Pittosporum tenuiflolium* Marjory Channon**	67 (n=1)		55 (n=1)	**12**	18/06/08	07/09/08	11.6
***Pittosporum tenuifolium* Elizabeth**	74 (n=1)		68 (n=1)	**6**	19/06/08	12/09/08	12.1
***Pittosporum tenuifolium* Garnettii**	87 (n=1)		79 (n=1)	**8**	16/06/08	12/09/08	12.6
***Pittosporum tenuifolium* Silver Queen**		31 ±7.3	26 ±6.2	**5**	12/10/07	15/01/08	13.6
***Pittosporum tenuifolium* Silver Queen (2)**	86 (n=1)		62 (n=1)	**24**	17/06/08	12/09/08	12.4
***Pittosporum tenuifolium* Warnham Gold**	70 (n=1)		57 (n=1)	**13**	18/06/08	12/09/08	12.3
***Prunus cerasifera* Spring Glow**		45 ±6.9	31 ±1.3	**14**	09/05/07	11/06/07	4.7
Rhamnus alaternus Argenteovariegata	86 ±2.0	80 ±2.1	79 ±3.1	4	16/01/08	23/05/08	18.3
Rhododendron Ginny Gee		82 ±8.3	90 ±4.1	-8	19/07/07	05/11/07	15.6
Rhododendron Scarlet Wonder	71 ±3.0	77 ±4.5	74 ±4.0	0	21/05/08	14/09/08	16.6
Ribes sanguineum Koja	93 ±2.9	96 ±1.8	97 ±0.2	-3	01/04/08	02/05/08	4.4
Rosmarinus Miss Jessops		97 ±1.0	99 ±0.7	-2	11/05/07	04/06/07	3.4
Sarcococca hookerianum digyna	100 ±0.3		99 ±0.8	1	22/07/08	12/09/08	7.4
***Solanum crispum* Glasnevin**		98 ±1.4	84 ±1.5	**14**	09/05/07	04/06/07	3.7
***Spiraea* Arguta**		94 ±1.0	65 ±3.0	**29**	08/05/07	04/06/07	3.9
***Spiraea* Arguta (2)**	77 ±8.5	73 ±1.5	59 ±1.0	**16**	17/04/08	23/05/08	5.1
Spiraea Arguta (3)	57 ±3.2		78 ±3.2	-21	06/06/08	16/07/08	5.7
***Spiraea japonica* Goldflame**		100 ±0.0	85 ±3.8	**15**	08/05/07	04/06/07	3.9
***Spiraea nipponica* Snowmound**		96 ±1.5	90 ±1.6	**7**	08/05/07	11/06/07	4.9
Teucrium fruticans compactum		44 ±7.6	29 ±8.2	**15**	11/06/07	24/07/07	6.1
***Viburnum sargentii* Onondaga**		55 ±7.1	34 ±16.2	**21**	26/06/07	17/09/07	11.9
Mean	***78.2***	***77.9***	***73.7***	***4.4***			

At New Place Nursery, the overall rooting % of 55 batches was 78.2% for ETS / Evaposensor control 77.9% for Nobel / Evaposensor control and 73.7% for Heron Timer giving a difference of +4.4 percentage points (pp) in favour of Evaposensor control on average. Of the 55 batches compared, 23 had showed an improvement of at least 5pp for the Evaposensor with 22 batches showing little difference (-5 to +5 pp), i.e. 82% of batches showed similar or better rooting.

The following subjects gave the best improvement in rooting under Evaposensor control at New Place: *Berberis darwinii* Compacta, Blueberry Chandler, *Ceratostigma, Hydrangea petiolaris, Pittosporum spp., Prunus cerasifera* Spring Glow, *Spiraea* Arguta, *Spiraea japonica* Goldflame, *Solanum crispum* Glasnevin, *Teucrium fruticans compactum, Viburnum sargentii* Onondaga.

Those that did less well included *Convolvulus cneorum, Ceanothus spp.* and *Halmiocistus sahucii*.

Table 5. Lowaters Nursery. Rooting results Year 2.
Means of typically four replicates of 20 – 104 cuttings per tray. Rooting % with SE of mean except where only 1 tray of cuttings available. Species in bold showed most improvement in rooting under Evaposensor mist control compared to Heron control.

	Mean % rooting					
Species	**ETS / Evapo**	**Heron**	**Diff. in % rooting with Evapo**	**Date stuck**	**Mean Date removed**	**Mean Weeks in propag'n**
***Alyogyne huegelii* Santa Cruz**	75 (n=1)	10 (n=1)	**65**	20/02/09	08/06/09	15.4
Artemisia Powis Castle	99 ±0.8	100 ±0.0	-1	07/05/09	02/07/09	8.1
Buddleja Pride of Longstock	99 ±0.7	96 ±2.0	3	20/06/08	15/07/08	3.6
Choisya ternata	84 ±5.9	63 ±13.1	**21**	17/06/08	28/10/08	19.0
***Cistus* Anne Palmer**	50 ±5.3	40 ±0.5	**11**	10/09/08	17/12/08	14.0
Cistus Grayswood Pink	83 ±2.7	80 ±14.6	3	11/09/08	17/12/08	13.9
Cistus incanus creticus	94 ±1.2	89 ±3.3	5	10/09/08	17/12/08	14.0
Cistus lasianthum decumbens	52 ±1.2	38 ±4.6	**14**	11/09/08	27/01/09	19.7
Cistus May Snow	7 ±0.8	6 ±1.3	1	12/09/08	17/12/08	13.7
***Cistus* May Snow (2)**	93 ±1.5	74 ±3.8	**19**	15/01/09	28/03/09	10.3
***Cistus* Silver Pink**	90 ±0.8	81 ±2.0	**9**	11/09/08	17/12/08	13.9
***Cistus* Sunset**	92 ±5.7	81 ±10.2	**11**	10/09/08	27/10/08	6.7
Cistus x purpureus	82 ±7.6	89 ±1.7	-6	10/09/08	17/12/08	14.0
***Coleonema pulchrum* Mellow Yellow**	85 ±1.9	27 ±27.4	**57**	20/06/08	27/10/08	18.4
***Coleonema pulch.* Mellow Yellow (2)**	32 ±8.6	11 ±10.6	**22**	23/01/09	27/05/09	17.7
Convolvulus cneorum	81 ±2.6	81 ±5.0	-1	03/09/08	27/01/09	20.9
***Coprosma* Dark Purple**	78 ±2.5	48 ±2.5	**30**	20/02/09	08/06/09	15.4
***Coprosma repens* Marble Queen**	35 ±5.0	18 ±7.5	**18**	20/02/09	08/06/09	15.4
Coprosma x kirkii Variegata	40 ±5.0	60 ±10.0	-20	20/02/09	08/06/09	15.4
Correa Dusky Bells	85 ±7.5	98 ±0.0	-13	19/08/08	27/10/08	9.9
Dorycnium Little Boy Blue	93 ±3.2	89 ±2.9	3	23/01/09	26/03/09	8.9
***Escallonia* Apple Blossom**	81 ±9.8	60 ±8.8	**21**	13/06/08	22/07/08	5.6
***Escallonia* C F Ball**	88 ±2.3	18 ±3.9	**71**	13/06/08	22/07/08	5.6
***Escallonia* Pink Pyramid**	28 ±4.9	0 ±0.0	**28**	13/06/08	22/07/08	5.6
Escallonia Pink Pyramid (2)	6 ±2.0	8 ±2.0	-2	22/12/08	17/03/09	12.1
***Euonymus fortunei* Blondy**	89 ±0.5	78 ±4.3	**11**	13/06/08	29/08/08	11.0
Euonymus fortunei Emerald and Gold	99 ±0.5	98 ±2.4	1	26/03/09	27/05/09	8.9
***Euonymus fortunei* Harlequin**	99 ±0.8	93 ±2.0	**5**	26/03/09	03/07/09	14.1
Euonymus japonicus Duc d'Anjou	98 ±2.5	96 ±0.8	2	26/03/09	20/07/09	16.6
Festuca Elijah Blue	100 ±0.0	100 ±0.0	0	16/06/08	12/07/08	3.7
Fuchsia genii	75 ±5.4	48 ±7.8	**28**	04/07/08	29/08/08	8.0
Grevillea Mt. Tamboritha	41 ±22.1	50 ±4.0	-9	27/08/08	27/01/09	21.9
Halimiocistus sahucii	59 ±6.3	68 ±3.4	-9	10/09/08	17/12/08	14.0
Halimium commutatum	49 ±0.5	23 ±6.7	**25**	11/09/08	17/12/08	13.9
***Halimium lasianthum* Concolor**	87 ±7.3	60 ±14.4	**27**	12/06/08	14/07/08	4.6
Halimium lasianthum Concolor (2)	24 ±2.9	23 ±3.8	1	11/09/08	28/10/08	6.7
Halimium ocymoides	46 ±17.6	1 ±1.3	**45**	04/07/08	29/08/08	8.0
***Halimium ocymoides* (2)**	75 ±5.9	0 ±0.0	**75**	05/02/09	08/06/09	17.6
Hebe Black Knight	25 ±6.3	34 ±2.5	-9	26/08/08	28/10/08	9.0
Hebe Garden Beauty Purple	84 ±5.4	91 ±3.4	-8	20/08/08	28/10/08	9.9
Hebe Valentino	30 ±11.0	50 ±10.3	-20	20/08/08	28/10/08	9.9
Houttuynia Pied Piper	100 ±0.0	99 ±1.3	1	11/06/08	22/07/08	5.9
Lavandula stoechas Hazel	75 ±6.3	80 ±6.6	-5	13/04/09	27/05/09	6.3
Mitraria coccinea	57 ±0.5	38 ±6.7	**20**	23/01/09	27/05/09	17.7
Myrtus romana compacta	88 ±3.2	40 ±13.2	**48**	18/11/08	08/06/09	28.9
Nemesia Cotton Candy	100 ±0.0	100 ±0.0	0	05/02/09	02/04/09	8.0
Nemesia Vanilla Mist	99 ±1.3	99 ±1.3	0	05/02/09	02/04/09	8.0
***Olearia* Combers Pink**	85 ±1.9	74 ±15.1	**11**	26/08/08	25/10/08	8.6
***Olearia* Master Michael**	33 ±5.3	7 ±2.1	**26**	26/08/08	25/10/08	8.6
Olearia x scilloniensis	95 ±0.5	96 ±2.1	-2	27/08/08	24/10/08	8.3
Patersonia occidentalis	99 ±1.3	75 ±5.4	**24**	11/06/08	15/07/08	4.9
***Phygelius x rectus* Ivory Twist**	100 ±0.0	93 ±1.7	**7**	22/01/09	08/05/09	15.1

Table 5 (continued). Lowaters Nursery. Rooting results Year 2.

	Mean % rooting					
Species	**ETS / Evapo**	**Heron**	**Diff. in % rooting with Evapo**	**Date stuck**	**Mean Date removed**	**Mean Weeks in propag'n**
***Phygelius x rectus* Sweet Dreams**	98 ±1.4	78 ±11.6	**20**	22/01/09	08/05/09	15.1
Polygala myrtifolia	89 ±1.4	50 ±1.0	**39**	17/06/08	25/09/08	14.4
Prostanthera cuneata	72 ±16.7	31 ±5.9	**40**	20/06/08	29/08/08	10.0
Prostanthera Mint Royale	63 ±9.0	91 ±6.3	-28	07/10/08	14/03/09	22.6
Rhamnus alaterna Argentiovariegata	11 ±0.6	32 ±6.7	-21	19/08/08	27/10/08	9.9
Rhodanthemum hosmariensis	74 ±6.5	83 ±3.3	-9	13/11/08	09/02/09	12.6
***Rosmarinus* Majorca Pink**	99 ±0.3	90 ±2.9	**9**	03/12/08	08/04/09	18.0
***Rosmarinus* Miss Jessops**	81 ±12.2	74 ±3.1	**6**	03/12/08	26/03/09	16.2
Rosmarinus Upright Blue	98 ±0.6	96 ±1.9	2	03/12/08	14/03/09	14.4
***Salvia leucantha* Santa Barbara**	99 ±0.5	89 ±2.4	**10**	06/08/08	29/08/08	3.3
Schizostylus Fenland Daybreak	100 ±0.0	100 ±0.0	0	06/06/08	12/07/08	5.1
Teucrium fruticans	96 ±0.6	91 ±3.7	**6**	23/09/08	17/12/08	12.1
***Ulmus procera* Jaqueline Hillier**	69 ±7.8	10 ±2.0	**59**	20/06/08	22/07/08	4.6
Vinca minor Azurea Flore Pleno	5 ±1.5	11 ±2.1	-6	11/09/08	17/12/08	13.9
***Vinca minor* Azurea Flore Pleno (2)**	92 ±2.9	55 ±21.2	**38**	25/03/09	27/05/09	9.0
***Vinca minor* Illumination**	69 (n=1)	62 (n=1)	**8**	25/03/09	09/06/09	10.9
Weigela Red Trumpet	64 ±7.1	91 ±8.2	-26	22/09/08	06/01/09	15.2
Mean	***72.7***	***61.0***	***11.7***			

At Lowaters Nursery, the overall rooting % of 55 batches was 72.7% for Evaposensor control and 61.0% for Heron Timer giving a difference of +11.7 percentage points (pp) in favour of Evaposensor control on average. Of the 69 batches compared, 37 had showed an improvement of at least 5pp for the Evaposensor with 18 batches showing little difference (-5 to +5 pp), i.e. 80% of batches showed similar or better rooting.

The following subjects gave the best improvement in rooting under Evaposensor control at Lowaters: *Alyogne huegelii* Santa Cruz, *Choisya ternata, Cistus cvs., Coleonema cvs.,* some *Coprosma cvs., Escallonia cvs., Fuchsia genii, Halimium spp., Myrtus romana compacta, Olearia cvs., Patersonia occidentalis, Phygelius x rectus cvs., Polygala myrtifolia, Prostanthera cuneata, Ulmus procera* and *Vinca minor cvs.* Those that performed less well under the Evaposensor included *Coprosma x kirkii* Variegata, *Correa* Dusky Bells, *Halmiocistus sahucii, Prostanthera* Mint Royale, *Rhamnus alaterna* Argentiovariegata, and *Weigela* Red Trumpet.

At Binsted Nursery, only a few subjects were compared, but these included *Dianthus* Dainty Dame, *D.* Fusilier, *D.* Pikes Pink and *D.* Whatfield Joy. Also *Rosmarinus officinalis, Oreganum vulgare, O. vulgare* Country Cream, *O. vulgare compactum, O. vulgare aureum*, *Chamaemelum nobile* (Double Flowered and Treneague), and *Santolina chamaecyparissus*. All gave good rooting with little or no difference between mist control treatments.

In general, the biggest rooting benefits from the Evaposensor occurred where the standard system failed to apply sufficient mist under high evaporation demand periods, and cuttings were stressed. This was more often the case at Lowaters Nursery than New Place Nursery, because Lowaters were running a drier regime[2]. Some subjects clearly didn't like the extra wetting to foliage typically applied by the Evaposensor at New Place and Lowaters during hot conditions, such as *Halmiocistus sahucii* and *Convolvulus cneorum*. Species with hairy or downy leaves are likely to hold water for longer and thus benefit from a drier regime. Unfortunately, in this trial, only one plot was available for each treatment and a single set-point had to be applied for the wide mixture of subjects on the bed at any one time, and was thus likely to not be optimal for some.

Speed of rooting and plug quality

For most subjects, rooting assessments for both treatments were done at the same time, and there were not obvious large differences in the speed of rooting between the Evaposensor controlled and standard controlled environments. Thus, only a single date and time-to-root period is shown in the results tables above. At Lowaters Nursery, however, several subjects did show evidence of faster rooting under the Evaposensor control. These included *Artemisia* Powys Castle, *Cistus* May Snow (batch 2), *Euonymus japonicus* Duc d'Anjou, and *Vinca minor* Illumination (2 – 3 weeks faster) with *Euonymus fortunei* Harlequin and *Polygala myrtifolia* showing 7 and 8 weeks faster rooting respectively under the Evaposensor treatment. More 'new' and 'fresher' shoot growth from plugs was also observed on the Evaposensor treatment for these and other subjects during and shortly after their time under mist.

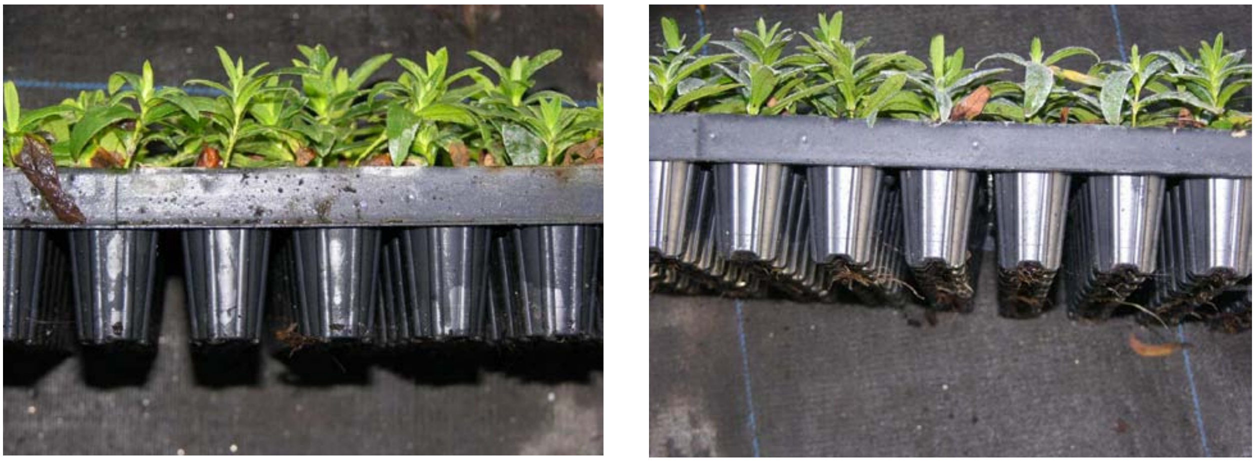


Photo 6. *Cistus lasianthemum decumbens* from Lowaters Nursery showing better early growth and plug quality from Evaposensor treatment (left) compared to standard mist control (right).

[2] More recently, under project HNS 159a, some nurseries have found that the Evaposensor control was giving better results with some subjects by avoiding *too much* wetting which was occurring with their 'wet leaf' or 'electronic leaf' standard control. Wet leaf control can apply excessive mist under dull or cool conditions and will typically continue to give some mist at night.

Photo 7. *Coleonema pulchrum* Mellow Yellow, Evaposensor treatment on left.

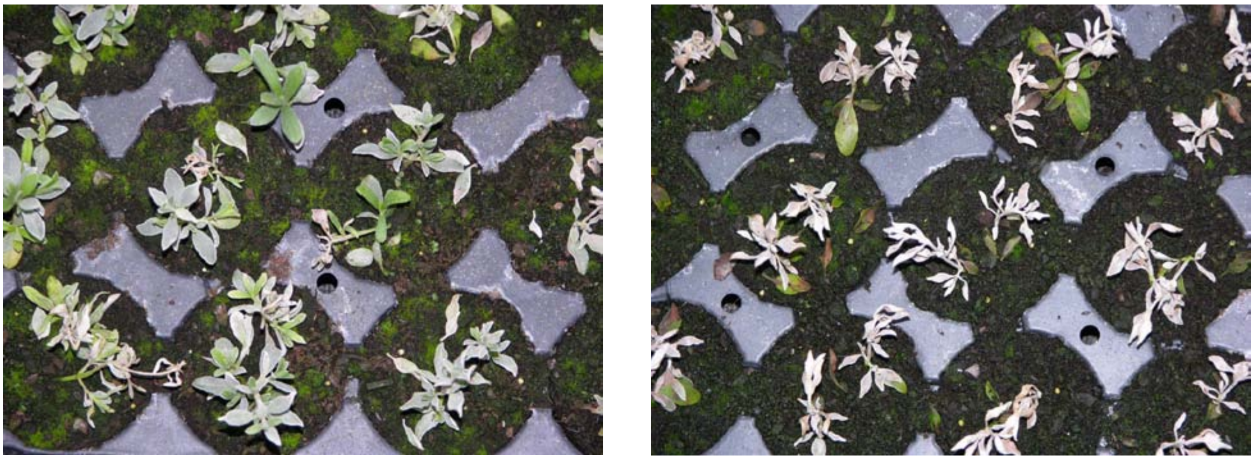


Photo 8. *Halimium ocymoides.* Rooting much better on Evaposensor control plot (left). Virtually no survival on standard Heron mist control due to desiccation

Grower comments from using Evaposensor mist control in HNS 159

'We have been very pleased by the simplicity of management of the device… there has been little training required to understand the system and the user interface is friendly and easy to understand with 2 simple adjustments controlling the whole unit…
The other benefit is that the Evaposensor beds continue to perform at their optimum without regular manual intervention, therefore at weekends and spring and autumn periods when weather can rapidly change we are not using valuable skilled staff time in making regular tweaks to the system which are sometimes missed…
The average [rooting] improvement was 12% across a range of genera including some unusual and often difficult plants…if we could reduce… labour by 12% this would [be worth] close to £800 pounds a year saving…'

Charles Carr, Nursery manager, Lowaters Nursery

'The very warm and dry weather we had a couple of weeks ago made the RH in our prop house very low; to the extent that our normal system was applying mist primarily because the humidity deficit had exceeded 14 g/kg (g water / kg air) – rather than due to Light sum. The Evaposensor was shooting from 0 to 14+ within 5 minutes, so it was effectively misting every 5 minutes - causing a complete saturation of the bed…
Previous experience of over-misting problems with our existing system led us to use a 15 minute minimum rest time so we adopted this for the Evaposensor bed – if we had not I think we would have suffered crop losses…
I do appreciate the chance to evaluate this technology – but, on balance, my experience so far does not suggest that the Evaposensor is an improvement on our existing technology.'

Martin Emmett, Nursery manager, Binsted Nursery

[Note Binsted Nursery was already running a very dry regime, partly in response to the range of material they were propagating and because of the lack of a positively drained standing base. They had already adopted a sophisticated mist control regime based on light-sum and humidity using a climate control computer].

'The advantage of the Evaposensor system is that it automatically takes care of day-to-day weather changes which in the main do not happen [with the timer based system]… I think the principle is very sound since its WLD illustrates what is going on around the cuttings. The fact that we have already installed two Evaposensors underlines our commitment towards further expansion of the system. I am particularly keen to look at it in polytunnels.'

John Hedger, Managing Director, New Place Nurseries

FINANCIAL BENEFITS OF THE PROJECT

The financial benefit from installation of Evaposensor control equipment will partly depend on the scale of overall improvement in % of useable cuttings produced and savings in labour and other inputs by minimising wastage. Other benefits are less straightforward to calculate financially, but still have a monetary value, such as ease of management, ability to rely less on skilled staff (especially for weekend or holiday cover), and the opportunities for self-propagating new or difficult cultivars that would otherwise have to be bought in.

Equipment costs as at autumn 2009 are about £200 for an ETS Controller and £150 for a Pt100 type Skye Evaposensor including 15 m cable.

The following example data, provided by Lowaters Nursery, indicates that the costs of installation of Evaposensor control equipment for their 200,000 cuttings/yr unit of a few hundred pounds would easily and rapidly be recouped by the benefits.

An average 12% increase in rooting was assumed, although Lowaters pointed out that this included some unusual and difficult genera, and believe this average could be increased with experience. For their size unit, some 81 hours of propagation labour / annum could be saved from wasted inputs, worth about £800 / year. Alternatively, an increase of 12% on a 200,000 annual liner production at £0.75 / unit would be an £18,000 increase in output.

Lowaters have observed that many of the subjects which performed best under the Evaposensor have been unusual cultivars, or those with limited stock material, where previously they may have missed their production target due to significant losses. Improving saleable outputs of these would be of significant benefit.

CONCLUSIONS

Hardware

Through collaboration with John Walker of Electronic and Technical Services Ltd (ETS) an evaposensor mist controller was developed and brought to market and is now available to growers at a price of about £200 (excluding the evaposensor itself). Compared with the obsolete Nobel equipment that it replaces, the ETS unit has many additional features, in particular:

- Very stable electronics
- Large digital display of WLD
- LEDs indicate current status of the control system
- Built in timers for control of burst length and minimum interval between bursts
- Can be used as a stand-alone mist controller
- Analogue output expands the options for integration with other equipment (e.g. existing mist controllers, irrigation sequencers, computers and loggers)

Grower experience

Grower experience with evaposensor controlled mist has been positive. Taking into account the additional grower feedback from HNS 159a (technology transfer), the main conclusions are as follows:

- Nursery managers and propagation unit staff readily grasp the basic concepts of the evaposensor and the use of the ETS unit, either as a stand alone controller or integrated into an existing mist control system so as to control multiple beds.
- Nursery staff soon become confident that the evaposensor system is making "sensible decisions" about misting intensity.
- Some nurseries are happy to leave the WLD set point alone, allowing the evaposensor to do all the work of compensating for day to day variations in weather and season. Others like to make occasional changes to the set point and appreciate the ease and repeatability of adjustment provided by the calibrated set point control knob. (We would hope that, in time, nurseries will use this feature to fine tune conditions on individual beds to suit particular types of cutting.)
- When capillary drainage is particularly limited (e.g. a thin layer of capillary matting on an almost level concrete floor), or there is a need for a particularly dry regime, then the "Interval" control knob is useful for setting an upper limit on mist frequency.

Rooting performance

Results varied between species and varieties, reflecting their differing needs, so conclusions are drawn from the average of well over 100 batches of cuttings:

- The evaposensor resulted in the rooting of an additional 12% of cuttings on one nursery, 4% of cuttings on a second nursery and had no effect either way on a third nursery. Similarly, in HNS 159a, average rooting results were as good as or better than those achieved with the nursery's existing control system.
- About 8 out of 10 species / varieties rooted as well or better under evaposensor control than under the nursery's existing control system.

How does evaposensor control increase rooting?

- Evaposensor control tends to vary the amount of mist applied more than other systems, such as timers, light-sum or the traditional "electronic leaf" (or "wet leaf") systems. At night and on dull days, the evaposensor applies none or very little (whereas an "electronic leaf" system continues to mist to keep the leaf wet at all times), but around midday and on bright days the evaposensor tends to apply more than other systems.
- It is likely, but not proven, that the increase in average rooting percentage achieved with evaposensor control derives from the way that it concentrates misting into periods of high evaporative demand.
- Whilst it was not possible to do side-by-side comparisons of different WLD settings within this project, the ability to adjust evaporative demand to suit particular types of cutting is likely to further increase average rooting percentage on nurseries that adopt this approach.

Additional applications of evaposensor control

- The development of the ETS mist controller has opened up a further application for evaposensor control: automatic scheduling of irrigation. This has now been successfully tested on HNS containers at Hillier Nurseries as part of HNS 97a ("Water LINK" project).

FURTHER WORK

A short project HNS 159a 'Promotion and Dissemination of Evaposensor Mist Control on Nurseries' ran from May to October 2009. Three nurseries were involved –
Boningale Nursery, Albrighton, Wolverhampton,
Living Landscapes Nursery, Barrow, Chester, and
Micropropagation Services, East Leake, Loughborough.

The nurseries' standard mist control (electronic leaf at Boningale and Living Landscape, and light integral at Micropropagation Services) were compared with Evaposensor mist control with some collection of environmental and rooting data where available. Growers were given the opportunity to see the systems and learn more about Evaposensor control at Growers' Walks held in October 2009.

Additional grower comments from HNS 159a

'It has been an easy system to adapt to and change from the conventional leaf system. Very quickly I found I could leave the sensor to totally control the misting, the beds did not become too wet or too dry making a very good rooting environment… I am very keen to have the entire mist house at Boningale changed to the Evaposystem…'

Nerys Arch, Propagation manager, Boningale Nursery

'I have found that the Evaposensor to be a very useful controller. It is more controllable on our system and keeps the mist beds drier at night than our wet leaf system.
I have found for subjects susceptible to over wetting the rooting is approximately 5 – 10% better than on the wet leaf beds. We should seriously consider controlling the whole system with an Evaposensor'.

David Crabtree, Manager, Barrow Nursery, Living Landscapes

Propagation issues requiring nursery based R&D

Experience and grower feedback during HNS 159 and 159a raised several issues that are worthy of further practical research on nurseries. The more controlled misting environment that the Evaposensor now offers enables these other topics to be studied.

There can be a dilemma between increasing mist to reduce desiccation stress or decreasing it to avoid waterlogging of the rooting medium. Capillary drainage, to suck excess moisture from the rooting medium offers a way out of this dilemma, and capillary sand beds have been used on some of the nurseries tested. However, practices such as covering beds with textiles to avoid splash and improve hygiene may interfere with good capillary contact. Also capillary matting is also sometimes used, and more tests are needed to evaluate ways of improving capillary drainage and beds. Related to this is the nature of the rooting medium, type of plug and tray, and how that may affect media drainage and rooting. There are now very many types, sizes and materials used in pre-prepared rooting plugs, trays and options for media mixes. There is a need for nursery based trials to compare rooting results and find practical ways for growers to measure air/water content of media across a range of plug and media types. Finally, systematic comparisons of different mist regimes to identify optimal set points for particular species and cultivars are needed to enable nurseries to get the best out of the Evaposensor mist control equipment.

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Boningale Nursery: Penny Fryer and Nerys Arch
Barrow Nursery, Living Landscapes: David Crabtree and Richard
Micropropagation Services: Neal Wright

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APPENDIX A - Further technical Information for growers considering using Evaposensor control

ETS Controller – connection options and modes of use

The development of the Mk 3 or commercial production version of the ETS controller incorporated a number of features, which enabled it to be used independently, or connected to an existing sequential timer in various configurations. While ETS Ltd may well make further refinements or models of the controller in future, the following describes the main modes of use currently possible.

i) Independent controller mode

In this mode, no other controller, such as a Heron or other timer, is required. The solenoid mist valve is wired into the ETS controller which provides a 24 V ac power supply. This arrangement is most suitable for propagation units with a small number (e.g. 1 to 4) of independently controlled beds. However, as the ETS only has one power output, each bed would require its own Evaposensor and ETS controller when used in this way. The Evaposensor is located on the bed being controlled ensuring that it is receiving a typical amount of mist for the bed, and that it is free from shading by cutting foliage or other obstacles such as mist riser pipes. It is connected to the ETS controller where it gives a continuous display of WLD or evaporative demand.

The timer controls on the ETS are used to set the mist burst length ('On seconds') and the *minimum* interval possible between bursts ('Off minutes'). Some interval is required to allow the mist to reach the sensor and the WLD to respond. Normally this is set to a low setting (e.g. 1 min), but the *actual* interval between bursts will normally be much longer and will automatically adjust according to the conditions affecting evaporation / transpiration rate. Using a minimum interval of 1 minute would effectively give full control of mist burst frequency to the Evaposensor and would be recommended for most circumstances. However, if frequent misting during high evaporative demand caused problems (e.g. waterlogged media, poor basal drainage, or for subjects sensitive to excessive leaf wetting) then raising the minimum misting interval as well as raising the WLD set-point could be used as techniques to limit mist output. By setting the minimum interval to a higher value (e.g. 10 or 20 mins), the influence of the Evaposensor under conditions of high evaporative demand would be limited. When normally the Evaposensor would apply a mist burst as soon as it reached the WLD set point, misting frequency would be capped and limited to the interval set on the dial. WLD could then rise significantly above the set point for periods between mist bursts, but this might be more acceptable than over wetting rooting media or cutting foliage.

ii) ETS linked to an existing mist timer or sequencer for single bed control

Instead of wiring the timer directly to the mist solenoid, it is wired through the contacts of the relay in the ETS evaposensor controller so that the timer provides the “opportunity to mist” at regular intervals but the evaposensor determines whether misting actually occurs. Burst length and interval controls determine the length and frequency of the “opportunity”. With a sequencer such as a Heron MCI-16, typically a continuous cycling program would be set up to provide the regular “opportunity to mist”. Other beds could continue to be run from separate timer programs on the Heron as usual. For this type of configuration the timer and solenoid power functions of the ETS are not used as these are provided by the other equipment. The above comments relating to setting a longer mist burst interval apply equally to this type of configuration.

iii) Multiple bed control

An economical way of providing control to multiple beds is to connect the ETS relay output to the ‘remote start’ input of a sequential controller. The example in Fig A1, below, illustrates this for a Heron control panel, although other controllers are available that will work similarly. Six propagation beds are allocated to Program 1 on the Heron, with the Evaposensor placed on Bed 1. Again, the mist duration / minimum interval settings on the ETS are not used, but replaced by the settings in the Heron program. When the WLD on Bed 1 reaches the set point, Program 1 runs, supplying mist to each bed sequentially. Some adjustment to the amount of wetting given to particular beds can be achieved by setting different burst durations for each bed in Program 1, thus enabling some water-sensitive subjects to receive less leaf wetting for example, or providing some weaning. The *frequency* of misting will, however, be determined by the conditions on Bed 1 and the WLD set point on the ETS controller.

If very different misting regimes are required on different beds, flexibility could be further increased by using an additional ETS + Evaposensor and connecting both to a multiple-remote-start input card. This means that two sets of beds could be controlled independently with one set at a low WLD set point (wetter or more supportive) and the other at a higher WLD (drier – e.g. for weaning and subjects that dislike too much wetting). This arrangement allows flexibility for switching any bed between the wet and dry regimes, switching it off completely or even switching it to a timer controlled regime.

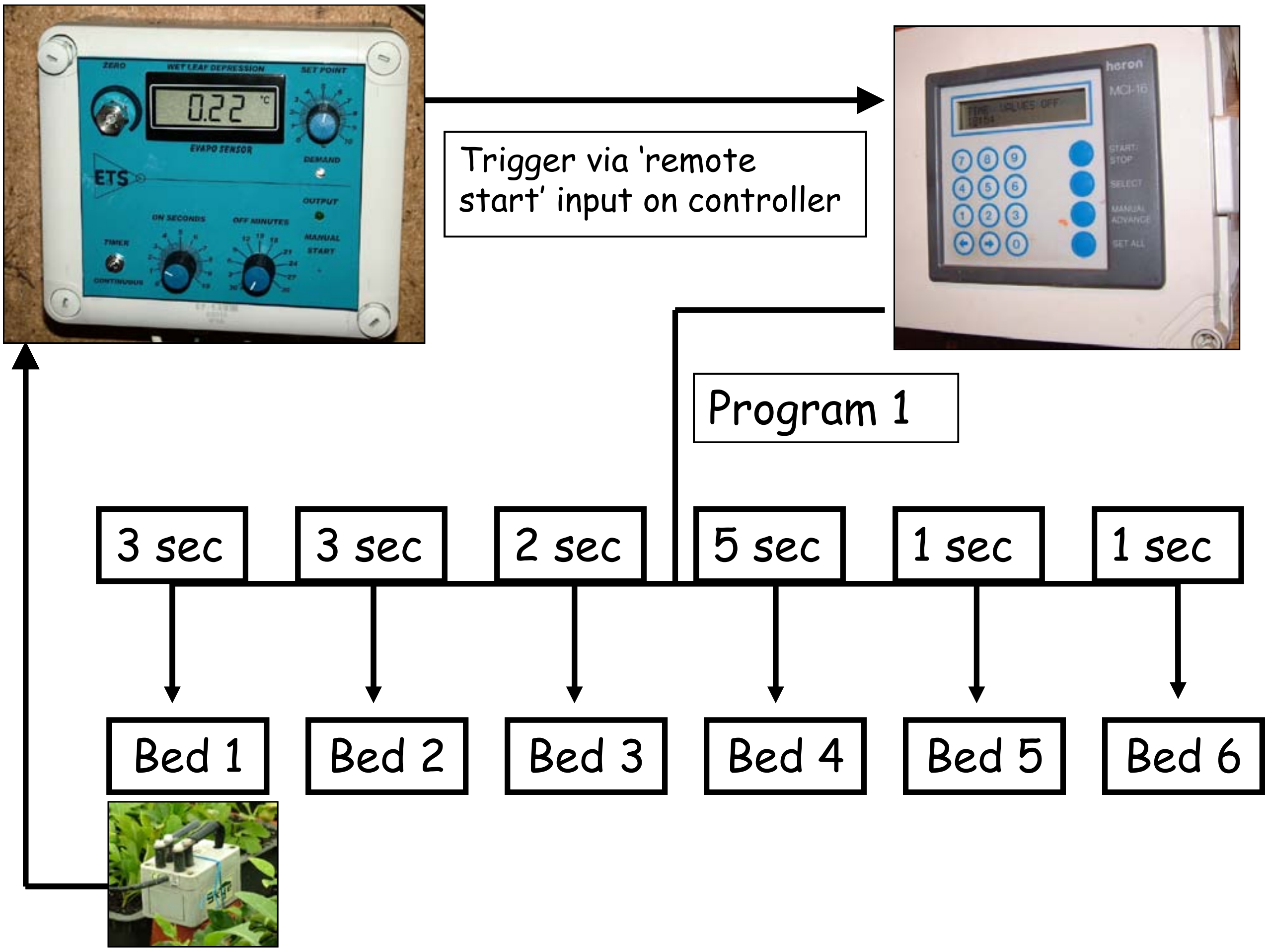

Fig A1. Example of how a single Evaposensor and ETS can be connected to a sequential controller, such as a Heron, to provide economical mist control to multiple beds.

iv) Other configurations and uses

Another option for configuring Evaposensor mist control is analogous to using light sum to trigger mist bursts (as part of the standard grower's scheduling method at Lowaters and Binsted Nurseries), but uses an accumulated evapotranspiration sum instead. In this mode, a signal from the ETS is fed to an integrator card in a sequential controller, and mist bursts are triggered once the accumulated ET sum exceeds a 'trip value' as programmed into the controller. As in Fig A1, multiple beds can be controlled in this way. In the follow-on project, HNS 159a, this configuration has been trialled at Brookside Nurseries (Micropropagation Services Ltd), East Leake, Leics, where the Evaposensor has been placed above the mist lines but below the shade screen, thus monitoring the ambient glasshouse environment. This has allowed more flexibility for allocating bed to batches of micropropagation or mini-cuttings, and for weaning plants in stages on a single bed while enabling the Evaposensor to be located in a fixed position. However, it does remove the 'closed-loop' control that having the Evaposensor in the cutting environment under the mist provides. Also the misting environment is not defined by a WLD set-point in this mode, and appropriate 'trip-values' for the control programme will vary between different facilities, and on the location of the Evaposensor, and will need to be determined for each installation. Only limited experience has been gained with this configuration so far, but initial results indicate it may be suited to e.g. very soft material such e.g. ex-micropropagation. Here it can be important to maintain a continuous film of water over the leaf surface and replace a quantity of water evaporated (control on an accumulated ET basis) rather than misting to keep a WLD or 'stress level' below a set point (control on a peak evaporative demand basis). In the latter case cutting surfaces may dry between mist bursts if WLD levels remain low for long periods (e.g. at night or under cool and dull conditions).

Finally, the Evaposensor + ETS controller can also be used to automate irrigation scheduling to growing crops. This mode is similar to that just described with a signal from the ETS fed to an integrator card in an irrigation controller such as a Heron. Longer irrigation doses (rather than short mist-pulses) are applied based on an accumulated evapotranspiration sum. Again, the duration of each dose can be adjusted between stations according to specific crop need, with the frequency or number of irrigations per day automatically adjusted for the weather by the Evaposensor control. This has been successfully demonstrated at Hillier Nurseries in 2009 as part of the HNS 97a 'Water LINK 2' project, and HDC should be contacted for further details and reports.

Practical set-up and maintenance

Chris Burgess and Richard Harrison-Murray are available to provide further consultancy and advice to tailor installations for specific nursery situations. The above section outlines the different modes of use for the Evaposensor, and the scale of operation and any existing mist control equipment will influence which of these options is most appropriate. Other considerations include to:

- Site the Evaposensor in a representative area of the propagation house which is receiving good mist coverage, typical light levels, and away from doorways or vents. Ensure it is not shaded by cuttings and is sited to the north side of any obstacles such as stanchions or mist risers.
- Order sufficient cable length for the Evaposensor to reach the ETS controller without joins, as in-line connections may deteriorate and affect electrical resistance over time. Consider whether spare cable is required to enable flexibility in siting the Evaposensor on different beds.
- Keep Evaposensor reservoir topped up as a weekly routine with distilled water using a 50 ml syringe.
- Occasionally clean algae from wick with an old toothbrush and rinse. Reverse or replace wick when it becomes faded or torn (e.g. annually).

- Clean any hard water or other deposits from dry leaf annually. Touch up leaves with matt black paint if required.
- Check zero-adjust on ETS controller annually, or if WLD display deviates more than 0.3 °C from zero in cool conditions at night. The WLD can be zeroed after both probes have been immersed in a pot of water for 5 mins to allow the temperature to equilibrate.